DYNAMICS OF ECOHYDROLOGY, GOVERNANCE, AND COMMUNITY LIVELIHOODS OF MIGORI RIVER WATERSHED, KENYA

STEPHEN BALAKA OPIYO

N85/28443/2019

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL PLANNING AND MANAGEMENT IN THE SCHOOL OF ENGINEERING AND ARCHITECTURE OF KENYATTA UNIVERSITY

JUNE 2023

DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other university.

Signature: ..... Date 20/06/2023

Stephen Balaka Opiyo (N85/28443/2019)

Department of Spatial and Environmental Planning, Kenyatta University

Declaration by Supervisors:

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

Signature: ..... Date 20/06/2023

Dr. Sammy C. Letema, PhD

Department of Spatial and Environmental Planning, Kenyatta University

Signature: ..... Date 20/06/2023

Dr. Godwin Opinde, PhD

Department of Spatial and Environmental Planning, Kenyatta University

DEDICATION

This PhD dissertation is dedicated with utmost affection and appreciation to:

My dear parents Mr. Stansilaus Opiyo and Mrs. Sofia Opiyo

My precious wife Martha Balaka and my lovely kids, Steve Junior and Stephanie Aluoch

My beloved siblings Elisha Opiyo, Hannah Opiyo, Jacktone Opiyo, Naomi Opiyo, Phoebe Opiyo (Deceased)

For being a great source of love, strength, inspiration and support during my studies

God bless you all, always and forever!

ACKNOWLEDGEMENT

As the intellectual and practical journey of working on this PhD thesis ultimately reaches its end, I wish to take this opportunity to thank those who walked with me and left an indelible mark on me. First, I would like to express my deepest respect and highest appreciation to my thesis supervisors Dr. Sammy Letema and Dr. Godwin Opinde for their wise counsel, motivation and constant guidance which not only led to the successful development of this Doctoral (PhD) research study but also continue to inspire me professionally and personally. I am highly grateful to all staff members of the Spatial and Environmental Planning Department, with special mention of Dr. Christine Majale whose leadership contributed to the swift and successful completion of this PhD journey. Special appreciation goes to my fellow DAAD students Arcadius and Orina for the friendship, commentaries and encouragement throughout this journey.

I am also immensely grateful to the leadership of Kenya Marine and Fisheries Research Institute (KMFRI) Kisumu Station, Director Dr. Chris Aura and Deputy Director Dr. Chris Nyamweya, for unreservedly availing me the research equipment, laboratory facilities and research assistants for the collection and analysis of water quality samples for a period of six months. I acknowledge with much gratitude the role played by KMFRI staff Mr. James Achiya and his team in coordinating the fieldwork for the water quality monitoring. I am also grateful to the research assistants who assisted with the household surveys and the professionals who directly or indirectly supported me during my field research period.

I am grateful to my dear parents, wife Martha, and siblings who provided moral support and prayers at every step of the way. Special thanks to my elder brother, William Opiyo and his wife, who have supported me throughout my academic journey.

Am greatly indebted to DAAD for granting me a full scholarship to undertake this PhD program at Kenyatta University. Lastly, I would like to bless God Almighty, from whom all the good things in my life come from. His grace got me this far in academia. All the Glory is to God, Amen!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of variance

APHA: American Public Health Association

CCME-WQI: Canadian Council of Ministers of the Environment Water Quality Index

CFA: Community Forest Association

DFID: Department for International Development

ESAs: External Support Agencies

GIS: Geographical Information System

HHs: Households

KFS: Kenya Forestry Service

KNBS: Kenya National Bureau of Statistics

LBDA: Lake Basin Development Authority

LSI: Livelihood Sustainability Index

LULC: Land Use and Land Cover

LVBC: Lake Victoria Basin Commission

LVI-IPCC: Livelihood Vulnerability Index - Intergovernmental Panel on Climate Change

LVSWWDA: Lake Victoria South Water Works Agency

NEMA: National Environmental Management Authority

RBM: River Basin Management

RBO: River Basin Organization

SARA: Semi-autonomous Regulatory Agency

SPSS: Statistical Package for Social Sciences

SWAT: Soil and Water Assessment Tool

USEPA: United States Environmental Protection Agency

WHO: World Health Organization

WRA: Water Resources Authority

WRUA: Water Resource Users Association

DEFINITION OF KEY TERMS

Climate change: Significant and long-lasting change in the Earth's climate and weather patterns (Huong et al., 2019).

Coordination: The process of establishing interconnections amongst stakeholders in order to achieve a common goal (Okok, 2015).

Ecohydrology: The study of the mutual interactions between ecosystems and the water cycle, exploring how changes in land use, climate, and hydrological processes affect the functioning and resilience of ecosystems, as well as water availability and quality (Xia et al., 2021). Ecohydrological processes include runoff trends and biogeochemical cycles.

Land use and Land Cover: The bio-physical covering of the earth surface and the nature by which it's utilized by humans (Alawamy et al., 2020).

Water quality: Describes the attributes of water – chemical, physical and biological – with regards to its suitability for a particular purpose (Adelagun et al., 2021).

Household: All people, related or otherwise, who reside in the same dwelling compound (enclosed or unenclosed), are answerable to one head, and have common cooking and eating arrangements (KNBS, 2019).

Livelihood vulnerability: A context that constitutes external trends and shocks that have an impact on the household's ability to sustain their livelihood (Azene, 2018).

Livelihood sustainability: A state where a livelihood can withstand and recover from external stressors and shocks, as well as preserve or improve its assets and capabilities in the present and future, without jeopardizing the ecological balance (Kedir, 2015).

Spatio-seasonal variations of water quality: The changes and fluctuations in the properties of water across different locations (spatial variations) and throughout different seasons (seasonal variations) (Zope et al., 2016).

Watershed governance: A condition in which ecological processes and human systems are closely considered at all decision-making stages in the management of watershed resources (Hanlon, 2017).

ABSTRACT

This study investigated the dynamics of ecohydrological processes, watershed governance, and livelihood systems of Migori River watershed. The objectives of the study were to; examine the institutional arrangements in the Migori River watershed management and their influence on the nature and level of coordination among the actors, evaluate the impacts of land use and land cover (LULC) changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 – 2020, assess the spatio-seasonal variations of water quality parameters of Migori River and associated household health risk implications in Migori River watershed, and assess the level of sustainability of community livelihoods in the Migori River watershed and its associated vulnerability to climate change impacts. The study adopted a mixed-method approach comprising case and cross-sectional study designs which enabled the collection of both qualitative and quantitative data from different sources. Governance assessment was based on semi-structured interview data qualitatively analyzed through content analysis in ATLAS.ti software. Simulation of hydrological changes due to LULC changes was performed using the Soil and Water Assessment Tool (SWAT) model embedded in QGIS, with analysis of LULC patterns from remote sensing data conducted based on maximum likelihood classifier algorithm. In assessing the water quality trends along with potential health risks, 18 physico-chemical and bacteriological variables were sampled and analyzed monthly for two seasons from six stations using standard procedures, and a health risk survey conducted with 90 households. ANOVA and T-test were used to test for the significant spatial and seasonal variations, respectively; whereas the overall water quality status was analyzed using the CCME water quality index (CCME-WQI). The community livelihoods' sustainability level in the watershed and its associated vulnerability to climate change impacts were analyzed using the Livelihood Sustainability Index (LSI) and Livelihood Vulnerability Index (LVI-IPCC), respectively, based on 318 households' survey data. The results on the structure and roles of institutions at various levels revealed adequate representation of the river basin management actors within the watershed; but the associations among these actors are weak due to conflicting and overlapping mandates, and gaps in the coordination processes. The watershed has undergone a substantial transformation between 1980 and 2020, with a considerable decline in shrub lands by 40.63%, grasslands by 84.86%, forests by 52.90%, water by 82.03%, and wetlands by 38.44%; whereas cultivated land, bare land and built-up areas have expanded over the same period by 34.25%, 132.28% and 461.20%, respectively. These LULC changes, majorly driven by population pressure and poverty, have contributed to the decline of actual evapotranspiration by 2.83%, potential evapotranspiration by 5.38%, and groundwater flow by 19.06%; and an increase in surface runoff by 32.57%, water yield by 4.82% and sediment by 84.58%. Water quality variables showed significant seasonal variability but no significant spatial differences at $p < 0.05$; with integrated analysis showing the river is polluted and potentially hazardous for human usage due to high bacteriological levels. The LSI and LVI-IPCC respectively categorized the watershed households as moderately sustainable and moderately vulnerable to climate risks, with no significant differences across the watershed zones ($p < 0.05$). The study concludes that the changes in land use practices and climate variability has negatively impacted hydrologic flows and has implications for watershed community livelihoods, which the existing governance framework may not effectively manage due to flaws in the institutional structure undermining coordination of stakeholders. The study recommends interventions in the institutional design of the governance system; and implementation of suitable land use zoning, multifaceted pollution control measures and rural development initiatives for enhancing household's adaptive capacity to climate change.

