CLIMATE CHANGE AND VARIABILITY EFFECTS ON INLAND FISHERIES: LAKE KARIBA, ZIMBABWE

By

Rodney Tatenda Muringai

213568453

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UNIVERSITY OF KWAZULU-NATAL

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PREFACE

The research work described in this thesis was carried out in the School of Agriculture, Earth and Environmental Sciences (SES), University of KwaZulu-Natal, Pietermaritzburg, from January 2020 to August 2022, under the supervision of Prof. Paramu. L. Mafongoya and Doctor Romano Trent Lottering (School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, South Africa).

I would like to declare that the research work reported in this thesis has never been submitted in any form to any other university.

It therefore represents my original work, except where due acknowledgements are made.

Candidate: Rodney T Muringai

Signed: [redacted]___ Date: 30/11/2022

As the candidate's supervisor(s), I certify the above statement and have approved this thesis for submission.

Supervisor: Prof. Paramu. L. Mafongoya

Signed: ____________________ Date: __________________

Co-supervisor: Doctor Romano. T. Lottering

Signed: _ [redacted]____ Date: 30/11/2022

DECLARATION 1: PLAGIARISM

I, **Rodney Tatenda Muringai**, 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,
4. this thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a) their words have been re-written, but the general information attributed to them has been referenced;
    b) where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced;
5. this thesis does not contain text, graphics, or tables copied and pasted from the Internet, unless specifically acknowledged and the source being detailed in the thesis and in the References section.

Signed: ______________________

Date: ________________________

DECLARATION 2: PUBLICATIONS AND MANUSCRIPTS

1. **Muringai, R.T.,** Mafongoya, P. and Lottering, R.T. 2022. Sub-Saharan Africa Freshwater Fisheries under Climate Change: A Review of Impacts, Adaptation, and Mitigation Measures. *Fishes,* 7, (3), p.131.
2. **Muringai, R.T.,** Mafongoya, P. and Lottering, R.T. 2022. Climate Change Perceptions, Impacts and Adaptation Strategies: Insights of Fishers in Zambezi River Basin, Zimbabwe. *Sustainability*,14, (6), p.3456.
3. **Muringai, R.T.,** Mafongoya, P. and Lottering, R.T. 2022. Vulnerability of inland small-scale fishing communities to climate change and variability: insight of Zambezi River Basin, Zimbabwe. *Environment, Development and Sustainability.* [Under Review]. Manuscript ID:
4. **Muringai, R.T.,** Mafongoya, P. and Lottering, R.T. 2022. Barriers and limits to climate change adaptation in inland fisheries: A look at small-scale fisheries of Lake Kariba, Zimbabwe. *International Journal of Climate Change Strategies and Management*. [In press]. Manuscript ID: IJCCSM-05-2022-0064.R1.
5. **Muringai, R.T.,** Mafongoya, P. and Lottering, R.T. 2022. Building resilience and reducing vulnerability to the effects of climate change in inland fisheries: Lake Kariba, Zimbabwe. [Submitted]. *Ecology and Society*. ES-2022-13647.

Author contributions:

All the above articles constitute an important part of my thesis. I am the lead author on these articles as they represent the publications generated from PhD studies. Consequently, I use my own collected data, empirical results and analysis. The articles were co-authored with my supervisors whose role was in the recommendation of revisions and edits to these articles.

DEDICATION

To my late father **Martin. M. Muringai** and my late mukwasha **Bernard Mufuka.**

Thank you for believing in me and pushing me to the greater heights.

Your presence will always be greatly missed.

To my unborn children, sorry for delaying your arrival in this world.

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ABSTRACT

African inland freshwater fisheries support the livelihoods of more than 12,3 million people, and fish is the main or only source of animal protein for approximately 200 million people or 20% of the African population. Several studies indicate that fish productivity and catch in freshwater ecosystems in Africa are declining because of stressors such as overfishing, pollution, illegal fishing, bad management, and climate change. Several researchers concur that climate change is one of the most significant stressor threatening fisheries as it interacts with and amplifies existing stressors. Fish resources are climate-sensitive, therefore, changes in climatic conditions, particularly temperature and rainfall, alter the fish's chemical and physiological processes, consequently affecting the livelihoods and food security of fishery-dependent communities.

Several empirical studies have been conducted to demonstrate the impacts of climate change and variability on fish production in African inland freshwater fisheries, including Lake Kariba, Zimbabwe. However, there is a paucity of information on the impacts of climate change and variability on fishery-dependent communities on the shoreline of Lake Kariba in Zimbabwe. To address the knowledge gap, this study investigated the effects of climate change on inland freshwater fisheries in two major fishing districts found along the shoreline of Lake Kariba namely Binga and Kariba/Nyaminyami Rural Districts in Zimbabwe. The study assessed the vulnerability of small-scale fishers and fishery resources to the effects of climate change and the fisher's perceptions of climate change. In addition, the fisher's adaptation strategies and the barriers and limits to adaptation were identified. Lastly, the study recommended strategies that can be adopted to build the resilience of freshwater fisheries to the probable effects of climate change.

The study employed a mixed-method research approach to collect data. Primary data were collected from small-scale fishers and key informants using a semi-structured questionnaire and focus group discussions, and secondary data of climate variables were obtained from the Meteorological Services Department of Zimbabwe. The data were subjected to different statistical analyses using IBM SPSS Statistics 27 and Microsoft Excel.Study findings indicate that small-scale fishers of Lake Kariba are aware of the climate change phenomenon. Most fishers indicated that the temperatures have increased (83.8%), rainfall decreased (73.6%) and the occurrence of extreme weather events such as droughts (56.9%) and floods (63.1%), has also increased in their respective areas. Fishers believe that the changing climatic conditions have adversely affected fish productivity and their fish catches, resulting in fishers employing several strategies to adapt to the changing environment and declining fish catches. These strategies include, but are not limited to, changing fishing gear, targeting new species, increasing fishing effort and days, adopting alternative livelihood strategies and migrating to a different fishing camp or village. A multinomial logistic regression model indicated that the fisher's experience positively and significantly influenced the adoption of all adaptation strategies except livelihood diversification.

The Livelihood Vulnerability Index (LVI) shows that fishing communities in the Kariba district are more vulnerable to the impacts of climate change than those in the Binga district, due to their lower adaptive capacity and marginalisation of fishing communities in the Kariba district. High dependency on climate-sensitive resources as the main livelihoods increased the sensitivity of the fishing communities to the impacts of climate change. Findings indicated that the fisher's ability to adapt to a changing environment and declining fisher resources was hindered by several factors such as fishing regulations, a lack of access to basic services, and institutions, lack of technologies, ecological limits and natural limits. Therefore, to build or strengthen the resilience of the fisheries sector in Lake Kariba, fisheries managers, the government, agents of development, non-governmental organisations and the resource users should ensure effective lake co-management, increase fishers' access to early warning systems, ensure stakeholder participation in decision-making processes, education and raise awareness, provide aid and basic services, conduct fish stocks assessments and formulate pro-sustainable fisheries policies.

This study contributed empirical evidence to current debates in the literature on the impacts of climate change on fishing communities, by enhancing an understanding of the characteristics and determinants of fishing communities' vulnerability, adaptation strategy and limits and barriers to the adaptation of fishing communities to climate variability and change. The findings form the basis for further detailed research into the vulnerability and adaptation of small-scale fishing communities to climate variability and change. Collaborations between researchers, extension officers, development agencies, and fishers to formulate climate adaptation strategies to promote resilience in the fishery sector for sustainable fisheries for the future generation is encouraged.

Keywords: vulnerability, adaptation, resilience, small-scale fisheries, Lake Kariba.

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ACRONYMS AND ABBREVIATIONS

BMU	Beach Monitoring Units
BRD	Binga Rural District
BREM	Biomass Random-Effects Model
CFP	Command Fisheries Programme
CPU	Civil Protection Unit
CPUE	Catch Per Unit Effort
CVI	Coastal Vulnerability Index
EWS	Early Warning Systems
FAO	Food and Agriculture Organisation
FOEN	Federal Office for the Environment
GCM	General Circulation Models
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GoZ	Government of Zimbabwe
GZFAP	Government of Zimbabwe Food Aid Progamme
HSSREC	Humanities and Social Sciences Research Ethics Committee
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
KRD	Kariba Rural District
LBB	Length-Based Bayesian Biomass
LED	Light-Emitting Diodes
LKFRI	Lake Kariba Fisheries Research Institute

LKNC	Lake Kariba Navigation Control
LKRI	Lake Kariba Fisheries Research Institute
LVI	Livelihood Vulnerability Index
MSDZ	Meteorological Services Department of Zimbabwe
NASA	National Aeronautics and Space Administration
NASAC	Network of African Science Academies
NGO	Non-governmental Organisations
PVI	Process Vulnerability Index
SDG	Sustainable Development Goal
SES	Social-Ecological System
SSA	Sub-Saharan Africa
SVI	Socio-economic Vulnerability Index
UNCTD	United Nations Conference on Trade and Development
UNDRR	United Nations Office for Disaster Risk Reduction
UNECA	United Nations Economic Commission for Africa
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNICEF	United Nations International Children's Emergency Fund
VMS	Vessel Monitoring Systems
WFFP	World Forum of Fisher People
ZNCCRS	Zimbabwe National Climate Change Response Strategy
ZPWMA	Zimbabwe Parks and Wildlife Management Authority
ZRA	Zambezi River Authority
ZRB	Zambezi River Basin

CHAPTER ONE

INTRODUCTION

1. Background and its problem

The effects of climate change are expected to be widespread across ecosystems, cultures, and economies, placing greater strain on all forms of livelihoods and food production, including those in the fisheries and aquaculture sector (Cochrane et al. 2009). Even though climate change has been a constant on the planet, the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report indicates that human activities have accelerated the rate of climate change through increased greenhouse gases (GHGs) emissions in the past five decades (IPCC, 2021). According to Seneviratne (2012: 115), 'climate change leads to changes in the frequency, duration, intensity, spatial extent, and timing of weather and climate extremes, and can result in unprecedented impacts'. Africa is considered to be one of the regions that will be severely affected by climate change and variability due to limited social, political, economic, and human capacity to adapt to the impacts of climate change (Medany et al., 2006; Chen and Ravallion, 2007). Additionally, Africa's heavy dependence on natural resources-based livelihoods makes it more susceptible to the impacts of climate change (Thompson et al., 2010). The United Nations Economic Commission for Africa (UNECA) states that agriculture is the backbone of African economies, as the sector employs more than 70% of the labour force and contributes approximately 25% of Africa's Gross Domestic Product (GDP) (UNECA, 2009). However, the agricultural sector in Africa is susceptible to the negative impacts of climate change. Williams and Rota (2011) state that, due to the underperformance of the agriculture sector owing to climate change and variability, more people will turn to fisheries as a source of livelihood and food supply.

The fisheries sector is widely recognised for its significant contribution to poverty alleviation, promoting socio-economic growth, enhancing food and nutrition security and improving the livelihoods of marginalised communities (Béné et al., 2016; Chan et al., 2019). In Africa, the fisheries sector employs approximately 12,3 million people with 50% employed as fishers, 42.5% are processors and 7.5% working in fish farming (De Graaf and Garibaldi, 2015; Obiero et al., 2019). Apart from employment creation, fish is the main or only source of animal protein for more than 200 million people in Africa (Mohammed and Uraguchi, 2013; Obiero et al., 2019). Rangel-Huerta et al. (2012), and Allison et al. (2013) state that human fish intake helps to reduce the risks of both malnutrition and non-communicable diseases such as coronary heart disease, cardiovascular diseases and high blood pressure. Hence, the significant contribution of fisheries to food and nutrition security led the Food and Agriculture Organisation (FAO), to recognise the role of fisheries in meeting the Sustainable Development Goal number two (SDG2): ending hunger, improving nutrition and realising food security (Bennett et al., 2018).

However, the fisheries sector is experiencing a plethora of anthropogenic stressors such as overfishing, pollution, illegal fishing, land-use change, and climate change (Marshall, 2012; Cohen et al., 2016; Kao et al., 2020). Research indicates that changing land-use and changing climate are the two most important stressors affecting the fisheries sector (Kao et al., 2020). In inland freshwater ecosystems, land-use change and changing climate may affect the ecosystem directly, as they alter the water temperature and water levels, and indirectly through changing the equilibrium between the inputs and outputs of sediments and nutrients (Harrod et al., 2019). Furthermore, climate change presents the most significant threat to fisheries as its effects interact and amplify existing stresses (Shelton, 2014; Barange et al., 2018; Harrod et al., 2019).

Fiorella et al. (2021) postulate that climate change is anticipated to exacerbate demands on inland fisheries and fundamentally alter freshwater ecosystems. Climate change impacts freshwater fisheries in several ways including warming temperatures, increased rainfall variability, habitat loss and the increasing occurrence and intensity of extreme weather events (Harrod et al., 2019). These climate change-related impacts affect fish productivity, fishing and its related operations, livelihood strategies and food security of communities dependent on fishery resources (Badjeck et al., 2010; Shelton, 2014).

The effects of climate change and variability are anticipated to be heaviest on small-scale fisheries (FAO, 2018), especially those in the tropical and subtropical areas where ecosystem productivity is declining as compared to temperate and polar ecosystems (Shelton, 2014). Declining fish productivity and catches of fishers due to climate change and variability has been reported in several African lakes including Lake Tanganyika, Lake Malawi, and Lake Chilwa (Lunduka, 2013; Cohen et al., 2016; Makwinja and M'balaka, 2017). In Zimbabwe, climate change and variability led to declining fish productivity in Lake Kariba, Lake Chivero and Lake

Manyame (Ndebele-Murisa et al., 2011; Utete et al., 2018). Declining fish productivity and catches will have adverse socio-economic effects on fishery-dependent communities.

The livelihood, food and nutrition security of inland small-scale fishing communities greatly depend on the ability of the fishing households or communities to adapt to the impacts of changing climatic conditions (Saroar and Routray, 2015). Bennett et al. (2014) and Pereira (2017) argue that the adaptive capacity of African fisheries is constrained by poverty, lack of alternative livelihood strategies, marginalisation, policy, infrastructure, and weak institutions. On the other hand, adaptation to the impacts of climate change and variability is enhanced by numerous factors including access to weather information, knowledge of climate change, livelihood assets, geographical location and various demographic and socio-economic factors (Saroar and Routray, 2015).

The Network of African Science Academies (NASAC) argues that a high adaptive capacity minimises vulnerability and enhances resilience (NASAC, 2015). Resilience is the capacity of a social-ecological system to withstand perturbations and to rebuild and renew itself afterwards (Stockholm Resilience Centre 2007b). Hence, in fisheries, resilience is the capacity of the fisheries sectors to withstand perturbations like changing climate factors such as rainfall and temperature and the ability of the sector to rebuild itself. Allison et al. (2007, p. 6) defined a resilient small-scale fishery in the developing world as "the one that absorbs shocks and reorganises itself following stresses and disturbance while still delivering benefits for poverty reduction". Fish harvest is regarded as the greatest threat to the resilience of small-scale fisheries (Allison, 2007), but fisher's knowledge of climate change and its associated impacts, adoption of new fishing technologies, policy, institutions, adaptive management strategies and risk management systems can enhance their resilience (Lovell, 2015).

Despite the little contribution to Zimbabwe's Gross Domestic Product (GDP), fisheries have been recognised for their significant contribution to employment, and food security (Kupaza et al., 2015). Local communities along lakeshores, dams and river basins have been renowned for exploiting fishery resources (Chisango, 2017). There is a lack of statistical data on the estimated number of people involved in fisheries in Zimbabwe (Kupaza et al., 2015), but the Ministry of Environment, Water and Climate (MEWC) state that Zimbabwe's fisheries sector supports more than 50 000 people who are directly involved in fisheries as a primary livelihood (MEWC, u.d).

The number of fishers in Zimbabwe is increasing because of the indigenisation policy, the need to address unemployment (Kupaza et al., 2015), and the recent Command Fisheries Programme (CFP). The Zimbabwe government introduced the CFP aiming to create employment, enhance food and nutrition security and improve accessibility to fisheries resources (MEWC, u.d).

1.1. Problem statement

The inland fisheries sector, particularly small-scale fisheries, in Zimbabwe supports thousands of people as a source of employment, livelihood and food security (Kupaza et al., 2015). However, the sector is susceptible to the impacts of climate change and variability along with other anthropogenic stressors. Changing climatic conditions have potential biophysical and socio-economic consequences on fishery resources and fishery-dependent communities. There is a vast knowledge of the effects of climate change and variability on fisheries, especially on fish production, in several marines and freshwater ecosystems in Africa, but little is known about its effects on fishing communities that depend on inland freshwater fisheries and their adaptation strategies, specifically in Zimbabwe. It is important to understand the localised and sector-specific impacts of climate change and variability for policy planning to enhance the adaptation and resilience of fishery resources and the resource users against climate change. Therefore, the study seeks to close this knowledge gap, adding to Zimbabwe's literature by exploring the effects of climate change and variability on small-scale fisheries in Lake Kariba, Zimbabwe.

1.2. Significance of the study

In southern Africa (excluding South Africa) more than 86% (10, 747) of the dams are in Zimbabwe (Ersdal, 1994). In rural communities, surface water is vital for the food production process and contributes to the livelihoods of millions of people through sustainable agriculture and fisheries. Zimbabwe's freshwater ecosystems have been recognised for their significant contribution to job creation, livelihoods and enhancing food security (Kupaza et al., 2015). However, scientific research indicates that the fisheries sector is vulnerable to the impacts of climate change and variability, but the IPCC (2012) argues that the impacts are not evenly distributed across regions, nations and population groups. Hence, the IPCC (2012) emphasises the importance of recognising the differences in vulnerability between and within communities. This provided the context for this research to investigate the localised impacts of climate change on fisheries and fishery-dependent people in Lake Kariba, Zimbabwe.

It is widely acknowledged that adaptation is one of the most important strategies used to address the impacts of climate change (Harvey et al., 2018). The IPCC conceptualise adaptation as "an adjustment in natural or human systems in response to actual or expected climate stimuli or their effects which moderate harm or exploits beneficial opportunities" (Saroar and Routray, 2015, p. 324). Pereira (2017) argues that the impacts of climate change vary and adapting to these impacts needs to be context specific. Adapting to the changing environment owing to climate change is inevitable, but the adaptation efforts can be impeded in several ways. Therefore, there is a need to identify local barriers and limits of climate change adaptation among small-scale fishers. The information generated might contribute to the formulation of strategies and policies intended to enhance small-scale fisher's adaptation and enhance climate resilience among small-scale fishing communities.

The study contributes to the current body of knowledge and instigates more research on fishing communities. Furthermore, the study findings might draw the attention of the government, non-governmental organisations (NGOs) and international organisations who will be willing to intervene in Zimbabwe's small-scale fisheries development to enhance resilience to the impacts of climate change.

1.3. Aim

The study investigated the effects of climate change and variability on the biophysical and socio-economic systems of small-scale fisheries of Lake Kariba in the Zambezi River Basin, Zimbabwe.

1.4. Objectives

- To review the existing literature regarding the impacts of climate change and variability on freshwater fisheries,
- To assess the small-scale fisher's perceptions of climate change and variability and their adaptation strategies,
- To assess the climate change vulnerability of fishing communities along the shoreline of Lake Kariba,
- To identify the barriers and limits to climate change adaptation among small-scale fishers along the shoreline of Lake Kariba,

- To provide strategies to strengthen resilience and reduce the vulnerability of inland fisheries to the impacts of climate change.

1.5. Research questions

i. What are the small-scale fisher's perceptions about the climate change phenomenon?
ii. Which adaptation strategies are being employed by fishers to deal with fluctuating fishery resources?
iii. Are fishing communities along the shoreline of Lake Kariba vulnerable to the impacts of climate change?
iv. What hinders the ability of fishers to adapt to the changing environment and fishery resources?
v. What can be done to enhance the resilience of small-scale fishers to the impacts of climate change and variability?

1.6. Study area

This study was done in two hydrological basins namely, Binga and Sanyati, under the Binga Rural District (BRD) and Kariba/Nyaminyami Rural District (KRD), respectively. These basins are located along the shores of Lake Kariba in Zimbabwe, situated at 17°37’22’S and 27°20’23’E for BRD and 16°49’25’S and 28°46’14’E for KRD (Figure 1.1). Lake Kariba is one of the largest artificial reservoirs (by volume), in the world (Beilfuss, 2012, Muchuru et al., 2016). The lake was built in 1956 mainly for hydroelectric power generation and it is shared between Zambia and Zimbabwe (Mukona and Mwiinga, 2021). The lake is divided into five basins namely, Binga, Mlibizi, Sanyati, Sengwe and Ume (Magqina et al., 2020). Besides supporting hydroelectric power generation, the lake supports both commercial and small-scale fisheries with more than 40 different fish species found in the lake waters (Makaure et al., 2015). There are 41 camps and villages (35 fishing villages and six fishing camps) along the lake shore (Ndhlovu et al., 2017). These fishing areas fall under the wildlife and safari protected areas, which are regulated directly by the Zimbabwe Parks and Wildlife Management Authority (ZPWMA). According to the Statutory Instrument 362 of 1990, farming and livestock rearing are not permitted in wildlife and safari protected areas (Ndhlovu et al., 2017).

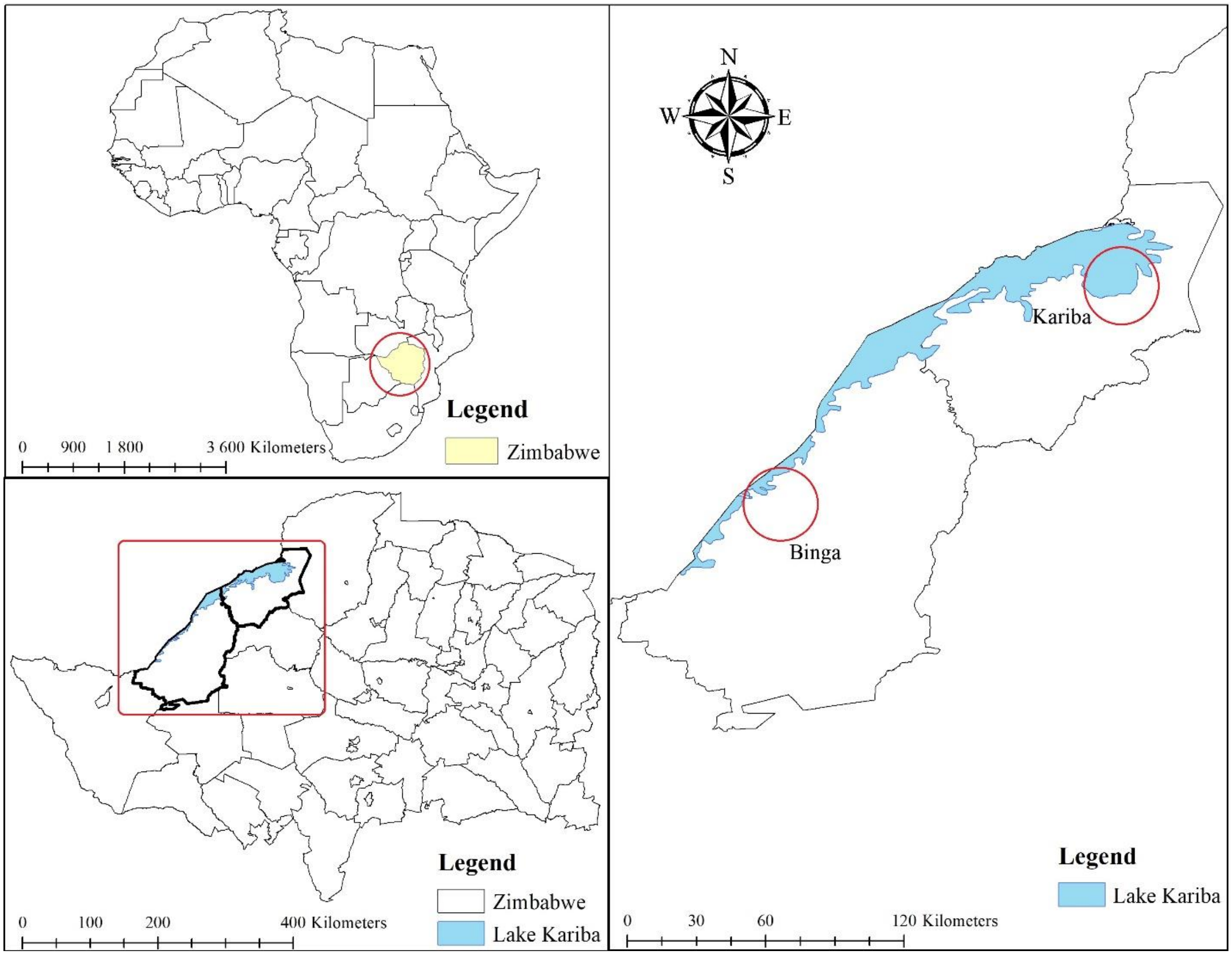

Figure 1.1: Location of the study areas. (*Source:* Author)

The climate of Kariba is generally tropical and semi-arid characterised by consistently high air temperatures, with mean annual temperature ranging between 24.4°C and 24.7°C and total rainfall averages above 610 mm per annum, but varies widely, ranging from 350 mm to 1 015 mm per annum (Ndebele-Murisa et al., 2013). Ndebele-Murisa et al. (2013) state that temperatures surrounding Lake Kariba have been rising at a faster rate than the IPCC regional projections for semi-arid regions of Africa. In addition, the average temperature of the lake rose by 0.7°C, at a rate of 0.03°C per annum between 1986 and 2011 (Mahere et al., 2014).

1.7. General methodology and study approach

A participatory research approach was employed in this study. To address the study objectives, primary data was obtained through semi-structured survey questionnaires (Appendix A), key informant interviews, observations, and focus group discussions (FGDs) guided by an interview guide (Appendix B). Data were collected from 120 fishers in six fishing camps/villages along the shoreline of Lake Kariba namely: Chinzonzo, Chikuyu and Intale in Basin 2 (Binga) and Gache-gache, Nyaodza and Fothergil in Basin 5 (Sanyati). Data collection and images of some of the fishing communities are shown in Appendix F.

The meteorological historical data were attained from the Meteorological Services Department of Zimbabwe (MSDZ). The quantitative data were subjected to statistical analyses using IBM SPSS Statistics version 27 and the qualitative data was subjected to thematic analysis.

1.8. Ethical considerations

This study was approved by the University of KwaZulu Natal, and an ethical clearance certificate, reference number HSSREC/00003055/2021 was granted by the Humanities and Social Sciences Research Ethics Committee (HSSREC) (Appendix D). The ZPWMA and the Zimbabwe Ministry of Local Government, Public Works, and National Housing permitted the study to be conducted in their areas of jurisdiction. Fishers' participation in the study was voluntary, and all participants gave verbal informed consent to participate in the study.

1.9. Thesis outline

This thesis was written in a manuscript (paper) format, where each chapter was a stand-alone paper. Five chapters of the thesis are research articles were either submitted, under review or published in peer-reviewed journals. Each research article was written as a stand-alone paper and can be read independently from the thesis, but each paper is linked and contributes to the overall aim and objectives of this study.

Chapter 1: provided the contextual background of the study, the study objectives and a general methodology employed in the study. **Chapter 2:** reviewed the existing literature and highlights the impacts of climate change on inland freshwater fisheries, adaptation strategies used by small-scale fishers to cope with fluctuating fishery resources, and fisheries management strategies. Lastly, the chapter highlighted the knowledge gaps and provides direction for future research. **Chapter 3:** This chapter assessed the fisher's perceptions of climate change and variability, perceived impacts of fisheries and their adaptation strategies. Additionally, the chapter assessed the factors influencing the adoption of adaptation strategies. **Chapter 4:** assessed the vulnerability of the fisheries sector to the effects of climate change and variability in two fishing districts using a composite index approach (Livelihood Vulnerability Index). **Chapter 5:** identified the barriers and limitations to climate change adaptation within fishing communities.

The findings were divided into two categories, namely, barriers and limitations. The chapter further discussed the barriers and limitation and provide suggestions to promote climate change adaptation. **Chapter 6:** provided strategies that can be implemented to build or strengthen the resilience of fishery resources and fishery dependent households to the impacts of climate change. **Chapter 7:** synthesised the major study findings and identifies relevant issues that may inform future research.

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CHAPTER TWO[1]

LITERATURE REVIEW

Sub-Saharan Africa Freshwater Fisheries under Climate Change: A Review of Impacts, Adaptation, and Mitigation Measures.

Abstract

Sub-Saharan Africa's freshwater fisheries contribute significantly to the livelihoods and food security of millions of people within the region. However, freshwater fisheries are experiencing multiple anthropogenic stressors such as overfishing, illegal fishing, pollution, and climate change. There is a substantial body of literature on the effects of climate change on freshwater fisheries in sub-Saharan Africa. This study reviews the existing literature and highlights the effects of climate change on freshwater fisheries, the adaptation strategies of fishery-dependent households in response to these effects, and fisheries' management and mitigation efforts in the face of climate change. The general effects of climate change on freshwater environments include warming water temperatures, increased stratification, modified hydrological processes, and increased pollutants. These effects adversely affect the physiological processes of fish and the overall wellbeing of fishery-dependent people. To cope with the effects of fluctuating fishery resources due to climate change and variability, fishery-dependent people have adopted several adaptation strategies including livelihood diversification, changing fishing gear, increasing their fishing efforts, and targeting new species. Several management attempts have been made to enhance the sustainability of fishery resources, from local to regional levels. This study recommends the participation of the resource users in the formulation of policies aimed at promoting climate change adaptation and the resilience of freshwater fisheries for sustainable development.

Keywords: fish productivity; eutrophication; socio-economic effects; resilience; small-scale fishers.

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2.1. Introduction

Freshwater fisheries provide low-cost protein, recreation, and commerce to hundreds of millions of people around the world, particularly in areas where alternative sources of nutrition and employment are scarce (McIntyre et al., 2016). According to the Food and Agriculture Organisation (FAO), inland capture fisheries contributed about 11.9 million metric tons of fish in 2017 alone, equal to 12.7% of the global fish catch, of which Asia and Africa are the biggest producers of inland fisheries (FAO, 2019). In regions where malnutrition is a critical concern, inland fisheries provide a key source of protein, fatty acids, and other micronutrients that are scarce in other food sources (Kolding et al., 2019; Muringai et al., 2021). In sub-Saharan Africa (SSA) alone, fish is a primary source of animal protein and micronutrients for over 200 million people, or about 30% of the African population (AUC-NEPAD, 2014). Besides the significant contribution to food and nutrition security, the inland fishery sector accounts for about 40.4% of the 12.3 million people employed in the fishery and aquaculture sector (De Graaf and Garibaldi, 2014). In some SSA countries such as Chad, Malawi, Mali, Mauritania, and Uganda, freshwater fisheries account for about 3 to 5 of the national gross domestic product (GDP) (World Bank, 2012).

Despite the nutritional and economic significance, SSA's inland freshwater fisheries are experiencing a plethora of anthropogenic stressors such as overfishing, pollution, illegal fishing, land-use change, and climate change and variability (Cohen et al., 2016; Bawuro et al., 2018; Kao et al., 2020; Magqina et al., 2021). These stressors have been acknowledged to have contributed to the noticeable decline in the fish production of wild capture fisheries in several African freshwater systems. For instance, Hara (2011) and Singini et al. (2013) indicated that overfishing led to a decline in the abundance of the commercially important chambo, the local name for three closely related fish species of tilapiine cichlids (namely *Oreochromis squamipinnis*, *Oreochromis lidole,* and *Oreochromis karongae*) in Lake Malombe and Lake Malawi. Moreover, Gaber et al. (2013) claimed that pollution of freshwater bodies, namely El-Rahawy and River Nile, resulted in several changes in the chemical and physiological processes of fish, affecting overall fish productivity. In addition, illegal fishing was also acknowledged to be threatening freshwater fisheries. For instance, Raji et al. (2012) stated that illegal fishing, which includes the use of incorrect gear and explosives, has severe repercussions on the crucial biomass of fish biodiversity and livelihood activities.

Kao et al. (2020) postulated that changing land-use, and changing climatic conditions are the two most important anthropogenic stressors, which may affect freshwater ecosystems directly, as they alter the water temperature and water levels, and indirectly through changing the balance between the inputs and outputs of sediments and nutrients. There is sufficient evidence that fish production in African inland fisheries is more dependent on the external climatic drivers than on human exploitation rates and numerous management interventions (Gownaris et al., 2018, Kolding et al., 2016). Studies such as those by Ndebele-Murisa (2011), Niang et al. (2014), and Woolway et al. (2020) argue that climate change is significantly altering freshwater ecosystems, adversely affecting fish productivity and human societies that are heavily reliant on fishery resources for livelihoods and food.

Climate change impacts on freshwater fisheries remain relatively under-examined when compared with those on marine systems, even though climate change is expected to exacerbate demands on inland fisheries and fundamentally alter freshwater ecosystems (Fiorella et al., 2021). The available literature indicates that some of the impacts of climate change on freshwater ecosystems include warming of the surface water, changes in the hydrological cycle, thermal stratification, eutrophication, and extreme weather events (Harrod et al., 2019; Bouraï et al., 2020; Islam et al., 2020; Littlefair et al., 2021). Faced with changing environmental conditions, aquatic species and human societies exhibit different responses associated with different processes. Macusi et al. (2015), Carosi et al. (2021), and Huang et al. (2021) postulate that aquatic species respond to changing climatic conditions through changes in distribution, phenology, extinctions, and biological adaptations, such as changing metabolic rates, growth, and reproduction.

Aquatic ecosystems and human societies, which are dependent on natural ecosystems for livelihoods and food supply, have adapted and continue to adapt to climate change's impacts. Vesseur (2015) posited that adaptation includes the idea of change in response to environmental change. Environmental change drives evolution in natural systems and promotes novel responses in human society (Vesseur, 2015). For example, based on the temperature size rule, the average size of fish can change in response to changes in water temperature (Ohlberger, 2013, Reddin et al., 2016). In response to changing aquatic species, fishers change their fishing gear, increase their fishing effort, diversify their livelihoods, and target new species, among other responses

(Musinguzi et al., 2016; Muringai et al., 2022). However, some fishers' responses to coping with the impacts of climate change and variability may further aggravate the stressors already being experienced by freshwater ecosystems. Climate-adaptive fishery management can mitigate most of the negative impacts of climate change on fish productivity, consequently benefiting human societies (Free et al., 2020).

Several studies, including those of Ndebele-Murisa et al. (2011), Katikiro and Macusi (2012), Mboya (2013), Mohammed and Uraguchi (2013), Cohen et al. (2016), Utete et al. (2018), and Muringai et al. (2020), investigated the impacts of climate change and variability on fisheries in SSA. However, despite the significant contribution of freshwater fisheries, knowledge of climate change's actual and potential impacts and variability on SSA inland fisheries is surprisingly limited. Harrod et al. (2019) stated that inland freshwater fisheries are neglected in climate research, leaving fisheries managers, fishers, and policymakers with little to no guidance concerning how inland fisheries will be affected by climate change and the future of those who rely on them for their livelihoods and food security. This will have critical implications for future food security and human wellbeing. Despite significant efforts to investigate the impacts of climate change and variability on inland fisheries at the community and national level, it is also important to understand the impacts of climate change on freshwater fisheries at a regional level. Thus, this article highlights the impacts of climate change on freshwater capture fisheries specifically in SSA based on the available literature and reports. Muringai et al. (2021) conducted a similar study; nevertheless, their study looked at the entire fishery sector (both marine and freshwater). This review, however, mainly focuses on freshwater wild capture fisheries, as marine and freshwater environments are affected differently by climate change. The impacts differ in both magnitude and intensity. In this review, the authors went further to provide the detailed impacts of changing climatic variables on freshwater fisheries, adaptation, fishery management, and climate change mitigation measures, which were more generalised in Muringai et al. (2021). The review is divided into different sections indicating trend changes of the climate variables that affect fisheries, the characteristics of inland freshwater fisheries, how climate change impacts the freshwater fisheries sector, adaptation measures, and fishery management strategies. This review article also provides directions for future research.