CHAPTER ONE: INTRODUCTION

1.1 Background

A Watershed is any land area that collects and drains all the rainwater to a specific common water body such as a lake, river or stream (Ekness, 2013). A watershed system is considered to be sustainable if it contains sufficient water resources in wetlands and streams and sufficient flora and fauna to support the livelihoods of the current and future communities (USGS, 2018). The sustainability of a watershed system is controlled by its ecohydrology, — the interactions between hydrologic flows, natural ecosystems, and biota (Cao et al., 2022); as well as its governance (Tantoh & Simatele, 2018).

Ecohydrological processes at the watershed level, influenced by factors such as geomorphology, land use and land cover (LULC), climatic elements, and soils, play a vital role in determining the capacity of watershed systems to sustain water and provide ecological services (Ekness, 2013). Studies indicate that changes in LULC and climate change are the two significant elements influencing watershed ecohydrological processes (Stosch et al., 2017; Li et al., 2021). LULC changes have a significant impact on water resources in watersheds, affecting both quantity and quality. They alter sediment regime, runoff volume, peak flow rate, and introduce nutrients, sediments, and pollutants downstream, leading to changes in the physical, chemical, and biological attributes of water (Bai et al., 2010; Ding et al., 2015). Climate change, on the other hand, affects the watershed ecohydrological processes by modifying the water cycle through alterations in the patterns of rainfall recharge and temperature regimes, and triggering extreme weather events like floods and droughts (Cao et al., 2022).

The interactions between LULC change and climate change in a watershed ecosystem lead to watershed deterioration, resulting in a decline in its capacity to sustain water and ecosystem services (Lal et al., 2012). This phenomenon poses a significant global threat to livelihoods, food security, and economic development (Mekonnen et al., 2015). Watershed deterioration causes water scarcity, reduced stream flow, increased sedimentation, water pollution, soil erosion, fertility depletion, and the loss of natural vegetation and forests (Marquis, 2015). Therefore, protecting and conserving watersheds is critical to safeguard livelihoods and ecological services, a recognition that has led scientists to link ecohydrology with integrated water resources management through watershed governance (Katusiime & Schütt, 2020). Watershed governance is aimed at sustaining water flow and ensuring the continuous provision of watershed services to meet societal needs and maintain the ecological integrity of aquatic biodiversity (Marquis, 2015). It involves considering both ecological processes and human systems at all decision-making stages in the management of watershed resources (Hanlon, 2017). Developing countries prioritize this governance approach due to the heightened vulnerability of their watersheds to deterioration (Swallow et al., 2008).

The problem of watershed deterioration is not limited to developing countries; it is a widespread issue globally as highlighted by the UNESCO (2018) report. However, it is believed to be more acute in Sub-Saharan Africa (Mengistu & Assefa, 2022). Kenya, a country in Sub-Saharan Africa, is among the nations in the region facing significant levels of watershed deterioration primarily caused by land degradation (World Bank, 2016). This is particularly evident in the Lake Victoria basin, where high population growth, climate variability, and over-utilization of natural resources contribute to the problem (Olang & Fürst, 2011; Onyango et al., 2021). The Lake Victoria basin consists of multiple watersheds,

one of which is the Migori River watershed. In this specific watershed, the capacity to continually provide adequate water resources of good quality and other ecological services is threatened by various factors, including deforestation, unplanned urbanization, intensive agricultural activities, and the impacts of climate change in the region (Lejju, 2012; Mugo et al., 2020). Despite these challenges, the impacts of the interplay between land uses and climate variability on the quality and quantity of hydrological flows, as well as on the sustainability of community livelihoods and the management dynamics of these effects within the existing devolved governance framework for the Migori River watershed, remain unknown. It is crucial to investigate these dynamics in order to generate actionable science that can inform the development of sustainable management interventions for the watershed.

1.2 Statement of the Problem

Migori River watershed occurs in the western portion of the Lake Victoria basin as one of the largest sub-basins. This region has experienced widespread LULC changes over the last 40 years due to high population growth and over-utilization of natural resources (Mugo et al., 2020). From 1978 to 2018, land conversion occurred primarily from forests and grasslands to agricultural lands and built-up areas, with Migori County losing about 51% of all its vegetation-covered land areas (Onyango et al., 2021). Future scenario-based land use modeling predicts that the loss of natural landscapes in the region could increase tremendously given the expansion rates of agricultural and urban areas (Onyango et al., 2021). At the same time, climate models predict a temperature rise of 1.3 to 4.5 °C, a decrease in future annual precipitation by 25%, and an increased frequency in the occurrence of extreme weather-induced events in this particular portion of the basin over the next 50 years (Kundzewicz, 2016; Olaka et al., 2019). Under these circumstances, the quantity and

quality of water resources, and the sustainability of community livelihoods in Migori River watershed may be adversely impacted due to alterations in ecohydrology.

Studies (such as Kathumo et al., 2012; Kaburi & Odera, 2014; Ogembo, 2018) have examined ecohydrological responses to LULC and climate change interactions in some of the watersheds across the region; however, there lacks a focus on Migori River watershed to account for local patterns of LULC change and climate variability. Furthermore, the influence of LULC and climate change interactions in this watershed on the sustainability of community livelihoods remains unknown. Current statistics indicate that in Migori County, where the watershed is located, the poverty rate is 46%, surpassing the national level of 36%, and this is projected to be exacerbated by the mutually reinforcing effects of land use and climatic change (such as floods, droughts, and heat stress) which will particularly impact the predominantly agro-based livelihoods of the area (GoK, 2019; County Government of Migori, 2020). Therefore, an in-depth understanding of the dynamics of ecohydrological processes and community livelihoods under changing LULC patterns and climate in this watershed is required to develop sustainable management interventions for the benefit of the ecosystems and socio-economic development. Moreover, since the ecohydrological and livelihoods circumstances of a watershed are directly linked to its management (Tantoh & Simatele, 2018), an understanding of the governance setup of the watershed is important. Migori River watershed, like other watersheds in Kenya, is currently governed by a unique devolved watershed management framework but the institutional arrangement of the framework and its influence on coordination among the actors remains unknown. This study examines the dynamics of ecohydrological processes, governance, and community livelihoods of the Migori River watershed.

1.3 Research Questions

1. How do the institutional arrangements in the management of Migori River watershed influence the nature and level of coordination among the actors?
2. How has land use and land cover changes impacted the trends of stream flow and sediment yields in Migori River watershed from 1980 – 2020?
3. How do spatio-seasonal variations of water quality of Migori River influence the suitability of the river water for household usage in the Migori River watershed?
4. How sustainable and vulnerable to climate change impacts are the household livelihoods' for the communities in the Migori River watershed?

1.4 Objectives of the Study

General Objective

Investigate the dynamics of ecohydrology, watershed governance, and livelihood systems of Migori River watershed.

Specific Objectives

1. To examine the institutional arrangements in the management of Migori River watershed and their influence on nature and level of coordination among the actors.
2. To evaluate the impacts of land use and land cover changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 - 2020.
3. To assess the spatio-seasonal variations of water quality parameters of the Migori River and associated household health risk implications in Migori River watershed.
4. To assess the level of sustainability of community livelihoods in the Migori River watershed and its associated vulnerability to climate change impacts.

1.5 Justification of the Study

Migori River watershed is of great ecological and socio-economic significance in the region as it hosts important fauna and flora and provides ecosystem goods and services vital for supporting livelihoods. Local populations around the watershed benefit from ecological goods like fuel wood, medicinal substances, pasture for animals, and water for households and industrial usage, among others. The watershed provides ecosystem services including regulating stream flow, purification of river inflows, erosion control, and sustenance of groundwater levels. The watershed is a vital source of water for numerous streams including Enoosaen, Remo, Ndiri, Nyogoto, Bungenech, Nyasarara, Nyagugo, Eko, Nyakonya, and Nyasare that flow into the Migori River that drains into the Lake Victoria. Therefore the watershed serves the water supply needs of about a million people in Migori County and contributes significant inflows to Lake Victoria.

Despite the ecological and socio-economic significance of this watershed, there is inadequate knowledge of the dynamics of ecohydrological processes under changing LULC patterns and climate which is crucial for any step towards its conservation and sustainable management. The watershed lies in an area facing considerable pressure from various anthropogenic pursuits like deforestation, unplanned urbanization, and intensive but poor agricultural practices which coupled with the climate change (Lejju, 2012), are expected to adversely disrupt its capacity to supply quality and adequate water resources and ecological services which can then negatively impact the livelihoods of the local communities. Thus there is a need to analyze the dynamics of ecohydrological processes under changing LULC patterns and climate of the watershed and their influence on the sustainability of local livelihoods.