2.2. Climate trends and extreme weather events

Distinctive seasonal climates characterise SSA, as the region lies in the tropics and includes tropical and subtropical climatic zones, except southern Africa (Stockdale, 2017). However, numerous local environmental factors such as differences in altitude, uninterrupted expanses of plateau and plains, and other localised variables within the zones generate varying climate and weather conditions within the region (Kotir, 2011; Stockdale, 2017). Temperature and rainfall are the main climate variables that are acknowledged to have direct impacts on inland fisheries (Harrod et al., 2019). Research conducted by Kundzewicz et al. (2014), Engelbrecht et al. (2015), and Gizaw and Gan (2017) showed that alterations in temperature, rainfall, and extreme weather events, and their distribution have been dramatic across the region. According to the National Aeronautics and Space Administration (NASA), the global mean temperature has increased by more than 1°C since 1880, and that two-thirds of this warming has occurred since 1975 at a rate of about 0.15°C to 0.2°C per decade (NASA, 2021). Temperatures across the African continent are increasing twice as fast as the global mean estimates of 0.4°C and 1.2°C per century for the Northern and Southern Hemispheres, respectively (Davis and Vincent, 2017). Even though trends seem to be prevalent across the region, changes in temperature are not always the same within the region (Kotir, 2011). This is due to differences in altitude and other localised variables such as vegetation density, the area covered by surface water, and landforms. Climate models further project an increase in temperature across the African continent in the 21st century, with SSA expected to experience the strongest warming in the region by 2050 (Greenpeace, 2020). Adhikari et al. (2015) projected that mean temperatures will likely increase by 1.4°C to 5.5°C by 2100 across Africa owing to climate change. Africa is susceptible to extreme rainfall variations from year to year because most of the region is semi-arid (Nicholson et al., 2018). According to Kotir (2011), Africa’s rainfall patterns are influenced by large-scale intra-seasonal and inter-annual climate variability, including occasional El Niño–Southern Oscillation (ENSO) events in the tropical Pacific, which cause frequent extreme weather events such as floods and droughts. The problem with the region is that it suffers from a paucity of historical data for drawing robust conclusions on the observed rainfall trends over the past century (Davis and Vincent, 2017; IPCC 2021).

Similar to the temperature patterns, rainfall patterns across Africa vary immensely and exhibit different scales of temporal and spatial variability (Kotir, 2011). In SSA, areas with sufficient historical data, such as southern Africa, the interannual variability of rainfall has increased over the past decades, but with recurrent droughts (Zhan et al., 2016; Lottering et al., 2021). Some parts of SSA have experienced an increase in rainfall, but overall, the decline in rainfall is more pronounced (Kotir, 2011). Rapid and statistically significant decreases in rainfall have been recorded in some parts of southern Africa (Girvetz et al., 2019), such as Botswana, Zimbabwe, and western South Africa (Niang et al., 2014). Nevertheless, some parts of east Africa are becoming wetter (Niang et al., 2014; Adhikari et al., 2015; Girvetz et al., 2019). Modelled rainfall projections through the 21st century is less certain than temperature projections and show higher spatial and seasonal dependence than temperature projections (IPCC, 2021). Over 80% of the climate models agree that rainfall will decrease over most parts of Africa (Niang et al., 2014). Mean annual rainfall is projected to decline by 5%, 4%, and 5% over central, western, and southern Africa, respectively (Zougmoré et al., 2016).

Climate change leads to changes in the intensity, frequency, duration, spatial extent, and timing of weather and climate extremes, and can result in unprecedented consequences (Seneviratne, 2012). In recent decades, Africa has suffered from a plethora of record-breaking climatic extremes, including heavy storms, heat waves, floods, and droughts due to climate change (Nangombe et al., 2018). The most frequent extreme weather events experienced in SSA are floods and droughts (Ongoma et al., 2018). For instance, southern Africa experienced 254 flood events, 130 large storms, and 88 droughts between the years 1980 and 2016 (Davis and Vincent, 2017). High temperatures and the unpredictability of both the temporal and spatial distribution of rainfall events will increase the occurrence of extreme weather events (Kotir, 2011). Climate models used to predict drought over southern Africa suggest that, with increased temperatures, the frequency and intensity of drought conditions will increase, but the effects vary across regions (Greenpeace, 2020). Models project that in the 2050s and 2080s; the frequency of short droughts is expected to increase by about 4–7% in the central, eastern, and southern parts of Africa (Gizaw and Gan, 2017).

2.3. Characteristics of sub-Saharan African inland fisheries

Inland fisheries are fisheries exploiting wild fishery resources in waters located inland from the coastline, such as lakes, wetlands, reservoirs, floodplains, rivers, streams, and even rice fields (Funge-Smith and Bennett, 2019). In 2017, inland freshwater fisheries accounted for 13% or

11.9 million ton of the total global fish catch, of which five million tons were from African inland capture fisheries (FAO, 2019). However, the reported figures of the inland fishery catch may be underestimated because many inland fisheries are subsistence and small-scale in nature, and most of the fish produced are consumed or traded locally without entering the formal economy (Bartley et al., 2015). Furthermore, the fish catch figures are understated because most inland fisheries operate in remote areas and have poorly defined value chains or infrastructure for dealing with catches from inland waters, and collecting dispersed information is costly (World Bank, 2012; Bartley et al., 2015). According to the World Forum of Fisher People (WFFP), inland fisheries are small-scale in nature and make little contribution to national GDPs (WFFP, 2017). Inland small-scale fisheries are characterised using low-technology fishing methods, the use of non-motorised vessels or no vessels at all, and limited post-harvest transportation (Funge-Smith and Bennett, 2019). Researchers argue that inland small-scale fisheries employ approximately four million people more than their marine counterparts (Funge-Smith and Bennett, 2019, Smith and Basurto, 2019). Small-scale fisheries are also characterised by a diverse workforce, with women representing about 50% of the workers (HLPE, 2014; Bartley et al., 2015). Women are found along the entire small-scale fishery value chain, but they mostly dominate the post-harvest sector (processing and trading) in most fishing communities (FAO, 2010).

Several studies have suggested that African inland fisheries are experiencing several challenges such as pollution, overexploitation, invasive alien species, hydrological disruptions, habitat loss, and the negative impacts of a changing climate (Tweddle, 2010; Ndebele-Murisa et al., 2011; Cohen et al., 2016; Lévêque and Paugy, 2017; Utete et al., 2018; Kimirei et al., 2021). These stressors have led to a decline in primary fish production and total fish catches, particularly for small-scale fishers (Welcomme and Lymer, 2012). Most studies, for example, Ndebele-Murisa et al. (2011) and Cohen et al. (2016), inculpated climate change, among other factors, for declining fish productivity in some of Africa's great lakes such as Lake Tanganyika and Lake Kariba.

2.4. Impacts of climate change and variability on SSA inland fisheries

Climate change and variability are expected to affect the fishery sector in multiple ways through changes in mean temperature, rainfall amounts and patterns, and the increasing occurrence and severity of extreme weather events. However, the precise consequences cannot be defined due to the limited availability of information on the impacts of climate change and availability on African inland fisheries (Bartley and Jorgensen, 2010). Figure 2.1 illustrates how climate change and its associated extreme weather events affect the socio-ecological systems (SES) of inland fisheries.

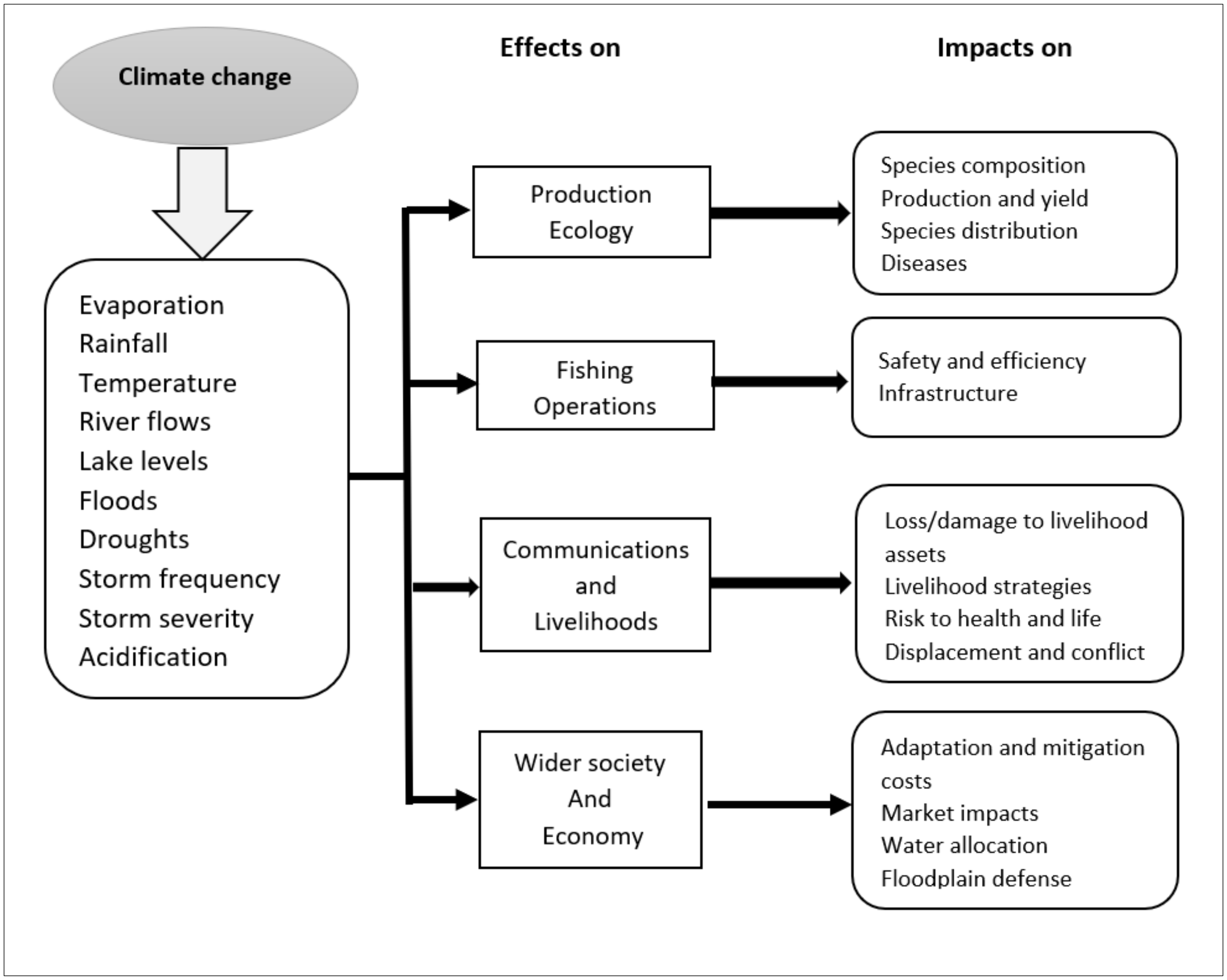

Figure 2.1: Climate change and variability impacts on inland fisheries (Adopted and modified from Badjeck et al. (2010)).

2.4.1. Water temperature

Water temperature is recognised as the most influential factor of all environmental stressors that affect inland freshwater fisheries (Ndebele-Murisa et al., 2011; Nyboer and Chapman, 2017). Freshwater species are likely to be strongly affected by warming water temperatures due to discrete ecosystem boundaries, limiting the potential of species range shifts for tracking thermal optima compared with marine species (Walberg, 2011; O'Gorman et al., 2016). Considering that inland freshwater fish are thermal conformers (poikilotherms), hence, fluctuations in water temperature have consequent effects on the fishes' biological and physio-chemical processes. These effects include, but are not limited to, growth and body size, metabolism, maturation, sex determination, mortality, migration, immune response, habitat suitability, reproductive success, and distributional shifts (O'Gorman et al., 2016; Harrod et al., 2019). Different fish species have different temperature tolerances, for instance, the dominant inshore fish species such as *Cichlidae* and *Cyprinodontiformes*, which are both extremely diversified have, have optimum temperatures of between 29^{o}C – 32^{o}C and 22^{o}C – 32^{o}C, respectively (Thibault and Schultz, 1978; McDonnell and Chapman, 2015).

There is limited literature on the effects of climate change and variability on primary and secondary productivity on SSA's inland waters. However, several studies have indicated that warming water temperatures have caused a decline in plankton, particularly phytoplankton (plants), productivity in SSA's lakes (Tierney et al., 2010; Ndebele-Murisa et al., 2014; Sanful et al., 2017). Plankton (phytoplankton and zooplankton), which form the aquatic food web, is sensitive to environmental change. A study by Abo-Taleb et al. (2016) revealed that increasing water temperatures have resulted in a decline in plankton in El-Mex bay, as illustrated in Figure 2.2. Simultaneously, fish metabolism increases with increasing temperatures (Nyboer and Chapman, 2017, O'Gorman et al., 2016); for instance, Nyboer and Chapman (2017) revealed that the Nile perch's (*Lates niloticus*) metabolism rate increased in response to increasing water temperatures. Therefore, if increases in metabolic demand are not matched by increasing plankton availability, fish populations are likely to decline or become extinct due to less food availability (Cohen et al., 2016, O'Gorman et al., 2016). For example, Magadza et al. (2011) detected that the Tanganyika sardine (*Limnothrissa miodon*) of Lake Kariba declined owing to shortages of food resources (zooplankton).

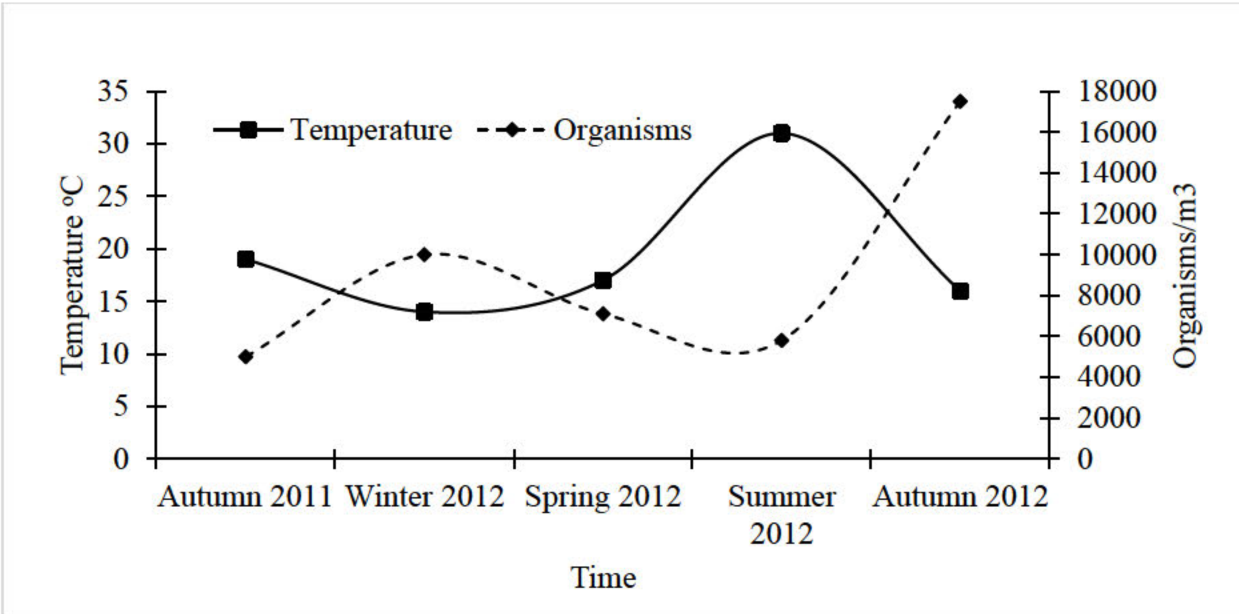

Figure 2.2: Correlation between seasonal temperatures and organisms (Plankton) abundance. Adopted from Abo-Taleb et al. (2016).

Water temperatures also act as a reproduction cue and influence physiological pathways associated with gamete development (Burt et al., 2011, Devkota and Kathayat, 2020). Water temperatures influence fishes' reproduction behaviour, spawning pattern and timing, gamete maturation, and the early life histories of fish (Devkota and Kathayat, 2020). Fish species that have limited ability to adapt to changing temperatures face a greater risk of extinction or extirpation (Olusanya and van Zyll de Jong, 2018). In fishery studies, the impacts of climate change are mostly associated with warming temperatures, and the effects of extreme cold temperature on fish have received little attention (Szekeres et al., 2016). Nevertheless, increases in water temperature variability due to climate change increases the potential of increased cold shock events (Szekeres et al., 2016). Cold shock refers to "the stress response that occurs when fish have been acclimated to a specific water temperature range and subsequently exposed to a rapid decrease in temperature, resulting in a cascade of physiological and behavioural responses" (Szekeres et al., 2016, p. 239). Research on marine fish has indicated that weather-induced cold shock events in 1940 resulted in large-scale fish mortalities. However, the impacts cannot be generalised for freshwater fish (Szekeres et al., 2016). Harrod et al. (2019) stated that this significant influence of temperature on fish physiological processes led Brett in 1970, to describe temperature as the master abiotic factor that affects freshwater fishes' capacity to support inland fisheries. Hence, the projected increase in temperatures over SSA will have potential adverse impacts on the inland freshwater fishery sector.

2.4.2. Thermal stratification

Surface water temperature is closely related to air temperature (Magee and Wu, 2017). Hence, surface water temperature increases in response to warming air temperatures owing to climate change. Increasing surface water temperature leads to changes in the density structure of lakes, with a layer of warmer, less dense water at the surface and cooler water at the bottom, known as thermal stratification (Vincent, 2009). The thermocline (sharp temperature gradient) forms at the contact zone of both layers as the warmer surface water layer (epilimnion) separates from the cooler water layer beneath during the stratification period (Ndebele-Murisa et al., 2014). Stratification limits the mixing of the epilimnion and hypolimnion layers, resulting in vertical profiles of different water temperatures, pH, and dissolved oxygen (Ndebele-Murisa et al., 2014). Furthermore, stratification limits nutrient flux into the upper surfaces (Mellard et al., 2011). Stratification is common in many deep tropical lakes in SSA, such as Chilwa, Malawi, Niger, Cabora Bassa, Chad, and Kariba (Ndebele-Murisa et al., 2014). For aquatic organisms, particularly fish, stratification limits habitable areas, forcing fish to balance between favourable temperatures and minimum dissolved oxygen requirements (Taabu-Munyaho et al., 2013). Most freshwater organisms are ectothermic (thermal conformers) and optimise their physiological performance by inhabiting habitats within specific thermal niches (Littlefair et al., 2021). Therefore, in the face of warming surface water temperatures in SSA, which is already regarded as the warmest are and is projected to warm faster than the mean global increase (Niang et al., 2014), surface water temperatures might exceed the physiological tolerances of some fish species. On the other hand, waters below the thermocline might have tolerable temperatures, but lack sufficient dissolved oxygen compared with the warm surface water, resulting in some fish species squeezing between these two extremes and experiencing niche compression during the stratified season (Taabu-Munyaho et al., 2013). In general, freshwater fish species respond to differences in thermal gradients in freshwater water bodies by shifting habitats (Taabu-Munyaho et al., 2013; Cornelissen et al. 2015; Agembe, 2018).

Contrary to Vincent (2009) and Ndebele-Murisa et al. (2014), who state that warming temperatures promote stratification, Mahere et al. (2014) and Marshall (2017) claimed that warming temperature weakens the thermocline (less pronounced stratification). A weak thermocline has been detected in studies by Mahere et al. (2014) and Marshall (2017) in Lake Kariba, which has been acknowledged to be experiencing warming temperatures. On the other hand, Mahere et al. (2014) and Marshall (2017) claimed that the perceived warming temperatures of Lake Kariba led to an increase in algal biomass and primary productivity. Therefore, the thermal stratification of inland freshwater bodies has and will continue to affect fish production, either by increasing or decreasing fish productivity.

2.4.3. Hydrological cycle

The hydrological cycle describes the continuous water movement above, on, and below the surface of the Earth (United States Geological Survey, 2016). It is affected by only two factors, which are human activities and climate (Wang et al., 2019). Climate change alters the present situation of the hydrological cycle and redistributes the water in terms of time and scale (Nan et al., 2011). Studies have shown that the global hydrological cycle has already responded to the observed increase in temperature over recent decades through changes in rainfall patterns, changes in runoff, and increased atmospheric water vapour content (Trenberth, 2011; Roudier et al., 2014; Hodnebrog et al., 2019). Several studies have agreed that climate change will affect both the quality and quantity of available water resources in the SSA region (Eludoyin and Olanrewaju, 2020; Ofori et al., 2021). According to the IPCC's climate projection models such as the General Circulation Model (GCM), the African dry tropics are projected to experience a decline in rainfall in the 21st century, ultimately affecting water availability and river runoff (Rameshwaran et al., 2021).

The aforementioned changes in the hydrological processes will affect water discharge patterns, consequently affecting water availability for fisheries, and physio-chemical processes and conditions (Harrod et al., 2019). Research has indicated that surface runoff plays two crucial roles in freshwater fisheries, which include transporting nutrient-supplying sediments (a source of fish feed) (Ipinjolu et al., 2013; Wang et al., 2016), and providing a suitable habitat for freshwater organisms (Miranda et al., 2020). During years of abundant rainfall and flooding, extensive nutrients are released in the flood plains, leading to explosive population growth at all levels in the fishery food chain (FAO, 2010). For example, a study by Mboya (2013) identified the number of fishers in the Mbita Division of Homa Bay County in Kenya increased when there was high rainfall, as compared with low rainfall periods, due to high fish productivity, influenced by the availability of fish feed and habitat suitability. In addition, several climate models have agreed that precipitation decreases with an increase in temperature (Harrod et al., 2019). Increasing temperature results in increased evaporation (Helfer et al., 2012), and the issue of evaporation and decreasing rainfall can lead to habitat loss and fishery degradation (Harrod et al., 2019). Drying up of lakes and a reduction in river flow have already been observed in arid and semi-arid regions of SSA (Urama and Ozor, 2010), which has negatively impacted the southern African fishery sector due to fishery habitat loss. For instance, the GCM, under the A1B emission scenario, projects that the river runoff in the Zambezi River basin will decline by between 13% and 34%, depending on the subregion, within the Zambezi region by 2030 (World Bank, 2010). This might negatively affect the fishery sector in the Zambezi River basin.

Furthermore, climate change and population growth in SSA have led to increased demand for freshwater resources by several sectors such as energy, manufacturing, and agriculture (Pierce, 2017). As a result, a fishery within a multi-user dynamic will probably lose out to other sectors (Cohen et al., 2019). Therefore, climate change is expected to alter the hydrological cycle, affecting the freshwater ecosystems' physio-chemical process, fish productivity, and human communities that are dependent on the ecosystem for food and livelihoods.

2.4.4. Eutrophication

Eutrophication is an enrichment of a relatively closed and slow-flowing water body (such as a river, lake, reservoir, or freshwater wetland) by dissolved nutrients that causes structural changes in the ecosystem, such as stimulation of the proliferation of algae and other plankton in the water, depletion of fish species, the general deterioration of water quality, and other effects that reduce and preclude use (Busobozi, 2017; Zhang et al., 2021). All water bodies are subject to natural and slow eutrophication processes, but in recent decades, anthropogenic activities have accelerated the progression and extent of eutrophication in several water bodies (Chislock et al., 2013; Nazari-Sharabian et al., 2018). The use of fertiliser for agricultural purposes, industrial effluent disposal, and sewage disposal into freshwater ecosystems are some of the human activities contributing significantly to eutrophication (Chislock et al., 2013).

Several studies have concurred that climate change and variability can directly or indirectly influence eutrophication within water bodies due to interactions between meteorological factors and nutrient availability (Moss et al., 2011; Xia et al., 2016; Nazari-Sharabian et al., 2018). Moss et al. (2011) stated that rising temperatures due to climate change lead to amplified rates of bacterial activity, which depletes oxygen from the water and stimulates the release of nutrients already present in the bottom sediments, increasing nutrient inputs in lakes and estuaries by increasing the rate of nutrient release from soils and the conversion of nutrients into forms that algae can easily use. In addition, increasing water temperatures accelerate the growth of cyanobacteria (a group of bacteria that grow in the water and are blue-green in colour) (Su et al., 2012; Zanchett and Oliveira-Filho, 2013; Nazari-Sharabian et al., 2018). Warming temperature increases the dominance, growth rate, geographical distribution, activity, and persistence of hazardous cyanobacteria species such as *Alexandrium catenella* and the diatom *Pseudo-nitzschia australis* (Rigosi et al., 2015; Lurling et al., 2018). These harmful cyanobacteria species produce highly toxic secondary metabolites known as cyanotoxins, which are hazardous to some aquatic species, animals, and humans (Zanchett and Oliveira-Filho, 2013). Cyanobacteria can affect fish species in several ways, including degeneration of fish tissue, reduced fertilisation, and fish mortality (Drobac et al., 2016; Zi et al., 2018; Moustaka-Gouni and Sommer, 2020). However, the effects vary among fish species, the toxins produced, and the concentrations ingested. In humans, some known toxins such as nodularins, microcystins, and cylindrospermopsins can cause gastrointestinal disturbances, skin toxicity, liver, and kidney damage (Zanchett and Oliveira-Filho, 2013).

Besides the temperature changes, which enhance algal blooms on water bodies, changes in the hydrological cycle also contribute to water eutrophication (Nazari-Sharabian et al., 2018). According to Nazari-Sharabian et al. (2018), rainfall and runoff play a significant role in transporting sediments and nutrients into the receiving water bodies. Rainfall is projected to increase in some parts of east Africa in the 21st century (Niang et al. 2014). Therefore, the water quality of freshwater bodies (for example, water bodies in East Africa) might be prone to high nutrient concentrations and increased contamination owing to increased rainfall and runoff, which are responsible for transporting and depositing sediments and nutrients into water bodies (Wang et al., 2016). On the other hand, in areas where rainfall is projected to decline, freshwater bodies are also prone to the risk of eutrophication due to low water flows and reduced water volume available for dilution of nutrients (Nazari-Sharabian et al., 2018). Eventually, the increased concentration of nutrients can cause deoxygenation by lowering the dissolved oxygen concentration (Knockaert, 2021), which is vital for fish survival. There is limited knowledge on the impacts of climate change on the eutrophication of freshwater systems specifically in SSA. However, the projected changes in climate factors are expected to interact and intensify eutrophication in SSA's water bodies, causing harm to both fish species and fishery-dependent communities.

2.4.5. Extreme weather events

Droughts and floods are the most recorded extreme weather events in most parts of SSA (Ongoma et al., 2018). The changes in the intensity, duration, and frequency of these extreme weather events can affect the fishery sector and fishery-dependent communities in several ways, such as changes in the amount of water flowing within the river (Woodward et al., 2016), damage or loss of stock (WorldFish Center, 2007), damage or loss of fishing equipment and infrastructure, loss of fishing days, and posing a danger to life (Musinguzi et al., 2016; Harrod et al., 2019). For instance, a study on the impacts of flooding on fishing families in the Pedro community in Nigeria revealed that 76% of fishers experienced a reduction in fish catches, destruction of fishing implements, loss of family income, and disruption of children's schooling due to flooding in their area (Chukwu, 2014). In addition, Bêche et al. (2009) stated that inland freshwater ecosystems are particularly susceptible to prolonged drought, because suitable habitat and refugia may be severely reduced or eliminated for periods ranging from hours to years. In a multi-user scenario, droughts increase human pressure on the already scarce freshwater resources through withdrawing freshwater from water bodies for agricultural use or manufacturing purposes, which can reduce habitat connectivity during dry days, adversely affecting aquatic species (Bêche et al., 2009). According to Lake (2008), water deficit due to droughts can cause streams to shrink in size and fall in level, cause standing water bodies to shrink in volume and surface area, and increase salinity in freshwater estuaries. Gao et al. (2011), for example, claimed that the shrinking of Lake Chad was due to persistent droughts and increased water withdrawal for agricultural purposes. The lake is believed to have shrunk from 22,000 km^2 to approximately 300 km^2 between the 1960s and the 1980s, resulting in a loss of fish habitat and a reduction in fish production (Gao et al., 2011; Eriegha et al., 2019). During the same period, drought conditions caused a 50% drop in fishery production in the Niger Delta (Roudier et al., 2014).

Therefore, the projected increase in extreme weather events over the SSA region will amplify the existing anthropogenic impacts on fisheries and fishery-dependent communities. However, extreme weather events do not only negatively affect fisheries; they can also enhance fish productivity. For instance, Talbot et al. (2018) suggested that flooding can also provide many benefits such as creating wildlife habitats, increasing fish production, recharging groundwater, and recharging wetlands. In addition, Mboya (2013) suggested that flooding increased fish production in the Mbita Division of Homa Bay County in Kenya. Therefore, the expected increase in flood events over SSA might positively benefit fisheries in the region.

2.4.6. Socio-economic impacts

2.4.6.1. Implications for Food and Nutrition Security

At present, SSA is home to more than 1 billion people (United Nations Department of Economic and Social Affairs, 2019), and population growth projections indicate that the SSA region could account for more than half of the world's population growth, with a projected addition of 1.05 billion people between 2019 and 2050 (Tusting et al., 2019). Fish and the fishery sector play an important role in supporting the food and nutrition security of the growing population. At present, fish is the main source of animal protein and micronutrients for approximately 200 million people or 30% of the continent's population (Obiero et al., 2019, Tran et al., 2019). In recent years, food insecurity has been rising in Africa. Hence, the continent is not on track to meet Sustainable Development Goal (SDG) Number 2, which aims to eliminate hunger by 2030 (FAO, 2019). About 256 million people or 20% of the African population are undernourished, of which 239 million people are in SSA and 17 million in North Africa (FAO, 2019). In addition, Mohammed and Uraguchi (2013) stated that SSA accounts for 28% of underweight children in the world. Fish can play a crucial role in addressing the issues of undernourishment, hunger, and underweight. Studies such as Psaki et al. (2012), Ijarotimi (2013), Drammeh et al. (2019), and Brglez et al. (2022) have suggested that insufficient food or nutrient intake is one of the key factors responsible for undernutrition. Fish is acknowledged to be a cheap source of animal protein, but is consumed in small quantities by low-income households (Marinda et al., 2018). Fish, particularly small fish such as Lake Tanganyika sardine, are rich sources of multiple essential micronutrients such as iron, calcium, zinc, vitamin A, and vitamin B12, which are usually lacking in most diets (Marinda et al., 2018). These small fish, which are widespread in some lakes of SSA (Cahora Bassa, Kariba, Kivu, and Tanganyika), can contribute significantly to low-income household diets and help alleviate undernourishment. Furthermore, Mohammed and Uraguchi (2013) indicated that deficiencies in essential and non-essential proteins and vitamins are the main causes of being underweight in children.

Studies have detected declining fish productivity and catches across several of SSA's freshwater ecosystems owing to climate change, for example, O'Reilly et al. (2003), Cohen et al. (2016), Ogutu-Ohwayo et al. (2016) and Utete et al. (2018). Declining fish catches, particularly those of small-scale fishers, adversely affect the food and nutrition security of fishery-dependent households or communities through a decline in animal protein availability and reduced income generated from fishing. The income generated from fisheries can be used for purchasing a variety of foods with higher calories, which enhance food and nutrition intake. Thus, the impacts of climate change on freshwater fisheries will worsen the existing problem of food and nutrition insecurity in SSA.

2.4.6.2. Economic Impacts

Inland fisheries support the national economies of several countries in SSA, such as Tanzania, Mali, Democratic Republic of Congo, Malawi, Mozambique, etc., mainly through employment creation, as a source of foreign currency, contributing to the GDP, and boosting government revenues through fishery taxes and agreements (De Graaf and Garibaldi, 2015). The sector is an economic base industry and supports several secondary economic activities such as boat construction, fish processing, and international logistics (Lam et al., 2012). There are limited national figures on the contribution of inland fisheries to employment and the GDP of African nations. However, the United Nations Conference on Trade and Development (UNCTD) stated that fish is one of the highest value traded commodities, accounting for about 10% of global agriculture exports, of which 53% of global fisheries exports are from developing countries, 43% from developed countries, and 4% from the least developed countries (UNCTD, 2017). There are inadequate fishery export data for most countries in SSA; however, in West Africa, fisheries contribute about 2% of the total exports (Lam et al., 2016, Zougmoré et al., 2016). West African countries such as Guinea-Bissau, Mauritania, and Senegal are net exporters of fish products. Therefore, fisheries contribute significantly to their national GDPs. In Zimbabwe, fisheries contribute significantly to job creation in the face of the high national unemployment rates (Kupaza et al., 2015).

Recreational fisheries contribute significantly to several national economies in SSA (Butler et al., 2020). The recreational fishery industry is common in several countries in SSA such as Angola (Butler et al., 2020), South Africa (du Preez and Hosking, 2011), and Zimbabwe (Magqina et al., 2021). du Preez and Hosking (2011) stated that the recreational trout (*Oncorhynchus mykiss*) fishing industry is a source of income and an employment creator in some of the most rural parts of South Africa. In West Africa alone, recreational fishing generates about USD 152 million per year for the region (Magqina et al., 2021). A study by Shelton et al. (2018) indicated that the trout population in freshwater ecosystems in South Africa decreased during warmer periods, thereby affecting recreational fishing. Therefore, the continuous warming of freshwater temperatures due to climate change might negatively affect the recreational fishing industry and the incomes and livelihoods of rural communities in the region.

National economies dependent on freshwater fisheries as a source of revenue and employment generation are highly vulnerable to climate change and variability. The observed impacts of climate change and variability on fisheries include changes in the distribution of fish species, declining fish productivity, shrinking fishing grounds, and the disappearance of valuable fish species (Ogutu-Ohwayo et al., 2016; Harrod et al., 2019). For example, research in West Africa has suggested that fish landings in this region are expected to drop by 26% by the 2050s under the Special Report on Emissions Scenario (SRES) A1B, and a substantial decline (about 50%) in fish landings is predicted in six West African countries (Ghana, Ivory Coast, Liberia, Nigeria, Togo, and Sierra Leone) under the same SRES A1B climate change scenario (Lam et al., 2012). Therefore, the predicted decline in fish landings under the SRES A1B climate scenario is expected to result in a 21% drop in total landed value and a 50% loss in fishery-related jobs by the year 2050 (Lam et al., 2012). Furthermore, the drought conditions observed in the Niger Delta of West Africa in the 1970s and 1980s resulted in losses of about USD 20 million per year (Roudier et al., 2014). In addition, small-scale fishers of Lake Kariba in Zimbabwe indicated that declining fish catches are affecting the income derived from fisheries and the related activities (Ndhlovu et al., 2017; Muringai et al., 2020).

Therefore, fast-tracking climate change will intensify the existing impacts of climate change on fisheries, such as declining fish productivity, consequently affecting the ability of the fishery sector to support economic growth through its contribution to the GDP and creating employment.

2.5. Fisheries climate change adaptation in Sub-Saharan Africa

Historically, nature and human societies have adapted to environmental change. Adaptation to climate change is generally defined as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (Parry et al., 2007, p. 27). The literature shows that freshwater fish species adapt to environmental change through changing their biological process and phenology (Gao et al., 2011, Tao et al., 2018). For instance, in ectotherms, which dominate freshwater ecosystems, the surrounding temperature influences metabolic rates. Since they cannot regulate their body temperature independently, any temperature change alters their metabolism, physiological processes, and growth rates (Gallo et al., 2017). Empirical studies on the effects of abiotic factors on the distribution of the Nile perch of Lake Victoria revealed a negative relationship between temperature and the Nile perch (Getabu et al., 2003, Goudswaard et al., 2011, Nyboer et al., 2020). In addition, James and Washington (2013) stated that fish species migrate to suitable habitats in the face of changing environmental conditions such as increasing temperatures. Fishery-dependent communities or households also adjust to fluctuating fishery resources. The adaptation of fishing communities to climate change can be autonomous or planned (Shelton, 2014), and can be at an individual, community, national, or regional level (Muringai et al., 2021).

Diversifying livelihoods, targeting new species, migration, changing fishing gear, and relying on social networks are some of the short-term strategies adopted by fishers, particularly small-scale fishers, to deal with the consequences of climate change (Limuwa et al., 2018, Musinguzi et al., 2016). For instance, fishers in Lake Wamala in Uganda changed their fishing gear, increased the time spent on fishing grounds, targeted new species, and diversified to non-fishery-related livelihoods to deal with the impacts of climate change (Musinguzi et al., 2016). Furthermore, Mgana et al. (2019) postulated that some fishers of Lake Tanganyika adopted new technologies such as homemade light-emitting diodes (LEDs) to enhance their fish catches. Besides the use of LEDs to catch fish, McLean et al. (2014) also reported that most households in Lake Tanganyika used mosquito nets to catch fish, which has had adverse effects on fish productivity.

Despite the need to adapt to changing fish productivity and fish distribution, some of the fishers' adaptation strategies are detrimental to freshwater ecosystems. They might result in the extinction of valuable species, consequently affecting the livelihoods and food and nutrition security of fishery-dependent people in the long term. Musinguzi et al. (2016) argued that fishers' strategies for increasing their productivity can be beneficial in the short term but can reduce the resilience of freshwater ecosystems due to unsustainable fishing practices. For example, the increasing number of fishing boats and illegal fishing gear used by fishers in Lake Victoria led to overexploitation and capture of immature fish, specifically the Nile perch (Natugonza et al., 2022). In addition, in Mida Creek, Kenya, about half of the small-scale fishers use mosquito nets as fishing gear, mainly targeting prawns and juvenile fish (Bush et al., 2017). In Lake Wamala, Uganda, fishers also changed their fishing gear by reducing the mesh size from 88.9mm to 38.1mm (a non-selective mesh size) (Musinguzi et al., 2016). The use of mosquito nets and nets with a smaller mesh size will result in the heavy exploitation of non-target species and juveniles (Makwinja et al., 2021).

Despite the fishers' efforts to adapt to changing natural ecosystems, Agrawal (2010) claimed that the capacity to adapt depends on how institutions regulate and structure their interactions amongst themselves and external actors. Thus, the success of fishers' adaptation efforts largely hinges upon the nature of existing formal and informal rural institutions (Mubaya and Mafongoya, 2017). For instance, inland fisheries contribute 85% of Tanzania's fish yield, and the Tanzanian National Adaptation Plan of Action mentions fishing in the section on water, but it does not highlight the impacts of climate change on inland fishers (Smucker and Wisner, 2021). In addition, the 2015 Fisheries Act of Tanzania mandated the creation of Beach Monitoring Units (BMUs), which are aimed at conserving fishery resources, to allow fish stocks to regrow (Smucker and Wisner, 2021). A 6-month ban on fishing in Lakes Nyumba and Mungu was imposed by these BMUs, thereby affecting the livelihoods and food security of fishery-dependent communities along the shores of Lakes Nyumba and Mungu. Fish stock conservation undermines the adaptation of fishers to declining fish catches; for example, in Botswana, capture fisheries fall under the Ministry of Environment, Wildlife, and tourism, and under a wildlife management approach, the focus is on conservation and less on sustainable utilisation of fisheries for food security (Mosepele and Kolawole, 2017).

On the other hand, a study by Mubaya and Mafongoya (2017) on the role of institutions in managing local level climate change adaptations in the Nyaminyami area (where fishing is the primary livelihood) located in Kariba Rural District in Zimbabwe revealed that institutions in

Nyaminyami played a significant role in facilitating climate change adaptations in the area through strengthening the education and health sector. Nevertheless, the potential adaptation strategies for fishers seem to be limited due to expensive fishing licences not being affordable for poor communities (Mubaya and Mafongoya, 2017). Therefore, local institutions play a crucial role in the success of fishers' adaptations to the impacts of climate change. Local institutions in SSA need to acknowledge the importance of fisheries to livelihoods and food security for the locals and acknowledge that the climate is changing at an alarming rate, and thus, there is a need to promulgate policies that enable fishing communities to adapt to the changing environment.

2.6. Fisheries management and climate change mitigation strategies

The 2030 SDG Number 14 highlights the importance of protecting, conserving, and sustainably using marine and aquatic resources for sustainable development (Griggs et al., 2013). Throughout history, traditional authorities and government institutions were and still are responsible for managing fish resources. Purcell and Pomeroy (2015) suggested that co-management should be adopted in the management of small-scale fisheries in developing countries, particularly in the tropics. Co-management is a "relationship between a resource user group and another organisation or government agency for management purposes in which some degree of responsibility and authority is conferred to both parties" (Purcell and Pomeroy, 2015). Sub-Saharan African countries such as Malawi, Mozambique, Nigeria, Senegal, South Africa, Zambia, and Zimbabwe have adopted co-management for managing fisheries, with the desire to improve fishers' compliance with fishery regulations by involving fishers in decision-making, and to reverse the depletion of fish stocks (Kaluma and Umar, 2021). According to Donda (2017), co-management of fisheries enables fishers to influence the decision-making process through information sharing, allowing them to acquire scientific information on the ecological conditions of their ecosystem. In the climate change adaptation context, access to scientific information such as weather forecasts enhances the adaptive capacity of fishing communities to the impacts of climate change (Donda, 2017). Moreover, co-management between fisheries managers and fishers can develop adaptive strategies by combining scientific information with local knowledge and experience of change and responses over time (Conde et al., 2005). This helps in the design and implementation of location specific and holistic adaptations and mitigation measures.

There is limited literature on the climate change mitigation strategies implemented by the fishery sector to deal with the impacts of climate change, particularly in the SSA region. Most common mitigation strategies are aimed at fish conservation, particularly curbing overfishing and fish species depletion. These strategies include, but are not limited to, the type of fishing gear used, restriction of access, the number of licences granted, and the time and period of the year when fishing is allowed (Kaluma and Umar, 2021).

2.7. Conclusion and recommendations

The study reviewed the existing literature and knowledge on the impacts of climate change on SSA's inland freshwater fisheries, and climate adaptation and mitigation strategies. The literature reveals that changing climate variables, particularly temperature and rainfall, alter the physiological and phenological processes of fish, which have contributed to the decline in fish productivity and fish catches in several freshwater bodies in SSA. Fishery-dependent communities use several different strategies to deal with the fluctuations in fishery resources. However, some of the strategies applied have detrimental effects on fish resources in the long run. Furthermore, the fishery management and climate mitigation strategies used by fishery managers and managing institutions mainly focus on the conservation of fishery resources, subsequently undermining the livelihoods and food security of the resource users. Effective fishery management and climate change adaptation and mitigation cannot be achieved without the inclusion of the resource users. Therefore, to formulate successful climate adaptation and mitigation strategies and policies, resources users' or fishers' participation in decision-making processes is crucial. The principal resource for adapting to the impacts of climate change is the fishers themselves, and their indigenous knowledge of the local environmental systems and their expertise. Hence, co-management between fisheries managers and fishers can help enhance fishers' adaptation to the impacts of climate change, and the involvement of fishers in policy making may result in the formulation of robust and holistic policies for sustainable fishery development.

However, the identified impacts of climate change on freshwater fisheries, fishers' adaptation strategies, and mitigation measures are location specific and vary greatly across regions or communities. Therefore, to fully understand the location specific impacts of climate change and how resource users adapt and safeguard the natural resources, this study encourages future researchers to conduct local climate change vulnerability assessments, as they are crucial for guiding local climate change adaptation and mitigation measures. Local studies should focus on assessing the biophysical and socio-economic impacts of climate change on freshwater fisheries. Furthermore, SSA is characterised by a paucity of statistical data on freshwater fish catches, the number of fishing vessels, and the total number of people engaged in fisheries, particularly at national levels; hence, fishery managers and researchers should record all the relevant fisheries statistics for monitoring and controlling fish stocks and fishing activities. The statistical data can also be used for future research purposes.

Link with the next chapter:

This chapter reviewed the existing literature related to changing climatic trends in the SSA region, the characteristics of small-scale inland fisheries, the impacts of climate change on freshwater fisheries, adaptation strategies used by fishers and management strategies of freshwater fisheries within the region. Therefore, the next chapter assess the fisher's perceptions of climate change, its impacts on the fisheries sector and their adaptation strategies, around Lake Kariba, Zimbabwe.

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CHAPTER THREE[2]

Climate Change Perceptions, Impacts and Adaptation Strategies: Insights of Fishers in Zambezi River Basin, Zimbabwe.

Abstract

The Zambezi River Basin is considered to be highly vulnerable to the impacts of climate change and adverse weather events which might cause serious environmental, economic, and social consequences for millions of people. Therefore, it is crucial to understand how natural resources dependent people perceive climate change, and how they adapt to the changes as it is very important for climate change adaptation policy formulation and its implementation. Therefore, this study seeks to assess fisher's perceptions of climate change, its impacts on fishery resources and livelihoods, and their adaptation strategies. Data were collected from 120 fishers in two basins (Binga and Kariba) along the shores of Lake Kariba using a mixed-method research approach. Meteorological data were obtained from the Meteorological Department Services of Zimbabwe (MSDZ). The findings show that fishers of Lake Kariba have observed changes in temperature and rainfall trends. The temperature historical data congruent fisher's observation of increasing temperature in both study areas. However, in Kariba Rural District, the rainfall historical data shows and increasing trend which does not agree with the fisher's perception of declining rainfall between the years 1987 and 2017. Fishers believe that the perceived changes of the climatic variables have led to a decline in fish productivity and fish catches. To cope with declining fish stocks and catches, fishers have adopted several adaptation strategies including, changing fishing gear, targeting new fish species, and increasing fishing effort. The study findings help to set a path towards local specific climate change adaptation strategies for small-scale fishers. This study provided relevant information for policy makers and fisheries stewards to formulate appropriate policies and programmes aimed at enhancing fisher's adaptation to climate change and promote sustainable fisheries.

Keywords: fish productivity; livelihoods; extreme weather events; small-scale fishers; Lake Kariba

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3.1. Introduction

Climate change is a significant global phenomenon threatening all aspects of human development and environmental sustainability, making it an issue of pressing political and social concerns. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report confirms and supports the notion that climate change and variability pose significant economic, social, and environmental threats globally (IPCC, 2021). Near surface temperatures in most parts of Africa have increased by 0.5^{o}C in the past five to ten decades, with minimum temperatures increasing faster than maximum temperatures (Niang et al., 2014). In addition, climate projections indicate that Africa's temperature is expected to rise faster than the global average increase during the 21st century (Davis and Vincent, 2017). In southern Africa, climate models project an increase in temperature of between 3.4^{o}C and 4.2^{o}C above the 1981–2000 average under the A2 scenario (greenhouse gases emissions increasing due to changing land-use caused by high population growth and less rapid increases in agricultural productivity), towards the end of the 21st century (Niang et al., 2014). Due to a lack of sufficient observational data across most parts of Africa, it is a challenge to draw robust conclusions on Africa's annual rainfall trends over the past decades (Niang et al., 2014, Nicholson et al., 2018). However, in areas where there is sufficient data, such as the Sahel, North Africa, and southern Africa, a decline in annual precipitation has been observed (Niang et al., 2014). Furthermore, climate projections models such as the Coupled Model Intercomparison Project Phase 5 (CMIP5) projects a very likely decreases in annual rainfall in most parts of Africa including southern Africa, West Africa, and northern Africa in the 21st century (Niang et al., 2014). Nangombe et al. (2018) state that the African continent has experienced a plethora of recording-breaking extreme weather events such as cyclones, floods, and droughts. In a study conducted by Gizaw and Gan (2017), the General Circulation Models (GCMs) indicate that the frequency of short droughts is projected to increase by 4 to 7% in the central, eastern, and southern parts of Africa between 2050 and 2080 (Gizaw and Gan, 2017; Muringai et al., 2021). Natural ecosystems, livelihoods and food and nutrition security of people dependent of climate-sensitive resources will be severely affected by the observed and projected changes in climate trends and increased incidence of extreme weather events.

The fisheries sector that supports livelihoods, generates jobs, and ensures food and nutrition security for millions of people in rural sub-Saharan Africa (SSA) is highly susceptible to climate change. Mohammed and Uraguchi (2013) argued that climate change and variability pose the most significant threat to fisheries than other stressors, because they interact and amplify the existing non-climatic stressors. Gownaris et al. (2018) and Kolding et al. (2016) also indicate that fish production is more dependent on the external climatic drivers than on management interventions and human exploitation rates, especially inland freshwater fisheries. The World Forum of Fisher Peoples (WFFP) stipulates that water bodies that support inland freshwater fisheries are experiencing warming water, increasing salinity, and decreasing water levels due to climate change (WFFP, 2017). These climate change impacts threaten freshwater species, fish habitats, and fishing grounds. For instance, studies by Ndebele-Murisa et al. (2011), Cohen et al. (2016) and Nyboer and Chapman (2017) indicate that elevated temperatures affect fish physio-chemical and biological processes such as metabolic rates, growth, and reproduction. Ndebele-Murisa et al. (2011) and Cohen et al. (2016) postulate that increasing temperatures due to climate change has significantly contributed to declining fish productivity in Lakes Kariba and Tanganyika, respectively. The IPCC Sixth Assessment Report postulate that climate change increases the vulnerability of freshwater fish species to local extinction and increased spreading of invasive species (IPCC, 2021).

In addition, extreme weather events due to climate change and variability disrupt fishing schedules, destroy fishing infrastructures such as fish landing sites and fishing boats, and cause harm and loss of lives (Musinguzi et al., 2016; Westlund, 2007). Generally, climate change scenarios project that maximum catch potential might decrease by 2.8% to 5.3% and 2.8% to 4.3% under RCP2.6 by 2050 and 2095 relative to 2000, respectively (Barange et al., 2018), indicating that climate change will adversely affect nations and communities that are dependent on the natural resource for livelihood and food. However, climate change and variability in fisheries vary across nations, regions, fishing communities, and households.

The significant effects of climate change on fishery resources, such as declining fish productivity and disruption of fishing schedules, are expected to result in profound impacts on the economic and social wellbeing of fishers (Shaffril et al., 2017). Literature shows that fishers have adopted several strategies to safeguard the livelihoods and food security. Martins and Gasalla (2018) state that fishers are able to adapt and cope with new conditions. In Malawi, some fishers of Lake Chilwa diversified their livelihoods to farming and pastoralism, while others migrated in response to the decrease in fish catches (Njaya et al., 2011). In Lake Wamala in Uganda, fishers diversified livelihoods, targeted new fish species, increased fishing time, changed fishing gear, increased fishing effort and changed fishing grounds to deal with declining fish catches owing to climate change (Musinguzi et al., 2016). However, adaptation practices are location specific and are determined by local specific knowledge and conditions.

Traditionally, climate change observations and projections, particularly at global and regional scales, have been primarily based on meteorological data and climate models such as GCMs (Kupika et al., 2019). Randall et al. (2007) argues that GCMs provide credible quantitative estimates of the current and future climate change, particularly at larger scales, namely, continental and global scales. Despite the capability of GCMs to provide good simulations of general atmospheric circulation at larger scales, they do not capture the finer detail required for local (national or community level) climate change assessments (White et al., 2009). However, reliable climate change information at finer spatial scales is required to formulate local adaptation policies to deal with the impacts of climate change and variability (White et al., 2009).

Boillat and Berkes (2013) state that the ability to observe and ascribe meaning to changes in weather phenomena occurrence and intensity is an important starting point for the capacity to adapt to climate change. Therefore, understanding how small-scale fishers conceptualise climate change, its effects on fisheries and their adaptation strategies to the effects of climate change is crucial for the development of climate change management actions and adaptation policies. Fishers' observations of local climatic conditions and peculiarities are crucial to understanding micro level climate change, which is often difficult to detect with climate models and they also help to understand the changes in climatic trends where historical data is missing (Martins and Gasalla, 2018).

Several studies such as Musinguzi et al. (2016), Limuwa et al. (2018), Hasan and Nursey-Bray (2018), Martins and Gasalla (2018) and Chen (2021) have been conducted globally and within the SSA region, assessing fishers' perceptions of climate change and their adaptation strategies. Muringai et al. (2019) assessed the fishers' perceptions of climate change and their consequences on small-scale fisheries in Lake Kariba but did not assess the adaptation strategies used by the fishers to deal with the consequences of climate change. Hence, there is a paucity of knowledge on fishers' perceptions of climate change and their adaptation strategies in Lake Kariba. Against that backdrop, this study seeks to assess the small-scale fishers' perceptions concerning trend changes of climatic factors and adverse weather events, impacts on fish resources and catches, and fishers' adaptation strategies. The study focuses on fishers as an integral part of the ecosystem, as their perception of the changing environment plays a crucial role in formulating climate change centred adaptation and mitigation actions for the present and future. The study was conducted in two rural districts (Binga and Kariba) found on the shores of Lake Kariba in Zimbabwe, mainly because it has been acknowledged to be vulnerable to climate change, and fisheries are one of the primary sources of livelihoods and food and nutrition security in the area (UNESCO, 2018).

3.2. Methodology

3.2.1. Study area

Lake Kariba is the third-largest man-made lake in the world measuring about 276 kilometres (km), with an average depth and width of 29 metres and 19 km, respectively (Magqina et al., 2020). The lake lies along the Zambezi River, bordering Zambia and Zimbabwe (16.5221°S, 28.7617° E) (Figure 3.1). The lake is divided into five hydrological basins namely Binga, Mlibizi, Sanyati, Sengwa, and Ume (Magqina et al., 2020; Ndhlovu et al., 2017). The construction of Lake Kariba along the Zambezi River led to the development of the fishing and tourism industries along the lakeshores benefiting the district (Conyers and Cumanzala, 2002). According to Ndhlovu et al. (2017) there are six fishing camps and 35 fishing villages along the shores of Lake Kariba. Small-scale fishing is the main livelihood strategy in these areas as all the camps and villages are within protected wildlife areas. The Statutory Instrument 360 of 1990 prohibits livestock rearing and farming in these protected areas (Ndhlovu et al., 2017).

This study mainly focused on two basins namely Binga and Sanyati, in Binga and Kariba Rural District, respectively (Figure 3.1). Binga Rural District (BRD) is in Matabeleland north, a northern province of Zimbabwe. Despite being regarded as one of the country's poorest districts, BRD is endowed with vast natural resources that include wild animals, hot springs, timber, and the mighty Zambezi River waters (Mago et al., 2015). The district is semi-arid with a tropical dry savannah climate (Manyena et al., 2008), characterised by low and erratic rainfall of less than 600 mm per annum and records high mean annual temperatures of about 30^{o}C (Matsa, 2019). According to Mago et al. (2015) BRD is well known for inhospitable climate conditions making it a drought-prone area. Conyers (2002) states that most parts of BRD are not suitable for agriculture since temperatures are high and rainfall is generally low and erratic. On the other hand, Kariba Rural District (KRD), is found in the Mashonaland West province of Zimbabwe. The climate of KRD is predominantly semi-arid (Ndebele-Murisa et al., 2011), characterised by mean annual rainfall of approximately 700 mm with high rainfall recorded during the rainy season (October- March). Additionally, the mean annual minimum temperature and the mean annual maximum temperature are about 24ºC and 30.7ºC, respectively. Most of the people in KRD are directly or indirectly involved in fisheries as a full-time or part-time activity.

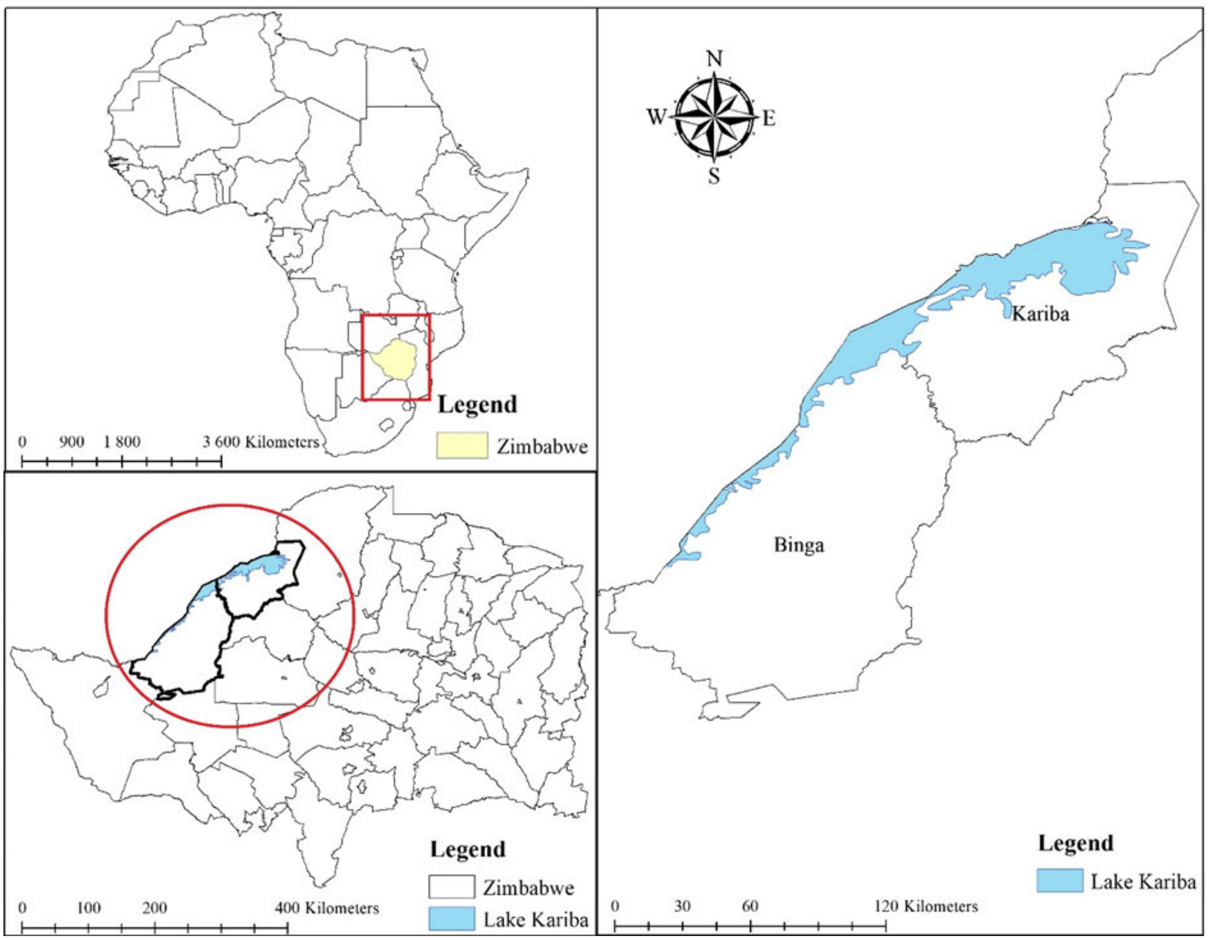

Figure 3.1: Map showing the location of the study area. (*Source*: Author).

3.2.2. Data collection

This study is based on both primary and secondary datasets collected from a survey of fishing households in BRD and KRD and Meteorological Services Department of Zimbabwe, respectively. Semi-structured questionnaires assessing fishers' observations, interpretation of changes in climatic trends, impacts of climate change on fisheries and adaptation strategies to changing conditions, were administered to the fishing households in KRD (November to December 2018) and in BRD (November to December 2020). A total of 120 household heads in fishing communities were purposely selected to participate in the study, 55 from BRD and 65 from KRD. Fishers were selected based on their availability and willingness to participate in the study. The participants' selection criteria were based on the involvement in fishing and its related activities, household head, and permanently residing in the study areas.

Fishers were asked (1) whether they had observed changes in temperature, rainfall, and frequencies of extreme weather events (drought and floods); (2) and if they had observed any changes, what changes they had observed; (3) the perceived consequences of these changes on fisheries, and (4) the adaptation strategies adopted to deal with the effects of climate change. Furthermore, eight key informant interviews were conducted with Lake Kariba Fisheries Research Institute (LKFRI) ecologists, traditional leaders, and village elders.

For triangulation purposes, four focus group discussions (FGDs) were held to share, validate, and explore the household survey findings and key informant interviews in greater detail (Kupika et al., 2019). The FGDs were made up of six to ten people, of which two discussions had mixed genders, one was only male and one only female participant. FGDs with separated genders were done to ensure that female participants fully participated and expressed their perceptions without male intimidation as in some cultures, women are not allowed to talk in the presence of male counterparts. Lastly, meteorological time-series data (temperature and rainfall) was obtained from the Meteorological Services Department of Zimbabwe (MSDZ). The time-series data was used to validate the perceptions of respondents about climate patterns and trends.

3.2.3. Data analysis

Data collected through the household survey questionnaire were coded by assigning numerical codes to the responses. The IBM SPSS Statistics version 27 was used for statistical analysis. Frequencies and percentages were mainly used to summarise the gathered household and perceptions information. The meteorological data were subjected to linear trend analysis using Microsoft Excel (2016). Furthermore, the multinomial logistic regression model was used to analyse the socio-economic factors and perceptions influencing the fishers’ choices of adaptation strategies to climate change (Jiri et al., 2015). In this model, the dependent variable was multinomial with several categories based on the climate change adaptation strategies identified in past studies. The model can be reduced to the following equation (1):

$$Yi=f(X1, X2, X3\ldots\ldots,X6) \qquad (1)$$

Where, Yi, the dependent variable, represents the climate change adaptation strategies selected by the fishers. In this case, the dependent variable (Yi) is coded 0 for "change fishing gear," 1 for "targeting new fish species," 2 for "increasing fishing time/days (increasing the number of days the fisher practices fishing activities)," 3 for "diversifying livelihoods," 4 for "increasing fishing effort (increasing fishing gear e.g. boats and nets)," 5 for "migrating to new fishing communities," and 6 for "no adaptation". X1 to X6 are explanatory variables that affect the fisher's choices. X1 = age, X2 = gender, X3 = Marital status, X4 = Education level, X5 = fisheries experience and X6 = fisher's perceptions. The "no adaptation" category was used as the base category to estimate the model of multinomial logical regression in this study. Table 3.1 describes and summarises the variables used in the model.

Table 3.1: Description of explanatory variables included in the regression model

Explanatory variables	**Coding**	**Category**
Age	Years	Continuous
Gender	0 = male, 1 = female	Dummy
Marital status	0 = married; 1 = otherwise	Dummy
Education level	0 = formal education; 1 = no formal education	Dummy
Fishing experience	Years	Continuous
Perception of Climate Change	0 = knowledgeable; 1 no knowledge	Dummy

The qualitative data gathered through key informant interviews and FGDs were transcribed and translated to English and analysed using content analysis by identifying recurring themes, trends, and keywords (Kupika et al., 2019 and Limuwa et al., 2018). Data were then classified into different themes based on fishers' perceptions of climate change, climate change impacts on fisheries and livelihoods, and the fishers' adaptation strategies. Some fisher's responses were also quoted in the study.

3.3. Results

3.3.1. Socio-economic profile of respondents

A total of 120 fishers in two districts, BRD and KRD, which are located along the shores of Lake Kariba participated in this study. The socio-economic characteristic of fishers across the two districts were collected, tabulated, analysed, and presented in Table 3.2. The age distribution of the fishers shows that the majority (32.5%) of the fishers who participated in the study were aged between 41 and 50 years, followed by the 31 to 40 age group which constituted about 29% of the participants. Fishers who were above 60 and below 20 years of age were represented least accounting for 7.5% and 3.3% of the total fishers who participated in the study, respectively. The majority of the study participants were males (76.7%) and females constituted 23.3% of the participants and most (78.3%) of the fishers were married and less than 1% (0.8) divorced. The literacy levels of respondents were found to be very high with more than 85% of the respondents had attended formal education which can be primary, secondary, or tertiary education. Furthermore, 62.5% of the fisher's households are comprised of four to six members and only 3.3% of the households have more than nine members. Approximately 80% of the respondents have stayed in the areas under study for more than 10 years. The study areas were characterised by high household dependents ratios as about 50% of the households have more than six economically dependent people.

Table 3.2: Socio-economic demographic profiles of fishers.

Household Characteristic		Study Areas		Total	Percentage
		Binga (*n*=55)	**Kariba (*n*=65)**	**(*n*=120)**	**(%)**
Age	<20	1	3	4	3.3
	21 – 30	4	6	10	8.3
	31 – 40	11	24	35	29.2
	41 -50	13	26	39	32.5
	51 – 60	19	4	23	19.2
	>60	7	2	9	7.5
Gender	Male	43	49	92	76.7
	Female	12	16	28	23.3
Marital Status	Never Married	4	11	15	12.5
	Married	43	51	94	78.3
	Divorced	1	-	1	0.8
	Widowed	7	3	10	8.3
Education Level	Never attended	5	9	14	11.7
	Primary school	12	14	26	21.7
	Secondary school	38	41	79	65.8
	Tertiary	-	1	1	0.8
Household Size	1 – 3	5	9	14	11.7
	4 – 6	31	44	75	62.5
	7 – 9	16	11	27	22.5
	>9	3	1	4	3.3
Period of Stay in the Area	<5	-	1	1	0.8
	6 – 10	3	7	10	8.3
	11 – 15	10	11	21	17.5
	16 – 20	8	16	24	20
	21 – 25	6	9	15	12.5
	26 – 30	5	11	16	13.3
	31 – 35	10	8	18	15
	>35	13	2	15	12.5
Household dependents	0	6	13	19	15.8
	1 – 3	10	11	21	17.5
	4 – 6	13	7	20	16.7
	>6	26	34	60	50

3.3.2. Fishers' perceptions of changes in climate trends and extreme weather events

Fishers were asked if the climatic variables in their respective communities have changed over the past 10 years. The findings indicate that 83.8% of the fishers believe that temperature has increased during the past 10 years (Table 3.3). During the FGDs, some of the fishers in BRD mentioned that:

> *When it comes to the issue of temperature and rainfall, everything has changed in the past 10 years. The weather was not as bad as it is now. The temperatures are very high throughout the day, and they are few cold days even during the winter season, which is different from what we used to experience in the past….* (Male, BRD)

> *We have already started experiencing hell on earth, in the past few years, from around August to March we are experiencing extreme hot days. Now I must wake up very early in the morning to cast my fishing nets because by eight in the morning it will be hot already….* (Male, BRD)

Fishers from Kariba District also perceived that the temperatures in their area are getting warmer as the following statements show:

> *The temperature has drastically increased in the past 10 years, the summer season has just become too hot, and I am starting to worry about how it is going to be in the next five to ten years from now….* (Male, KRD)

> *Some days are just becoming too hot for me. If I remember well in the past few years, we were not experiencing hot days as we are experiencing today ….* (Female, KRD)

The majority of the fishers (76.3%) believe that the amount of rainfall received in their respective areas has decreased during the last 10 years. Results from the FGDs also show that fishers from both districts believe that rainfall has declined and becoming more unpredictable. Some fishers expressed that:

> *The way it is hot these days we also expect good rains. We used to know that if we have two or three consecutive hot days then it rains but nowadays it can be hot for several days or weeks without a single drop of rain …* (Female, KRD)

We used to receive considerable amounts of rainfall usually from late October to March but now September and October are usually dry, and we receive little rainfall maybe towards the end of November. Generally, the amount of rainfall is decreasing that is why we are experiencing a lot of drought seasons… (Male, KRD)

This area is in the low veld region, and it is generally characterised by low rainfall, but in recent years our area is becoming drier and drier, rainy days have decreased and when it rains the rainfall is not enough to fill up the lake or sustain our crops …. (Female, BRD)

In addition, a key informant in BRD mentioned that:

The rainfall patterns in this area are becoming more and more unpredictable as we can have long periods of little rainfall causing serious drought situations, and then sometimes we get rainfall of high intensity we usually cause flooding. However, from my personal experience, the area is becoming dry, there is a noticeable decrease in the amount of rainfall received …. (Male, BRD)

Extreme weather events are common features in the study areas. Most fishers (63.1%) indicated that in the past 10 years there has been an increase in the occurrence of droughts, 56.9% also indicating that the occurrence of floods has increased, and 37.5% perceiving that the lake water level has decreased (Table 3.3). A key informant and a fisher said that:

The water level is always fluctuating with the low water level being very common during the winter season and the level increasing during the rainy season. In recent years, the water level is no longer reaching the higher levels it used to reach in the previous years which might be associated with low rainfall and high evaporation due to increasing temperatures …. (Key Informant, KRD)

In the past few years, the water level is not rising as it used to during most rainy seasons. During the rainy season, the water level used to rise and cover all those small shrubs close to the banks of the lake …. (Male, BRD)

The statements in the group discussions generally corroborated with most responses from the household questionnaires as the fishers emphasised increasing temperature, declining and unpredictable rainfall patterns, increasing occurrence of droughts, and decreasing surface water level (Table 3.3). However, the nuanced views on floods seen in the household interviews were not repeated in the group discussions where fishers did not agree on an increased incidence of floods.

Table 3.3: Fisher's perceptions of changing climate trends over the past 10 years.

Climate Parameters	Participant's response			
	Increase (%)	**Decrease (%)**	**No Change (%)**	**Do not know (%)**
Temperature	83.8	11.9	4.3	-
Rainfall	5.6	76.3	6.3	11.8
Frequency of floods	56.9	12.5	21.9	8.7
Frequency of droughts	63.1	18.1	3.8	15
Surface water levels	25	37.5	30.6	6.9

3.3.3. Empirical evidence of climate variability and trends

The perceptions of fishers about the observed trends of climate variables in the past 10 years were compared with meteorological time-series data, and correspondences were confirmed on perceptions about the temperature in both study areas. Congruent to the fisher's perceptions of increasing temperatures, the results from the temperature historical data show an overall increase in temperature between 1987 and 2017 (Figure 3.2), but the increase is insignificant in both BRD (R^2 = 0.0004, $p > 0.05$) and KRD (R^2 = 0.0015, $p > 0.05$) (Figure 3.3). Figure 3.3 shows a variation in the mean annual temperature over the 1987 – 2017 period. The temperature anomalies in Figure 3.3 show a slight increase in temperature in both study areas reflecting warming temperatures. The temperatures were warmest in 2002 in both BRD (28.2^{o}C) and KRD (27.3^{o}C) and the lowest below-average temperatures were recorded in 2011 (23.6^{o}C) in BRD and 2013 (23.3^{o}C) in KRD.

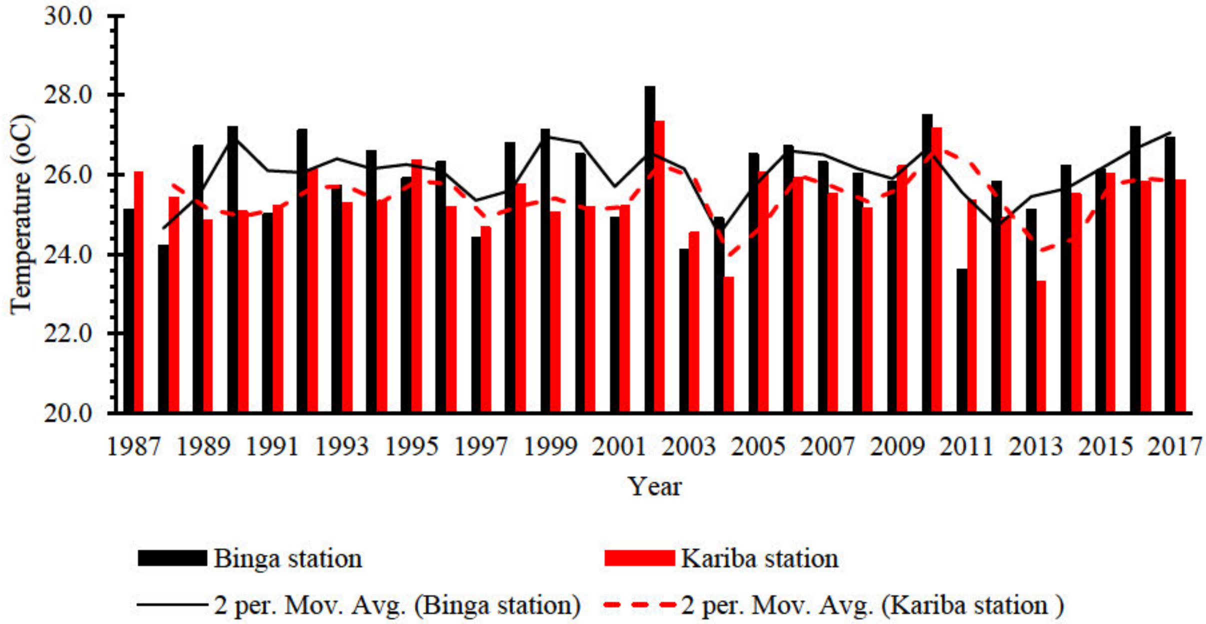

Figure 3.2: Mean annual temperature for BRD and KRD districts (1987-2017) (*Source*: Zimbabwe Meteorological Services Department, Binga and Kariba Station).

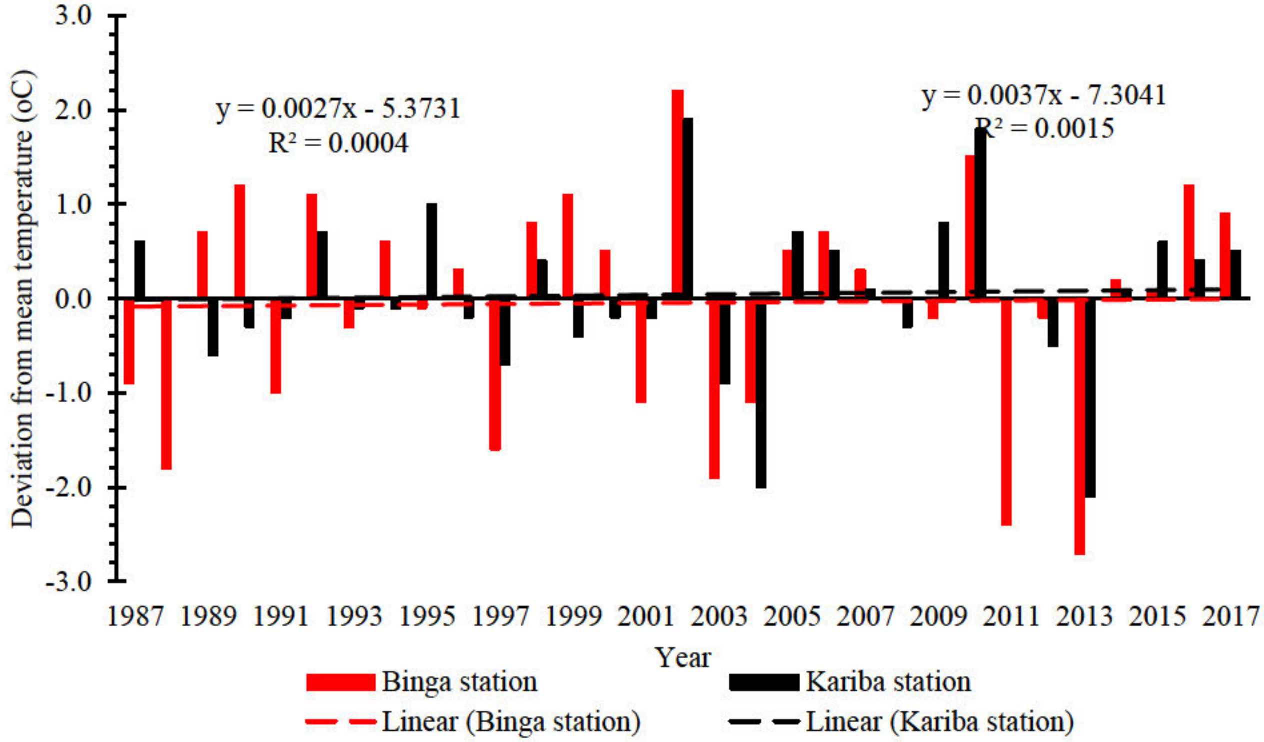

Figure 3.3: Deviation of mean annual temperature anomalies for BRD and KRD districts (1987 – 2017) (*Source:* Zimbabwe Meteorological Services Department, Binga and Kariba Station).