Moreover, there is a notable research gap in our understanding of how multi-level governance for watersheds in Kenya operates within the current devolution framework established in 2012, as no studies have evaluated its impact on the watershed governance structure. This study addresses the opportunities and challenges related to the implementation of a devolution-based watershed management framework in Kenya, aiming to inform policy decisions for enhancing sustainable development and management of watershed resources, benefiting both ecosystems and socio-economic development.

1.6 Significance of the Study

This study provides an important contribution to practice and theoretical fronts. The study presents opportunities and challenges associated with the implementation of a devolution-based watershed management framework that can inform policy decisions for improving the watershed governance in Kenya. The findings of water quality monitoring of the Migori River provide the objective evidence required to make sound decisions about water quality management to safeguard public health. The study has generated insights into historical LULC change patterns and associated drivers in the Migori River watershed which can help the Migori County government and other decision-makers in developing sustainable land management strategies. Further, evaluation of ecohydrological responses to these land use changes will guide policy decisions concerning the availability and sustainable management of water resources for the benefit of the ecosystems and socio-economic development.

Since literature (USAID, 2020; Nyika, 2022) indicates that rural livelihoods in Kenya are expected to bear some of the worst effects of climate change, the study provides insights on

the level and sources of households' livelihood vulnerability to climate variability in the study area; which can inform the development of better-targeted climate change adaptation and mitigation measures by policymakers and development partners. Moreover, insights from livelihood sustainability analysis for the study area can aid relevant authorities in designing poverty-relief programmes aligned with the local needs.

1.7 Scope and Limitations of the Study

The study was restricted to Migori River watershed occurring within the Migori County between the bases of Chepalungu Forest in Emuria-Dikiri Sub-county of Narok County and the point where the river enters Lake Victoria. Lack of adequate previous studies on the relationships between human activities and the environment in Migori County was a limiting factor to this research.

The spatial analyses of LULC changes in the study area, carried out using moderate resolution Landsat satellite images, covered a period of forty years (1980 - 2020). In determining the hydrological response to LULC changes, the study applied the SWAT model and the hydrological simulation analyses were limited to stream flows and sediment yields in the study area. Acquisition of complete long-term meteorological datasets (especially relative humidity, solar intensity and wind speed) required for SWAT simulation was a limiting factor due to presence of few gauging stations within the county.

Evaluation of the spatial and seasonal trends in water quality conditions in Migori River was limited to selected physicochemical parameters (Dissolved Oxygen concentration, Temperature, Conductivity, pH, Salinity, Total Dissolved Solids, Turbidity, Total Hardness,

Total Alkalinity, and dissolved nutrients) and bacteriological properties (fecal coliforms). The selected physicochemical and bacteriological variables were sampled and analyzed monthly for six months, between September 2021 and February 2022 covering the wet and dry seasons, from the upstream, midstream, and downstream stations distributed along the river.

The Livelihood Vulnerability Index (LVI) framed within the Intergovernmental Panel on Climate Change (IPCC) vulnerability framework (LVI-IPCC), used in assessing the level and sources of households' livelihood vulnerability to climate variability, was limited to a set of 47 indicators; whereas the Livelihood Sustainability Index (LSI) framed within the DFID framework, used in assessing the sustainability of livelihood systems of households in the study area, was limited to a set of 43 indicators.

1.8 Assumptions of the Study

The study was conducted based on the following assumptions:

1. The environmental conditions in Migori River watershed were relatively stable during the water quality sampling time frame.
2. The study also assumed that the selected sampling stations were representative of the whole river ecosystem.
3. The respondents for the study provided honest and truthful responses.
4. The weather generator engine system in SWAT model was able to accurately fill in incomplete or missing weather datasets where necessary.

1.9 Thesis Organization

Chapter 1: Describes the background of the research and presents the statement of the problem, study objectives, research questions and study's justification. It also outlines the significance, scope, limitations, and assumptions of the study.

Chapter 2: Reviews relevant literature on watershed ecohydrology with a focus on LULC changes, its drivers, and effects on the hydrological flows and water quality. It also provides an overview of watershed governance concept and reviews policy and legal framework relevant to water and watershed resources management in Kenya. The sustainable livelihoods framework and its elements, and theoretical underpinnings of the study are also outlined in this chapter. Finally, the chapter presents a conceptual framework that outlines the variables for the study and their interconnections before summarizing the knowledge gaps identified from the literature review that should be filled through research.

Chapter 3: Describes the research site, and outlines the research design, sampling procedures, data collection tools and techniques, data analysis and presentation techniques, and ethical considerations adopted for the study.

Chapter 4: Presents analyses and discussions of the study findings according to study objectives, as well as a reflection on theories, methods and approaches adopted for the study.

Chapter 5: Summarizes the major study findings per objective, presents conclusions based on the results, provides recommendations for the study, and finally suggests areas that require further research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter is organized into six broad sections. The first one reviews relevant literature on watershed ecohydrology with a focus on land use and land cover changes, its drivers, and effects on the hydrological flows and water quality. The second section provides an overview of the watershed governance concept and reviews legal, policy and institutional framework relevant to water and watershed resources management in Kenya. The third section discusses the sustainable livelihoods framework and its elements. The fourth section provides the theoretical underpinnings of the study. The fifth section presents a conceptual framework that outlines the variables for the study and their relationships. The sixth reviews methodologies pertinent to the study. Finally, the seventh section summarizes the knowledge gaps identified from the literature review that should be filled through research.

2.2 Watershed Ecohydrological Dynamics

Ecohydrology describes the interactions between hydrologic flows, natural ecosystems, and biota (Ekness, 2013). Ecohydrological research primarily focuses on understanding the interconnections, interplay, and feedback between ecological processes and hydrologic flows, and how these linkages and interactions appear and impose visible controls at various scales (Li et al., 2021). At the watershed or catchment level, ecohydrological processes constitute complex systems affected by numerous interacting variables including geomorphology and vegetation, land use and land cover (LULC), climatic elements, as well as soils (Cao et al., 2022). Available literature indicates that alterations in LULC and climate are the two most important elements influencing watershed ecohydrological processes

(Stosch et al., 2017; Li et al., 2021). Therefore, this section discusses the process of LULC changes and how they influence the quality and quantity of water resources at a watershed level.

2.2.1 Land Use and Land Cover Change and its Drivers

Land use and land cover are two distinct terms that are frequently treated as identical or even used interchangeably by several researchers (Rawat & Kumar, 2015). Lillesand et al. (2015) differentiate between the two terms by stating that, the land cover represents the bio-physical elements available on the earth surface such as the soil, vegetation, and water bodies, while land use represents the purposes for which these bio-physical elements on the earth surface have been altered such as agriculture, deforestation/afforestation, and urbanization among others. The two terms of land use and land cover (LULC) when spelt together describe the condition of the earth's surface as dictated by the interplay between the natural processes and anthropogenic factors (Camara et al., 2019).

LULC changes result from the intersection of numerous factors characterized as drivers. These drivers/causes can influence LULC change either directly or indirectly (Munthali et al., 2019). Direct drivers of LULC change are sometimes referred to as proximate causes while indirect drivers are sometimes referred to as underlying causes (Song et al., 2018). The difference between the two is that proximate causes (direct drivers) are factors linked to human undertakings that directly transform the land cover e.g. urbanization or agriculture, while indirect causes (indirect drivers) are the basic forces that prompt the proximate causes e.g. government policies and technological advancement (Meshesha et al., 2016). The

underlying drivers of LULC change cuts across the biophysical, demographic, cultural, social, technological, economic, political, institutional factors (Xu et al., 2020).

2.2.2 Hydrological Response to Land Use Patterns

Changes in LULC impact the availability of water resources in watersheds through modification of the processes of hydrology (Koneti et al., 2018). According to studies (Nie et al., 2011; Wu et al., 2013), changes in LULC alter the distribution of water in the hydrological processes such as evapotranspiration, rainfall-runoff, rates of water interception, percolation, and recharge of groundwater reserves. Such alteration leads to increasing peak flows, enhanced and runoff volumes, and a high incidence of flooding (Fang et al., 2013). The impact of LULC on the hydrology differs from one setting to the next depending on the land cover regime involved (Gashaw, 2020).

Urbanization in the watersheds is characterized by the construction and/or expansion of impervious surfaces such as pavements, tarmacked roads, and rooftops among others (O'Driscoll et al., 2010). The existence of impervious surfaces hinders water percolation into the soil hence producing voluminous surface runoff (Jacobson, 2011). Moreover, the impervious surfaces of developed urban areas cause the reduction of both the soil water content and evapotranspiration rates (Wu et al., 2013). Urbanization in watersheds reduces the roughness of the surface of the landscape which impacts the scale and timing of the discharge of groundwater and runoff leading to alterations in the scale and incidence of floods (Pai & Saraswat, 2011). Further, the extension of impervious surfaces in urbanized watersheds hampers runoff water infiltration into the ground thereby effectively contributing

to a reduction in baseflow and ultimately decreasing the level of groundwater reserves (Onyango et al., 2021).