The meteorological data confirmed the fisher's perception of decreasing rainfall for the BRD (Figure 3.4). Figure 3.4 shows that the total annual rainfall in BRD decreased between 1987 and 2017. Contrary to fishers' perception of declining rainfall in KRD, the meteorological data shows a perceptible increase (about 30%, R^2 = 0.3091, $p < 0.05$) of rainfall in KRD and the period 2004 – 2007 is characterised by above-average rainfall, indicating that rainfall has increased (Figure 3.5). Figure 3.5 depicts annual rainfall variation for BRD and KRD between 1987 and 2017, which had a mean annual rainfall of 532.7 mm/year and 689.3 mm/year, respectively. The study areas are characterised by highly variable rainfall patterns between 1987 and 2017 as shown by the rainfall anomalies (Figure 3.5). Between 1987 and 2017, BRD is mainly characterised by below-average rainfall (below 532.7 mm. year), particularly between the years 2000 and 2016. KRD is mainly characterised by above-average rainfall (above 689.3 mm/ year) between 1987 and 2017.

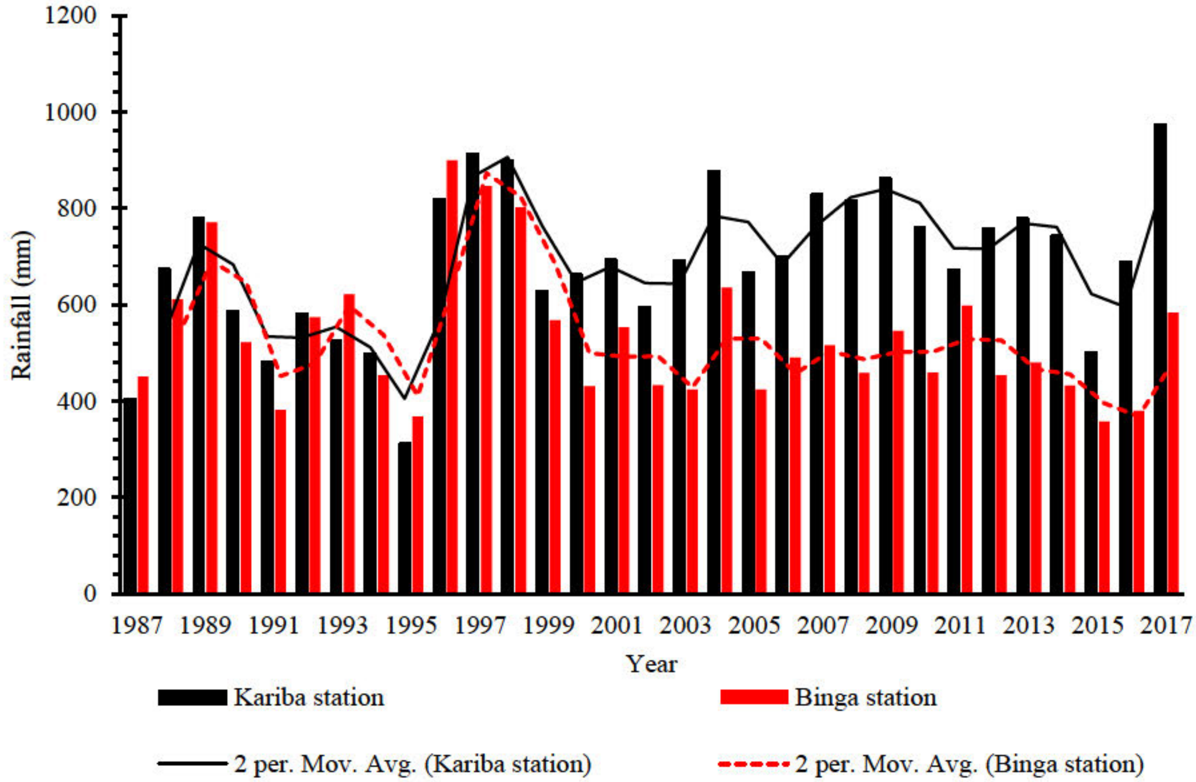

Figure 3.4: Total annual rainfall for BRD and KRD districts (1987-2017) (*Source*: Zimbabwe Meteorological Services Department, Binga and Kariba Station).

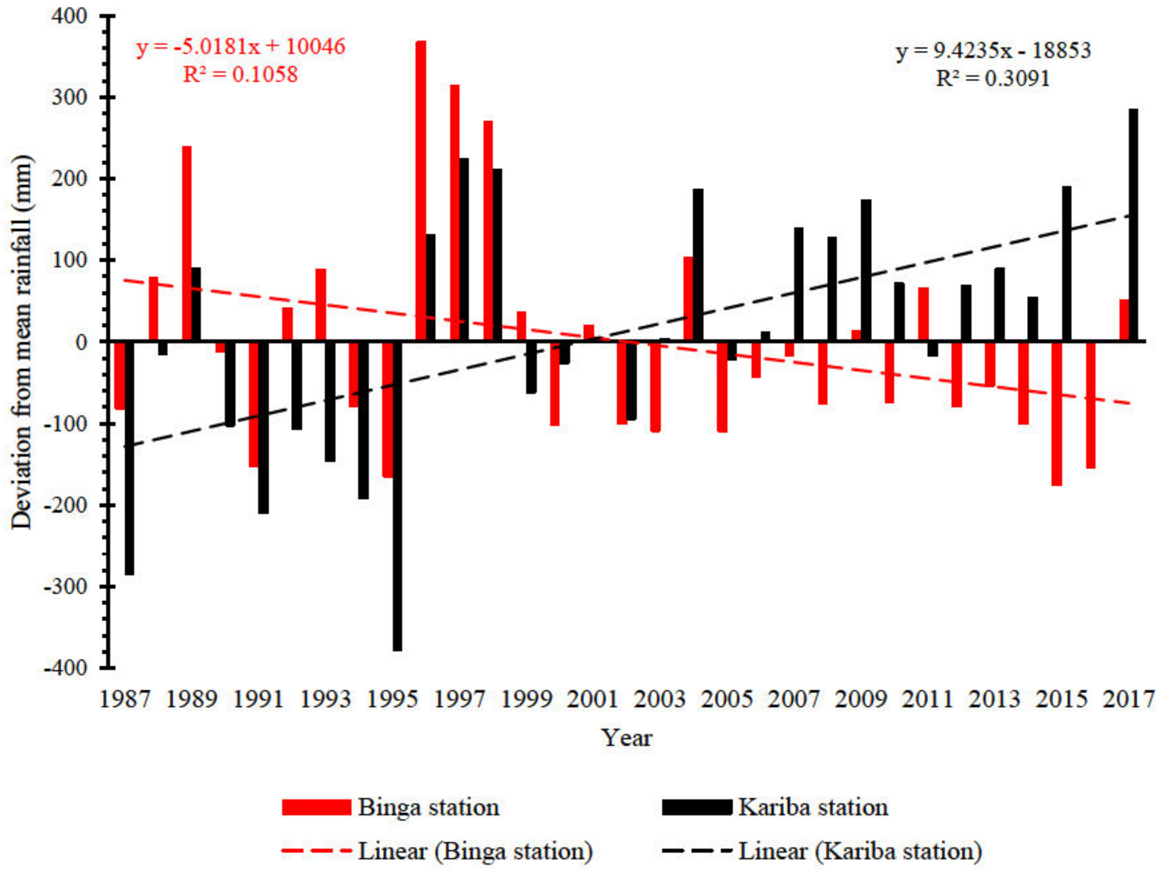

Figure 3.5: Deviation of total annual rainfall anomalies for BRD and KRD districts (1987 – 2017) (Source: Zimbabwe Meteorological Services Department, Binga and Kariba Station).

3.3.4. Observed weather changes and their impacts on fisheries

Fishers and key informants were aware of the impacts of climate change on fisheries and human wellbeing. Climate change has generally led to a decline in fish production in most freshwater fisheries in the sub-Saharan African region. Based on results shown in Figure 3.6, 63.3% of the fishers indicated that climate change has resulted in declining fish stocks. Most fishers (58.5%) reported changes in fish species composition, 45.3% indicating an increase in invasive species (cray fish), due to climate change. The decline in fish stocks owing to climate change has led to a decrease in profits obtained from fisheries as indicated by 55.3% of the fishers. Fishers also perceive that the shrinking of fishing grounds and food insecurity is a result of climate change as indicated by 49.3% and 76% of the fishers, respectively (Figure 3.6).

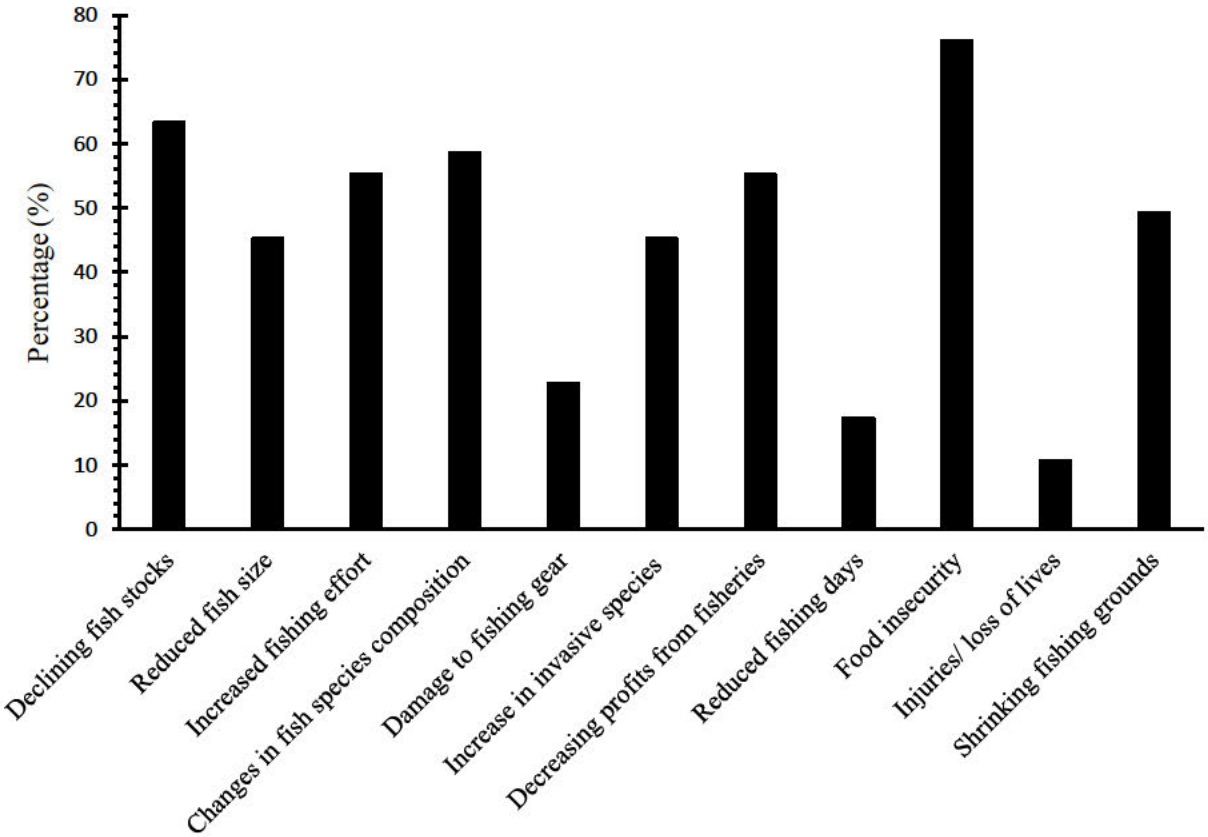

Figure 3.6: Fisher's perceptions on the impacts of climate change on fisheries and fishing communities.

In the FGDs, changes in rainfall and temperatures patterns were perceived as the main climatic factors affecting the fisheries sector as a whole. However, most fishers expressed more concerns about the declining total amount of rainfall than increasing temperatures as the following statements show:

> *I have been fishing in Lake Kariba for more than 30 years now and over time I have noticed that the amount of rainfall we used to receive has declined to cause the lake water level to decline and small water bodies close to our community are drying up. Our prescribed fishing grounds are shrinking due to disappearing surface water resulting in reduced fish catches for us. I used to catch lots of fish in a day and now I have to fish for three or four days to get the same amount I used to get in a day ...* (Key informant, Kariba)

> *I am a full-time gill net fisher and climate change, particularly changes in rainfall patterns have affected my fishing profits. Fish come with rains, but in the past years, the rainfall is too little to increase fish availability. During the rainy season, my fish catches used to be amplified but that is no longer the case these days …* (Male, Kariba)

> *The rain has become more unpredictable, and the rainy season is now shorter which is affecting our overall food security situation. Fish is our main source of animal protein and now we are catching less of it if we eat most of the catch, we won't have a surplus to sell. Droughts are affecting our crops as well; we are not harvesting enough crops to sustain us for the whole year …* (Female, Binga)

3.3.5. Adaptation strategies of fishers in response to changing climate

Fishing is the main occupation for all study participants. The high degree of dependence on fishing activities requires major adaptation measures as the sector is directly affected by climate change. The study findings in Table 3.4 show that fishers adopted a range of practices in response to the perceived effects of climate change on fisheries. The most common responses indicated by the fishers included increasing fishing effort (45%), increasing fishing time/days (44.2%), changing fishing gear (42.5%), and targeting new fish species (20%) (Table 3.4). Other responses included diversifying livelihoods (14.2%) and migrating to new fishing communities (7.5%). However, the type of adaptation strategies used by fishers is influenced by several socio-economic factors and perceptions of climate change.

The multinomial logistic regression (MNLR) model was used to estimate the effect of socio-economic characteristics and perceptions on the fisher's decision to select climate change adaptation strategies. The results indicate that the fisher's experience positively and significantly influenced the adoption of all adaptation strategies except livelihood diversification (n = 120; 1.257, $p > 0.05$) (Table 3.5). Moreover, the results show that the level of education positively and significantly affected the fishers' decision to change their fishing gear (n = 120; 1.708; $p < 0.05$) and to diversify their livelihoods (n = 120; 2.249; $p < 0.05$). Table 3.5 shows that the fisher's perceptions of climate change positively influenced the fishers' decision to target new fish species and diversify livelihoods as climate change adaptation strategies showing statistical significance of n = 120; 1755; $p < 0.05$ and n = 120; 2.300; $p < 0.05$, respectively (Table 3.5).

Table 3.4: Adaptation strategies adopted by fishers

Strategies	**Frequency (*n*=120)**	**Percentage (%)**
Change fishing gear	51	42.5
Targeting new fish species	24	20
Increasing fishing time/ days	53	44.2
Diversifying livelihoods	17	14.2
Increased fishing effort	54	45
Migrating to a new fishing community	9	7.5

NB: Fishers can adopt more than one adaptation strategy.

Variable	Change fishing gear		Targeting new fish species		Increasing fishing time/ days		Diversifying livelihoods		Increased fishing effort		Migrating to a new fishing community	
	Coeff.	Sig.(*p*-value)	Coeff.	Sig. (*p*-value)	Coeff.	Sig. (*p*-value)	Coeff.	Sig. (*p*-value)	Coeff.	Sig. (*p*-value)	Coeff.	Sig. (*p*-value)
Age	-1.687	0.215	-1.632	0.207	1.577	0.304	**4.203**	**0.035***	0.771	0.052	0.020	0.892
Gender	-0.002	0.996	0.232	0.564	0.603	0.139	0.128	0.257	**0.888**	**0.030***	-0.055	0.257
Marital status	0.129	0.638	0.037	0.895	0.049	0.224	0.290	0.063	-0.014	0.771	-1.607	0.230
Education level	**1.708**	**0.048***	0.218	0.721	0.153	0.812	**2.249**	**0.009***	1.747	0.068	0.0153	0.670
Experience	**0.314**	**0.006***	**0.323**	**0.004***	**0.384**	**0.001***	1.257	0.066	**0.331**	**0.004***	**-3.345**	**0.072****
Perception on CC	0.029	0.415	**1.755**	**0.040***	0.183	0.877	**2.300**	**0.007***	2.211	0.010*	-0.004	0.927
Base category		No Adaptation										
Total number of observations		120										
Likelihood ratio Chi^2		141.564										
Log Likelihood		-123.567										

Table 3.5: Socio-economic and perception determinants of climate change adaptation strategies adopted by fishers

Significant at *5% and**10% probability level, respectively.

3.4. Discussion

3.4.1. Fishers' perceptions of climate change and variability

Fishers are aware of climate change and there is consensus that temperature and rainfall trends have changed over the past decade. These findings are in line with Dube and Nhamo (2020); Mahere et al. (2014) and Ndebele-Murisa et al. (2013) findings that also detected increasing temperatures in areas around Lake Kariba. According to Ndebele-Murisa et al. (2013) in the past decades temperatures in areas surrounding Kariba have been rising at a faster rate than the IPCC regional projections for the semi-arid regions of Africa. Furthermore, studies by Martins and Gasalla (2018) and Hasan and Nursey-Bray (2018) also reported that fishers perceived an increase in temperature in the South Brazil Bight and coastal Bangladesh, respectively. This increasing temperature trend is of great concern as several studies such as Cohen et al. (2016); Gobler et al. (2018) and Harrod et al. (2019) have demonstrated that increasing water temperatures, caused by increasing air temperatures, bear adverse impacts on freshwater ecosystems fish productivity.

The linear regression analysis of rainfall data (Figures 3.4 and 3.5) validates the fishers perceived decrease in the total amount of rainfall received in BRD and not in KRD. The fishers' perceptions are reinforced by Magadza (1994) and Ndebele-Murisa et al. (2011) whose study findings revealed that rainfall in the Zambezi valley is decreasing by between 1 to 6 mm per decade. However, the disparities between the results from the linear regression analysis of the rainfall data in this study and Ndebele-Murisa et al. (2011) and Magadza (1994) might be attributed to the differences in periods analysed. For instance, this study's findings indicate that total annual rainfall increased between 2003 and 2017, while Ndebele-Murisa et al. (2011) analysed rainfall data from 1964 to 2008. Contrary to this study's findings, a study by Muchuru et al. (2016) on the variability of rainfall over the Lake Kariba catchment area in the Zambezi River basin, which includes BRD and KRD, revealed a normal distribution of rainfall across the catchment area. On the other hand, findings by Hasan and Nursey-Bray (2018) indicate that most fishers in Bangladesh observed increasing rainfall over the past decades. The differences between the two findings might be attribute to the geographical locations of the study areas as the ZRB is in the southern hemisphere and Bangladesh is in the northern hemisphere, which are characterised by different climates.

The government of Zimbabwe (GoZ) postulated that Zimbabwe is susceptible to periodic droughts attributed to El Niño events (GoZ, 2012). In the current millennium, devasting droughts were experienced in 2001/02, 2002/03, 2004/05, 2006/07, 2011/12, 2015/16, and 2018/19 (Frischen et al., 2020; GoZ, 2012 and USAID, u.d). These recurrent drought episodes coupled with variable rainfall patterns have caused water levels to fluctuate in Lake Kariba (USAID, u.d). This supports the fishers' perceptions on increased drought occurrence and decreasing surface water levels.

3.4.2. Perceived impacts of climate change and extreme weather events on fisheries

Understanding the perceptions of fishers about the effects of climate change and adverse weather events is an important basis to build climate change adaptation and mitigation measures. This study found that fishers in Lake Kariba agreed that changing climatic trends and extreme weather events owing to climate change have affected the freshwater ecosystem and the livelihoods of the fishery-dependent households. Several studies found that drought events can have severe effects on freshwater fisheries such as disturbing fish habitats (Arantes et al., 2013 and Lusardi et al., 2016), fish physiological functioning (Whitney et al., 2016), spawning (Perkin et al., 2015), and fish assemblages (Lennox, 2019). For instance, the decline in the Nile tilapia in Lake Wamala (Uganda), was associated with reduced lake levels since the 1980s due to droughts, which may have created unfavourable conditions that reduced the volume and area of open water habitat reducing breeding and nursery areas (Musinguzi et al., 2016). Lake water levels decrease due to persistent low rainfall and drought events which affect fish production. Maulu and Musuka (2018) state that the decline of Lake Kariba's water level in 2014 led to the sudden decline observed in the annual production of fish, in metric tonnes.

Furthermore, fishers perceived that, floods caused damage to fishing gear, disrupted fishing schedules, and sometimes lead to injuries or loss of lives. These finds correspond to Musinguzi et al. (2016) and Westlund (2007) who reported that floods damaged fishing boats, fishing gear, damaged landing sites, and reduced fishing days in Uganda and caused loss of lives in Indonesia, respectively. Additionally, fishers in Tam Giang Lagoon, Vietnam state that floods damage their fixed fishing gear such as bottom nets and coral nets (Ha and Thang, 2017). However, injuries and loss of lives of fishers in Lake Kariba are associated with strong winds that increase the severity of waves, for instance, the most violent wave locally known as the "*Binga wave*", which capsizes boats leading to drowning and loss of life. On the other hand, research indicates that floods recharge the water bodies thereby increasing the surface water level which provides habitat for fish production. This causality was observed by Njaya et al. (2011) in lake Chilwa and Mboya (2013) in Mbita division-Homa bay county in Kenya.

Fishers in Lake Kariba could not associate changes in temperature to any direct effects on fisheries. However, research shows that temperature drives most of the biological and physio-chemical processes in aquatic environments (Harrod et al., 2019). Ficke et al. (2007) state that all freshwater fish are exotherms that cannot regulate their body temperature through physiological means and their body temperatures are almost identical to their environments. Since freshwater fishes are ectotherms, warming temperatures can elevate physiological functions and increase metabolic demands, which directly affects productivity, growth, reproductive success, thermal tolerance, and food consumption (Benateau et al., 2019; Cohen et al., 2016; Ficke et al., 2007; Muringai et al., 2021; O'Gorman et al., 2016 and Whitney et al., 2016). For example, a study by Nyboer and Chapman (2017), which investigated the effects of elevated temperatures and acclimation time on the Nile perch (*Lates niloticus*) of Lake Victoria, found that exposing Nile perch fish to increasing temperatures for three weeks resulted in reductions in the standard metabolic rate of the fish consequently affecting the growth rate. In addition, warming temperatures affect primary productivity and plankton abundance in freshwater ecosystems. Primary productivity and plankton abundance have declined in several African great lakes such as Lakes Kariba, Kivu, Malawi, and Tanganyika (Muringai et al., 2021 and Ndebele-Murisa et al., 2013). Ndebele-Murisa et al. (2011) found that warming water temperatures led to a decline in Kapenta (*Limnothrissa miodon*) fish catches. Hence, the perceived declining fish stocks and fisher's fish catches in Lake Kariba can be associated with the observed increasing temperatures.

Besides playing a crucial role in recharging lake water, rainfall plays a significant role in transporting nutrient-supplying sediments into the lake (Wang et al., 2016), which is a source of fish feed. Bootsma and Hecky (1999) postulate that high rainfall brings nutrient fluxes into lakes through rivers. Nutrient availability in the lake enhances fish production. Therefore, despite the increasing trend in the rainfall meteorological data of KRD, the perceived change in rainfall patterns affects fish production. Fishing is the primary livelihood and source of food for the fishers in BRD and KRD, hence, the changing environment and declining fish resources led fishers to adapt and develop strategies to deal with the effects of climate change.

3.4.3. Adaptation strategies of fishers in response to changing climate

Fishers of Lake Kariba interpret and react to climate change impacts in different ways based on perceived impacts of climate change on fishery resources, which may help them to cope with the impending changes. This study findings showed that fishers of Lake Kariba demonstrated the capacity to adapt to the declining fish abundance, changing fish species composition, and reduced fish size. Increasing fishing effort and fishing days might be the most beneficial adaptation strategies for the fishers to deal with declining fish catches. Sanders and Morgan (1976) defined fishing effort "as the product of fishing power and the number of unit operations and is, therefore, the total effective area covered by the gear during a number of unit operations. In Lake Kariba, fishers have increased their fishing gear to increase their fish catches. This finding coincides with Nyamweya et al. (2020) who found that fish catches in Lake Victoria increased with increasing fishing effort. However, the increasing fishing effort strategy may be beneficial for a short period and have detrimental effects on fish abundance, in the long run, thereby jeopardising the capacity of fish resources to sustain fishers' livelihoods and food security.

Fishers of Lake Kariba changed their fishing gear to deal with the change in fish species composition and reduced fish sizes. A study by Karenge and Kolding (1995), indicated that the fish species composition in Lake Kariba was changing. Fish species such as the *C. gariepinus*, *Labeo* spp and *Distichodus* spp which were the abundant species in the 1960s have declined rapidly and now the *S. zambezenis* seems to be most abundant fish species (Karenge and Kolding, 1995). Most of the fishers in the surveyed communities are gillnet fishers who use nets to catch fish. However, small-scale fishers of Lake Kariba mainly target *Oreocromis niloticus*, *H vittatus* and *T rendalli* fish species due to their economic and diet significance. Changing fishing gear is a widely used strategy used by several fisheries across the globe to deal with dwindling fish stocks. For instance, Makwinja et al. (2021) found that fishers in Lake Malombe in Malawi changed their fishing gear to cope with the declining fish stocks. In Lake Wamala, gillnets, which are the dominant fishing gear used by small-scale fishers, the mesh size dropped from 88.9 mm to 38.1 mm which is below the legal mesh size of 127mm (Musinguzi et al., 2016). Furthermore, McLean et al. (2014) also reported that most households in Lake Tanganyika used bed nets to increase their fish catches. These fishing practices might increase fish catches in the short term, and not be sustainable in the long term, putting the livelihoods and food security of the future generation at risk. For instance, a study by Pedroza-Gutiérrez and Lopez-Rocha (2016) indicates that increasing fishing effort and changing gear type are the main causes of overfishing, and they led to a decline in total fish production in Mexico.

The tilapia (*Oreochromis*) also known as the bream is the most popular fish caught and traded by small-scale fishers in Lake Kariba. Maulu and Musuka (2018) state that the tilapia fish population in Lake Kariba has declined, which forces small-scale fishers to target new species. The fishers pointed that they are targeting new fish species for food and selling to generate income. These perceived changes in fish species composition are supported by Karenge and Kolding (1995), who state that the fish composition is Lake Kariba is changing with *S. zambezensis* becoming the dominant species. Hence, fishers are targeting the *S. zambezensis* for food and economic gains. Musinguzi et al. (2016) reported similar findings indicating that fishers in Lake Wamala observed a decline of the Nile tilapia and increasing dominance of the African catfish, which created different fishing opportunities for fishers.

Smaller groups of fishers indicated diversification of livelihoods and migration to new fishing grounds as some of the strategies adopted to cope with declining fish resources. Diversification of livelihoods by small-scale fishers has been reported in Lake Malawi (Limuwa et al., 2018) and (Musinguzi et al., 2016). Brugère et al. (2008) argue that diversifying to non-fishery activities could be the most beneficial adaptation strategy for fishers as non-fishery activities can provide income during periods of low fish catches. However, in the areas under study, agriculture or livestock production is prohibited Statutory Instrument 362 of 1990, which limits livelihood options for fishers of Lake Kariba (Ndhlovu et al., 2017). Therefore, some adaptation strategies adopted by fishers to cope with declining fish resources are location specific.

The results of the factors influencing the adoption of specific adaptation strategies by fishers suggest that the fisher’s experience is the most significant and positive factor influencing the choice of adaptation strategies of fishers. Fisher's experiences allow them to react and act against the effects of climate change on the fisheries sector. This finding is in agreement with the study by Sereenonchai and Arunrat (2019) which found that fisher's experience played a significant role in influencing fishers' decision to adopt adaptation strategies in Chumphon province of Thailand. Studies on crop farmers, Tazeze et al. (2012); Oyekale and Oladele (2012), and Nhemachena et al. (2014) also found that farming experience influences the farmer's decision to adapt to changing climatic conditions and the type of adaptation strategies adopted. Fisher's education level and perceptions about climate change significantly influenced the fishers' choice to adopt some adaptation strategies. Several studies have shown that the level of education correlates with the level of knowledge and the ability to make sound decisions (Jiri et al., 2015). Furthermore, the fisher's perceptions influenced the fishers' choice of adaptation strategy, because fishers have observed and experienced changes in fishery resources owing to climate change. This is supported by Nhemachena and Hassan (2007) who state that farmers who noticed changes in climate had higher chances of adopting strategies to respond to the changes caused by climate change.

3.5. Limitations of the study

The fishers' perceptions of climate change, its effects on fisheries and adaptation strategies employed by fishers are specific to fishers in Lake Kariba and cannot be generalised to represent other small-scale fishers in Zimbabwe or the ZRB at large. Additionally, due to limited time, inadequate human and financial resources and limited access to some remote areas, data was collected from a small group of fishers based on their availability and willingness to participate in the study. Therefore, the sample is not an ultimate representation of all fishers in the area as the data saturation might not have been achieved. The study assessed the socio-economic factors that influenced the adoption of adaptation strategies employed by fishers, but did not further investigate the influence and role of institutions in enhancing climate change adaptation in fishing communities found in the Zambezi River Basin in Zimbabwe.

3.6. Conclusion

The assessment of the fisher's perceptions about climate change, its impacts on fisheries, and fisher's adaptation strategies revealed that fishers have observed changes in temperature and rainfall trends over the last 10 years. Fishers have observed an increase in temperature and a decline in rainfall over the years. The frequency of extreme weather events, particularly drought, has increased. These observed changes have adversely affected the fisheries sector in multiple ways, including but not limited to, fish habitat loss, declining fish stocks, reduced fish catches, reduced profits from fishery-related activities, food security, and increased threat to fisher's lives. Fishers in Lake Kariba have adopted several strategies such as changing fishing gear, increasing fishing time, increasing fishing effort, targeting new fish species, adopted alternative livelihoods and migration to deal with changing fisheries resources due to climate change.

However, some of the strategies adopted by fishers are detrimental and could enhance unsustainable fishing practices that can reduce the resilience of the ecosystem. Moreover, the fisher's decisions to adopted certain adaptation strategies are mainly influenced by the fisher's fishing experience, perceptions about climate change, and education level.

These local perspectives, when combined with scientific results for the study area, shed light on fishers social, economic, and environmental vulnerabilities, and can help inform local decision-making in terms of developing climate change adaptation measures. The study suggests the incorporation of fisher's perceptions of climate change and adaptation strategies used by fishers when formulating climate change adaptation policies for the fisheries sector. To understand how fishers perceive and adapt to climate change at a regional level, future researchers should conduct similar studies in fishing communities within the basin. Furthermore, there is a need to assess local determinants of climate change adaptation and the role of institutions on enhancing adaptation within fishing communities.

Link to next chapter:

This chapter assessed the fisher's perceptions of climate change and its effects of the fisheries sector and their adaptation strategies. Based on the fisher's perceptions, the fishers of Lake Kariba are vulnerable to the impacts of climate change. Therefore, the next chapter assess the local vulnerability of fishing communities found on the shoreline of Lake Kariba.

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CHAPTER FOUR[3]

Vulnerability of Inland Small-scale Fishing Communities to Climate Change and Variability: Insight of Zambezi River Basin, Zimbabwe.

Abstract

Climate change poses serious environmental, social, and economic challenges for societies with high dependence on fisheries for livelihoods and food security. Nonetheless, there is limited research on the vulnerability of inland fishing communities to climate change. This study assessed the vulnerability of fishing households to the impacts of climate change in two fishing districts. Primary data were collected from fishing households in Binga and Kariba Rural Districts. A total of 120 survey questionnaires were administered to 120 household heads who were purposively selected. The data obtained were used to construct a Livelihood Vulnerability Index (LVI). The findings signify that Binga Rural District showed greater vulnerability in terms of socio-demographic profile, livelihood strategies, social networks, health, natural disasters and climate vulnerability major components of the index, while Kariba Rural District was more vulnerable in terms of food. Furthermore, the findings indicate that Kariba Rural District is more vulnerable (0.05) to the impacts of climate change and vulnerability despite showing lower exposure, sensitivity coupled with low adaptive capacity than Binga Rural District (0). The Livelihood Vulnerability Index indicated that inland fishing communities are vulnerable to the impacts of climate change, therefore, policymakers, governments and agents of development should focus on formulating policies and programmes that enhance the adaptation of fishing communities to the impacts of climate change.

Keywords: livelihoods, adaptation, Livelihood Vulnerability Index (LVI), small-scale fishers, Lake Kariba.

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4.1. Introduction

Climate change is affecting global fisheries and the societies that depend on them (Le Bris et al., 2018). In Africa, fisheries provide a direct source of livelihood to over 10 million people, and more than 200 million people depend on fish as the main or only source of animal protein (Kolding et al., 2016; Obiero et al., 2019). However, the contribution of the fisheries sector to livelihoods and food security is challenged by its vulnerability to climate change. There is a growing body of literature on the impacts that climate change has on inland fisheries productivity and fishery-dependent communities, for example, see Ndebele-Murisa et al. (2011), Macusi et al. (2015); Cohen et al. (2016), Ogutu-Ohwayo et al, (2016) and Huang et al. (2021). Some observed and anticipated consequences of climate change on inland freshwater fisheries include phenological (e.g., developmental timing, timing of migration and spawning), assemblage dynamics (e.g., species composition, species richness, evenness, species interactions), distributional (e.g., range shifts, changes in population distribution), demographic (e.g., survival, growth, abundance, density, recruitment) and evolutionary processes (e.g., hybridization, maturation rate) (Lynch et al., 2016; Myers et al., 2017). In addition, adverse weather events such as cyclones, droughts, and floods may further disrupt fishing operations and destroy fishing assets such as boats, fishing gear, fish landing sites, and other community infrastructure (Westlund, 2007). Therefore, the lives, livelihoods, and food security of fishery-dependent people are vulnerable to the impacts of climate change and variability. According to the Intergovernmental Panel for Climate Change (IPCC), small-scale fishing communities are considered vulnerable to the negative impacts of climate variability and change, which is due to their high dependence on climate-sensitive occupations (IPCC, 2007).

Based on current observations and regional climate projections for sub-Saharan Africa (SSA), air temperatures are generally increasing while the rainy season's extent and intensity are shortening and increasing the frequency and intensity of cyclones (Niang et al., 2014). Hence, fisheries and fishing communities within the region need to adapt to minimise the negative effects of climate change and variability on human lives and fishery-dependent livelihoods. Understanding the vulnerability of fisheries and fishing communities to the impacts of climate change is central to designing appropriate adaptation and mitigation measures targeted at enhancing the resilience of fisheries' socio-ecological systems. In the climate change context, the IPCC (2021) defines vulnerability as "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity". In the fisheries context, vulnerability is described as the degree to which fisheries are susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes (Islam et al., 2014). Thus, fisheries' vulnerability to climate change can be described as exposure to changing climatic variables (such as temperature and rainfall) and extreme weather events. The sensitivity of fisheries production, and the ability of fishers to adapt to the effects of climate change and variability by, for example, diversifying livelihoods, changing fishing gear or targeting new fish species.

Fisheries in the Zambezi River Basin (ZRB) cannot be spared from the impacts of climate change and variability. Commercial and subsistence fishing are major activities throughout the ZRB system, which covers numerous large lakes and several highly productive flood plains (Tweddle et al., 2015). Studies by Magadza (2011), Ndebele-Murisa et al. (2011), Ndhlovu et al. (2017), Utete et al. (2018), Muringai et al. (2019) and Ng'onga et al. (2019) indicated that inland fisheries under ZRB are being affected by changing climatic conditions. For example, Ndebele-Murisa et al. (2011) stated that Lake Kariba's surface water temperature warmed by 2^{o}C over the past decades leading to a decline in productivity of *Limnothrissa miodon*, commonly known as Kapenta fish. Previous studies on ZRB claim that the basin will experience the greatest decrease in runoff compared to the rest of Africa, which is due to a projected 10% decrease in rainfall by 2100 (Fant et al., 2015). Surface water runoff plays a crucial role in recharging water bodies such as dams, lakes, and rivers and transporting nutrient-supplying sediments into freshwater ecosystems (Wang et al., 2016). Therefore, increasing variability in rainfall patterns in SSA will directly affect surface water levels and fish productivity in several inland freshwater bodies, due to a reduced surface runoff, which recharges water bodies and sediment transportation. Fishers reported that low surface water levels in Lake Kariba led to the shrinking of fishing grounds, causing conflict between fisheries management authorities and fishers, consequently affecting fish productivity and fish catches (Muringai et al. 2019).

However, fisheries' vulnerability to the effects of climate change is not homogeneous across the globe, regions, nations, or communities. Several studies focused on assessing the vulnerability of fishery systems to the effects of climate change and variability on global and national scales, for example, Allison et al. (2009), Cinner et al. (2012), Blasiak et al. (2017) and Le Bris et al. (2018). Hence, there is limited knowledge on the vulnerability and localised effects of climate change on fishery systems, particularly in the ZRB. In addition, Allison et al. (2009) suggested that future vulnerability analysis should be ecosystem specific, that is, either marine or inland fisheries, to use the most relevant climate drivers in that system. Assessing the vulnerability of local inland fisheries and fishing communities to the effects of climate change and variability helps to identify and characterise actions that can help minimise the negative impacts of climate change (Islam et al. 2014) and support the successful implementation of various climate-resilient policies (Koya et al., 2017). The FAO (2015) argues that local climate change vulnerability assessments are crucial for guiding specific adaptation actions. In addition, localised vulnerability assessments will assist in raising awareness of the risks and opportunities of changing climatic conditions and advances to the existing body of literature and scientific research.

4.2. Approaches to vulnerability assessments

In the last four decades there has been extensive research and developments within the field of vulnerability moving from its initial formation within the natural hazards discipline to encompass more social-ecological systems and the sustainable livelihoods framework (Barsley et al., 2013). The complexities of measuring vulnerability at various geographical, spatial, temporal and social dimensions have resulted in a multitude of different methodologies for measuring vulnerability (Barsley et al., 2013). In the fisheries and aquaculture sector, several indicator-based methodologies such as, the Coastal Vulnerability Index (CVI), the Physical Process Vulnerability Index (PVI), the Socio-economic Vulnerability Index (SVI), and the Livelihood Vulnerability Index (LVI) are often used as a means of measuring vulnerability and can produce measurable outputs (Barsley et al., 2013).

The LVI was developed by Hahn et al. (2009) and is based on the IPCC's definition of vulnerability, which encompasses exposure, sensitivity and adaptive capacity to the impacts of climate change and variability. According to Hahn et al. (2009), the LVI approach comprises several variables which capture the level of households' exposure to natural hazards such as floods, droughts and cyclones owing to climate change, the household’s adaptation capacities and their sensitivity to climate change impacts. Barsley et al. (2013) state that the LVI is targeted toward assisting development practitioners, development organisations, governments and policymakers in implementing vulnerability assessments. The LVI is suitable for district-level vulnerability assessment of climate change (Barsley et al., 2013), and it is designed to be flexible so that users can refine and focus their analyses to suit the needs of each geographic area (Hahn et al., 2009). Moreover, an alternative method was developed to calculate vulnerability, the LVI-IPCC. Instead of using one weighted average as in the LVI approach, this method calculates three weighted averages of the major sub-components of the LVI according to the three contributing factors of exposure, sensitivity and adaptive capacity (Hahn et al., 2009). Therefore, the first approach (LVI), expresses the LVI as a composite index comprised of seven major components while the second aggregate the seven into the IPCC's three contributing factors to vulnerability: exposure, sensitivity, and adaptive capacity (Hahn et al., 2009; Adu et al., 2018). Based on its ability to measure vulnerability at district levels, the LVI took precedence in this study.

4.3. Methodology

4.3.1. Description of the study area

This study was conducted in fishing districts along the shores of Lake Kariba in Zimbabwe (Figure 4.1). The lake was formed because of the damming of the Zambezi River in the 1950s to generate hydroelectricity (Hasimuna et al., 2019). The lake is divided into five hydrological basins, namely, Binga, Mlibizi, Sanyati, Sengwa and Ume (Magqina et al., 2020). However, besides supporting hydropower generation, the construction of Lake Kariba led to the development of the fishing and tourism industries along the lake shores benefiting the communities surrounding the lake.

This study mainly focused on two basins, namely, Binga and Sanyati, which fall under the Binga Rural District (BRD) and the Kariba Rural District (KRD), respectively. BRD records high mean annual temperatures of about 30^{o}C and is characterised by low and erratic rainfall of less than 600 mm per annum. KRD is predominantly semi-arid (Ndebele-Murisa et al. 2011) and is characterised by mean annual minimum temperature and mean annual maximum temperature of about 24^{o}C and 30.7^{o}C, respectively. Furthermore, the area receives a mean annual rainfall of approximately 700 mm with high rainfall recorded during the rainy season (October- March).

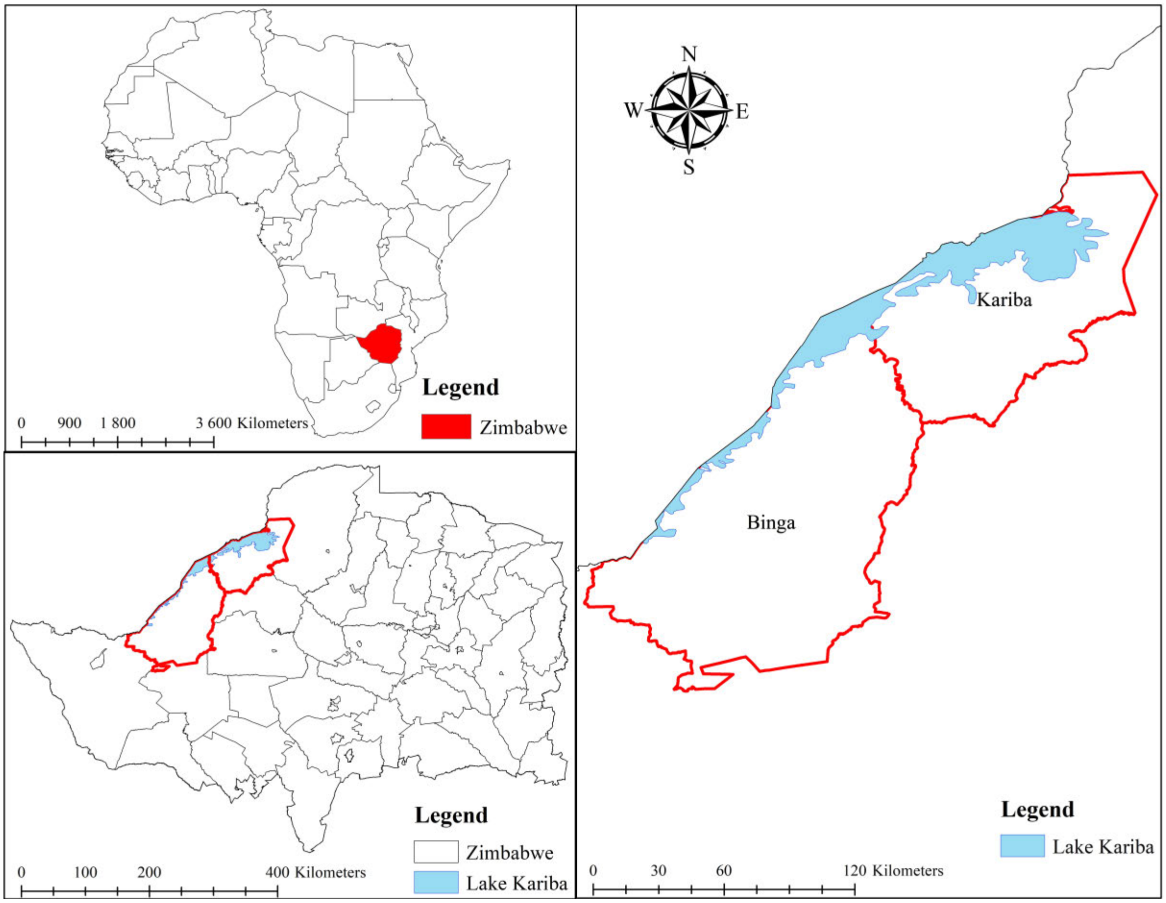

Figure 4.1: Map showing the location of the study areas. (*Source*: Author)

4.3.2. Data source and sampling procedure

This study used both primary and secondary data to address the research objective. Primary data was collected from the small-scale fishers in the two basins, which were randomly selected from the five basins of Lake Kariba, Zimbabwe. A survey questionnaire was administered to 120 household heads, 55 in BRD and 65 in KRD, who were purposively selected to participate in the study. A total of 120 fishers participated in the study because of constraints associated to accessibility of other fishing communities. The fishers were selected based on their availability and willingness to participate in the study. The questions that were asked about the fisher's exposure, sensitivity and adaptive capacity were based on existing literature on vulnerability analysis. The questionnaire covered 27 key variables, which were used in computing the LVI as well as other variables to achieve the other objectives.

Additionally, secondary data on temperature and rainfall were collected from the Meteorological Services Department of Zimbabwe (MSDZ). The reference period for the meteorological historical data was between 1987 and 2017. This range was preferred based on the definition of climate change, which is believed to be measured after 30 years.

4.3.3. Data analyses

This study used the LVI and LVI-IPCC approaches to estimate the livelihood vulnerability of small-scale fishing households to the impacts of climate change and variability.

4.3.3.1.Calculating the LVI: Composite Index Approach

The LVI includes seven major components sourced from Hahn et al. (2009) namely, socio-demographic profile (SDP), livelihood strategies (LS), social networks (SN), health (H), food (F), water (W), and natural disasters (ND) and climate variability (CV) (Table 4.1). Each major component is comprised of several indicators or sub-components developed based on a review of the literature on each major component. The indicators are measured at a different scale; therefore, they were then standardised as an index using Equations (1) or (2). Where a sub-component had a positive relationship with vulnerability, equation (1) was used, and equation (2) was used where a sub-component had a negative relationship with vulnerability.

$$Index_q = \frac{S_q - S_{min}}{S_{max} - S_{min}} \quad (1)$$

$$Index_q = \frac{S_{max} - S_q}{S_{max} - S_{min}} \quad (2)$$

Where, S_q is the original sub-component for district q, S_{min} and S_{max} are the minimum and maximum values, respectively. After standardising the a, they were then averaged using Equation (3) to generate the index of each component.

$$M_q = \frac{\sum_{i=1}^{n} Index_{sqi}}{n} \quad (3)$$

Where, M_q is one of the seven major components for district *q*: [socio-demographic profile (SDP), livelihood strategies (LS), social networks (SN), health (H), food (F), water (W), or natural disasters (ND) and climate variability (CV)], $Index_{sqi}$ represents the sub-components, indexed by *i*, that make up each major component, and *n* is the number of sub-components in each major component. Once values for each of the seven components for a district are calculated, the respective average for each district can be calculated using Equation (4) to obtain the district-level LVI:

$$LVI_q = \frac{\sum_{i=1}^{7} W_{Mi} M_{qi}}{\sum_{i=1}^{7} W_{Mi}} \tag{4}$$

Equation (4) can also be expressed as Equation (5):

$$LVI_q = \frac{W_{SDP}SDPq + W_{LS}LS_q + W_{SN}SN_q + W_H H_q + W_F F_q + W_w W_q + W_{NDCV}NDCV_q}{W_{SDP} + W_{LS} + W_{SN} + W_H + W_F + W_W + W_{NDCV}} \tag{5}$$

where LVI_q is the Livelihood Vulnerability Index for district *q*, which equals the weighted average of the seven major components. According to Sullivan (2002), the weights of each major component, W_{Mi} are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall LVI (calculations illustrated in the supplementary material). In this study, the LVI is scaled from 0 (low vulnerable) to 0.9 (extremely vulnerable). The scale of LVI values ranges from: 0 – 0.29 (Not vulnerable), 0.30 – 0.49 (Vulnerable/ Moderate), 0.50 – 0.69 (Very vulnerable), and 0.70 – 0.89 (extremely vulnerable).

4.3.3.2. Calculating the LVI-IPCC: IPCC Framework Approach

The LVI-IPCC framework approach was developed as another method for calculating the LVI that incorporates the IPCC vulnerability definition, which states that climate vulnerability was described as a function of a community's exposure (*E*), sensitivity (*S*), and adaptive capacity (*AC*) to climate change (Williams et al., 2020). Exposure of the study population was measured by the number of natural disasters that have occurred in the past 10 years, while climate variability was measured by the average standard deviation of the maximum and minimum monthly temperature and monthly precipitation over a 30-year period. Furthermore, sensitivity was measured by assessing the current state of a district's food and water security and health status. Adaptive capacity is measured by the demographic profile of a district, the types of livelihood strategies employed, and the strength of social networks. The sub-components outlined in Table 4.1 as well as Equations (1) to (4) were used to calculate the LVI-IPCC using Equation (6) as follows:

$$CF_q = \frac{\sum_{i=1}^{n} W_{Mi} M_{qi}}{\sum_{i=1}^{n} W_{Mi}} \qquad (6)$$

Where, CF_q is the IPCC-defined contributing factor (*E*, *S*, *AC*), for district q, M_{qi} are the major components for district q, W_{Mi} is the weight of each major component, and *n* is the number of major components in each contributing factor (CF). After exposure, sensitivity, and AC were calculated, the three contributing factors were combined using Equation (7):

$$LVI - IPCC_q = \left(E_q - AC_q\right) * S_q \qquad (7)$$

Where, $LVI - IPCC_q$ is the LVI for district *q* expressed using the IPCC vulnerability framework, *E* is the calculated exposure score for district *q* (equal to the natural disaster and climate variability major component), *AC* is the adaptive capacity score for district *q* (weighted average of the SD, LS, and SN major components), and *S* is the calculated sensitivity score for district *q* (weighted average of the H, F, and W major components) (calculations illustrated in the supplementary material). The LVI-IPCC was scaled from -1 (least vulnerable) to 1 (most vulnerable). In this study, the LVI, radar chart and the vulnerability triangle were developed using Microsoft Office Excel 2016 as described by Hahn et al. (2009).

4.4. Results and analysis

4.4.1. Household vulnerability index

The results obtained from the data analysis are reported in two parts. The first part is a comparative analysis of the LVI of the two fishing districts using the individual major components along with their respective sub-components (Table 4.1), and the second part deals with the LVI contributing factors and LVI-IPCC.

Through empirical analysis, the vulnerability indices of the major components ranged from 0.22 to 0.83 (Table 4.1). Being relative values, the indices values were compared across the two fishing districts. Based on the findings, the vulnerability of the socio-demographic profile component of the LVI showed that the fishing districts were moderately vulnerable to climate change impacts. However, BRD (0.3), was more vulnerable than KRD (0.25). The dependency ratio (0.73), the percentage of heads of household that never attended or finished primary school (0.09), and the number of households with family members needing daily assistance (0.16), were higher in BRD than in KRD, which reported (0.58), (0.07) and (0.09), respectively. However, the percentage of female-headed households was higher in KRD (0.25), as compared to BRD (0.22).

In this study context, the livelihood strategies component comprises three sub-components. The component shows that BRD and KRD fishing districts are vulnerable to the impacts of climate change. The findings reveal a greater vulnerability in BRD (0.61) than in KRD (0.56). BRD showed higher vulnerability (0.47), in terms of the percentage of households with family members working in a different community than KRD (0.55). This implies that fishing households in KRD have a higher number of family members working in other communities. Some family members in other communities send food parcels and remittances to relatives, which helps in enhancing their resilience to the impacts of climate change. Furthermore, BRD presented greater vulnerability (1.00), based on the percentage of households' dependent on fisheries as their main source of income than KRD (0.98). All sampled households in BRD relied on fisheries as their main source of income, unlike in KRD where some fishers are also groceries traders based in the fishing communities. High reliance on fisheries for livelihoods and income, particularly in KRD, might be due to the prohibition of farming and livestock rearing in safari and wildlife protected areas. KRD showed greater vulnerability (0.16), based on the average index of livelihood diversification than BRD (0.36). This indicates that fishing households in BRD practiced more diversified livelihood activities than in KRD. Households with fewer livelihood activities tend to be more vulnerable to the impacts of climate change.

The social network major component consisted of four sub-components. When all the sub-components were aggregated, BRD showed moderate vulnerability (0.46), as compared to the KRD component which showed that the district is not vulnerable (0.22) to the impacts of climate change. The study findings show that fishers in both fishing districts receive help more than they provide to others. This might be attributed to their socio-economic status and inadequate household resources to be able to help other households. In addition, the findings showed that 65% of the fishing households in BRD did not visit their local government for assistance in the past 12 months while 9% of fishing households in KRD did not approach their local government for assistance in the same period. This implies that fishing households in BRD were not aware of the social relief food parcels that were being offered by the district councils through the Government of Zimbabwe Food Aid Progamme (GZFAP), to the households within their jurisdiction. During the data collection period, non-governmental organisations (NGOs), such as the World Vision and United Nations International Children's Emergency Fund (UNICEF), and Save the Children, were actively providing aid monthly, particularly in BRD.

The health major component comprised four sub-components. After aggregating all the sub-components, the LVI results show that fishing households in both BRD (0.36) and KRD (0.34), were vulnerable to the impacts of climate change (Table 4.1). However, KRD showed greater vulnerability (0.75) than BRD (0.33) in terms of the average time taken to reach a health facility. This is because the sampled fishing camps/villages were far from Kariba town and can only be accessed by using boats, unlike fishing camps in BRD, which were in proximity to health facilities and availability of roads that made access easy, especially Intale fishing camp, which had access to tarred roads. The percentage of households with a family member with chronic illness was relatively low in both BRD (0.09) and KRD (0.02). Furthermore, the percentage of households with family members that missed school or work due to illness was higher in BRD (0.36) than in KRD (0.05). Fishing households in BRD were more vulnerable to malaria than in KRD giving an average malaria exposure, and prevention index of 0.65 and 0.52, respectively.

The food major component consisted of three sub-components. The percentage of fishing households dependent on fisheries for food was high in both BRD (1.00) and KRD (1.00). This signifies that fish is the main or only source of animal protein in the respective districts. The percentage of households struggling for food was higher in KRD (0.83) than in BRD (0.78). The percentage of households with decreasing fish production was higher in KRD (0.66) than in BRD (0.62). After aggregating all the sub-components of the food major component, the results showed that both BRD (0.80) and KRD (0.83) were extremely vulnerable to climate change impacts.

The water major component consisted of three sub-components. When all the sub-components were aggregated, the indices showed extreme vulnerability in both districts, nonetheless, BRD showed greater vulnerability (0.77) than KRD (0.72) (Table 4.1). The percentage of households that utilise a natural water source was similar in both districts and all households depend on Lake Kariba as a source of water for drinking and domestic use. The household average time to the water source was higher in BRD (0.31) than in KRD (0.17). From observation, communities in KRD are near the Lake unlike in BRD. Both districts showed similar index values indicating great vulnerability (1.00) in terms of the percentage of households that do not have a consistent water supply.

Table 4.1: Indexed Sub-components, Major Components and Overall LVI for BRD and KRD

Major Components	Sub-components/ indicators	Sub-components value		Major Components Value	
		BRD	KRD	BRD	KRD
SDP	Dependency ratio.	0.73	0.58	0.3	0.25
	Percentage of female-headed households.	0.22	0.25		
	Percentage of households where the head of household did not finish primary school.	0.09	0.07		
	Percentage of households with family members needing assistance.	0.16	0.09		
LS	Percentage of households whose family members work outside the community.	0.47	0.55	0.61	0.56
	Percentage of households who depend on fisheries as their main source of income.	1.00	0.98		
	Average index of livelihood diversification.	0.36	0.16		
SN	Average receive: Give ratio.	0.45	0.34	0.46	0.22
	Average Borrow: Lend money ratio.	0.29	0.24		
	Percentage of households that have not gone to their local government for assistance in the past 12 months.	0.65	0.09		
H	Average time to a health facility.	0.33	0.75	0.36	0.34
	Percentage of households with a family member with chronic illness.	0.09	0.02		
	Percentage of households with family members miss school or work due to illness.	0.36	0.05		

	Average malaria exposure, prevention index.	0.65	0.52		
F	Percentage of families who depend on family fisheries for food.	1.00	1.00	0.80	0.83
	Percentage of households struggling for food	0.78	0.83		
	Percentage of households with decreasing fish production.	0.62	0.66		
W	Percentage of households that utilise a natural water source.	1.00	1.00	0.77	0.72
	Average time to water source.	0.31	0.17		
	Percentage of households that do not have a consistent clean (portable) water supply.	1.00	1.00		
NDCV	The average number of floods, drought, and cyclone events in the past 10 years.	0.57	0.53	0.44	0.41
	Percentage of households that did not receive a warning about the pending natural disasters.	0.73	0.55		
	Percentage of households with an injury or death because of recent natural disasters.	0.09	0.17		
	Percentage of households that reported damaging of assets (i.e., boats, fish landing sites, property, livestock etc.) due to adverse weather events.	0.60	0.75		
	Mean standard deviation of the monthly average of average minimum monthly temperature (years: 1987–2017).	0.14	0.21		
	Mean standard deviation of the monthly average of average maximum monthly temperature (years: 1987–2017).	0.39	0.27		
	Mean standard deviation of monthly average precipitation (years: 1987–2017).	0.58	0.41		
Overall LVI				**0.51**	**0.45**

Notes: SDP = Socio demographic profile, LS = Livelihood strategies, SN = Social networks, H = Health, F = Food, W = Water, NDCV = Natural disaster and Climate variability, LVI = Livelihood Vulnerability Index, % = Percentage, BRD = Binga Rural District and KRD = Kariba Rural District.

The natural disaster and climate vulnerability major component consisted of seven sub-components (Table 4.1). The LVI analysis indicated that BRD showed higher vulnerability (0.57) based on the average number of floods, drought, and cyclone events that occurred in the past 10 years than those that occurred in KRD (0.53). The fisher's responses differed between the two districts despite the proximity of the districts and their similar climate environment. This might be due to the differences in fisher's perceptions or observations about the occurrence of adverse weather events. Furthermore, the percentage of households that did not receive a warning about the pending natural disasters was higher in BRD (0.73) than in KRD (0.55). The Lake Kariba Navigation Control (LKNC) shares information about the prevailing weather conditions within and in areas surrounding the lake, however, most fishers do not have access to the information due to a lack of devices such as radios, televisions (TV) and mobile phones. Additionally, some fishing camps such as Chinzonzo in Binga do not have radio and TV reception (signals), which increases the vulnerability of the fishing households to the impacts of climate change and variability. The percentage of households that reported an injury or death because of recent natural disasters was higher in KRD than in BRD with indices of (0.17) and (0.09), respectively. Fishing households in KRD showed greater vulnerability (0.75) in terms of the percentage of households that reported damaging of assets (i.e., boats, fish landing sites, property, livestock etc.) due to adverse weather events than in BRD (0.60). According to both districts, damages were mostly on shelters and boats. Fishers are not permitted to build permanent shelters within fishing camps and villages, hence, the temporary shelters built by fishers are prone to damage from adverse weather events such as cyclones, and floods (see appendix E, Figure A1). Furthermore, KRD had a higher number of households owning boats than in BRD and the boats were prone to destruction particularly from harsh winds and crashes during periods of low lake water levels.

Meteorological historical data over a 30-year period (1987–2017) showed that the mean standard deviation of the monthly average minimum temperature was higher in KRD than BRD with indices of 0.14 and 0.21, respectively. Furthermore, the mean standard deviation of the monthly average maximum temperature index showed greater vulnerability in BRD (0.39) than in KRD (0.27). Indices recorded for BRD and KRD in relation to the mean standard deviation of monthly average precipitation (1987–2017) were 0.58 and 0.41, respectively. This signifies that BRD is more vulnerable based on a mean standard deviation of monthly average precipitation than KRD.

After aggregating the LVI values of the natural disaster and climate variability major component, the indices show that both BRD and KRD are moderately vulnerable with indices values of 0.44 and 0.41, respectively.

Figure 4.2 summarises the results of all the major components. The vulnerability radar diagram ranges from 0 (least vulnerable) to 0.89 (extremely vulnerable). BRD showed greater vulnerability in terms of the socio-demographic profile, livelihood strategies, social networks, health, water and natural disasters and climate vulnerability. KRD was more vulnerable in terms of food.

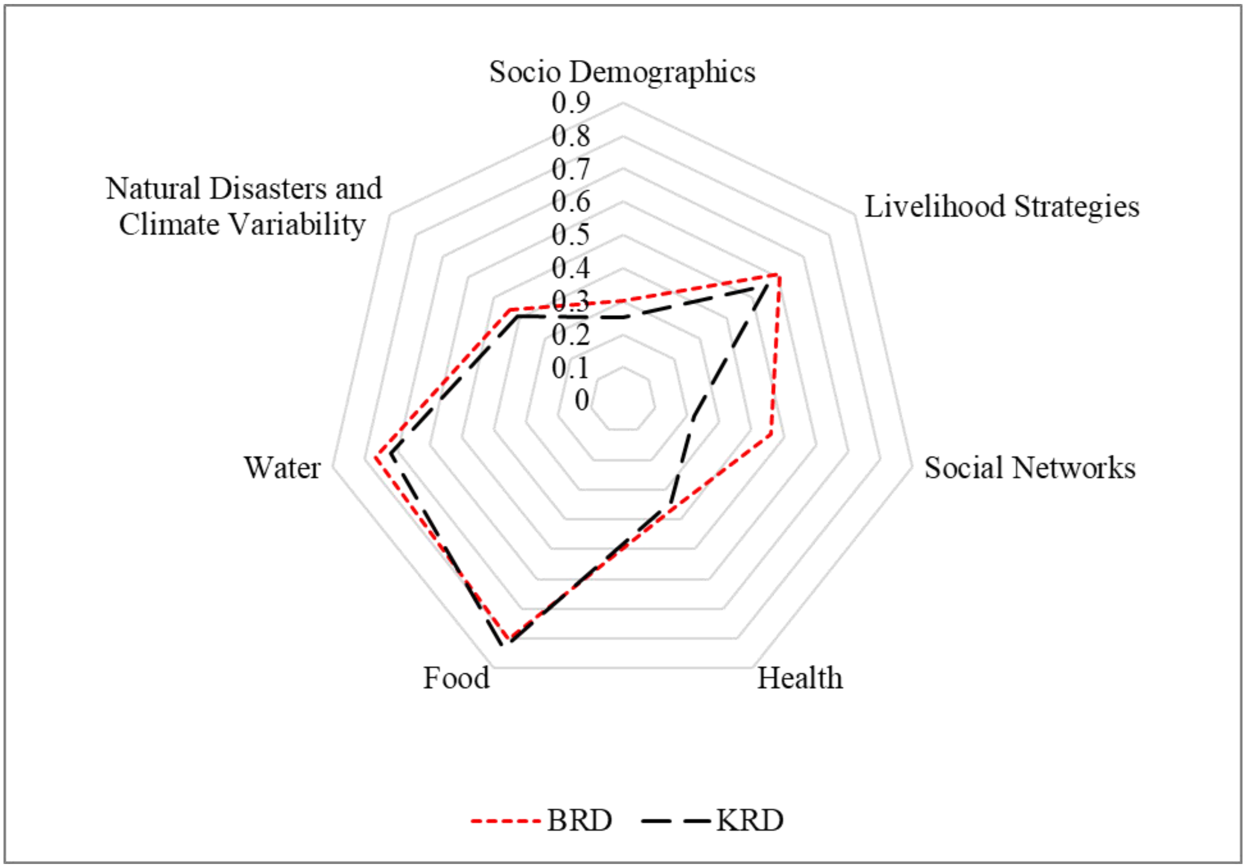

Figure 4.2: Vulnerability radar (spider) diagram of the major components of the LVI for BRD and KRD. (*Source*: Author)

4.4.2. LVI – IPCC: Binga Rural District versus Kariba Rural District

The LVI-IPCC main component was calculated by grouping the seven major components into three categories, that is, exposure, sensitivity, and adaptive capacity also termed CF. The sensitivity and adaptive capacity categories of vulnerability were made up of the aggregated scores of three major components each except for exposure, which was made up the score of only one major component. The LVI-IPCC estimates for BRD and KRD were 0 and 0.05, respectively (Table 4.2). This suggests that, overall, KRD (0.05) was more vulnerable than BRD (0) in terms of climate change and variability.

The vulnerability triangle (Figure 4.3) presents the IPCC definition of vulnerability, which encompasses exposure, sensitivity, and adaptive capacity. The findings of the three dimensions of vulnerability presented in Figure 4.3 ranges from 0 (low contributing factor) to 0.7 (high contributing factor).

Based on the findings, the vulnerability triangle (Figure 4.3) depicts that fishing households in BRD had greater exposure, sensitivity and adaptive capacity to the climate change and variability impacts than those in KRD. However, within the sensitivity dimension of vulnerability, KRD showed greater vulnerability (0.83), in terms of the food major component than BRD (0.80). This implies that fishing households are experiencing more food shortages owing to perceived declining fish catches and household incomes.

Table 4.2: LVI - IPCC for Binga and Kariba Rural Districts

Contributing Factors	Major components	Major components values		Number of sub-components per major component	Contributing factor values	
		BRD	**KRD**		**BRD**	**KRD**
Exposure	Natural disasters and Climate Variability	0.44	0.41	7	0.44	0.41
Sensitivity	Health	0.36	0.34	4	0.62	0.60
	Food	0.80	0.83	3		
	Water	0.77	0.72	3		
Adaptive capacity	Socio-economic demographics	0.30	0.25	4	0.44	0.33
	Livelihood Strategies	0.61	0.56	3		
	Social Networks	0.46	0.22	3		
LVI – IPCC Score					**0**	**0.05**

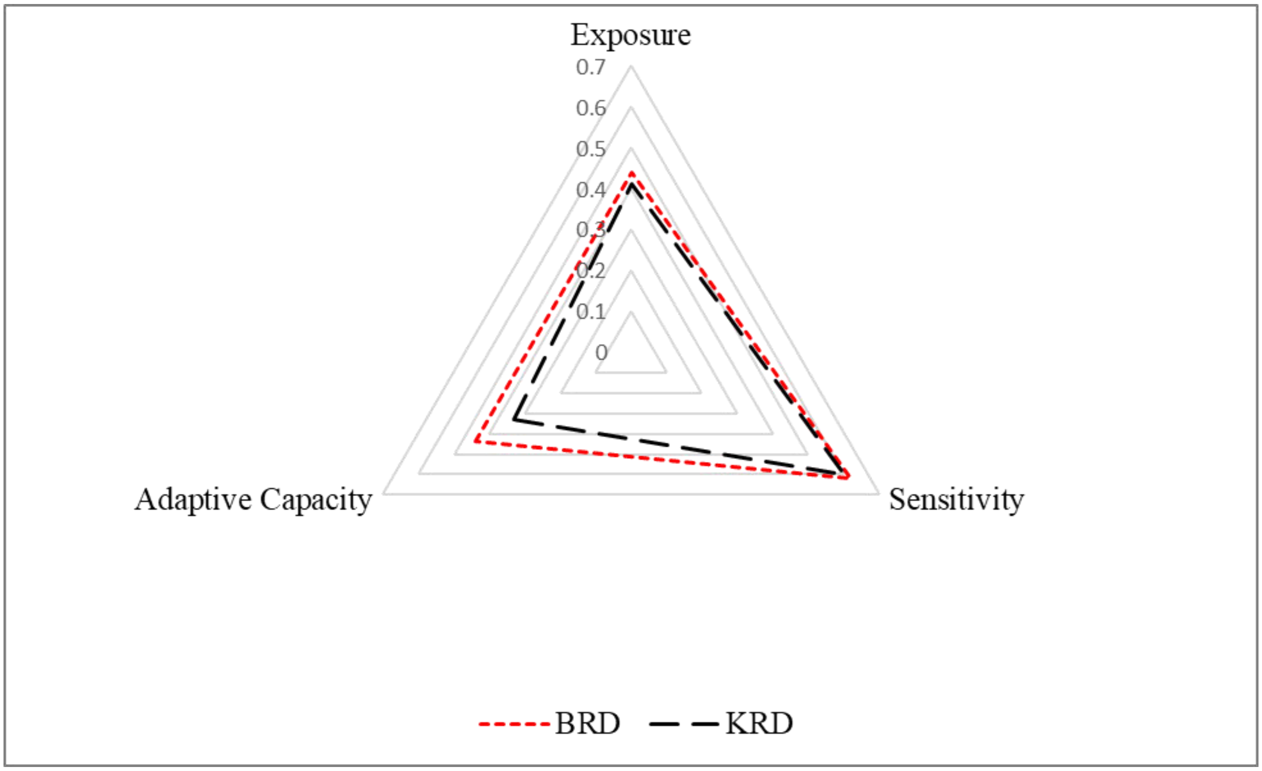

Figure 4.3: Vulnerability Triangle Diagram of LVI-IPCC for BRD and KRD. (*Source*: Author)

4.5. Discussion

Understanding what makes inland fishing communities vulnerable to the impacts of climate change is a critical task for researchers, governments, development agents, and civil society. In this study, the vulnerability of fishing communities to the impacts of climate change and variability was assessed using a recognised composite index, the LVI and LVI- IPCC. The results of this study revealed that BRD and KRD fishing districts are vulnerable to the impacts of climate change and variability, which is due to their high dependency on climate-sensitive resources. However, the vulnerabilities are not homogeneous between the districts. The variation in vulnerability between the districts depends on the fishing household's characteristics within each district.

The fishery-based livelihoods of households in Binga and Kariba Rural districts are exposed to the impacts of climate change and variability, particularly changes in temperature and rainfall patterns, and the increasing occurrence of adverse weather events. Ndebele-Murisa et al. (2013) and Mahere et al. (2014) whose studies detected increasing temperatures and increasing rainfall variability around Lake Kariba support this assertion. Moreover, Swain et al. (2012), Fant et al.

(2015) and Kupika et al. (2019) postulate that the Zambezi River Basin, which encompasses the Binga and Kariba Rural districts, is particularly susceptible to the impacts of climate change and variability. Adverse weather events, particularly floods, have become an annual event in most parts of the basin where they previously occurred infrequently or never occurred (Tauya and Matowanyika, 2013). In this study context, the exposure of aquatic resources to increasing temperature, rainfall variability and adverse weather events have negative impacts on both the aquatic species and human communities dependent on them for food and livelihoods. For instance, studies by Cohen et al. (2016), Whitney et al. (2016) and Nyboer and Chapman (2017) found that warming temperatures negatively affected fish productivity in freshwater ecosystems mostly resulting in declining productivity and fish catches. Furthermore, studies by Westlund (2007) and Musinguzi et al. (2016) also found that adverse weather events owing to climate change can damage fishing gear and properties and increases the risk of injury or death. The differences in the exposure dimension of vulnerability between the two districts might be attributed to the differences in fisher's perceptions of changing climatic trends and their related impacts.

The sensitivity of fishing communities to the impacts of climate change is mainly determined by dependency on fishery resources for food and livelihoods. Fishing and its related activities are the main livelihood strategies in BRD and KRD, which generates income and is the main source of food supply for the fishing households. Several researchers such as O'Gorman et al. (2016), Nyboer and Chapman (2017), Olusanya and van Zyll de Jong (2018), and Devkota and Kathayat (2020) agree that fishery resources are highly sensitive to changes in climatic factors, especially changes in temperature and rainfall patterns, which affect fish productivity. Furthermore, the lack of alternative livelihood strategies within the study sites led to some fishers or members of fishing households to migrate from the fishing communities in search of opportunities in other places. These findings are similar to those of Njaya et al. (2011) and Islam (2013) whose studies found that small-scale fishers in Lake Chilwa (Malawi) and Bangladesh migrated to other areas to cope with the impacts of climate change, respectively. Furthermore, a study by Ndhlovu et al. (2017) concluded that small-scale fishers of Lake Kariba are sensitive to climate change due to several factors such as increased fishing pressure due to population increase in fishing communities, declining fish catches, low-income from fishing and heavy dependence on fishing for a livelihood.