Activities related to farming and grazing operations in the watershed impact the hydrological dynamics of infiltration capacity, runoff, and evapotranspiration process (Paul, 2016). The growing of seasonal row crops at the expense of the perennial crops led to a decrease in evapotranspiration (Zope et al., 2016). Besides the ET process, studies have reported that conversion of vegetated areas to agricultural farms leads to a decrease in the amount of water contained in the soil (Wu et al., 2013). Rigorous activities carried out in the farms have the effect of decreasing the roughness of the landscape surface which therefore reduces the pore spaces available for water storage in the soil (Gashaw, 2020).

Vegetation-covered landscapes such as forests, grasslands, and woodlands play positive roles in the regulation of hydrological processes in a watershed, as they encourage water infiltration into the ground resulting in better groundwater recharge and decreased vulnerability of flooding in the basin due to reduced streamflow (Zhang & Schilling, 2006; Paul, 2016). Increased streamflow and flood incidences, reduced baseflow and groundwater recharge, decreased evapotranspiration, and sedimentation of river channels have all been attributed to the conversion of vegetation covered landscapes in the watershed to other LULC types such as farmlands and urbanization (Ghaffari et al., 2010; Li et al., 2017).

2.2.3 Water Quality Response to Land Management Practices

Water quality refers to the suitability of the water for various intended purposes (Giri & Qiu 2016). Previous studies indicate that the water quality of rivers is very susceptible to land use practices (Vörösmarty et al., 2010; Tu, 2011; Zope et al., 2016). As the rivers navigate the

watershed landscape, the river waters become exposed to the biological, chemical, and physical features of the earth's surface which consequently alters the water quality (Ding et al., 2015).

Land use practices in the watershed region associated with deforestation, urbanization and intensive agriculture contribute to the water pollution of rivers among other water bodies (Olusola et al., 2018). The nature of water pollution problems depends on the geological and topographical configuration in the river watershed (USGS, 2018). Water pollution problems connected to anthropogenic land use practices in the watershed are caused by either point source pollutants (such as effluents from domestic and industrial sources) or diffuses also known as non-point sources (e.g. run-off) (Giri & Qiu, 2016). Different types of land use practices cause water pollution via one or both of the aforementioned water pollution mechanisms.

Agriculture is among the most widespread land use management type. According to Xu et al. (2014), arable land is a key land use practice impacting river water quality. Agricultural activities contribute to non-point source water pollution since they generate both organic and inorganic materials that would end up in the rivers and streams as runoff causing non-point source water pollution (Yu et al., 2015). The organic matter eroded from the heavily cultivated agricultural lands contains various nutrients especially nitrogen and phosphorus (Bowden et al., 2015). These chemicals are then deposited into rivers and streams through runoff during rainfall. These nutrients also influence the drinking water quality parameters of a river ecosystem, rendering the water unsafe for human consumption.

Water pollution arising from the effects of urbanization occurs through both diffuse and point-source mechanisms (Mena-Rivera et al, 2017). Urbanization is a land management practice characterized by the construction and/or expansion of impervious surfaces (Waters et al., 2014). Through the storm runoff, urbanization land uses causes the deposition of sediments, nutrients, toxic heavy metals, petroleum chemicals, and fecal coliforms into the urban water resources such as rivers and groundwater (Zhao et al., 2015; Musyimi et al., 2017).

Forestry is a land management type that essentially encompasses all vegetation cover and grasslands. Forested lands contains increased vegetation cover which biologically filters and retains nutrients and other organic matters as the river navigates the watershed downstream hence improving water quality (Tu, 2011).

2.3 Watershed Governance

2.3.1 Overview of Watershed Governance and the IWRM Approach

Watershed governance describes a condition in which ecological processes and human systems are closely considered at all decision-making stages in the management of watershed resources (Hirokawa, 2012). It is basically characterized by three key elements, i.e., various levels of authority (Hanlon, 2017), numerous actors (Brown, 2008), and various sectors relevant to the use and conservation of watershed resources (Corsame, 2016).

Brandes and O'Riordan (2014) affirm that there are six guiding principles for watershed governance, i.e., water for the environment; holistic approaches; transparency and participation of key stakeholders; subsidiarity and distinct decision-making responsibilities;

sustainable funding and capabilities; and accountability and autonomous monitoring. These principles influence the institutional framework for watershed governance. The composition of the institutional framework (arrangement of the various actors such as people, institutions, and sectors) for watershed governance differs significantly from place to place. According to Parkes et al. (2010), when the actors are explicit, the institutional framework for watershed governance of a particular region can be organized based on hydrological boundaries or political boundaries. In these jurisdictions, certain watershed-based entities have the authority to design, publicize, and implement their programs, whilst others only serve as advisors (Okok, 2015). Effective watershed governance, therefore, requires coordination of various actors in the planning and management of water, land, and associated resources so as to ensure water quality, social and economic wellbeing, as well as the sustainability of vital ecosystems (Chen, 2008; Hanlon, 2017).

Watershed governance can take four major forms/systems namely, monocentric/hierarchical, polycentric governance, collaborative governance, and public-private partnership (Katusiime & Schütt, 2020). Monocentric governance is a system where most powers are concentrated at the top levels of government and resource management directives are issued from the top to the bottom (Katusiime & Schütt, 2020). Polycentric governance consists of numerous organized decision-making units, each with substantial autonomy and positioned at different levels (Tarko, 2015). Collaborative governance is a system in which a single or many government bodies actively engage non-government stakeholders in a formalized, consensus-based, and deliberate collective decision-making process to formulate or enforce public policy or administer government programs or investments (Ansell & Gash, 2007). Public-private partnership is a relatively new modernized public management paradigm

inspired by the desire to reinforce governance with economics and commerce (Asif & Dawood, 2017).

Of these four forms, collaborative governance is the most popular watershed governance form since it brings together actors from the general public, government entities, intergovernmental institutions, non-governmental organizations (NGOs), corporations, universities, and networks that formulate and implement policies (Gibson, 2018). Jerop (2018) opines that collaborative governance enables the identification of common interests of the stakeholders, which in turn enhances the capacity of these stakeholders to work together in finding shared objectives and constructive strategies to meet the largest public need.

The Integrated Water Resources Management (IWRM) is universally regarded the most significant tool for the implementation of a collaborative watershed governance approach (Al-Faraj, 2015). The concept describes a process that facilitates the involvement and coordination of all relevant stakeholders in the planning and management of water, land, and associated resources to optimize the resulting economic and social benefits in an equitable fashion while maintaining the sustainability of critical ecological systems (GWP, 2012; Watson et al., 2019). Historically, the concept began gaining traction in 2000s after it was adopted by the UN in 2000 and was then incorporated as a component of the Millennium Development Goals (Khanna et. al., 2016).

The Global Water Partnership created by the UN to operationalize the concept, stipulates that the IWRM is guided by four principles (known as the Dublin Principles) i.e., freshwater is a scarce and susceptible resource that is critical to the sustenance of life, economic growth,

and the ecosystem; a participatory approach involving relevant stakeholders should be the basis for the management and conservation of water resources; women play a significant role in water supply, management and protection; and water possesses economic worth in all its various purposes and must be treated as an economic good (GWP, 2012). IWRM addresses water quality and quantity issues, diversity of stakeholders and management roles at multiple levels, water resource allocation, ties to land use, and claims across jurisdictional borders (Khanna et al., 2016).

2.3.2 Policy and Legal Framework Relevant to Water and Watershed Resources Management in Kenya

(A) Overview of Key Policy Framework

This section highlights the key policy documents that are currently in used in Kenya to provide guidelines to the entire water resources sector.

(i) National Policy on Water Resources Management and Development (Sessional Paper No. 1 of 1999)

Formulated in 1999, the policy mainly focuses on improving water supply for agricultural, household, livestock development, and manufacturing use to realize the Millennium Development Goals (MDGs) (RoK, 1999). The policy make provisions for: protection, conservation, and preservation of accessible water resources in Kenya, as well as allocating them in a sustainable, fair, and cost-effective manner; supply of high-quality water in adequate volumes to address diverse water demands such as poverty reduction, while also maintaining safe wastewater treatment and disposal, and environmental conservation;

creation of an efficient and productive institutional arrangement that ensures greater participation of all stakeholders, including the local communities and the corporate sector, in the planning and conservation of water resources in Kenya; and establishment of a stable and sustainable financial structure for proper and effective development and management of the water supply and sanitation. Having been established a decade prior to the new Kenyan Constitution of 2010, these policy provisions are not in direct relevance to devolution issues.