Feyissa et al. (2018) suggest that the vulnerability to the impacts of climate change is not only measured by the exposure and sensitivity strength, rather, but it is also a matter of adaptive capacity. Based on this study's findings, the adaptive capacity of small-scale fishers of Lake Kariba is limited due to a higher population, which is not economically active, high dependency on a climate-sensitive resource for livelihoods and food, lack of external aid/intervention and lack of access to weather information and early warning systems. Senaratna et al. (2014) and Zommers and Singh (2014) argue that early warning systems are central to reducing vulnerability to the impacts of climate change. As indicated by Islam et al. (2014) in their study on barriers and limits to climate change adaptation within fishing communities in Bangladesh, the lack of early warning systems increased the fishers' risk to the impacts of climate change.

Furthermore, based on observations, the two fishing districts are characterised by a lack of infrastructure (roads, sanitation and electricity). Nevertheless, the factors affecting the adaptive capacity of fishers varied between the districts. Fishers in BRD have access to roads and during the study period, some households received aid in the form of food parcels and cash from World Vision and Save the Children. However, the same fishers perceive that they do not have access to natural resources, as the use of the resources is controlled by the ZPWMA. According to Islam et al. (2014) and Ludeña and Yoon (2015) the adaptive capacity of fisheries systems is determined by the availability and access to livelihood assets (physical, natural, human, social, and financial), enabling infrastructure, distribution of resources access to information and technology and institutional capacity. These factors that affect the adaptive capacity of small-scale fishers are interrelated, for instance, the lack of roads affects the market accessibility and delays the delivery of humanitarian aid. Additionally, the vulnerability of these fishing communities is exacerbated by the low level of economic development. Zimbabwe's poor economic performance hinders the adaptive capability of small-scale fishers and fuels the sensitivity of fishing communities to the impacts of climate change. The high level of unemployment in Zimbabwe is increasing the overall population of fishers (Kupaza et al., 2015), which increases the pressure and demand of the already dwindling fish resources affecting the profitability of the existing fishing households.

4.6. Conclusions and recommendations

This study attempted to assess climate change vulnerability in terms of its dimensions of exposure, sensitivity, and adaptive capacity, of fishing communities along the shores of Lake Kariba using the LVI and LVI – IPCC. The findings revealed that the fishing communities along the shores of Lake Kariba in Zimbabwe are vulnerable to the impacts of climate change due to their high dependency on fishery resources for livelihoods and food supply and their low adaptive capacity. The Binga Rural District is characterised by high exposure, sensitivity and adaptive capacity compared to Kariba Rural District. The high dependency on climate-sensitive resources increases the vulnerability of the communities to changing climatic conditions, because changes in temperature and rainfall patterns affect fish productivity in freshwater ecosystems. Furthermore, adverse weather events disrupt fishing schedules, destroy assets, and threaten human life. Drawing from these findings, the study proposes policy measures aimed at reducing the sensitivity of fishing communities and improving their adaptive capacity. The adaptive capacity of these fishing communities is determined by the availability and access to physical, natural, and financial capital and the ability to diversify their livelihood strategies.

This study's findings provided valuable knowledge about the current state of vulnerability of the small-scale fishing communities along the shores of Lake Kariba. Furthermore, the obtained findings form a baseline, which can be updated regularly, against which to establish long term ongoing monitoring and continuous assessment of climate change vulnerability. Moreover, the findings inform stakeholders, governments, NGOs and policymakers on priority areas that need intervention to enhance climate adaptation and resilience to the effects of climate change. Given the growing demand of fishery resources and the growth of the sector, conducting climate change vulnerability studies such as these is crucial to the implementation of climate change mitigation and adaptation policies that will be effective in securing the future sustainability of inland fisheries, prioritise communities based on the greatest need of intervention and understand the drivers of vulnerability within natural resource dependent communities to inform future research directions.

This study's findings are solely based on responses obtained from fishers, hence, the study suggests future research incorporate secondary data such as and remotely sensed data, to validate fisher's perceptions of exposure to the impacts of climate change. Most indices reflect the current state of vulnerability rather than future challenges which limits the reliability of the indices. In addition, future studies may focus on improving the index composition and construction methods to improve the reliability and accuracy of the index results.

Link to next chapter:

This chapter analysed the livelihood vulnerability of fishing communities along the shoreline of Lake Kariba. The findings show that, communities in Kariba/Nyaminyami district are more vulnerable to the impacts of climate change than those in Binga Rural District, due to low adaptive capacity. Therefore, the following chapter attempted to identify localised barriers and limits to climate change adaptation among small-scale fishers.

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CHAPTER FIVE[4]

Barriers and Limits to Climate Change Adaptation in Inland Fisheries. A Look at Small-scale Fisheries of Lake Kariba, Zimbabwe.

Abstract

Climate change has adversely affected the functioning of the ecosystem and provisions of valuable goods and services to humankind. However, adaptation is the most effective way to deal with climate change's negative effects. Globally, adaptation to climate change is emerging as an important developmental challenge. There are several barriers and limits that restrict people's ability to address the negative impacts of climate change or manage risks in a way that maximises their welfare. Thus, this study attempted to identify and characterise the barriers and limits to adaptation of small-scale fishers of Lake Kariba in Zimbabwe. A qualitative research approach was used in this study to collect and analyse data. Four focus group discussions were conducted in Binga and Kariba rural districts. The data were subjected to thematic analysis of key perspectives drawn from small-scale fishers. The findings reveal that adaptation is hindered by several barriers such as regulatory, access to services, institutional and technological. Furthermore, ecological and natural limits were also identified as limitations to climate change adaptation. These barriers and limits interact in complex ways and constrain the ability of fishers to adapt. The study recommends policymakers and development agencies to adopt a bottom-up approach when designing and implementing climate change adaptation policies and actions, to identify the types of barriers and limits that can hinder the success of climate change adaptation efforts.

Keywords: adaptation, fisheries sector, livelihoods, small-scale fishers, Lake Kariba, Zambezi River Basin

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5.1. Introduction

Climate change induced risks threaten several countries around the world. Poor countries are particularly vulnerable to climate change-related risks because of their low adaptive capacity and the heavy reliance on climate-sensitive sectors such as agriculture (crop and livestock production, forestry and fisheries) for livelihoods and food supply (Aryal et al., 2021). The African freshwater fisheries sector which supports livelihoods and contributes to food and nutrition security for millions of Africans cannot be spared from the effects of climate change and variability. In freshwater fisheries, climate change affects the fisheries sector in three ways, (i) by shifting the physical and chemical conditions such as increased water temperature, stratification and habitat loss (Harrod et al., 2019), (ii) affecting the biological conditions of freshwater environments such as species abundance, fish metabolic rates and reproduction (Dallas and Rivers-Moore, 2014, Nyboer and Chapman, 2017), and (iii) impacting the socio-economic condition such as reducing fish catches and disrupting fishing activities (Rahman et al., 2021). There is considerable evidence that fish production in African freshwater fisheries, in general, is more dependent on external climatic drivers than anthropogenic factors and various management interventions (Kolding et al., 2016). Notwithstanding the contribution of anthropogenic activities to decreasing fish production and catches, climate change is considered to be a significant factor, because it interacts with and amplifies the existing anthropogenic stressors (Mohammed and Uraguchi, 2013, Muringai et al., 2021). For instance, studies by Ndebele-Murisa et al. (2011), Cohen et al. (2016), Musinguzi et al. (2016) and Nyboer et al. (2020) found that changing climatic parameters such as temperature and rainfall adversely affect freshwater fisheries in African water bodies, resulting in the decline of fish productivity and fish catches. Moreover, in the Zambezi River Basin (ZRB), human activities such as increased fishing effort, reduced mesh size and use of environmentally destructive fishing gear contribute to the decline in fish catches (Tweddle et al., 2015).

In Lake Kariba, the impacts of climate change and variability threaten livelihoods and food security for thousands of people who are directly or indirectly associated with small-scale fisheries. Therefore, small-scale fishers’ adaptation to fluctuating fishery resources due to climate change is inevitable. Di Falco et al. (2012) and Purwanti et al. (2022) postulate that adaptation is the most effective way to deal with climate change’s negative effects. According to the IPCC (2007), adaptation refers to adjustments in social-ecological systems' behaviour that are carried out in response to observed or anticipated changes to reduce damaging impacts or to take advantage of new opportunities. Similarly, Shaffril et al. (2017) define climate change adaptation as the anticipation of negative effects of environmental change, implementation of appropriate mitigation measures and seizing of opportunities that may emerge. Adaptation is divided into two categories: planned adaptation and autonomous adaptation (Shelton, 2014). According to the International Fund for Agricultural Development (IFAD), planned adaptation is the increase in adaptive capacity achieved by mobilising institutions and policies to generate or reinforce conditions conducive to effective adaptation and new technology and infrastructure investment (IFAD, 2014). On the other hand, autonomous adaptation is the continual use of current knowledge and technology in response to climate-related changes (IFAD, 2014). Therefore, adaptation can be proactive (planned) or reactive (autonomous). In fisheries, most adaptation strategies used have been implemented in response to changing fishery resources (autonomous), rather than proactive (Bahri et al., 2021). In this study, both autonomous and planned responses to the effects of climate change are regarded as adaptation.

Despite being inevitable to addressing the impacts of climate change and variability, adaptation efforts are impeded in several ways. The existence of barriers and limits to adaptation led Schipper and Burton (2009) to state that the 'adaptation deficit is getting wider', that is, the implementation of adaptation is not keeping pace with the ever-increasing need. Barriers and limits restrict people's ability to identify, assess and manage risks in a way that maximises their welfare (IPCC, 2012; Islam et al., 2014). Some researchers use the terms barriers and limits to adaptation interchangeably, while others distinguish their meanings (Eisenack et al., 2014; Islam et al., 2014). This study considers a barrier to adaptation as "an impediment to specified adaptation efforts, for specified actors in their given context that arise from a condition or set of conditions" (Eisenack et al., 2014). The IPCC's fifth assessment report characterises adaptation barriers (synonymous with adaptation constraints) as "factors that make it harder to plan and implement adaptation actions or that restrict options" (Moser and Ekstrom, 2010). Barriers can be reduced or overcome with concerted effort, creative management and change of thinking (Adger et al., 2009; Moser and Ekstrom, 2010). On the other hand, "limits are conditions or factors that render adaptation ineffective as a response to climate change and are largely insurmountable" (Adger, 2007). Limits are experienced when thresholds associated with natural ecosystems and social systems are exceeded (IPCC, 2012). For instance, swift climate change can change the physical environment and limit adaptation likelihood.

Barriers and limits to climate change adaptation can be separated into distinct but interrelated categories: natural, social, technological, institutional (formal or informal), economic and human resources (Jones and Boyd, 2011; Eisenack et al., 2014; Islam et al., 2014; McNamara et al., 2017). The barriers and limits to the adaptation of small-scale inland fisheries are location specific and cannot be generalised at macro-scales as the success and relevance of adaptation strategies has more to do with the governance and the context they operate in. Therefore, there is a need to understand local barriers and limits of climate change adaptation among small-scale fishers, as the barriers and limits can jeopardise the ability of small-scale fishers to cope with environmental change. In addition, Eisenack et al. (2014) argue that identifying and analysing barriers and limits to adaptation helps to identify opportunities to overcome them. Additionally, understanding local barriers and limits that inhibit the application of climate adaptation strategies is an important starting point for the implementation of good and effective management practices (Bahri et al., 2021).

It is against this backdrop that this study attempted to identify and characterise the barriers and limitations to the adaptation of small-scale fishers of Lake Kariba in Zimbabwe. The fishers were asked about the factors that hinder their ability to adapt to the changing environment due to climate change. To the best of our knowledge, this is the first study to investigate the barriers and limits to climate change adaptation of small-scale fishers of Lake Kariba in Zimbabwe. Through this, barriers and limits which restrict individuals or fishing communities from adapting the most suitable and sustainable forms of adaptation can be identified. The findings intend to inform policy and decision-makers on factors influencing adaptation at the local level and to assist in the development of comprehensive and coherent policies aimed at improving the resilience of small-scale fishers of Lake Kariba to the effects of climate change.

5.2. Methodology

5.2.1. Description of study area

The study was conducted in fishing communities along the shores of Lake Kariba, characterised by poor infrastructure and high dependency on fisheries for livelihoods and food security. Lake Kariba is the second-largest man-made Lake in Africa, by volume (World Bank, 2010). The lake is in the northwestern part of Zimbabwe (Figure 5.1), approximately 365 km from Zimbabwe's capital city, Harare (Marowa et al., 2021). Lake Kariba was constructed by the damming of the Zambezi River in 1956 and the lake borders Zambia and Zimbabwe. According to the World Bank, (2010), Kariba basin, which is one of the four subbasins of the ZRB, hosts 85% of the 30 million people living in the ZRB. Lake Kariba is divided into five hydrological basins according to the rivers that flow into it (Ndhlovu et al., 2017). There are six fishing camps and 35 fishing villages within the five hydrological basins (Ndhlovu et al., 2017). The fishing communities are under the jurisdiction of the Zimbabwe Parks and Wildlife Management Authority (ZPWMA); therefore, humans share the habitat with wild animals (Ndhlovu et al., 2017, Marowa et al., 2021). Small-scale fishing is the main livelihood activity in these fishing communities, as livestock rearing and farming are not permitted in wildlife protected areas according to the Statutory Instrument 362 of 1990.

Fishing camps in the Kariba (Nyaminyami) Rural District (KRD) are only accessible by boats, as there are no road networks connecting the communities to the nearest town(s). In KRD health facilities are in Kariba town, which is about 30 km from Gache-gache and 35 to 40 km from Nyaodza fishing camps. However, fishing camps in the Binga Rural District (BRD) have gravel road access and all the fishing communities are within 15 km radius from the Binga general hospital. Moreover, the fishers sell their fish produce to fisher buyers with valid fish trading licences. The fish sales are done at the fish landing sites as transportation of fishery resources from the landing sites requires a trading licence.

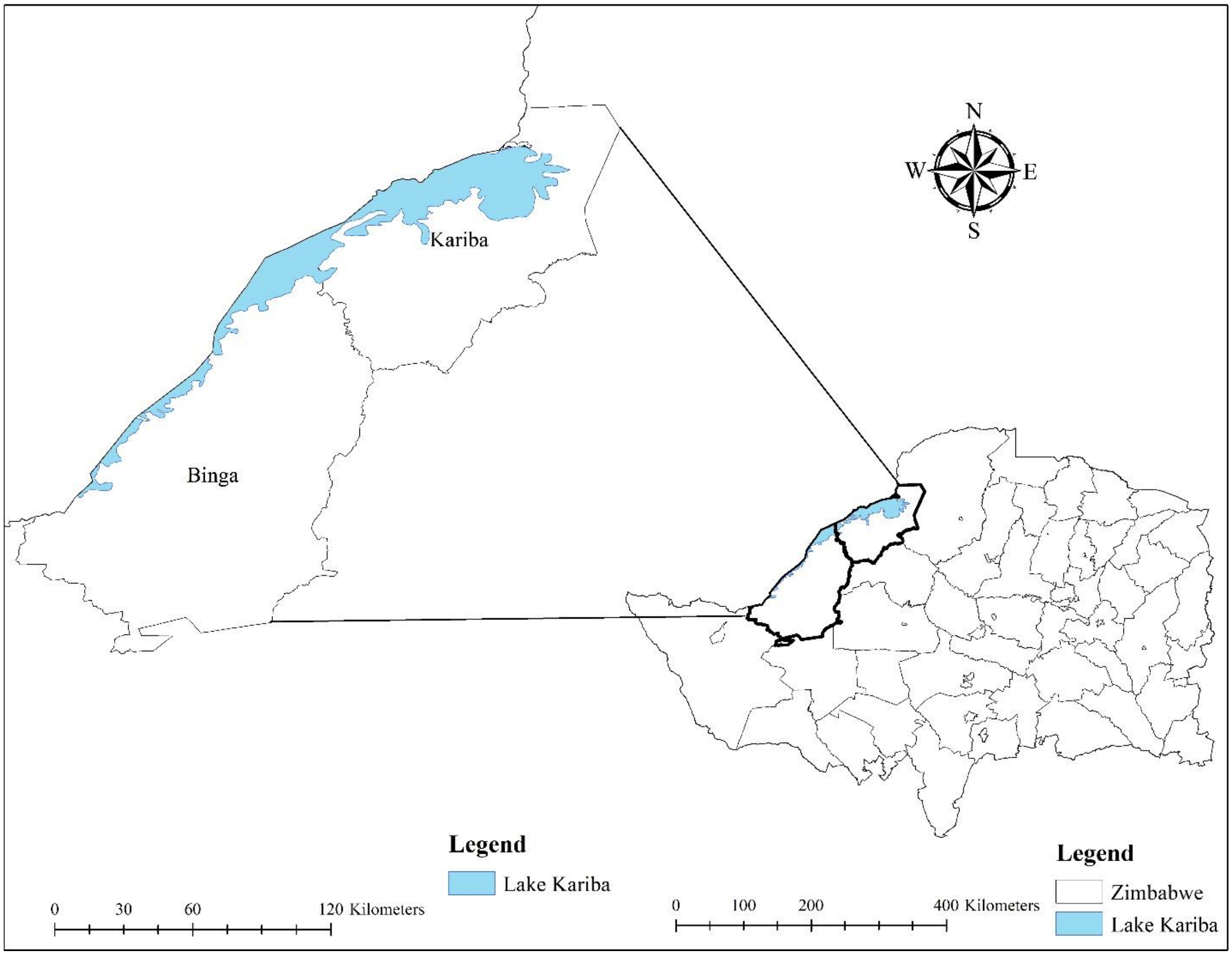

Figure 5.1: Map of study area (*Source*: Author)

The climate is subtropical with an annual rainfall of between 400 to 700 mm depending on the location (Chifamba, 2019). The area has one rainy season with most of its rain falling between October and March. The mean annual air temperature around Lake Kariba is above 31^{o}C (Chifamba, 2019), and the surface water temperatures range from 18^{o}C to 31^{o}C throughout the year (Magqina et al., 2021).

5.2.2. Data collection

This study used a qualitative research approach. The study focuses on the process elements of adaptation which are typically intangible and difficult to quantify, hence, qualitative research methods were considered to be more suitable than quantitative methods. Data were collected through focus group discussions (FGDs), key informant interviews and observations. In total, four FGDs were held in two fishing districts which are on the shores of Lake Kariba, that is, BRD (Chinzonzo and Intale fishing camps) and KRD (Gache-gache and Nyaodza fishing camps). The FGDs were made up of six to ten people each. One FGD with both males and females was held in each district and one FGD with female members only was held in each community as well. The FGDs with female members were only done to ensure that female participants fully participated and expressed their opinions without being intimidated by their male counterparts, as in some cultures, women are not allowed to talk in the presence of male equivalents. The FGDs were guided by a series of questions and probing questions emerged during the discussion.

5.2.3. Data analysis

The qualitative data collected through FGDs, key informant interviews and observations were subjected to thematic analysis. To identify the main types or themes of barriers and limits that hindered climate change adaptation in their respective areas, a thematic analysis method was adopted because the study reports the experiences, meanings and reality of participants (Fennell et al., 2016). To address this study's objective, the researcher followed Castleberry and Nolen's (2018) steps of conducting a thematic analysis, which include: compiling, disassembling, reassembling, interpreting and concluding.

The first step of the data analysis was to compile the data. During this stage, the researcher transcribed the data obtained from FGDs and interviews and organised all the data that was included in the analysis. Secondly, the compiled and organised data was separated (disassembled). At this stage, the data were separated to create meaningful groups through coding. According to Austin and Sutton (2014, p. 439) coding is "the process by which raw data are gradually converted into usable data through the identification of themes, concepts, or ideas that have some connection with each other". Generally, coding enables researchers to identify differences and similarities within a data set. Thirdly, the categorised data was put into context with each other to create themes. Braun and Clarke (2006) state that "a theme captures something significant about the data in relation to the research question and represents some level of patterned response or meaning within the data set". Therefore, in this stage, the disassembled data was reassembled. The fourth step was interpreting the reassembled data. The interpretation of the data did not wait until the end of the data analysis process, the researcher interpreted the data from the first three stages: compiling, disassembling and reassembling. Data interpretation helped the researcher to identify the barriers and limits of climate adaptation among fishing households, through thematic patterns identified within the data. The last stage of the data analysis process was making conclusions.

According to Yin (2015), conclusions are the response to the research questions or purpose of the study. The study findings were reported as themes in the results section.

5.3. Results

The factors affecting the fisher's adaptation to climate change were divided into two categories: barriers and limits. The thematic analysis revealed six major themes: (i) regulatory, (ii), access to basic services, (iii) institutional, (iv) technological, (v) ecological, and (vi) natural limits. The major themes were complemented by various subthemes as shown in Table 5.1.

Table 5.1: Themes and subthemes relating to the perceived barriers to climate change adaptation of small-scale fishers

Category	Theme	Sub-theme	Examples of indicative quote
Barriers	Regulatory	Lack of entitlement	“We do not own any land around us in this community” (female, KRD) “We are not permanent residents in this community) (male, BRD)
		Infrastructure	“We are not allowed to build proper houses” (male, KRD) “We do not have fish storage facilities” (female, BRD)
		Fishing regulations	“We pay high fines if we break the fishing regulations” (male, KRD) “The permitted fishing grounds are becoming smaller” (male, KRD)
	Services	Health	“We do not have any clinic in this village” (female, BRD) “It is not easy to get medical assistance in case of emergency” (male, KRD)
		Markets	“Making profits from fishing is difficult because there is no market for the produce” (female, BRD) “Some of our catches go to waste as we cannot easily sell all of it” (male, KRD)
		Infrastructure	“The roads are bad, and it is difficult to take our fish to the market (female, BRD) “Boats are the only mode of transport used by fishers and fish buyers because there are no roads” (male, KRD)
	Institutional	Fishing practices	"The parks officers take our fishing nets if they find the nets in the water after 6 AM" (male, KRD) “The fines imposed on us are too high” (male, KRD)
		Lack of support	"The government never helps us during the drought or flood periods" (female, KRD) “I have never seen any government or NGO agent in this community” (male, BRD)
	Technological	Weather forecast, Early warning systems	“We use our own knowledge to forecast the weather conditions” (male, BRD) “Sometimes we get hit by the cyclones and harsh winds during our fishing operations, we do not get warning information from the meteorological experts who are responsible for informing us about the prevailing weather conditions” (male, KRD)
	Ecological limits	Ecological	"Fish productivity has decreased over the past years" (male, KRD) "The crayfish feeds on the fish caught by our nets" (male, KRD)

Limitations			“The severity of droughts is affecting our fish catches” (male, KRD)
	Natural limits	Weather events	“The fish catches rot quickly because of high temperatures” (female, BRD)
		Lake water levels	“The water levels have decreased reducing our fishing grounds” (male, KRD)

5.3.1. Barriers to climate change adaptation

5.3.1.1. Regulatory

According to fishers in Lake Kariba, the rules and regulations imposed on fishing communities and fishing activities by the government and fisheries management agencies such as Lake Kariba Fisheries Research Institute (LKFRI), an affiliate of the Zimbabwe Parks & Wildlife Management Authority (ZPWMA), affect their ability to adapt to the effects of climate change and variability. Despite residing in the fishing communities for several decades, fishers lack entitlement to natural resources including the land and the fishery resources. Some fisher pointed out that, "*I was born and raised here, my father was a fisher, but still, they say we are not permanent residents in these fishing communities"…* (male, KRD) and "*the fish do not belong to us anymore as the fisheries officers tell us how much fish we can catch at a given time, and they arrest us if we break the rules*" ….(male, BRD).

In addition to the lack of entitlements to land and fishery resources, fishers are not allowed to build permanent physical structures in the study areas. Fishers stated that: *"We cannot construct proper houses for our families as we are not allowed to permanently reside here…*(male, KRD) and *"During times of adverse weather events, our shelters are usually destroyed as they are temporary structures that cannot withstand heavy rains or strong winds*…(male, KRD). The ZPWMA regulations only allow those practicing fishing from fishing camps to fish for limited periods and regularly travel back to their communal areas and construction of any permanent housing structure is prohibited (Ndhlovu et al., 2017). However, some small-scale fishers indicated that these fishing communities are their permanent homes, and some have inherited their homes from their parents who used to fish in Lake Kariba.

Additionally, fishers believe the regulations imposed by LKFRI affect their fish catches. Small-scale fishers attribute their declining fish catches to some of the rules and regulations imposed by LKFRI. The LKFRI's main functions include regulating fishing activities, law enforcement, issuing of fishing permits, conducting research and providing fisheries extension services (LKRF, u.d). Fishers indicated that the LKFRI determine the permissible fishing grounds and during drought periods the fishing grounds shrink, resulting in a decline in fish catches. Furthermore, the confiscation of illegal fishing gear by LKFRI fisheries officers disrupts fishing schedules and the overall profits from fisheries.

5.3.1.2. Access to services

Fishers indicated that they have limited to no access to basic services such as health facilities, water and sanitation, markets, roads, and electricity. The lack of health facilities in the study area, especially in KRD, affects the ability of fishers to adapt to the adverse effects associated with climate change such as injuries and diseases. Extreme weather events and strong wind such as the Binga wave, which is common in the study area, pose risk to the lives of fishers. Fishers reported the incidence of injuries caused by the Binga wave during fishing operations, and with little or no access to a health facility, the likelihood of recovering or surviving is threatened. Moreover, increasing temperatures tend to favour the geographic expansion of several infectious diseases, and extreme weather events may help create opportunities for more clustered disease outbreaks (Wu et al., 2016). Therefore, the lack of health facilities in fishing communities along Lake Kariba affects the ability of the fishers to adapt to the effects of climate change.

Additionally, lack of access to markets, roads and electricity impedes the ability of fishers to adapt to the impacts of climate change. Fishers argue that they do not have a secure market for their fish, especially diverse fish species. Some fishers postulated that: "*Most of our customers come here to buy breams (Tilapia) and tigerfish (Hydrocynus vittatus) and they are not interested in other fish species*"…(female, KRD) and "*I find it difficult to sell fish if they are not breams or tigerfish because it is difficult to find a sales market for a new fish species*"….(male, KRD). Furthermore, the lack of infrastructure such as roads makes it difficult for fishers to reach their markets with fresh produce. Post-harvest storage is of great concern because of the lack of electricity, fish catches are mostly sold fresh or dried. However, storing fresh fish is a challenge in warm temperatures and might result in fish loss, consequently, in declining profits from fish sales.

5.3.1.3. Institutional barriers

Institutional and governance barriers are more pertinent in the Kariba district than in fishing communities in the Binga area. Fishing activities on the Zimbabwean side of Lake Kariba are regulated and monitored by LKFRI and ZPWMA. These formal institutions determine the fishing gear type that can be used by gillnet fishers, the fishing boundaries and fishing times. To cope with the issue of declining fish catches, the small-scale fishers of Lake Kariba changed their fishing gear, increased their fishing effort, and increased their fishing times. However, the strategies employed by fishers to deal with the fluctuating fisheries resources are prohibited. Therefore, the adaptation strategies used by fishers subject them to persecution and confiscation of their fishing gear which jeopardises their ability to adapt. One of the fishers in KRD said: "*I have lost most of my fishing profits paying fines for leaving my fishing nets in the water after the approved fishing times*"…(male, KRD). Furthermore, according to the Statutory Instrument 362 of 1990 implemented by the ZPWMA, farming or livestock rearing is prohibited in wildlife protected areas, hence, fishers in these fishing communities cannot diversify their livelihoods into other agricultural activities as sources of income or food supply during periods of low fish productivity. The lack of institutional support from government institutions and non-governmental organisations (NGOs), in the fishing communities also affects the ability of fishers to adapt to climate change. The fishers indicated that they do not receive outside aid from both the government and NGOs.

5.3.1.4. Technological barriers

Small-scale fishers in the study areas highlighted that they cannot receive the weather forecast information because of a lack of appropriate technologies such as televisions and radios. Lack of access to weather forecast information and early warning systems is more pertinent in BRD than in KRD due to marginalisation. Unlike in KRD where some fishers have radios and have access to the Nyaminyami radio station, which broadcasts weather forecast information of areas around Kariba town, fishers in BRD pointed out that they do not have access to weather information as they do not have radios or televisions. Fishers in BRD rely on their indigenous systems to forecast weather conditions, which are mostly not accurate. One fisher said "*I depend on my knowledge to forecast the prevailing weather conditions and several times I have experienced harsh conditions while in the lake fishing"* …. (male, BRD). Inaccurate weather prediction can thus increase fishers' exposure and vulnerability and hinder adaptation strategies. Dang et al. (2019) state that lack of access or the unavailability of weather information restricts people's adaptation to the impacts of climate change. In addition, the fishing boats used by the fishers are non-motorised and can be easily damaged by adverse climate conditions, posing threats to fishing assets and the lives of fishers.

5.3.2. Limits to climate change adaptation

5.3.2.1. Ecological limits

Fishers reported declining fish productivity and fish catches within their respective areas. Fishing is the main livelihood activity and source of food supply for fishing communities on the shores of Lake Kariba. Thus, declining fish productivity and catches consequently affects the fisher's income/ profitability and the household's overall food and nutrition security. Due to low incomes from fisheries, fishers are not able to invest in alternative livelihood activities. To express the level of income and desire to diversify livelihoods, a fisher from BRD said "*the fish catches are declining, and my income is declining too, for me to start a new business I need money to invest in that business" ...* (female, KRD). Furthermore, fishers indicated that the existence and the increase in crayfish (invasive species) are affecting their fish catches. The crayfish feeds on the fish trapped in the fishing nets.

Additionally, the fishing communities fall under the wilderness and safari protected areas, hence, fishers and wild animals such as elephants, buffalos, hippopotamus, and crocodiles share their habitat. Fishers postulated that wild animals pose serious threats to their livelihood and lives. For instance, one fisher said "*hippos destroy our boats/canoes when we are casting nets in the lake"* …(male, KRD). Marowa et al. (2021) found that 30% and 16.6% of the fishers of Lake Kariba indicated that hippopotami destruct their livelihoods by destroying boats and drowning boats, respectively. Furthermore, 60% and 33.3% of the fishers indicated that hippopotami kills and injure people in their communities, respectively. Therefore, the fishers' interaction with wild animals further jeopardises their ability to adapt to changing fishery resources owing to climate change.

5.3.2.2. Natural limits

Lake Kariba falls within the Zambezi River basin, which is a risk zone for climate change and already experiencing drastic changes to its climate (Swain et al., 2012). Tumbare (2008) states that the basin is prone to cyclic flood and drought events. The fishers reported that the severity and frequency of drought have increased over the past decade. Fishers also indicated that the temperatures are increasing, rainfall becoming more variable and unpredictable and surface water levels decreasing. They consider that the increase in extreme weather events, increasing temperatures and a decline in freshwater availability are the main natural limitations which are causing them to suffer and negatively affect the fisheries sector. Moreover, fishers highlighted that cyclonic storms and strong winds disrupt fishing schedules, destroy fishing assets, and pose risk to the lives of fishers making adaptation to climate change more difficult to implement.

5.4. Discussion

Our empirical investigation advances the conceptual understanding of barriers and limits to climate change adaptation within fishing communities. Natural and anthropogenic factors act as either barriers or limits to climate change adaptation depending on how and when they impact on action and outcomes. This study identified six types of barriers and limits to adaptation in fishing communities along the shores of Lake Kariba in Zimbabwe. The barriers identified include, regulatory, access to services, formal institutions, and technological and the limits include ecological and natural limitations. These barriers and limits identified in the current study have been identified in past studies such as Regmi and Bhandari (2013), Islam et al. (2014), Muller and Shackleton (2014), Davies et al. (2020) and Chenani et al. (2021), however, there are also some differences as the barriers and limits are location specific. Nevertheless, in this study regulatory barriers and ecological limits are significant additional barriers to adaptation experienced by small-scale fishers.

Regulations can impede the ability of fishers to adapt to the effects of climate change. Moser and Ekstrom (2010) postulate that the implementation of an adaptation strategy must be legal and feasible within existing policies, laws, rules, regulations, programmes, and mandates. However, most of the adaptation strategies adopted by small-scale fishers of Lake Kariba are illegal. From a conservative point of view, the regulations, rules, and laws imposed on fishing activities promote the long-term sustainability of fisheries resources through sustainable fishing practices. For instance, the Ministry of Fisheries and Aquaculture Development in Ghana implemented several control measures such as vessel monitoring systems (VMS) to deal with overexploitation of fishery resources through illegal and unregulated fishing practices (Afoakwah et al., 2018). On the other hand, from a utilitarian perspective, the regulation of fishing activities undermines the fisher's ability to adapt to climate change and change fishery resources. For instance, the difference in regulation frameworks between Zambia and Zimbabwe affects the fisher’s ability to adapt. In Zambia, the fishing regulations are more utilitarian compared to Zimbabwean regulation framework. Therefore, it is evident that the fishing regulations in Lake Kariba are affecting the fisher's overall fish catches, incomes, and food security.

Lack of access to basic services such as health facilities, roads and electricity impedes the ability of communities to adapt to the effects of climate change. Watts et al. (2015) postulate that climate change will increase the risk of injury, disease, and death due to increased risks of food- and water-borne diseases, increased risk of vector-borne diseases and increased risk of undernutrition. Already, USAID (2019) indicates an increase in malaria incidence in Binga and Kariba districts. Ngarakana-Gwasira et al. (2016) suggest that the parasite and the vector that spreads malaria are sensitive to climate variables, especially temperature and rainfall. Watts et al. (2015) argue that the health sector plays a pivotal role in protecting the health and wellbeing of populations from the effects of climate change. Therefore, the availability and accessibility of health facilities in fishing communities might enhance the fisher's ability to adapt to the impacts of climate change. Additionally, a study by Sewell et al. (2019) found that communities with better access to roads have better socio-economic conditions compared to those with poor road infrastructure. Thus, the lack of roads in the fishing communities of Lake Kariba impedes the fisher's ability to adapt to the impacts of climate change due to poor socio-economic conditions.

Several studies such as Regmi and Bhandari (2013), Balaban and Balaban (2015), Islam and Nursey-Bray (2017), Mubaya and Mafongoya (2017) and Chenani et al. (2021) indicate that institutions play a crucial role in enhancing or obstructing adaptation to climate change. The success of adaptation efforts depends on the nature of existing formal and informal institutions (Mubaya and Mafongoya, 2017). According to Agrawal (2008), institutions influence adaptation in three ways, (i) they structure impacts and vulnerability, (ii) they mediate between individual and societal reactions to climate impacts and hence influence adaptation outcomes, and (iii) they operate as conduits for external resources to facilitate adaptation and thus governing access to such resources. In fishing communities of Lake Kariba, fishers indicated that institutions managing the Lake Kariba water and fisheries resources jeopardise their ability to adapt due to rules of fishing practices. In addition, there are no institutions to provide aid during periods of adverse weather events.

Furthermore, technological barriers which are also pertinent in the fishing communities were associated with a lack of access to weather and climate information and early warning systems. These findings parallel the findings of Islam et al. (2014) where one-third of fishers in Padma and Kutubdia Para fishing communities in Bangladesh indicated that they did not have access to the weather forecast. However, in Bangladesh, the absence of a radio signal was responsible for hindering access to weather forecast information, whereas, in Lake Kariba, the access to weather forecast information was mainly due to the lack of electronic devices such as televisions and radios.

The ecological and natural limits identified in this study increase the vulnerability of fishers and fishing communities to the negative effects of climate change. Sharing the habitat with wild animals in areas surrounding Lake Kariba affects the ability of fishing households to adapt to the impacts of climate change. Both fishing communities (BRD and KRD) fall within wilderness and safari protected areas. The Zimbabwean Statutory Instrument Statutory Instrument 362 of 1990, which protects wilderness and safari areas, prohibit livestock rearing and farming in these protected areas (Ndhlovu et al., 2017; Marowa et al., 2021). Consequently, fishers cannot diversify their livelihoods during times of adverse weather conditions. Literature shows that agriculture is a safety net for fishers, for instance, fishers of Lake Chilwa diversified to farming and pastoralism in response to the decrease in fish catches (Allison et al., 2007; Njaya et al., 2011). Moreover, the existence and abundance of the invasive species (crayfish) might be exacerbated by climate change. Aquatic systems may become more vulnerable to invasion as climate change progresses (Sorte et al., 2013). Therefore, the fish catches of small-scale fishers are at risk of being devoured by the crayfish, consequently affecting the fisher's income, food security and ability to adapt to climate change.

Furthermore, the natural limits increase the fishing communities and fisher's exposure to adverse weather events such as droughts and floods, increasing temperatures and rainfall variability. These changes in climatic parameters and adverse weather events threaten fisheries in several ways. For instance, increasing temperatures alter fish's physiological processes (Whitney et al., 2016), rainfall determines fish habitat availability and adverse weather events disrupt fishing schedules, destroy fishing gear and pose risk to human life (Musinguzi et al., 2016). The vulnerability to the impacts of climate change also increases indirectly due to all types of barriers. For instance, the lack of access to weather forecast information and early warning systems (i.e., technological barrier) increases the exposure of fishers to adverse weather events such as cyclones and harsh winds and constraints adaptation of fishers at the local scale.