(ii) The Kenya Vision 2030

It was released in 2008 with the goal of empowering Kenya into becoming a highly industrializing, middle-income nation by 2030 (RoK, 2008). This flagship program is built around three main pillars: social, political and economic, which are executed through consecutive 5-year medium-term plans. Under the social pillar, this Vision aims to transform the two sectors of water and sanitation, and the environment. It calls for the government to intensify conservation and management of strategic water sources while also exploring innovative methods of harvesting and utilizing both rainwater and groundwater. Since its inception, the Vision has initiated numerous water catchment management projects in various parts of the nation to bolster water security. However, it has been pointed out that, due to its nationwide scope, its implementation at the local levels has been a little more complex as it does not address issues of devolution since it was formulated and adopted prior to the new Kenyan Constitution of 2010.

(iii) National Climate Change Response Strategy, 2010

In terms of water resources management, the Strategy recognizes that Kenya has scarce and unevenly distributed water resources and that the changing climate might exacerbate this already perilous condition by affecting precipitation, further impacting the temporal and spatial availability of water resources. To cushion the water resources from these effects, the NCCRS Strategy has provisions for (MEMR, 2013): building the inter-basin and intra-basin water exchanges to move water from water-rich areas to water-scarce places; increasing investment in decentralized municipal water recycling systems for both household and industrial consumption to reduce water wastage; constructing and managing a suitable water infrastructure stock; increasing water quality assessment capability; safeguarding and preserving natural drainage regions, riverbanks, and waterways from sedimentation and pollution; employing financial tools such as subsidies to encourage the use of water-efficient technology; and constructing embankments and dredging rivers to safeguard flood plains. However, the implementation strategy for this policy does not account for the devolution. As a result, the duties and responsibilities of the national and county governments are unclear.

(iv) National Wetlands Conservation and Management Policy, 2013

This policy was launched in 2013 with the overall goal of ensuring that wetlands are used wisely and managed sustainably to ensure that their environmental services and socio-economic benefits are preserved for Kenya's current generations and the generations to come (MEMR, 2013). To reach this goal, it lays out provisions for: increasing and conserving wetlands' structure and functioning; enhancing institutional arrangements for wetlands protection and management; building an effective legal and governance framework for the

integrated utilization and management of wetlands; expanding scientific research and knowledge on wetlands in Kenya; and encouraging transboundary collaborations on management of wetland resources. Lack of a clear strategy for community involvement in wetlands conservation remains to be a key gap in this policy.

(v) Kenya National Water Master Plan, 2030

As an operationalization blueprint for the Vision 2030 goals for the water sector, the National Water Master plan 2030 outlines specific measures for increasing Kenya's overall water supplies, capacity for water resource assessment and management, harvesting and storage capability, to fulfill both household and industrial demands (JICA, 2013). In this policy, the water balance, the level of water demand which would necessitate comprehensive water management measures, and the vulnerabilities of the nation's water resources to climate change effects are documented alongside the action plans for sustainable management and development of Kenya's water resources. The policy, however, has two major gaps: it does not provide sufficient frameworks for Private Public Partnerships in the water resources management sector; and neither does it provide funding structures for on-site and non-sewered sanitation.

(vi) National Environment Policy, 2013

The National Environment Policy 2013 seeks to promote sustainable utilization and management of natural and environmental resources. In the context of freshwater ecosystems, the policy recognizes the need for the government to implement multifaceted strategies for conservation and management of freshwater ecosystems. These include

designing and executing integrated freshwater resources management programs and plans; building an institutional framework that supports payment-for-environmental-services programs to aid in watershed management and preservation; fostering sustainable utilization and conservation of resources from freshwater ecosystems using river basin management plans; facilitating the restoration and conservation of degraded freshwater ecological systems; and synchronizing and coordinating the functions of several regulatory authorities responsible for the management of freshwater ecosystems and wetlands.

Although the policy strongly references incorporating communities in the conservation of freshwater ecosystems, it addresses the conservation of catchment areas superficially; hence lack strong actionable measures. In addition, the policy provided for the formulation and enactment of a National Soil Conservation Policy to address soil erosion issues; however this is yet to be developed.

(vii) The National Water Policy, 2017

The policy was formulated to address the gaps involving the utilization and management of shared water resources and watersheds to contribute to the achievement of SDG 6 (MEMR, 2013). It is aimed at achieving sustainable water resource management and equitable access to water services for all Kenyan citizens. It emphasizes integrated water resources management, effective governance, and institutional frameworks. The policy focuses on water security, climate change resilience, and promoting equitable access to clean water and sanitation. It highlights the need for integrated planning and management of water supply and sanitation services, as well as measures to control water pollution. Additionally, the policy recognizes the importance of water for productive use and economic development

while ensuring sustainability and minimizing negative impacts. Overall, it provides a comprehensive framework for addressing water management challenges in Kenya, including water quality, access, and productivity. The policy, however, does not adequately provide for community participation in the sanitation sector.

(viii) The Big Four Agenda 2018 - 2022

The policy recognizes that water would play a significant part in the achievements of the Big Four agenda namely, affordable housing, universal health care, and food security, and manufacturing. Therefore, it calls for, provision of hydro-meteorological and water quality data for planning; effective and efficient catchment conservation; enforcement and control of legislation and policies governing the management and sustainable utilization of water resources (WRA, 2019). Though a presidential order requiring operations of state agencies to be aligned with these four policy priorities was issued, the implementation and monitoring framework for this policy, within the context of devolution, remains unclear and hence challenging.

(ix) National Forest Policy, 2020

Concerning water resources, the policy contains provisions for nurturing healthy forests to boost water resources by replenishing subterranean aquifers and regulating stream flows; implementation of integrated forest management strategies and programs, to help reduce encroachment and land degradation in watersheds; promotion of the preservation and development of water catchment regions using appropriate soil and water conservation approaches; promotion of the rehabilitation, preservation, conservation, and management of

degraded watersheds and other environmentally sensitive places; and evaluation, analysis, and compilation of regular reports on the ecological integrity of forest reserves together with water towers. However, in the policy, there is no strategy or provision in place to share forest benefits with local communities in order to encourage them to actively participate in conservation.

(x) Agriculture Sector Development Strategy (ASDS) 2010-2020

This policy was formulated to operationalize the Vision 2030 goals for the agricultural sector. It provides for enhancing conservation and management of the environment and natural resources including wetlands, forests, mangroves, among others; protection, conservation and management of catchments, water bodies, and river banks; development of large water masses and river basins; and protection, conservation and sustainable management of wildlife and forest resources. However, having been formulated and adopted before the new Constitution of Kenya 2010, its institutional framework doesn't capture issues of devolution; hence its application is hampered by the fact that agriculture sector is a devolved function.

(xi) National Land Policy (2009)

This was adopted in 2009 with the aim of securing rights over land and providing for sustainable growth, and poverty alleviation. It provides for the sustainable management and conservation of land-based resources including fragile freshwater ecosystems; promotion of benefit-sharing from land-based natural resources; and addressing historical land tenure insecurity issues. The policy, however, has some design gaps. It is silent on how to manage

and regulate the utilization of ecologically-sensitive lands and those under threat of degradation, such as very steep slopes. Also, although it has proposed measures for the conservation and management of fragile ecosystems including wetlands, their implementation under the devolved system of government is vague as it was formulated and adopted before the new Constitution of Kenya 2010.

(B) Overview of Key Legal Framework

(i) Environmental Management and Coordination Act (EMCA) 1999

The EMCA 1999 was enacted 1999 with the primary aim of strengthening the management of environmental and natural resources, including water (as stipulated in section 2. The Act provides an institutional framework that has ramifications for the integrated management of transboundary water resources. It mandates environmental management with the goal of attaining sustainable land use, a goal also supported by other laws governing water resource management. In section 42, the Act has provisions for the conservation and protection of freshwater resources (i.e. lakes and rivers) and wetlands. Section 44 is concerned with the preservation of hilltops, slopes, mountainous regions, and forests to safeguard watersheds, reduce soil erosion, as well as regulate anthropogenic encroachment. To protect these landscapes, the Act proposes measures for: implementation of farming systems that conserves soil water and land surface; ensuring appropriate carrying capacity for livestock; curb soil erosion; disaster preparedness; and protection of these landscapes from human encroachment. In Part IX, the Act contains provided for the establishment of a water quality regulation tool known as the water quality standards, developed in 2006 by the NEMA under the Environmental Management and Coordination (Water Quality) Regulations 2006.

Though EMCA is comprehensive in its coverage of environmental issues at the industrial, commercial, and domestic sectors, its implementation mostly focuses on urban areas, with less emphasis on environment in rural areas where catchment areas mostly exist.

(ii) The Constitution of Kenya (CoK) 2010

Although the Kenyan Constitution, which is the supreme legislation, does not directly mention water resources, it does contain a set of unique environmental provision that relates to water resources management. First, the preamble acknowledges that the environment is part of the heritage of the Kenyan people who are committed to respect it and manage it in a sustainable manner that ensures its availability for the generations to come. Furthermore, Article 42 guarantees everyone the right to a clean and healthy environment, whereas Article 70 guarantees restitution in the event of a violation of their rights. Article 43 assures that everyone has the right to access clean, safe water in sufficient amounts.

Under Article 64, sustainable land resource management, and effective protection and conservation of environmentally vulnerable areas (such as rivers and wetland resources), are some of the concepts that underpin land management. In Article 69, the State and individuals are obligated to promote the sustainable usage, management, and protection of the natural resources (including water resources), as well as ensuring fair distribution of the benefits earned. In addition, under article 69, the Constitution requires the state to promote public participation in environmental conservation, management, and protection.

The Constitution is a long-term national document with a wide scope; it does not explicitly address "catchment areas" or "ecosystems," and hence might be viewed as unclear on watershed conservation issues.

(iii) The Water Act 2016

The Water Act of 2016, which replaced the Water Act of 2002, establishes a governance framework for the entire water sector and aligning it with the central principle of devolution set forth in the Kenyan Constitution of 2010. In the Constitution, the national government is charged with the responsibilities of proprietorship, exploitation, and management of water resources, protection of consumer rights, and national public works whereas the county governments were given the responsibilities of water supply, sanitation, watershed management, and county public works. The Water Act of 2016 restructured the duties and responsibilities of the major institutions involved in water resources management and development. Furthermore, the Act includes requirements for developing a five-year integrated water services policy that includes plans, and activities for stewardship, conservation, regulation, and management of water resources. The legislation also tackles the utilization of water resources to meet human and animal needs, the protection of ecosystems to ensure the sustainability of the environment, as well as the obligations of public-private partnerships and county governments.

Despite the comprehensiveness of the Water Act 2016 in dealing with the water sector, it still has certain gaps which need to be addressed. First, Act does not give much attention to shifting residential and industrial fresh water consumption to a more sustainable level. Second, the Act authorizes WRA to set and regulate water quality standards, a function also

held by NEMA under the EMCA 1999; this conflict causes difficulty in implementation. Lastly, the Act gives County governments the legal authority to form WSPs, but WSPs can only offer services after WASREB has granted them a license, which is done directly.

(iv) Wildlife Conservation and Management Act 2013

Concerning water resources, the Act provides for the sustainable protection, conservation and management of water catchment areas (including forests and wetlands) existing within the game parks, reserves and protected areas (Ramsar sites). The Act provides for the institution of community wildlife associations (CWAs) responsible for coordinating the implementation of conservation measures in conservancies and sanctuaries, including watersheds, forests, and wetlands contained in them, through participatory and inclusive decision-making processes; however, some of these duties are also held by Water Resource Users Associations (WRUAs) and Community Forest Associations (CFAs) and therefore their effective implementation could be hindered by the conflicts that may arise. WRUAs and CFAs are community-based organizations legally tasked with managing and conserving water resources and forest ecosystems, respectively (Muthoni & Cheboiwo, 2020; Ombogoh et al., 2022). The Another weakness of this Act is its failure to provide sufficient frameworks for promoting Private Public Partnerships in conservations within protected areas and the watersheds contained in them.

(v) The Forest Conservation and Management Act 2016

The Act provides for the establishment, protection, sustainable utilization, conservation and management of forests and forest resources for the purposes of maintenance and

conservation of water catchment areas. Notably, the Act gives the Kenya Forest Service the authority to manage all forest resources in the country, while also giving the county governments the responsibility of implementing national forest policy and administering community forests in their jurisdictions. This has created confusion and hindered effective collaboration between the two agencies. Another gap in the design of this Act is that it fails to promote indigenous afforestation.

(vi) The Agriculture, Fisheries and Food Authority Act (AFFA) of 2013

This Act constitutes a significant legislative framework relevant for integrated water resources management of most basins (including the Migori River watershed) because it governs agriculture which is the major form of land utilization. The provisions outlined in Part IV of the Act are supportive of conservation of soil and water resources, including prevention of soil erosion and land degradation. The Act provides for the preservation of slopes, water sources and drainage areas by regulating agricultural activities on riparian zones. However, the Act fails to regulate cultivable slopes hence extremely steep hillsides might well be cultivated, potentially causing land degradation and landslides. Also, it does not provide for suitable penal measures for triggering land degradation or failing to adopt sustainable land management practices.

(vii) The Land Act (2012)

This legislation was enacted in 2014 to operationalize Article 68 of the Constitution of Kenya 2010. Regarding water catchment areas, it emphasizes sustainable conservation, management and protection of land resources including critical biodiversity, forests and

fragile ecosystems; it streamlined security of tenure and land access rights; it reinforced inclusivity and public involvement in the conservation, management and protection of public lands and the environment; and it gave the government the authority to acquire land for programs that will benefit the general public such as catchment protection. However, this Act failed to establish sufficient limitations for land subdivision; hence there are still uneconomical subdivisions of lands taking place. It also failed to provide proper protection for the poor and landless against exploitation by the wealthy.

(viii) Lakes and Rivers Act (2009)

This Act provides for the protection of lakes, rivers, and associated biodiversity from degradation, including prohibiting dredging activities. This Act can essentially be viewed as a duplication of efforts because most of the issues it covers are also addressed under the Water Act (2016) and the EMCA (1999).

(ix) Water Resource Management Rules (2007)

This is a legal notice that was formulated to give effect to the provisions of Water Act. With regards to catchment areas, its Part II deals with rules surrounding water resource use permits, Part V contain rules for water quality monitoring, Part IX contains rules for identification, demarcation and conservation of catchments and riparian areas; and Part X provides catchment management measures. It also provides for the establishment of forums for conflict resolution. Notably, the capacities to enforce compliance of these Rules are largely missing in the Act.

2.4 Sustainable Livelihoods

2.4.1 Livelihood Concept

A livelihood describes the strategies and means of making a living (Alhassan, 2010). A comprehensive definition of livelihood, widely accepted by the scientific community states that "Livelihood comprises the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household" (Baffoe & Matsuda, 2018). This ideology was subsequently wholly adopted incorporated into the Sustainable Livelihood Framework developed by the United Kingdom's Department for International Development (DFID) (2001). The framework characterizes a spectrum of livelihood outcomes based on the numerous relationships, which go far beyond income metrics. The themes of vulnerability and sustainability are considered by SLF (Scoones, 2009). The key elements of SLF and their interactions are summarized in Figure 2.1.

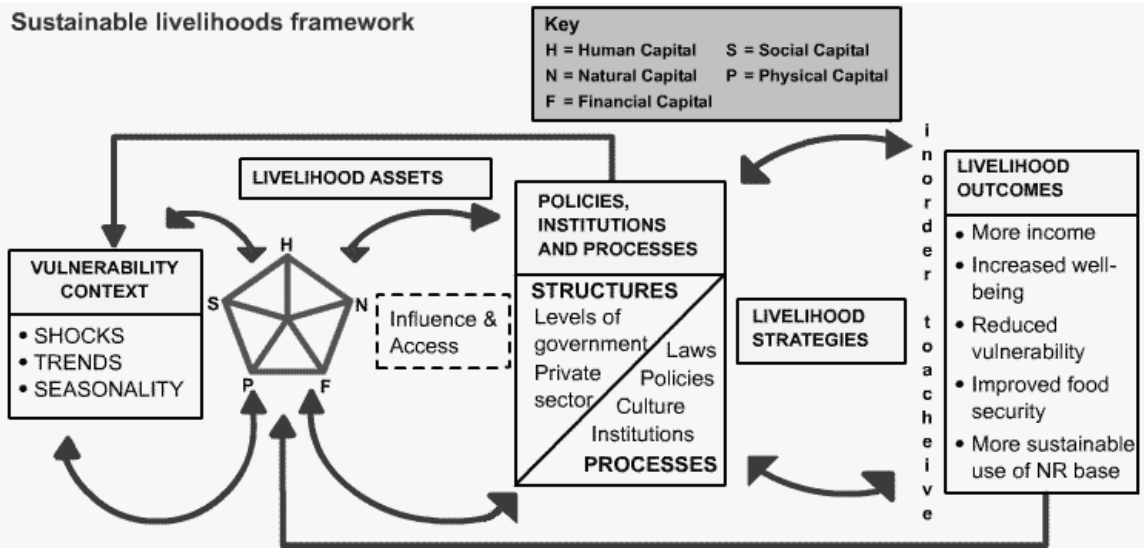


Figure 2.1: Sustainable livelihood framework (DFID, 2002)

2.4.2 Elements of Sustainable Livelihood Framework

The five SLF elements are; vulnerability, livelihood assets, policies, institutions, and processes, livelihood strategies, and livelihood outcomes (Yin et al., 2020).