The impacts of climate change are expected to become more apparent in the fisheries sectors and fishery-dependent households and nations are expected to adapt to its effects. However, barriers and limitations will inevitably stall, prevent, or halt coping responses, making it more of a problem to design and apply successful adaptation responses (Jones and Boyd, 2011). Local and broader factors originating from both internal and external sources interact in a complex way to combine to impede adaptation (Islam et al., 2014). However, Moser and Ekstrom (2010) postulate that policymakers can gain a better understanding of the climate change adaptation process by using an analytical classification of barriers to adaptation. This can help them deal more effectively with local adaptation barriers and limitations, as well as community challenges to overcome them (Moser and Ekstrom, 2010).

5.5. Implication for policy

Research indicates that individuals, communities, or nations dependent on climate-sensitive resources for livelihoods, income and food security are encountering different barriers and limits to implementing climate adaptation strategies and not all resource users can respond to some or all the obstacles. This is the case with the studied fishing communities along the shores of Lake Kariba in Zimbabwe. Zimbabwe crafted a National Climate Change Response Strategy (NCCRS) in 2014 and the National Climate Policy was completed in 2017, in which climate change adaptation is treated as a national priority (Ministry of Environment, Climate, Tourism and Hospitality Industry, 2020). However, the NCCRS provides strategies to curb climate change in agriculture; energy; transport; health; mining; tourism; industry and commerce; water and forestry sectors, and nothing specific to the fisheries sector. The fisheries sector in Zimbabwe employs thousands of people and provides food for hundreds of thousands of people, particularly the poor and marginalised groups. Therefore, the national climate change adaptation policy should provide adaptation actions and planned interventions, which are specific to the fisheries sector and fishing communities at the district, provincial and national levels. Furthermore, besides focusing on formulating adaptation actions, governments should also focus on formulating policies aimed at mitigating the effects of climate change, for instance, reducing greenhouse gases emissions, to overcome the limits.

5.6. Conclusions and recommendations

This study sought to identify and characterise the barriers and limits to the adaptation of small-scale fishers of Lake Kariba in Zimbabwe to climate change. Small-scale fishers in fishing communities along the shores of Lake Kariba suffer from a host of climate change adaptation barriers and limits. These include regulatory, access to services, institutional, technological, ecological, and natural limits. These barriers and limits are also interconnected and combine to constrain adaptation. For instance, technological barriers increase the fisher's exposure to the effects of climate change and variabilities such as cyclones and harsh winds. Furthermore, this study revealed that the barriers and limits identified are similar and support other study findings, but they manifest distinctively according to the localised governance and geographical conditions. As one of the most crucial but undervalued food production systems, the fisheries sector, just like crop farming and livestock rearing, should be prioritised in the formulation of climate change adaptation policies and plans of action. Even though this study's findings are supported by other studies, these findings have some limitations and more research on these barriers and limits is necessary. This study employed qualitative techniques to gather and analyse data, with a small study sample and covering a small geographical area. Therefore, we suggest future researchers to conduct studies covering a larger population of fishers in different areas to describe the typologies of the obstacles that hinder adaptation. Moreover, future research should also seek to understand how climate change adaptation is shaped, debated, and influenced at the national level and how institutions play a role in enabling adaptation at the local level. The study recommends policymakers and development agencies to adopt a bottom-up approach when designing and implementing climate change adaptation policies and actions, to identify the types of barriers and limits that can hinder the success of climate change adaptation efforts.

Link to next chapter.

This chapter identified the barriers and limits to climate change adaptation among fishing communities. The findings are solely based on the fisher's perceptions. Thus, the following chapter provides strategies that can be employed to address identified barriers and limits to enhance climate change adaptation and strengthen the fisheries sector's resilience.

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CHAPTER SIX[5]

Building Resilience and Reducing Vulnerability to the Effects of Climate Change in Inland Fisheries: Lake Kariba, Zimbabwe.

Abstract

Inland freshwater fisheries make a significant contribution to the livelihoods and food and nutrition security of millions of people in sub-Saharan Africa. However, the inland fisheries sector is experiencing a plethora of both climatic and non-climatic related stressors. This is also the case with Lake Kariba in Zimbabwe. Research indicates that the lake is experiencing declining fishery resources owing to overexploitation of the fishery resources and climate change. These anthropogenic and climatic stressors have adverse impacts on fishery resources and fishery-dependent communities. Therefore, based on findings of studies done in Lake Kariba that are related to the fisheries sector and climate change, this study provides strategies that can be adopted and implemented by fisheries managing authorities, government, development agencies and resources users to build or strengthen the adaptive capacity and resilience of the fisheries sector to stressors, especially climate change and overexploitation. These strategies include but are not limited to increasing access to early warning systems, encouraging stakeholder participation, provision of basic services, education and raising awareness, co-management, providing external aid, fish stock assessment and policies. The adoption and successful implementation of these strategies will ensure the sustainability of fishery resources through resource conservation and safeguard the livelihood and food security of small-scale fishers.

Keywords: adaptation, vulnerability, socio-ecological system, small-scale fishers, livelihoods, Lake Kariba.

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6.1. Introduction

Climate change is having profound impacts on aquatic ecosystems and communities dependent on fisheries for livelihood and food and nutrition security. The Food and Agriculture Organisation (FAO) states that in the tropical regions, the effects of climate change are causing and are anticipated to continue to cause potentially significant changes in temperature, rainfall patterns and the frequency and severity of adverse weather events, consequently affecting the production ecology and biodiversity of aquatic systems (FAO, 2021). There is adequate empirical evidence showing that the impacts of climate change and variability have led to reduced fish production and catches, species composition, extinctions and distribution in inland freshwater ecosystems (Cohen et al., 2016; Herrera et al., 2020; Winfield et al., 2016). Reid et al. (2019) postulate that increasing water temperature and altered hydrological cycle owing to climate change, are threatening about 50% of inland fish species. This creates socio-economic vulnerabilities in terms of livelihood, income opportunities and food and nutrition security in fishery-dependent communities or regions. Climate change will not only affect the biophysical process of aquatic ecosystems and fishery-dependent people, but it will also increase conflicts over access to resources, challenge both the governance and institutional frameworks used to manage fisheries and jeopardise the realisation of broader societal goals linked to fisheries including the United Nations Sustainable Development Goals (SDGs) of reducing poverty, enhancing food security, curbing climate change and improving life below the water (Mason et al., 2022).

Based on climate change projections, temperatures, the frequency of adverse weather events, and aridity are projected to increase in Sub-Saharan Africa (SSA), particularly in the inland subtropics (Serdeczny et al., 2017). Furthermore, climate change is projected to change rainfall patterns, with a particularly pronounced decline in Southern Africa and an increase in East Africa (Niang et al., 2014; Serdeczny et al., 2017). A study by Magadza (2011) detected a warming trend in areas surrounding Lake Kariba, with seasonal rates of 2ºC above the 1990 baseline. According to Parry et al. (2007), that rate of warming is likely to cause significant ecosystem changes. For instance, studies by Ndebele-Murisa et al. (2011) and Phiri et al. (2021) found that changes in climatic factors such as temperature and rainfall were associated with the decrease in Kapenta (*Limnothrissa miodon*) catch per unit effort in Lake Kariba. Moreover, a study by Maulu and Musuka (2018) concluded that water levels received during a particular rainy season affected the Tilapia (*Oreochromis niloticus*), species abundance and its distribution in Lake Kariba. Small-scale fishers (gillnet) of Lake Kariba in Zimbabwe mainly target fish species which are caught by fishing nets, namely, tilapia, tigerfish *(Hydrocynus vittatus*), Bottlenose (*Mormyrus longirostis*), and Cornish jack (*Mormyrops anguilloides*) (Information obtained during field survey, 2021). These species cannot be spared from the effects of changing climate.

Therefore, achieving the SDGs aimed at improving human wellbeing and healthy aquatic ecosystems within the context of climate change will require building the capacity to prepare for, resist, cope with, recover from or adapt to a given stressor, that is building climate change resilience (Mason et al., 2022). According to Mason et al. (2022), building resilience within the fisheries sector ensures the sustainability of aquatic ecosystems, fishery resources and human benefits. In this study context, fisheries managers, development agents, researchers, policymakers, the government and civil society should build or strengthen both the ecological resilience and social resilience of the sector. Holling (1973) defined ecological resilience as the capacity of a system to absorb or recover from a disturbance while retaining its essential structure and function. On the other hand, social resilience is the ability of human groups or communities to deal with external stresses and disturbances due to social, political, and environmental change (Adger, 2000). The IPCC (2007: 89) further joins the two concepts and defines resilience as a "system's capacity to anticipate and reduce, cope with, and respond to and recover from external disruptions". However, the human and ecology interdependency forms socio-ecological systems where changes in ecological systems affect society and vice versa (Ojea et al., 2017). This study adopts the IPCC definition of socio-ecological resilience which states that it is the ability of a socio-ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change (IPCC, 2007).

Climate change resilience has three core components: absorptive capacity, adaptive capacity and transformative capacity (Béné et al., 2012). According to the Network of African Science Academies (NASAC), adaptive capacity is the ability of a system to adjust to the impacts of climate change, to moderate potential damages, take advantage of, or cope with the consequences (NASAC, 2015). Contrastingly, transformative capacity is the ability to create a fundamentally new system when ecological, social or economic structures make the existing system unsustainable (Walker et al., 2004). The absorptive capacity entails the various strategies employed by individuals or households to moderate or buffer the impacts of shocks on their livelihoods and basic needs (Béné et al., 2012). Figure 6.1 illustrates an analytical framework intended to improve the understanding of what “building or strengthening resilience” means and the framework is based on the aforementioned components of resilience.

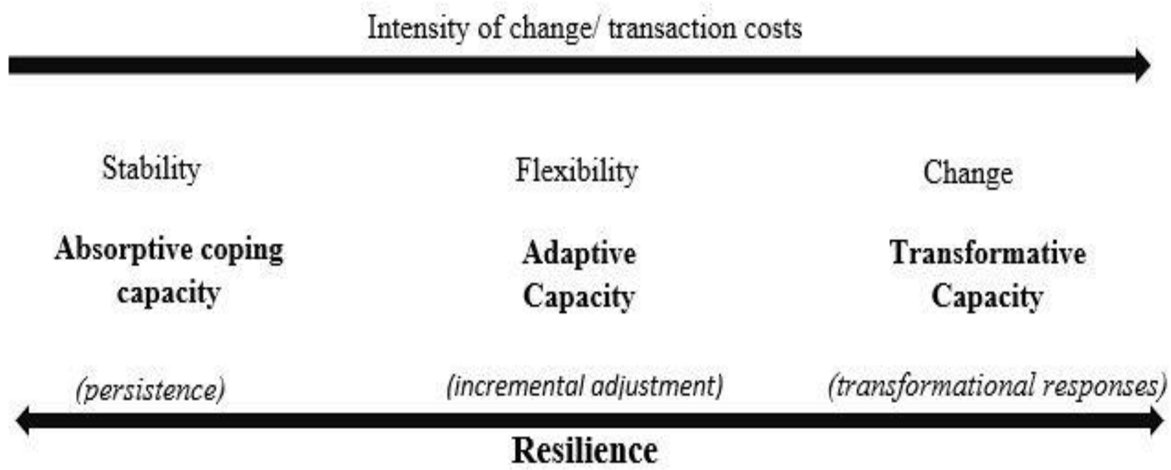

Figure 6.1: The resilience framework. *Source*: Adapted from Béné et al. (2012).

Béné et al. (2012) argue that building resilience would require interventions that strengthen the three components of resilience (absorptive capacity, adaptive capacity and transformative capacity), at multiples levels. Literature shows that there are several ways of building resilience to climate change such as, but not limited to, increasing access to localised climate information and early warning systems, livelihood diversification, promotion of innovation and local research, availability of extension workers with proper training in climate change and variability, access to credit, infrastructure and access to technologies, policies, increase climate change awareness, community-based management and conserving biodiversity and habitats (NASAC, 2015; Jiri et al., 2017; Ojea et al., 2017). Strengthening the general resilience of the fisheries sector reduces its vulnerability to climate change. Roy (2018) postulate that the two main reasons for strengthening resilience to climate change are to prevent the system from moving to an undesired state in the face of climate change and to nature and preserve the components of the system that build resilience and allow the system to renew and rearrange after a shock.

Against the backdrop, this study suggests strategies that can be adopted by fisheries managers, development agencies, policymakers, the government and resource users to strengthen the resilience against climate change within the fisheries sector to achieve the SDGs. The suggested strategies provided in this study are based on the findings of studies that have been conducted in Lake Kariba and its surrounding areas in Zimbabwe. Table 6.1 summarises the findings of the previous studies that show the existing climatic and non-climatic challenges and opportunities within Lake Kariba fisheries that need to be addressed to strengthen the sector's resilience against climate change. Moreover, this study also acknowledges the importance of other anthropogenic stressors in weakening the resilience of fisheries against the impacts of climate change. Thus, the study will suggest strategies aimed at addressing both climatic and non-climatic stressors that weaken the resilience of the fisheries sector to climate change.

Table 6.1: Summary of findings of studies done in Lake Kariba

Author(s)	Summary of findings
1. Kolding et al. (2003)	Lake Kariba has more than 50 different fish species, five of which are introduced. Two of the introduced species, *Serranochromis robustus* and *Tilapia rendalli*, might have invaded the lake naturally. Hence, only three species have established in the lake, *Oreochromis macrochir*, *Limnothrissa miodon* and *Oreochromis niloticus*. The lake is characterised by changes in relative species composition which can be attributed to the natural species succession that the lake has undergone since its creation. Currently, about 63% of the fishable area in Zimbabwe is available to the inshore fishery. Unlike the Zambian side of the Lake, fish stocks on the Zimbabwean side are moderately exploited due to much more regulated and enforced resulting in fishing pressure and fishing pattern which has not changed much over time. The artisanal catch rates are similar both in Zambia and Zimbabwe, however, Zambian fishers might have maintained their catches by decreasing the mesh sizes and using the fish driving technique. The fishing pressure on the Zambian side of the lake resulted in reduced stock sizes but does not have any negative impact on the community structure. Besides the effects of fishing pressure, the catch per unit effort (CPUE) is highly correlated with mean annual water level fluctuations. The water levels have a significant effect on the overall stock sizes. The findings indicate that holding everything else constant, the annual catch rates become more and more dependent on the changing environmental conditions when the fishing effort increases, and the stock levels are reduced.
2. Magadza et al. (2011)	Regression analysis of temperature historical data indicates that temperatures around Lake Kariba have increased by almost 4.8^{o}C over 100 years and the lake warmed by an average of 1.54^{o}C between 1965 and 1990. The rainfall data showed that rainfall has declined over the past decades. These changes in climatic variables have led to the lake's phytoplankton being dominated by Cyanophyceae and a huge reduction in crustacean zooplankton. Therefore, the

	warming of the lake affected the food chain productivity of the lake resulting in a decline in the pelagic fishery yield.
3. Ndebele-Murisa et al. (2011)	Since 1964, the temperatures around the Kariba area have been rising, with the maximum temperature rising faster than the minimum temperatures. Rainfall is decreasing at a rate of 0.63 mm per year, whereas evaporation rates have increased by 31% since 1963. These changes in climatic factors have adversely affected the *Limnothrissa miodon* (Kapenta) fish production. Kapenta fish production and small-scale fisher's catches have decreased significantly since 1974. The variations in Kapenta fish catches were attributed to all the climatic factors as well as the water levels, with the water levels exerting the greatest effect on Kapenta fish production, followed by maximum temperature, evaporation and rainfall. However, the lake water levels are largely influenced by climatic factors. Rainfall and temperature account for a significant portion of the variation in the water levels.
4. Ndebele-Murisa et al. (2013)	Nine downscaled climate models used to investigate the possible future climate of Lake Kariba under the future emission scenarios of the Intergovernmental Panel on Climate Change's (IPCC) A2 and B1, near (2046–2065) and far future (2081–2100) scenarios reflected that the Lake Kariba and is surrounding areas are projected to get drier. Rainfall is projected to decrease by between 3% to 27.46% except for the early rainy period (October–November) where rainfall is expected to increase under the A2 scenario and a projected increase in March under both scenarios for both the near and far future periods. Furthermore, according to the models, both maximum and minimum temperatures are expected to increase by an average of 3.17^{o}C–3.42^{o}C by 2100. The polynomial model which was used to investigate the consequences of the projected future climatic conditions, based on the median of all nine models for the future, on the production of the sardine fish *Limnothrissa miodon* (Kapenta) predicts that Kapenta fish production in Lake Kariba could continue to decline.
	The Australian redclaw crayfish (*Cherax quadricarinatus*) is invading the Sanyati basin of Lake Kariba. The

5. Marufu et al. (2014)	chances of the crayfish (invasive species), to dominate the new environment will increase if the environmental conditions are similar to those of its native environment. Crayfish grow best at temperatures of between 20–33 °C in their natural range and Lake Kariba has satisfactory temperatures for the growth of these crayfish. Moreover, the absenteeism of native freshwater crayfish species and other possible crustacean competitors such as crabs in Lake Kariba creates a potential ecological niche for the establishment of crayfish. The crayfish is an omnivore that feeds on plant detritus and animals. Fishermen of Lake Kariba reported the presence of mainly adult crayfish of greater than 15cm in their catches.
6. Muchuru et al. (2016)	Mean monthly and annual rainfall totals historical data for the period 1970 to 2010 from a network of 13 stations across the Lake Kariba catchment area of the Zambezi River basin were analysed in order to characterise the spatial-temporal variability of rainfall across the catchment area. The findings indicate that the 13 network stations in the Kariba catchment exhibited similar annual and seasonal rainfall variability patterns about 78% of them demonstrated normal distribution. Based on the analysis results, there were no seeming significant shifts in the annual and seasonal rainfall data in the Kariba catchment area. The rainfall data does not show a significant positive or negative trend.
7. Marshall (2017)	Climate change is not the main driver behind the decline in fish stocks in Lake Kariba. The decline in fish stocks is mainly attributed to fishing activities. Research done in closed areas both in Zambia and Zimbabwe shows that the catch per unit effort (CPUE) in gill nets decreased steadily in Zambia, but the CPUE increased in Zimbabwe until it was around 2.5 times greater than in Zambia. Therefore, declining fish stocks are due to increased fishing efforts (overfishing).
	The small-scale fishery groups in Lake Kariba, Zimbabwe are sensitive to changing climate due to several factors, such as low-income from fishing, increased fishing pressure due to population increase in fishing communities,

8. Ndhlovu et al. (2017)	heavy dependence on fishing for a livelihood, lack of adequate fishing equipment and declining fish catches. Low water levels reported by 80% of the fishers could be climate induced. The low water levels amplify sensitivity because of reduced fishing grounds also resulting in fishers competing with wild animals, especially hippopotamus and crocodiles for the remaining fishing grounds. Besides the impacts of climate change, wildlife also disrupts fishing schedules and damage fishing gear.
9. Magadza et al. (2020)	Adding to his previous study Magadza (2011), the present study concluded that global warming-induced the emergence of *Cylindrospermopsis raciborskii*, resulting in ecosystem disruption and leading to the decline of the *Limnothrissa miodon* (Kapenta) based fishery in Lake Kariba, rather than the decline in crustacean zooplankton food for fish.
10. Magqina et al. (2020)	Fishing pressure and fish poaching from artisanal fishers are probably threatening the *Hydrocynus vittatus* (tigerfish) population in Lake Kariba. The tigerfish catches in Lake Kariba have declined over the past years forcing the fishers to resort to fish poaching to catch enough fish to sustain their livelihood. The high number of female tigerfish caught during the fishing tournament might be responsible for the decline in fish catch. Female tigerfish are the ones usually caught during recreational activities and through the casting of twine gillnets, which has the potential to extremely change the population structure of the fish species, as there would possibly be a further reduction in the number of juveniles and hence a general decline in tigerfish abundances. Climate change might also contribute to the decline in tigerfish due to dwindling food sources.
	Small-scale fishers in communities found along the shores of Lake Kariba in Zimbabwe are facing several climatic and non-climatic challenges which are affecting their livelihood and their overall wellbeing. The fishes indicated that attacks from wild animals, especially crocodiles and hippopotamus, have been threatening their lives and disrupting their fishing activities. Lack of access to weather information because of no access to technological

11. Muringai et al. (2020)	devices made the fishers to be more vulnerable to adverse weather events. The invasion of the crayfish fish species has been identified as a threat to fishers as the predator fish feeds on fight caught by the fisher's nets. Additionally, fishing is the main and at times the only livelihood for the fishers, however, their fish catches are declining affecting their household incomes and food security. Fishers also stated that the lake is characterised by harsh winds and strong tides which disrupt fishing activities. Lack of fishing gear and lack of coordination between two institutions managing fishing activities (Zimbabwe National parks and Wildlife Authority and Lake Kariba Fisheries Research Institute), affect the fisher's fishing operations. Lastly, fishers mentioned that their fishing boundaries are shrinking which is negatively affecting their catches. Shrinking fishing boundaries are a result of decreasing water levels which might be attributed to climate change.
12. Marshall (2021)	The decline of the *Limnothrissa miodon* (Kapenta), fishery in Lake Kariba has been attributed to climatic change. The temperatures at Kariba station increased between 1962 and 2008 but not in a steady linear manner. However, there is a misinterpretation that, increasing temperatures led to changes in stratification of the water column of the lake and the incorrect assumption that changes in zooplankton and phytoplankton were a result of climate change. These factors were believed to be responsible for the decline in Kapenta catches. However, stratification and changes in zoo and phytoplankton occurred long before there was any evidence of warming. There was no significant correlation between catch per unit effort (CPUE), when the Lake was coolest ($p > 0.05$) and when it is warmest ($p > 0.05$) and fully stratified, so the declining CPUE was attributed to temperature changes. However, there was a significant correlation between the flow of the Zambezi River and CPUE until 1996 but the relationship broke down abruptly after that. Therefore, the decline of Kapenta catches is certainly a result of a great increase in fishing capacity as the number of fishing vessels is presently about three times the recommended level.
	The shrinking habitat has increased human-wildlife conflict in Lake Kariba. Fishermen in fishing camps

13. Marowa et al. (2021)	surrounding Lake Kariba are competing for limited resources with wild animals, particularly crocodiles and hippopotamus. The wild animals threaten the lives and livelihoods of the people living in the fishing camps. The study participants stated that crocodiles kill and eat people, injure people, destroy fishing nets, eat fish in the fishing nets, drown nets and disturb the laying of nets. Furthermore, the hippopotamus kills and injures people, chases people, disturbs the laying of nets, drowns boats, and destroys boats. The fishermen further indicated that national parks authorities delay responding to problem animal reports in the fishing camps. The human-wildlife conflict might be because of increasing fishing pressure due to current high unemployment which has led to many people encroaching the fishing camps either as fishers or as fish buyers, and they are often preyed on by crocodiles. Additionally, human–crocodile conflict in Kariba is attributed to the decrease in water levels. Fishers reported that their fishing grounds were reduced as a result of low lake water levels leading to increased human–crocodile interaction.
14. Muringai (2022)	Fishers in Lake Kariba, Zimbabwe perceive that the temperatures in Binga Rural District and Kariba Rural District have warmed, and rainfall has declined in the past 10 years. Analyses of the meteorological historical data from 1987 to 2017 show that temperatures are warming in both districts. However, in contrast to the fisher's perceptions of declining rainfall in Kariba, the meteorological historical data reveals an upward trend in the annual total rainfall in Kariba. The frequency of extreme weather events, especially droughts and floods has increased over the past 10 years. Fishers indicated that the impacts of climate change and variability have several adverse effects on the fisheries sector including damaging fishing gear, changing fishing species composition, reducing fish size, declining catches, increased fishing effort, increased invasive species, decreasing profits from fisheries, reduced fishing days, food insecurity, shrinking fishing grounds and increased risk of loss of life and injuries for fishers. To adapt to the effects of climate change and variability, fishers increase their fishing effort, change fishing gear, target new

	species, increase fishing time/ days, diversify their livelihoods and migrate to new fishing communities. Moreover, the fisher's experience, level of education and perceptions influenced the fisher’s decision to adopt adaptation strategies to cope with the changing fishing environment.

6.2. Overview of the study area

Lake Kariba is a man-made lake that was created in 1958 along the Zambezi River and shared between Zambia and Zimbabwe (Kolding et al., 2003). The lake is in the Northwestern part of Zimbabwe (Figure 6.2), approximately 365km from Harare the capital city of Zimbabwe (Ndebele-Murisa et al., 2013). According to Ndhlovu et al. (2017), the Lake is the predominant water body that supports both commercial and small-scale fishing contributing significantly to the economies of Zimbabwe and Zambia. Lake Kariba is divided into five basins namely, Binga, Mlibizi, Sanyati, Sengwa and Ume (Magqina et al., 2020). Mavuru et al. (2022) state that Basins 1 and 2 are more riverine while Basins 3 to 5 are lacustrine.

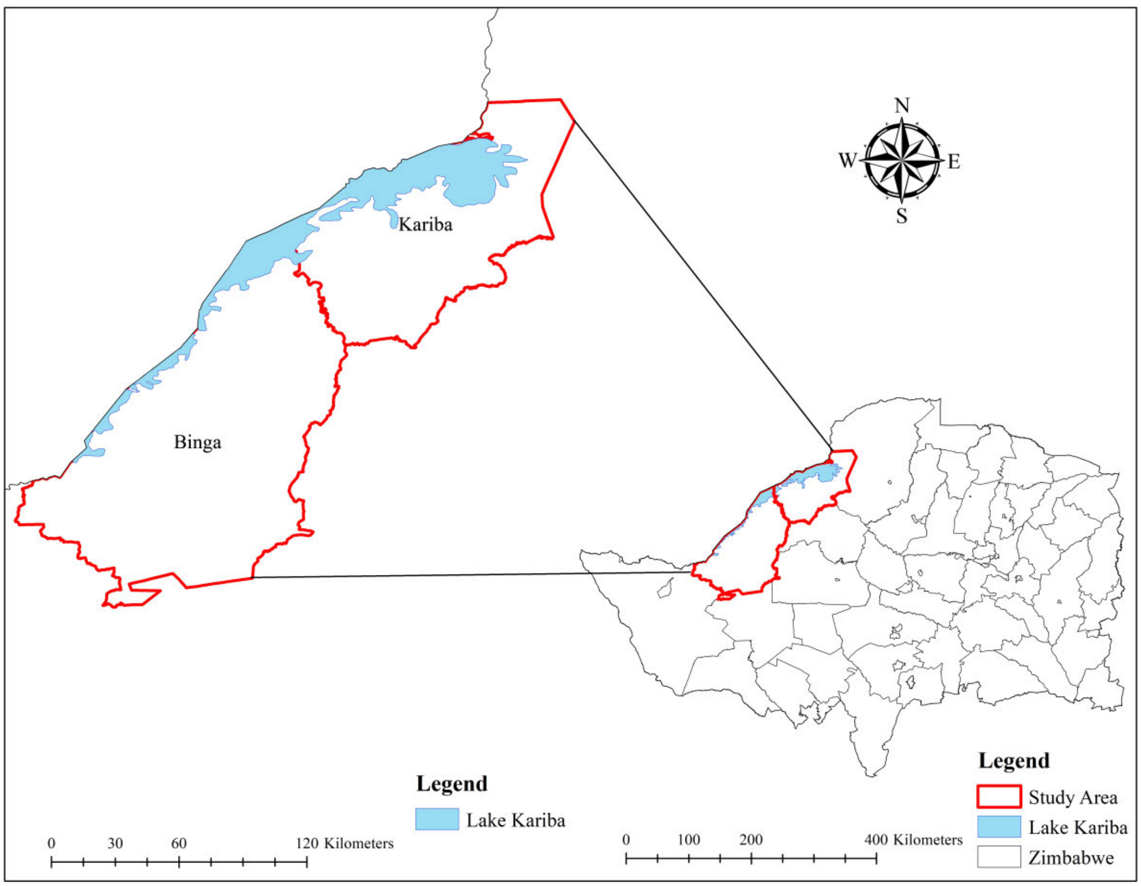

Figure 6.2: Location of study area (*Source*: Author)

The areas surrounding Lake Kariba are predominantly characterised by tropical and semi-arid, with four distinct seasons in the Gwembe Valley where the lake is located (Ndebele-Murisa et al., 2013). The seasons are dry-cool (June – July), dry-hot (August – October), rainy (November

– February) and post-rainy (March-May) (Ndebele-Murisa et al., 2013). The mean temperature is between 20°C to 27°C and the annual average rainfall ranges from 500mm to 700mm (Mavuru et al., 2022). The surface water temperature reaches 32°C from October to December and drops to 18°C between June and August (Magqina et al., 2020).

6.3. Fisheries in Lake Kariba

According to the (FAO, 2022), Lake Kariba is the largest fishery in Zimbabwe, contributing approximately 90% of the country's total fish production. The lake supports semi-industrial Kapenta fishing and small-scale inshore fisheries mainly by village communities around the lakeshore largely using gillnets (FAO, 2022). Kapenta fish accounts for almost 90% of the lake's total fish catch, however, the following species are also caught in the lake, namely: squeaker (*Synodontis zambenzensis*), tigerfish, bottlenose fish, cornish fish, mudsuckers (*Gillichthys mirabilis*), and burble fish (FAO, 2022). In recent years, the lake has also been proliferated by a new species the Redclaw crayfish (Marufu et al., 2014; FAO, 2022).

Small-scale fishing in Kariba started around 1962 and about 60% of the lake is open to fishing (Mavuru et al., 2022). To date, there are 41 fishing communities along the shoreline of Lake Kariba, of which six are fishing camps and 35 are fishing villages (Ndhlovu et al., 2017). Fish is the pivot of these communities, which are also characterised by the highest per capita fish consumption than other areas in the country (FAO, 2022). Post the land reform programme, catches from small-scale fishers in Zimbabwe were no longer recorded, therefore, there is a paucity of statistical data on the quantities of catches per given period. However, in the past decades fish production levels have been declining due to several factors such as overexploitation (Marshall, 2012) and climate change (Magadza, 2011; Ndebele-Murisa et al., 2011; Muringai et al., 2020).

6.4. Strategies to build the resilience of Lake Kariba's fishery

6.4.1. Increasing fisher's access to early warning systems (EWS)

The United Nations Office for Disaster Risk Reduction (UNDRR) defines EWS as 'a set of capabilities needed for the timely and meaningful generation and dissemination of alert information to individuals, communities and organisations at risk for optimal preparedness and response and at the appropriate time to reduce the likelihood of injury and death' (UNDRR, 2011: p.4). Baudoin et al. (2014) state that EWS can strengthen livelihood resilience to climatic shocks at the local level through enhancing preparedness. Researchers such as Cochrane et al. (2009), De Young et al. (2012) and Shaffril et al. (2019) assert that EWS are crucial in enhancing climate change adaptation and resilience in the fisheries sector.

Studies by Murinagai et al. (2019; 2022) indicate that fishers in Lake Kariba are vulnerable to the effects of climate variability and extreme weather events such as floods, droughts, cyclones and harsh winds. The Lake Navigation Control, which is under the state Department of Transport, monitors activities within Lake Kariba including weather-related conditions and passes the information to the public in Kariba through the Nyaminyami radio station. However, fishers have limited access to the weather information due to a lack of devices that are used to access the weather information such as radios, televisions and smartphones. In Binga Rural District (Basin 2), fishing communities such as Chinzonzo and Chikuyu do not have a reception of radio signals. Therefore, the government and development agencies should provide fishers with technologies for EWS to ensure that the fishers have access to real-time weather information and predicted adverse weather events to aid fishers in planning their fishing operations. Access to future weather information also reduces the fisher's risk of injury or death due to climate-related events. As a result, fishers' access to weather information through EWS will enhance the fisher's adaptability and resilience to climate change impacts.

6.4.2. Stakeholder participation in decision-making processes

Stakeholder participation, also termed citizen participation, stakeholder involvement, public participation, stakeholder engagement or community engagement (Sarzynski, 2015), is crucial in strengthening social-ecological resilience and the capacity to adapt to environmental change (Robinson and Berkes, 2011). According to the USAID (2013: p 1) participation refers to "opening up official organisational processes to include relevant and interested stakeholders to take part in decision-making and problem solving". Tompkins and Eakin (2012) and Manyani et al. (2017) argue that active stakeholder participation enhances resilience and promotes the sustainability of livelihood adaptation strategies employed during times of severe climatic conditions. On the contrary, if fisheries managers lack the understanding of the resource user adaptation strategies, they can increase communities' vulnerabilities to climate variability (Allison et al., 2007).

Therefore, in this study context, fisheries managers of Lake Kariba such as the Lake Kariba Fisheries Research Institute (LKFRI) and the ZPWMA, non-governmental organisations (NGOs), working in some fishing communities, such as the Zimbabwe Red Cross, and District Councils should involve fishers in the design and implementation of fisheries management strategies and climate change adaptation strategies. Mhlanga and Mhlanga (2013) and Bell et al. (2020) state that stakeholders within the fisheries sector should be involved in activities such as, but not limited to, resource monitoring (catch and effort data collection), law enforcement, designing of the systems for distributing permits or licences, formulation of any rules and regulations and sustainable fishing practices strategies. For instance, during a field visit, fishers in Binga Rural District pointed out that, Zambian fishers are intruding into their fishing territories, poaching their fish resources, and using destructive fishing methods such as fish driving and twine nets (glass nets). Hence, fishers can work with ZPWMA law enforcement to apprehend fish poachers.

Moreover, the adoption of a bottom-up approach assists policymakers and fisheries managers to design and implement local specific measures to deal with and adapt to the impacts of climate change, since local communities may be at the forefront of damaging climate change impacts (Ross et al., 2015). Furthermore, the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries postulate that stakeholder participation ensures that the roles and responsibilities within the context of fisheries co-management are clarified (FAO, 2015).

6.4.3. Provision of basic services

Fishing communities along the shoreline of Lake Kariba in Zimbabwe are characterised by a lack of basic services such as electricity, potable water, sanitation, fishing gear suppliers and credit facilities. According to the World Bank (2020), the lack of basic services such as infrastructure, social protection, health care and financial services are strong predictors of vulnerability to climate change. The World Bank (2020) further states that if vulnerable communities do not have access to financial, technical, and institutional resources, no adaptation strategy will be successful. Therefore, as one of the most crucial, but undermined food production sectors in Zimbabwe, the government and development agencies should prioritise the fishery sector and provide the fishers with basic services such as electricity, clean and safe water, sanitation, credit facilities and availability of fishing gear suppliers. Khan (2014) argues that the availability of electricity increases the availability of services. In this study context, the availability of electricity in fishing communities enhances communication and access to weather information or forecasts which helps the fishers to plan their fishing schedules and prepare for adverse weather events. Furthermore, access to safe drinking water and sanitation contributes significantly to households' recovery from climate shocks (Khan, 2014). Access to credit facilities plays a key role in building climate change adaptation and resilience. Fishers in Lake Kariba can use credit to finance their fishing operations, diversify their livelihoods or cushion their households during times of climatic shocks and poor fish catches.

6.4.4. Education and raising awareness

Fishers of Lake Kariba exhibited awareness of the climate change phenomenon and its impacts on the fishery sector (Muringai et al., 2022). However, fisheries managers and development agencies still have the responsibility to further educate the fishers and raise awareness of the effects of some fishing methods and gear used by the fishers. Due to declining fish catches reported by small-scale fishers (Ndhlovu et al., 2017; Muringai et al., 2020), some fishers are employing destructive fishing techniques to increase their fish catches. These techniques include reducing the mesh size of the fishing nets (Marshall et al., 1982), fishing driving technique (locally known as "*ndombolo*"), and use of twine nets. Some fishers are not aware of the detrimental effects associated with such fishing techniques being employed. For instance, a study by Silvano et al. (2017) detected that the use of small mesh size nets caught a smaller proportion of adult fish, smaller fish, more species, and more rare species increasing the risk of regional species extinctions. Fishers of Lake Kariba might not be aware of these impacts. Hence, fisheries experts, managers and extension services should raise awareness of such practices to safeguard the sustainability of fishery resources.

6.4.5. Co-management

Co-management encompasses sharing roles and responsibilities for resource management between states, civil society, institutions, resource users and any relevant stakeholders (Obiero et al., 2015). Research shows that Lake Kariba is managed and operated by the Zambezi River Authority (ZRA) under the ZRA Acts of 1987 of Zambia and Zimbabwe (Tumbare, 2008). However, ZRA does not have prosecuting/enforcement responsibilities, hence, such responsibilities are provided by 14 organisations in both Zambia and Zimbabwe that have a legal mandate on the management of Lake Kariba and its tributaries (Tumbare, 2008). According to Tsiko (2022), Zambia and Zimbabwe held bilateral talks in March 2022 about improving fisheries management and reducing overfishing as efforts to enhance the conservation and sustainable use of fishery resources within the lake. Concerns over the declining fish stocks resulted in the two nations engaging in management talks. Research shows that Lake Kariba can sustain a maximum of 500 rigs (fishing boats), but currently there are over 1500 fishing rigs in the lake (Tsiko, 2022). Therefore, there is a need for the two states to adhere to their agreed fishing regulations as stipulated in the bilateral or international agreements on shared water management. For instance, in this study context, to reduce overfishing and build ecological resilience to the impacts of climate change, the states should restrict the number of fishing permits/licences issued and ensure law enforcement through lake patrols and the persecution of law breaches.