(i) Livelihood Assets (Capitals)

The asset pentagon is at the center of the livelihoods paradigm, indicating that livelihoods are made up of 5 categories of assets (or capitals): natural, financial, human, physical, and social (Abbassi et al., 2020). Natural Capital refers to the stock of natural resources like land, water and forestry, from which ecological goods and services that sustain livelihoods are generated (Jaganathan et al., 2019). Financial Capital encompasses all economic instruments and services employed by individuals or households to pursue multiple livelihood choices (Morse & McNamara, 2013). Human Capital refers to the knowledge base, skills set, labor capacity, and healthfulness that collectively allow individuals to seek various livelihood choices and achieve their livelihood goals (Kedir, 2015). Physical Capital describes the primary infrastructural facilities (like transport system, water supply, health care and telecommunications) and production instruments (like farm machinery and household goods) required to sustain livelihoods (Huang et al., 2021). Social Capital describes relationships of trust that enhance cooperation, lower transaction costs, and may serve as the foundation for unstructured safety nets among the impoverished (Altasseb, 2021).

(ii) Vulnerability Context

The SLF conceptualizes that individuals and communities are seen as operating in a vulnerable perspective (Darwin, 2014), and therefore evaluating vulnerability is a key component of livelihood analysis (Hautala, 2013). Ludena et al. (2015) defines vulnerability

as an individual's or a community's attributes and circumstances that influence their capability to foresee, adapt to, combat and mitigate the impacts of natural disasters. Disasters happen whenever various risks interact in susceptible situations with less capability to ease the negative consequences of the risks (Hahn et al., 2009). The SLF distinguishes between three categories of vulnerability: trends, shocks, and seasonality (Huong et al., 2018). Trends comprise factors (such as technological advancement, resources, population, and governance) that are sensitive to transformation and the ones that are most likely to continue on their current path (Hautala, 2013). Shocks are described as incidences that ensue unexpectedly and erratically and differ in strength, like civil conflict, natural calamities, retrenchment, and a decline in agricultural prices for farmers, deterioration in livestock/crop health (Shah et al., 2013). Seasonality has to do with the natural cycle of events such as droughts and floods, and it is one of the contributing factors to hunger and poverty (Devereux et al., 2012; Alam et al., 2017).

A community's or household's asset portfolio and livelihood strategies determine whether and to what extent they can cope with trends, seasonality, and shocks (Panthi et al., 2016). The extent of vulnerability is influenced by their capacity to deal with a variety of threats, including market fluctuations, droughts, and farm diseases (Panthi et al., 2016). Crises and insecure circumstances put the livelihoods of communities at risk, so each household may be subjected to various types and natures of risks based on their livelihood strategies and assets.

(iii) Policies, Institutions and Processes (PIPs)

Policies, institutions, and processes (PIPs) were grouped under the "transforming structures and processes" component of SLF because the three are tightly intertwined contextual

elements that have a significant impact on all livelihood aspects (Darwin, 2014). Legese et al. (2016) notes that, within the SLF, policies are described as courses of action created and implemented by governments or NGOs to achieve specific objectives. Policies have a significant effect on people's livelihoods because they can influence whether or not relevant institutions become concerned with the livelihoods of those living in poverty (Hautala, 2013; Baffoe & Matsuda, 2018). Organizations and institutions regulate the influence of policy on the livelihoods of individuals and communities (Darwin, 2014). Institutions can be formal (include laws and commercial rules) or informal (include social traditions such as patron-client relationships) (Darwin, 2014). Processes make up the last element of the PIPs, and it represents the mechanisms that shape policies and institutions (Li et al., 2020).

(iv) Livelihood Strategies

Livelihood strategies are activities and options that individuals undertake to earn a living (Altasseb 2021). These activities typically consist of a variety of actions aimed at increasing asset bases and gaining access to commodities and services for consumption (Tackie-Yarboi, 2020). Individuals, households, and communities adopt a variety of livelihood strategies on a local and global scale (Scoones 2009).

There are three types of livelihood strategies that can be found in rural communities: livelihood diversification, which refers to the process of developing varied sets of income-generating activities and social support capacities to achieve the desired livelihood objective (Ellis 2000; Mahama & Maharjan, 2017); agricultural intensification and/or extensification, whereby intensification entails increasing the productivity of agricultural land by leveraging labor and technological investments while extensification constitutes expanding the quantity

of land that is cultivated (Nasrnia, & Ashktorab, 2021); and migration which refers to a circumstance whereby a member or members of a family depart the resident household for a while, in response to economic and environmental challenges (Zhang, 2019).

These activities are often applied as coping or adaptive strategies for achieving desirable livelihood goals (Serrat & Serrat, 2017). Adaptive strategies entail adjusting one's livelihood strategy (either by maintaining or broadening one's income portfolio) in response to long-term trends, to improve existing security and prosperity, or to lessen vulnerability and poverty (Hautala, 2013). Coping strategies, on the other hand, are short-term means employed in response to immediate risks, stresses, and shocks (Paudel-Khatiwada et al., 2017).

(v) Livelihood Outcomes

The accomplishments or products of livelihood strategies that improve people's lives and alleviate poverty in the wider context are known as livelihood outcomes (Ding et al., 2018). They are the objectives that households intend to achieve when pursuing various livelihood choices. Individuals, households, and communities will experience different outcomes depending on their circumstances (Darwin, 2014; Guo et al., 2019). According to the Department for International Department (2000), there are five groups of livelihood outcomes; increased well-being, more income, lessened vulnerability (which translates to increased resilience to risks, stresses and shocks), enhanced food security, and greater sustainable utilization of the environmental resource base.

2.5 Theoretical Underpinnings

2.5.1 Driving Forces–Pressures–State–Impacts–Responses (DPSIR) Framework

The concept of DPSIR was originally developed in 1999 by the Organization of Economic Co-operation and Development (Essayas, 2010) and was immediately adopted by the European Environmental Agency as a framework for structuring ecological information about particular environmental issues and identifying existing drivers, effects, practical responses, and patterns, as well as the interlinkages between these elements (Odontsetseg et al., 2009; Essayas, 2010).

The DPSIR framework is made up of five interlinked components namely, Driving Forces (D), Pressures (P), State (S), Impacts (I) and Responses (R) Aly-Abdelrehim (2012). In this model (Figure 2.2), *driving forces* (human-induced factors and actions that have a beneficial or adverse influence on the environment), created by natural or anthropogenically-induced events resulting from environmental, economic, or social aspects, generate *pressures* (the deliberate or inadvertent forces that different driving forces put on the environment) on the environment, and thus, visible changes in its *state* (the assessed quality of the environment at a given time and how it has been affected by ecological pressures). The *impacts* (positive or negative effects on the ecological systems or human health brought about by the alterations in the state of the environment), therefore, produced elicit *responses* (societal measures undertaken to address specific impacts observed on the environment) at the policy-making level, either as an environmental reaction or as a natural response (Tsai et al., 2009; Essayas, 2010; Aly-Abdelrehim, 2012).

DPSIR model was created to provide a method for identifying indicators and providing feedback to decision-makers on the health of the environment and the ensuing implications on political decisions taken or to be undertaken in the future. The model relies on indicators to explain the most important aspects of the environment as well as other topics addressed in policy evaluations (Gessesew, 2017). According to Mathetsa (2015), this model is beneficial in articulating the causes and implications of ecological concerns as well as comprehending their patterns via interconnections between the framework's components.

This framework has been utilized by several scholars to better comprehend the cause and effect connections that exist between humans and their environmental influences (Carr et al., 2007; Essayas, 2010; Aly-Abdelrehim, 2012; Mathetsa, 2015). In this study, DPSIR framework was applied to an ecologically sensitive watershed, taking into consideration the aspects of identifying the drivers and pressures exerted on the watershed resources and livelihoods of the communities residing in it. In the present study, the elements of the DPSIR framework were identified as follows: the *Driving forces* are represented by population growth, resources utilization for the provision of human needs like water, food, health, shelter, and culture; *Pressures* are represented by changes in LULC, and quantity or quality of water resources; State is represented by the dynamics of physico-chemical and biological water quality variables, stream flow patterns and sediment yield trends assessed using various indicators; *Impacts* are level of water contamination and level of livelihoods sustainability and vulnerability; and *Responses* is represented by the governance framework which outlines the institutional arrangements emanating from the legislative and policy initiatives taken by governments in response to alterations in the status of the watershed ecology.

The DPSIR framework however, does not provide a comprehensive understanding of *Driving forces* for ecological changes, since the *Driving forces* are essentially perceived as external forces destroying the ecological zone that require protection rather than as socio-economic and cultural processes that are integrated with biodiversity functioning. To address this, the study used concepts from the Socio-ecological System (SES) framework.