Institutions and regulatory services can have significant consequences on how a fishery socio-ecological system responds to climate change (Ojea et al., 2017). Therefore, when regulating fishing activities and controlling entry into fisheries, the governments should not undermine the resources user's livelihoods. The Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries suggest that where there are transboundary and shared waters and fishery resources, governments should work together to ensure that the tenure rights of small-scale fishing communities that are granted are protected (FAO, 2015).

6.4.6. Provision of external aid

To strengthen the fisher's adaptation to climate change and variability, the government, donor Organisations, NGOs, the private sector and civil society should provide aid or relief to fishing communities during times of climate change-related calamities. According to Section 30 of the Constitution of Zimbabwe, the state is obliged to take all practical measures, within the limits of the resources available to it, to provide social security and social care to those who are in need. The government of Zimbabwe assisted the vulnerable groups through several social safety net programmes. However, research indicates that the performance of the social security nets is poor due to low levels of coverage and inadequate benefits for its clients (Munro, 2005). Small-scale fishers in fishing communities found along the shoreline of Lake Kariba are one of the vulnerable groups that do not benefit from the social safety nets. Hence, the government of Zimbabwe needs to recognise this group and the significant role they play in food production and extend their relief progammes to reach fishers, particularly during periods of adverse climatic conditions such as droughts which affect fish production. Donor organisations and the private sector can also extend their donations through social relief in fishing communities. Studies by Awal (2013) and Hassan et al. (2013) show that social safety nets played a significant role in enhancing climate adaptation in Bangladesh.

6.4.7. Assessment and monitoring of fish stocks

Fish stock assessment aims to provide estimates of the current biomass and stock structure of a given water body for effective harvest regulation (Walters and Martell, 2002). Cadrin and Dickey-Collas (2014) further describe stock assessment as the synthesis of data on life history, fishery monitoring, and resource surveys for estimating the stock size and harvest rate relative to sustainable reference points. The implementation of stock assessment methods to build climate change adaptation and resilience is promising, but rapidly developing (Free et al., 2020). Several stock assessments models can be used to assess relative stock estimates such as the Biomass random-effects model (BREM) (Trenkel, 2007), Environmental DNA (eDNA) (Takahara et al., 2012), underwater stereo cameras (Boldt et al., 2018), and length-based bayesian biomass (LBB) (Zhang et al., 2021).

Therefore, the LKFRI and research institutions, such as the University of Zimbabwe which has a research station in Lake Kariba, should invest in stock assessment technologies to enable them to continuously assess the fish biomass within the lake to estimate the stock levels. Cadrin and Dickey-Collas (2014) state that regular stock assessments help fisheries managers to determine the stock status and give management advice for realising conservation objectives. Furthermore, biomass reference points can be used to provide scientifically recommended harvest amounts (Brown et al., 2012). Kolding et al. (2003) state that the lake is a man-made artificial environment which is gradually but constantly changing in terms of biological species succession. Hence, stock assessment can help fish managers identify species that are declining in biomass and emerging species. Therefore, stock assessment strengthens ecological resilience in the face of climate change through conserving and minimising the overexploitation of fishery resources.

6.4.8. Policies

Policymakers should formulate policies aimed at building the resilience of the fisheries sector to the impacts of climate change at multi-levels. Policies formulated should ensure that fishery resources are conserved without undermining the resource user’s livelihood and food security. In this study context, the policies should minimise or curb the overexploitation of the fishery resources to avoid the extinction of some valuable fish species. Moreover, the policies should promote climate change adaptation among small-scale fishers by encouraging inclusive governance of the fishery resources and protecting fishers' tenure rights. Lastly, the local and national governments should formulate and implement policies that attract investment in the fisheries sector. For instance, the Ministry of Environment, Water and Climate recognised the significance of the fisheries sector to poverty eradication and ensuring food security and formulated the National Fisheries Policy that provides an enabling environment for the sector to grow (Ministry of Environment, Water and Climate, u.d). The policy led to the initiation of a Command Fisheries Programme intended at enhancing food and nutrition security, creating employment, improving accessibility to fisheries resources and building the resilience of local communities against the effects of climate change (Ministry of Environment, Water and Climate, u.d). The local and national governments should ensure the successful implementation of such policies to strengthen the resilience of the fisheries sector to the impacts of climatic and non-climatic stressors.

Moreover, the Zimbabwe National Climate Change Response Strategy which provides a framework for a comprehensive and strategic approach to aspects of adaptation, mitigation, technology, financing, public education and awareness (Ministry of Environment, Water and Climate, u.d), provides strategies to enhance climate change adaptation in different economic sectors, but the fisheries sector was neglected. Therefore, at the national level, the climate adaptation and mitigation policies should encompass the fisheries sector when designing climate change adaptation policies and strategies.

6.5. Conclusions

This study sought to explore strategies that can be adopted by fisheries managers, development agencies, the government and fishery resources users to strengthen the fisheries sector’s resilience to the impacts of climate change and variability in Lake Kariba. These strategies include increasing fishers access to EWS, stakeholder participation in decision-making, provision of basic services, education and raising awareness, co-management, provision of external aid, assessment and monitoring of fish stocks, and formulation of policies aimed at enhancing climate change adaptation and resilience. Some of the strategies are interrelated, for instance, stakeholder participation in decision-making processes results in resource users also playing a role in the lake's co-management. However, the success of the proposed strategies depends on the willingness and commitment of the relevant players to build climate change resilience of small-scale fishers. Furthermore, the success also depends on the availability of resources, particularly financial resources, and human expertise. Due to the complexities associated with socio-ecological systems, future researchers should assess the viability and feasibility of the implementation of the aforementioned strategies.

The proposed strategies are based on findings of studies done in Lake Kariba that are relevant to the fisheries sector. Therefore, the proposed strategies are specific to fishing communities found along the shoreline of Lake Kariba in Zimbabwe and cannot be generalised to other inland fishing communities in Zimbabwe. The study recommends future research to assess the adaptation strategies employed by small-scale fishers at a national scale to inform policies aimed at building climate change adaptation and strengthening socio-ecological systems. Finally, there is a need to adopt an ecosystem approach on managing inland fisheries. The ecosystem approach integrates the management of land, water and living resources to promote conservation and sustainable development.

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CHAPTER SEVEN

Conclusions and Recommendations.

7.1. Introduction

This study investigated the effects of climate change and variability on the biophysical and socio-economic systems of small-scale fisheries of Lake Kariba in the Zambezi River Basin, Zimbabwe. The study findings are inline with the existing literature on the impacts of climate change on freshwater fisheries as highlighted in the literature review. Therefore, this chapter presents concluding remarks and recommendations based on the study's main findings. The main findings of each objective of the study are described in the subsequent sections of this chapter.

7.2. Summary of findings

7.2.1. Objective 1: To review the existing literature regarding the impacts of climate change and variability on freshwater fisheries.

The literature review revealed that inland freshwater fisheries, particularly in sub-Saharan Africa (SSA), are susceptible to the impacts of climate change and variability. The observed and projected changes in rainfall and temperature trends have already and are expected to adversely affect the inland fisheries sector. Freshwater fish production in African inland fisheries is more dependent on external climatic drivers than on human exploitation rates and numerous management interventions. Therefore, warming temperatures and increasing rainfall variability in the region have altered freshwater ecosystems, resulting in declining fish production and catches. In response to changing environmental conditions, aquatic species (fish) respond by changing their biological and physio-chemical processes such as reproduction, spawning time, growth and metabolism rates. Moreover, changes in rainfall patterns alter the hydrological system, thereby, affecting fish habitat. The availability of fish food (nutrients) is affected by reduced runoff, resulting in less food for fish. Furthermore, the increased occurrence of extreme weather events such as droughts and floods does not only affect fish production, but also affects the lives and livelihoods of fishery-dependent households. Extreme weather events damage fishing equipment and infrastructure, disturb fishing schedules and increase the risk of injury or loss of life.

To cope with declining fish production and catches owing to climate change and variability, fishers have adopted several strategies such as diversifying livelihoods, changing fishing gear, increasing fishing effort, targeting new species, migration, and relying on social networks are some of the short-term strategies. However, some of these strategies used by fishers, for example, changing fishing gear and increasing fishing efforts can be beneficial in the short-term, but can have detrimental effects and can reduce the resilience of freshwater ecosystems due to unsustainable fishing practices. Additionally, the capacity of fishers to adapt depends on how institutions regulate and structure their interactions between fishers and external actors.

7.2.2. Objective 2: To assess the small-scale fisher's perceptions of climate change and variability and their adaptation strategies along Lake Kariba shoreline.

It is crucial to understand how small-scale fishers perceive climate change and variability, its effects on fisheries and how they adapt to its effects. The study findings show that the small-scale fishers in Lake Kariba are aware of the climate change phenomenon. To describe the changing climate in their respective communities, fishers state that temperatures and the occurrence of extreme weather events such as droughts and floods have increased over the past decade. Rainfall is believed to have declined over the same period. Results from the regression analysis of temperature historical data provided by the meteorological services department validate the fisher's perception of increasing temperature in the study areas. These findings are also supported by several other study findings, which indicate that temperatures are increasing in this area and globally. The regression analysis agrees with the perceptions of fishers in Binga Rural District and disagrees with the perceptions of fishers in Kariba that rainfall is declining. The perception of declining rainfall in the Kariba district might be due to recently experienced droughts in the area, which do not significantly change the overall trend.

Fishers reported that fish production and their fish catches have declined due to changing climate. However, climate change cannot be solely responsible for declining fishery resources. To deal with declining fishery resources, fishers have adopted several strategies including changing fishing gear, targeting new species, increasing fishing time and effort, diversifying livelihoods and migrating to new fishing communities. The adoption of these strategies by fishers was mainly influenced by the fisher's fishing experience, education level and perception of climate change. These key findings can help inform local decision-making in terms of developing climate change adaptation measures based on fisher's insights. Using fishers' perceptions in making decisions related to climate change adaptation is crucial for the success of the implementation of the strategies, as fishers have a sense of ownership of the decisions made.

7.2.3. Objective 3: To assess the climate change vulnerability of fishing communities along the shoreline of Lake Kariba.

The findings show that the fishing communities found along the shoreline of Lake Kariba are vulnerable to the impacts of climate change and variability. However, the vulnerabilities are not homogenous across the fishing communities. Fishing communities in the Kariba district are more vulnerable than those in the Binga district. The differences between the vulnerabilities were mainly due to the difference in the fishing communities' adaptive capacity. Fishing communities in Kariba showed a significantly lower adaptive capacity than those in Binga, which is attributed to higher marginalisation.

These findings provided valuable knowledge about the current state of vulnerability of the small-scale fishing communities along the shores of Lake Kariba. The findings suggest that the government, NGOs and agents of development should prioritise fishing communities in the Kariba district, based on the greatest need for intervention, when it comes to issues of development and building resilience and adaptive capacity of the fisheries sector. Lastly, vulnerability indices such as the LVI used in this study enables researchers or development agents to successfully measure vulnerability at a local or community level.

7.2.4. Objective 4: To identify the barriers and limits to climate change adaptation among small-scale fishers.

Small-scale fishers use several different strategies to deal with the changing environment and fishery resources. However, several barriers and limits restrict the fisher's ability to address the negative impacts of climate change or manage risks in a way that maximises their welfare. Based on the fisher's perspective, their ability to adapt to the changing environment and declining fish catches is hindered by several barriers such as regulations by the fisheries management authorities, a lack of access to services, and institutional and technological barriers. Furthermore, natural and ecological limits also jeopardise the fisher's ability to adapt. The key difference between the barriers and the limits is that barriers are considered resolvable or mutable, while limits are seen to be absolute or unsurpassable. That is, barriers can be overcome through collective action between governments, agents of change and fishers unlike limits such as changing climate which cannot be solved, especially in the short term. However, the findings show that these barriers and limits are also interconnected and combine to constrain adaptation. Furthermore, measures that are used to conserve the fishery resource, mainly based on the theories of sustainable fisheries management, are seen as barriers that affect fishers' ability to adapt to the changing environment. However, without those management measures, the fishery resources will be overexploited due to unsustainable fishing practices. The findings suggest that fisheries managers and policymakers should adopt a bottom-up approach to designing and implementing robust climate change adaptation policies and actions.

7.2.5. Objective 5: To explore strategies to strengthen resilience and reduce the vulnerability of inland fisheries to the impacts of climate change.

Given the impacts of climate change and variability and factors undermining the ability of small-scale fishers to adapt to the adverse impacts caused by climate change, fisheries managers, the government, development agencies, NGOs and the fishers must build resilience and reduce the vulnerability of the fisheries sector to climate change effects. The study suggested that to strengthen the resilience of fishery resources and fishery-dependent communities to the impacts of climate change, there is a need to conserve the fishery resources and implement effective fisheries management systems. The study provided eight strategies that can be employed to build the fisheries sector's adaptation and resilience to the impacts of climate change. These strategies include increasing the fisher's access to early warning systems, ensuring stakeholder participation in decision-making processes, providing basic services, educating and raising awareness on the impacts of fishing practices, ensuring co-management, provision of external aid during periods of climate calamities, assessment and monitoring of fish stocks and designing and implementation of policies aimed at building resilience and climate change adaptation of the fisheries sector. However, the successful implementation of these strategies mainly depends on resource availability, particularly financial and human expertise.

7.3. Conclusions

The growing demand for fishery resources makes the fisheries sector an important food production system. However, fish production within a freshwater ecosystem is more dependent on external climatic drivers than any other anthropogenic factors. Therefore, this study sought to investigate the impacts of climate change on inland small-scale fisheries in Lake Kariba, Zimbabwe. Based on the findings, the study concludes that the small-scale fisheries sector in the study areas along the shores of Lake Kariba are vulnerable to the effects of climate change and variability. Changing climatic conditions have adverse impacts on the freshwater ecosystem and fish production which affects the livelihoods and food and nutrition security of fishery-dependent households. The fishing communities or households are particularly vulnerable to the effects of climate change due to their high dependence on climate-sensitive resources, low adaptive capacity and marginalisation. The vulnerability of the fisheries sector is also being fuelled by increasing fishers' population and poor economic performance. Therefore, to safeguard the lives, livelihoods and food security of these fishing communities, there is a need for collective action and collaborations between all the relevant stakeholders within the fisheries sector. Collective action is needed to conserve the fisheries resources and collaborations are needed on research and formulation of robust policies. To promote the sustainability of the fishery sector, the government, research institutions and policymakers should recognise the sector as an important food production system, which is particularly vulnerable to several stressors including climate change and formulate effective management strategies, and policies and attract investment.

7.4. Recommendations

Based on the study findings, the study recommends the following:

7.4.1. For action:

- To ensure sustainable fish stocks and incomes for the future generation, fisheries managers should conserve the fishery resources by limiting the number of fishers, monitoring the fisher's fishing practices and monitoring fish stocks.
- There is a paucity of data on fish harvests in Lake Kariba, therefore, fisheries managers and fishers should record their harvest to monitor the quantity of the harvest per given period. Harvest data can also be used in future research.
- The civil protection unit (CPU), Lake Navigation and the MSDZ should design and implement an EWS that is specific to fisheries to promote disaster preparedness, minimising the negative impacts of climate change and variability.

7.4.2. For policy:

- The significance of the fisheries sector to economic development, poverty alleviation and food security in Zimbabwe is less pronounced. Therefore, the government, policymakers and agents of development should ensure that the fisheries sector is entrenched in their policies, as a key sector that can contribute to economic development, poverty alleviation and food security.
- Climate change adaptation strategies specific to the fisheries sector were neglected in the ZNCCRS, which provides a framework for a comprehensive and strategic approach to

aspects of adaptation, mitigation, technology, financing, public education, and awareness. Climate change adaptation strategies are not universal across different sectors. Thus, policymakers should recognise fisheries as a stand-alone sector which requires different strategies to adapt to climate change. Policies should be specific to the fisheries sector.

7.4.3. For future research:

- This study was done in fishing communities found along the shoreline of Lake Kariba in two districts, hence, the findings are specific to the sampled communities. To have a strong scientific basis on the impacts of climate change on freshwater fisheries, studies should be done on a wide scale (i.e., provincial, national, and regional). Findings can be used for cross-nation comparison, help countries learn from each other and inform international policies on shared freshwater resources.
- This study mainly focused on the impacts of climate change on small-scale fishers as the resources end user. Thus, future research should investigate the impacts of climate change and variability across the fisheries sector value chain.
- This study provided strategies that can be adopted and implemented to strengthen climate change resilience within the fisheries sector. Therefore, the study recommends future researchers to assess the viability of implementing the strategies.

APPENDICES

APPENDIX A: Household Survey Questionnaire for Small-scale Fishers.

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Climate change and variability, vulnerability, and adaptation of small-scale fishers

Date of survey……………………………. Village……………………………………

Socio-economic Demographics

a) Age:…………………

b) Gender

0.	Male
1.	Female

c) Marital status

0.	Never married
1.	Married
2.	Divorced
3.	Widowed

d) Education level

0.	Never attended school
1.	Primary education
2.	Secondary education
3.	Tertiary

e) Number of household members…………………………………..

f) How many household members are below 15 years and above 65 years of age? ………………………..

g) How many economically active (**18 - 65** years) household members are not working? ………………….

h) Do any members of your household require daily care because of age, physical or mental condition, illness or disability?

0. Yes	1. No

i) How long have you been involved in the fishing industry?................................years.

Climate change and variability and its impacts

a) Have you ever heard of the term climate change?

0. Yes	1. No

b) Where do you find information about climate change?

0. TV	1. Radio	2. Newspaper	3. School	4. Family/ friends	5. NGO/ Government agencies	6. Other

c) If answer is other, Please Specify;………………………………………………………………

d) Do you think that your community is being or is going to be affected by climate change?

0. Yes	1. No

e) Have you noticed any long-term changes in temperature in your area?

0. Yes	1. No

f) If answer is **YES:** What major changes in temperature patterns have you observed over the last 10 years?

0. Increasing temperatures	1. Decreasing temperatures	2. No observed changes

g) Have you noticed any long-term changes in rainfall in your area?

0. Yes	1. No

h) If answer is **YES:** What major changes in rainfall patterns have you observed over the last 10 years?

0. Increasing rainfall	1. Decreasing rainfall	2. No observed changes

i) How do you evaluate the trend of the climate variables change over the last ten years?

0. The change has become severe	1. Slow change	2. No visible difference has been observed	3. No change

j) Do you have access to scientific weather information from the Meteorological service department?

0. Yes	1. No

k) Is it the information you need?

0. Yes	1. No

l) If the answer to l is "No", What kind of information do you want?

....

m) Do you receive any early warnings for possible adverse weather events such as droughts, floods, heat wave or storms?

0. Yes	1. No

n) How many times has this area ben affected by flooding in the past 10 years?...........................

o) How many times has this area been affected by droughts in the past 10 years? ………………

p) What physical assets have you lost or has been severely damaged by flooding or storm events? ……………………………

q) Was any one in your household injured in any severe weather event?

0. Yes	1. No

r) Please indicate which elements that you think will be disrupted by climate change.

0. Fish stocks	
1. Fishing points/ grounds	
2. Fish catches	
3. Profits from fisheries	
4. Risking lives of the fishers	
5. Fish processing	
6. Fish marketing	
7. Drinking water	
8. *Food security	

*Food Security = Earn enough money to buy food for two meals per day for the family.

Livelihood Strategies

a) Sources of income (*rank the most important source using 1= most important and 4= least important*)

0. Fishing	
1. Fish processing	
2. Fish trading	
3. Boat making	
4. Fishing labourer	
5. Farming	
6. Pension	
7. Remittances	
8. Social networks	
9. Other:……………………………………	

b) Have you introduced a new source of income for your household?

0. Yes	1. No

c) How many household members migrated to a different area for work?............................

d) How can you describe your income compared to 5 years ago?

0. Increased	1. Decreased	2. No change

e) Where does your household get most of its food?

0. Fishing	
1. Farming	
2. Purchasing	
3. Donations (Government/ NGO aid)	

Other (*please specify*) …………………………………………………….

f) Where do you collect your water from?

0. Piped water	1. Well	2. Borehole	3. Lake

g) Interviewer to observe the materials used to build the respondents house

0. Common cement bricks	
1. Clay bricks	
2. Wood	
3. Mud	
4. Grass walls	
5. Grass roof	
6. Asbestos/ tiles	
7. Other:	

j) Do you own a boat?

0. Yes	1. No

k) How many fishing nets do you own?..

l) Which season do your practice your fishing activities?

0. Rainy season	1. Dry season	2. All year round

m) Do you attend fishing workshops?

0. Yes	1. No

n) According to you, state three challenges facing the fishery sector right now.

………………………………………………………………………………………………

………………………………………………………………………………………………

o) Does your household grow crops?

0. Yes	1. No

p) If answer to (q) is YES, please identify the crops that your household grows?

Crop	Yes	Area under cultivation (Hectors)
Maize		
Beans		
Vegetables		
Sorghum		
Other		

q) Do you sell or butter trade crop surpluses?

0. Yes	1. No

r) Do you have access to credit?

0. Yes	1. No

s) Average distance of the houses from the Lake ……………………………Km.

t) Does your household have the opportunity in practice to use the following when you need them?

Item	**Yes**	**Distance**
0. Shelter		
1. Sanitation		
2. Electricity		
3. Market		
4. Fish landing facilities		
5. Roads		

6. Grocery market		
7. Local government office		
8. Disaster office		
9. Fisheries office		
10. Meteorological services office		
11. Communication (Mobile phones)		
12. Educational institution		
13. Justice		

Climate change effects on fish production

u) What is your average fish catch or fish that you process per day? …………….?

v) How do you describe the trend of your fish catches for the past 10 years?

0. Increasing	1. Decreasing	2. No change

w) What do you think might be the contributing factor to the change in fish catches trend?

0. Climate change	1. Overfishing	2. Pollution	3. Conflict	4. Illegal fishin g	5. Predator species	6. Other

Climate Change Adaptation

a) Are you a member of any fishing cooperative or organization?

0. Yes	1. No

b) If answer to (a) is YES, please mark the appropriate type of cooperative or organization or social group that you are a member of from the list below.

0. Fishing	
1. Group Marketing	
2. Religious/ Faith based group	
3. Savings and loan	
4. Farming or gardening	
5. Other	

c) During times of extreme weather events such as droughts or floods, do you get assistance from any of your social groups in form of money, clothing, shelter or food?

0. Yes	1. No

d) During times of extreme weather events such as droughts or floods, do you give assistance to any of your social groups in form of money, clothing, shelter or food?

0. Yes	1. No

e) During tough times, have you visited your local government for assistance in the past 12 months?

0. Yes	1. No

f) Are they any government agencies/ NGOs/ corporations/ research institutions working in your community to improve your livelihoods, sustainable development and mitigate climate change?

0. Yes	1. No

g) If answer is Yes, please state the names of the government agencies/ NGOs/ corporations/ research institutions

…………………………………………………………………………………………………

…………………………………………………………………………………………………

h) Have your fishing practices changed over the past 10 years? (**Adapted to changes**)

0. Yes	1. No

i) If answer to [e] is YES, the list below is a list of climate change adaptation strategies employed by fishers in several fishing communities. Please indicate which strategies you have adopted to deal with the impacts of climate change and variability.

0. Migrating to a new community	
1. Adopting an alternative livelihood	
2. Increasing fishing time	
3. Decreasing fishing time	
4. Changing fishing gear	
5. Targeting new fish species	
6. Other ………………………………………………	

j) If answer to (a, 1) is YES, which other alternative livelihood has your household adopted?

…………………………………………………………………………………………………

k) Does the government, NGOs or private institutions assist fishers in the time of extreme weather events?

0. Yes	1. No

J) How long does it take you to get to a health facility?....................km

h) Is anybody in your family chronically ill (they get sick very often)?

0. Yes	1. No

i) Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school?

0. Yes	1. No

j) Which months of the year is malaria particularly bad?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

k) How many mosquito nets do you have?...

List some of the barriers and limits that affect your fishing activities or ability to adapt to the changing environment.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Food Security

l) Does your family have adequate food the whole year?

0. Yes	1. No

m) How many months a year does your family have trouble getting enough food?......................

End

Tatenda, Siyabonga, Thank you!!

APPENDIX B: Focus Group Discussion Checklist (Interview Guide).

Checklist questions for climate change vulnerability and adaptation of fishing communities

1. Can you please explain what you have observed on rainfall and temperature trends over the past 10 years?
2. Has changing climate caused any problems in your community?
3. How do people in your area adapt to challenges caused by climate change?
4. What are the main sources of income for the majority of the people?
5. Are they any organizations or government agencies relaying early warning and climate change information in your area?
6. What are some of the problems that you face as fishers that affect your ability to adapt to climate change?
7. How effective do you feel the co-ordination of government, NGO's and humanitarian aid is?
   - How can this be strengthened?
   - What are the shortcomings?

APPENDIX C: Livelihood Vulnerability Index (LVI) Supplementary Material (Chapter 4).

Section A: Household Questions.

Table A 1.1: Major components and sub-components comprising the Livelihood Vulnerability Index (LVI) developed for two rural districts of Binga and Kariba.

Major components	Sub-components	Explanation of sub-components	Survey question
	Dependency ratio	Ratio of the population under 15 and over 65 years of age to the population between 19 and 64 years of age.	Could you please list the ages and sexes of every person who eats and sleeps in this house? If you had a visitor who ate and slept here for the last 3 days, please include them as well.
Socio-demographic profile	Percent of female-headed households	Percentage of households where the primary adult is female. If a male head is away from the home >6 months per year the female is counted as the head of the household.	Are you the head of the household?
	Percent of households where head of household did not finish primary school.	Percentage of households where the head of the household did not finish primary school.	Did you finish primary school?
	Percentage of households with family members needing assistance.	Percentage of households that have at least one family member requiring assistance.	Do you have a family member that requires physical assistance (paralysed or sick)?
	Percentage of households whose family members work outside the community.	Percentage of households that report at least one family member who works outside of the community for their primary work activity.	How many people in your family work in another community?
Livelihood strategies	Percentage of households who depend on fisheries as their main source of income.	Percentage of households that report only fisheries as a source of income.	Is fishing or its related activities the only source of your household income or you have other sources?
	Average index of livelihood diversification.	The inverse of (the number of fisheries livelihood activities +1) reported by a household, e.g., A household that fishes, raises animals, and collects natural resources will have a Livelihood Diversification Index = 1/ (3 + 1) = 0.25.	Same as above.
	Average receive: Give ratio.	Ratio of (the number of types of help received by a household in the past month + 1) to (the number of types of help given by a household to someone else in the past month + 1).	In the past month, did relatives or friends help you and your family: (e.g., with money, food or medicines, sell fish products or other goods produced by family or take care of children). In the past month, did you and your family help relatives or friends: (same choices as above)?
Social Networks	Average Borrow: Lend money ratio.	Ratio of a household borrowing money in	Did you borrow any money from relatives or

		the past month to a household lending money in the past month, e.g., If a household borrowed money but did not lend money, the ratio = 2:1 or 2 and if they lent money but did not borrow any, the ratio = 1:2 or 0.5.	friends in the past month? Did you lend any money to relatives or friends in the past month?
	Percentage of households that have not gone to their local government for assistance in the past 12 months.	Percentage of households that reported that they have not asked their local government for any assistance in the past 12 months.	In the past 12 months, have you or someone in your family gone to Any government offices for help?
Health	Average time to a health facility.	Average time it takes the households to get to the nearest health facility.	How long does it take you to get to a health facility?
	Percentage of households with a family member with chronic illness.	Percentage of households that report at least one family member with chronic illness.	Is anybody in your family chronically ill (they get sick very often)?
	Percentage of households with family members miss school or work due to illness.	Percentage of households that report at least one family member who had to miss school of work due to illness in the last 2 weeks.	Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school?
	Average malaria exposure, prevention index.	Months reported exposure to malaria*Owning at least one bed net indicator (have bed net = 0.5, no bed net = 1) (e.g., Respondent reported malaria is a problem and they do not own a bed net = 3*1 = 3).	Which months of the year is malaria particularly bad? How many mosquito nets do you have?
Food	Percentage of families who depend on family fisheries for food.	Percentage of households that get their food primarily from fisheries.	Where does your family get most of its food?
	Percentage of households struggling for food	Average number of months households struggle to obtain food for their family	Does your family have adequate food the whole year, or are there times during the year that your family does not have enough food? How many months a year does your family have trouble getting enough food?
	Percentage of households with decreasing fish production.	Percentage of households that reported a change in fish catches.	How do you describe the trend of your household fish catches?
Water	Percentage of households that utilise a natural water source.	Percentage of households that report the lake or river as their primary water source.	Where do you collect your water from?
	Average time to water source.	Average time it takes the households to travel to their primary water source.	How long does it take to get to your water source?
	Percentage of households that do not have a consistent water supply	Percentage of households that report that water is not available at their primary water source everyday	Is this water available everyday?
	The average number of floods, drought, and cyclone events in the past 10 years.	Total number of floods, droughts, and cyclones that were reported by households	How many times has this area been affected by a flood/cyclone/drought in 2007–2017?

		in the past 10 years.	
	Percentage of households that did not receive a warning about the pending natural disasters.	Percentage of households that did not receive a warning about the most severe flood, drought, and cyclone event in the past 10 years.	Did you receive a warning about the flood/cyclone/drought before it happened?
	Percentage of households with an injury or death because of recent natural disasters	Percentage of households that reported either an injury to or death of one of their family members because of the most severe flood, drought, cyclone or wind in the past 10 years	Was anyone in your family injured in the flood/cyclone, drought or harsh wind? Did anyone in your family die during the flood/cyclone/drought/ harsh wind?
Natural Disaster and Climate Variability	Percentage of households that reported damaging of assets (i.e., boats, fish landing sites, property, livestock etc.) due to adverse weather events	Percentage of households that reported either a damage in household assets such as boats, fishing nets, shelter, animals etc. owing to a severe flood, drought, cyclone or wind in the past 10 years	Has any of your assets been damaged by a flood/cyclone, drought or harsh wind?
	Mean standard deviation of the monthly average of average minimum monthly temperature (years: 1987–2017).	Standard deviation of the average daily maximum temperature by month between 1987 and 2017 was averaged for each district.	1987–2017: provincial data; weather station based within the districts or proximity.
	Mean standard deviation of the monthly average of average maximum monthly temperature (years: 1987–2017).	Standard deviation of the average daily minimum temperature by month between 1987 and 2017 was averaged for each province.	1987–2017: provincial data; weather station based within the districts or proximity.
	Mean standard deviation of monthly average precipitation (years: 1987–2017).	Standard deviation of the average monthly precipitation between 1987 and 2017 was averaged for each province.	1987–2017: provincial data; weather station based within the district or proximity.

Section B: Calculations For Chapter 4.

Calculation A

Table S2: Calculating the Food major component of Binga Rural District (BRD).

Sub-components for food major component	Sub-component values for BRD	Max sub-component value for study population	Min sub-component value for study population	Index value for BRD	Food major component values for BRD
Percentage of families who depend on fisheries for food. (F_1)	100	100	0	1.00	0.80
Percentage of households struggling for food. (F_2)	78	100	0	0.78	
Percentage of households with decreasing fish production. (F_3)	62	100	0	0.62	

- Step 1: (repeat for all sub-component indicator):

$$Index_{Food1BRD} = \frac{S_q - S_{min}}{S_{max} - S_{min}} = \frac{100-0}{100-0} = \mathbf{1.00}$$

- Step 2: (repeat for all major components):

$$M_q = \frac{\sum_{i=1}^{n} Index_{sqi}}{n} = \frac{F_1 + F_2 + F_3}{3} = \frac{1 + 0.78 + 0.62}{3} = \mathbf{0.8}$$

- Step 3: (repeat for all districts):

$$LVI_q = \frac{W_{SDP}SDPq + W_{LS}LS_q + W_{SN}SN_q + W_H H_q + W_F F_q + W_w W_q + W_{NDCV}NDCV_q}{W_{SDP} + W_{LS} + W_{SN} + W_H + W_F + W_W + W_{NDCV}}$$

$$= LVI_{\boldsymbol{BRD}} = \frac{4*0.3 + 3*0.61 + 3*0.46 + 4*0.36 + 3*0.8 + 3*0.77 + 7*0.44}{4+3+3+4+3+3+7}$$

$$= LVI_{BRD} = \frac{1.2 + 1.83 + 1.38 + 1.44 + 2.4 + 2.31 + 3.08}{27} = \mathbf{0.51}$$

Calculation B

Table S3: Calculating LVI-IPCC for BRD.

Contributing factors	Major components for BRD district	Major component values for BRD	Number of sub-components Per major component	Contributing factor values	LVI-IPCC value for BRD

Exposure	Natural disasters and Climate variability	0.44	7	0.44	
Sensitivity	Health	0.36	4	0.62	**0**
	Food	0.80	3		
	Water	0.77	3		
Adaptive capacity	Socio-demographic profile	0.30	4	0.44	
	Livelihood strategies	0.61	3		
	Social networks	0.46	3		

- Step 1: (calculate indexed sub-component indicators and major components as shown in Section B (Calculation A), taking the inverse of the adaptive capacity sub-component indicators: Socio-demographic Profile, Livelihood Strategies, and Social Networks)
- Step 2: (repeat for all contributing factors: exposure, sensitivity, and adaptive capacity):

$$Sensitivity_{BRD} = \frac{\sum_{i=1}^{n} W_{Mi} M_{qi}}{\sum_{i=1}^{n} W_{Mi}} = \frac{4*0.36+3*0.8+3*0.77}{10} = 0.62$$

- Step 3: (repeat for all study areas):

$$LVI - IPCC_{BRD} = (0.44 - 0.44) * 0.62 = \mathbf{0}$$

APPENDIX D: Humanities and Social Sciences Research Ethics Clearance Form

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

08 September 2021

Mr Rodney Tatenda Muringai (213568453)
School Of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear Mr Muringai,

Protocol reference number: HSSREC/00003055/2021
Project title: CLIMATE CHANGE AND VARIABILITY EFFECTS ON INLAND FISHERIES: ZAMBEZI RIVER BASIN, ZIMBABWE
Degree:

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 01 July 2021 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

This approval is valid until 08 September 2022.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

All research conducted during the COVID-19 period must adhere to the national and UKZN guidelines.

HSSREC is registered with the South African National Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Professor Dipane Hlalele (Chair)

/dd

Humanities and Social Sciences Research Ethics Committee
Postal Address: Private Bag X54001, Durban, 4000, South Africa
Telephone: +27 (0)31 260 8350/4557/3587 **Email:** hssrec@ukzn.ac.za **Website:** https://research.ukzn.ac.za/Research-Ethics

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

APPENDIX E: ZIMPARKS Research Permits.

PARKS AND WILDLIFE ACT [CHAPTER 20:14] OF 1996

RESEARCH PERMIT

Ref: 151/43/P/REND
Fee paid: US$50.00
Receipt Numbers: 100596 (HQ)
Permit Number: 23(1) (C) (II) 33/2022

ISSUER

PARKS AND WILDLIFE MANAGEMENT AUTHORITY (The Authority)

PERMIT HOLDER
Rodney T Muringai (Student Number: 213568453) : A PhD Student at University of Kwazulu-Natal in the Department of Agricultural, Earth and Environmental Sciences Whose registered address for business is Pietermaritzburg Campus, Life Sciences Campus, Carbis Road, Scottsville, South Africa: Contacts +263 777113535

Research Supervisor: Prof P L Mafongoya.
Research Co-supervisor: Dr R Lottering.

REF: DM/Gen/ (T)

PERMIT NO.:23(1) (C) (II) 53/2018

PERMIT TO CARRY OUT RESEARCH IN PARKS ESTATES

Permission is hereby granted on the authority of the Minister of Environment, Water and Climate in terms of section 23(1) (c) (ii) of the Parks and Wildlife Act, Chapter 20:14 to:

Rodney T Muringai
College of Agriculture, Engineering and Science
University of KwaZulu- Natal
Pietermaritzburd, South Africa

Supervisor; Dr Denver Naidoo.
Co-supervisor; Professor P L Mafongoya

To carry out a research and investigate the effects of climate change on Livelihoods and food security among fishing communities in Kariba.

APPENDIX F: Images of Fishing Communities and Data Collection Process.

Figure S1: Shelters in fishing communities: Chinzonzo, Binga.

Figure S2: Data collection in Kariba and Binga districts.

Figure S3: Gache-gache fishing camp, Kariba.

Figure S4: Fisher and non-moterised fishing boat.