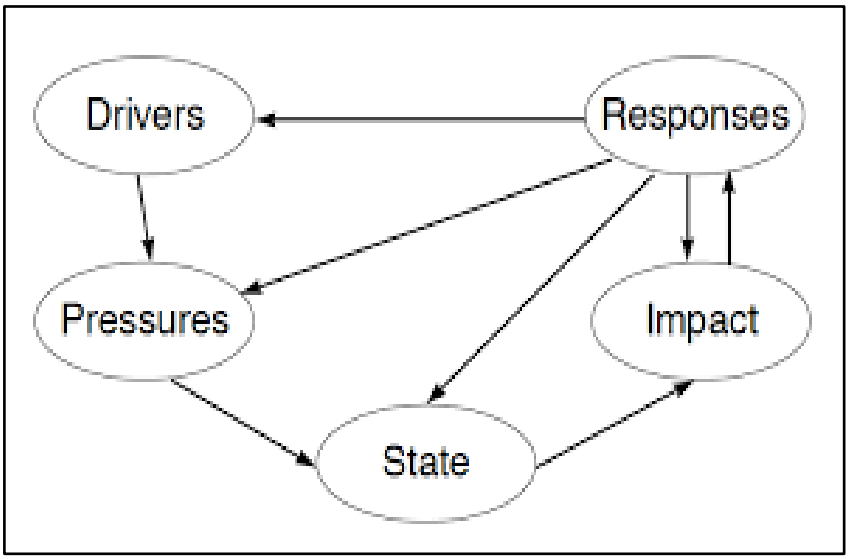


Figure 2.2: Driving Forces-Pressure-State-Impact-Response (DPSIR) framework elements (Mathetsa, 2015)

2.5.2 The Socio-ecological System (SES) Framework

Socio-ecological systems are made up of ecological systems, the goods and services they supply, and the humans who utilize and control them (Leslie et al., 2015). In these systems, the ecological, social, cultural, political, technological, and economic components are closely interconnected (Özerol, 2013). They are distinguished by complicated and evolving interdependence among ecological and social components (Gain et al., 2020), across spatial-temporal scales (Schlüter et al., 2014), often leading to feedbacks that might intensify or

suppress change (Levin et al., 2013). SESs are multilayered, multidimensional systems in which ecological and social components interact with one another via continuous bidirectional exchanges and feedback mechanisms (Goulden et al., 2013). Pollard et al. (2008) assert that the degree of interactions and the responsiveness to feedback affect the condition and quality of the socio-ecological system. The SES's new condition in reaction to triggers is a metric of the SES's adaptability, resilience versatility, and sustainability.

Under this framework, the SES comprises two major components ecological and human (Goulden et al., 2013), with the ecological component consisting of soils, biogeochemical cycling, and evolution of and interactions between species; whereas the human component comprises communities or institutions via which sociological dynamics like as livelihood strategies, demographical processes, and technology are structured. Management strategies, adaptation mechanisms, and resource utilization are all the result of the interaction between these two major components (McGinnis & Ostrom, 2014). Certain SES exchanges lead to sustainable results, while some others fail (Leslie et al., 2015). Hence, when consumers of the ecosystem notice a loss in an ecosystem resource, they will adopt various management strategies (Özerol, 2013). Whenever one component of the SES is understood, the information can be applied to another component. Therefore, if the ecological system's integrity is disrupted, the consequences reflect in the social system, and contrariwise (Chapin et al., 2009).

An assessment of the interactions within the socio-ecological systems can be conducted based on a combination of parameters found within four basic first-tier subsystems of SES namely, Actors, Resource System, Resource Units, and Governance System. SES is

conceptualized by McGinnis and Ostrom, (2014) as interplay of four basic components of Actors, Resource System, Resource Units, and Governance System, moderated by economic, social, and political circumstances. The framework illustrates how various types and levels of governance impact resource users and is relevant at multiple scales, and has been extensively employed across several disciplines to understand the factors that influence natural resource management (McGinnis & Ostrom, 2014).

In the present study, the components of the SES framework were identified as follows: the *Actors* were the water users; *Resource System* was the Migori River watershed; *Resource Units* were river and land; and *Governance System* was represented by the existing institutional arrangement of the watershed, as currently defined by the existing legal and policy framework in Kenya, which encompasses catchment managers, forest managers, agricultural managers, land administrators among others. However, the SES framework does not explain the nature and level of coordination of actors in the governance system. To address this, the study additionally uses concepts from network governance theory.

2.5.3 Network Governance Theory

Although the concept of network governance can be traced back to earlier studies by Provan and Milward (1995, 2000, 2006), it was Provan and Kenis (2008) that fully developed and established the concept as a theory for understanding governance (Isett et al., 2011). Governance refers to a shared goal or outcome reached through the interactions between various stakeholders (Torfing, 2010) whereas network also known as (policy networks) refers to a collection of governmental and non-state entities or organizations that are interested in a particular area of decision-making since they are mutually dependent and thus

have a collective objective (Isett et al., 2011). Because institutions cannot function in complete isolation, they develop networks in order to acquire resources like funds, technical skills, and information from each other (Klijn & Koppenjan, 2014).

According to Tropp (2007), the governance of water resources is characterized by interconnections and interactions between agencies and entities involved in decision-making. These interactions and interconnections exist vertically from local levels to international levels and horizontally across institutions, sectors/industries (Okok, 2015). Isett et al. (2011) point out that a collaborative network is formed when a group of governmental bodies and non-governmental organizations and corporations cooperate (independently or collaboratively whilst retaining their independence) to dispense public services and goods.

The process of establishing interconnections amongst stakeholders in order to achieve a common goal is referred to as coordination (Okok, 2015). Additionally, coordination is the process of aligning the activities of certain actors with the activities of others in order to attain a shared goal, and governance is the process of directing these activities in a specific direction (Pedersen et al., 2011).

Using the network governance theory as a framework for watershed governance analysis, this present research looked at how networks are managed and adapted to accomplish a shared objective of conserving and managing water and watershed resources in the Migori River watershed within the context of the existing legal and institutional framework. The emphasis here is on the coordination of the numerous actors involved in the river basin management of the Migori River watershed. The network governance theory however, does not explain the influence of governance actors' policies and management outcomes on the

livelihoods of individuals and communities living in the watershed. To address this, the study further uses concepts from Sustainable Livelihoods Approach (SLA).

2.5.4. Sustainable Livelihoods Approach (SLA)

The concept of SLA was first developed in 1992 by Chambers and Conway (Su et al., 2019). The concept was immediately adopted with slight modifications by the UK's Department for International Development and was later endorsed by the UN during the Environment Summit in 1992 (Tackie-Yarboi, 2020). The Sustainable Livelihoods approach operates on three fundamental levels: as a broad development goal, a system of core development principles, and a framework for analysis (Alhassan, 2010).

Farrington et al. (2002), indicates that SLA's overall aim is to improve the long-term viability of societies' welfare, with a precise concentration on the livelihoods of households and communities living in poverty. The SLA's development principles were designed to contribute to the understanding of poverty and the intervention measures that may be used to help persons living in poverty improve their livelihood situations (Mazibuko, 2013; Khuzwayo, 2016). The guiding principles of SLA include people-centered, participatory and responsive, sustainable, dynamic and holistic, and empowerment (Khuzwayo, 2016).

The third level of SLA is the analytical framework, commonly known as the SLF, which has already been discussed in section 2.4.2 and summarized in Figure 2.1. The five elements of the SLF are vulnerability, livelihood assets, policies, institutions, and processes, livelihood strategies, and livelihood outcomes (Alhassan, 2010). These SLF elements are useful indicators for analyzing the livelihood aspects of various communities because they help to explain poverty and the activities and policies that can be used to alleviate it with a

conservational dimension. Additionally, SLF allows local impoverished communities to be seen as decision-makers with their aspirations and not just dependents (Soulineyadeth, 2014). The SLF has been previously applied successfully in examining various aspects of livelihood conditions in watersheds and wetlands (Agustina, 2008; Saini et al., 2014; Mwanga, 2019). Therefore, it was found to be a relevant theoretical underpinning for this study. In this study, the SLF was used to understand the level of sustainability, vulnerability to climate change impacts, and adaptive capacity of livelihoods in the Migori River watershed.

2.6 Conceptual Framework

The study conceptualized a framework demonstrating the interactions between LULC change, climate variability, water resources and community livelihoods in a watershed system, as mediated by the existing watershed governance structure (Figure 2.3). The framework conceptualizes that the interplay between Land Use/Land Cover and climatic changes in the watershed (*independent variables*), driven by regulations and policies within institutions (*intervening variables*), affect the functioning of socio-ecological systems — hydrology, water quality and livelihoods — of the watershed (*dependent variables*). Therefore, sustainability in the watershed is achieved when the ecological processes on geomorphology and the intervening variables (institutional arrangement and coordination) contribute to optimization of the water resources and resilience in the community livelihoods.

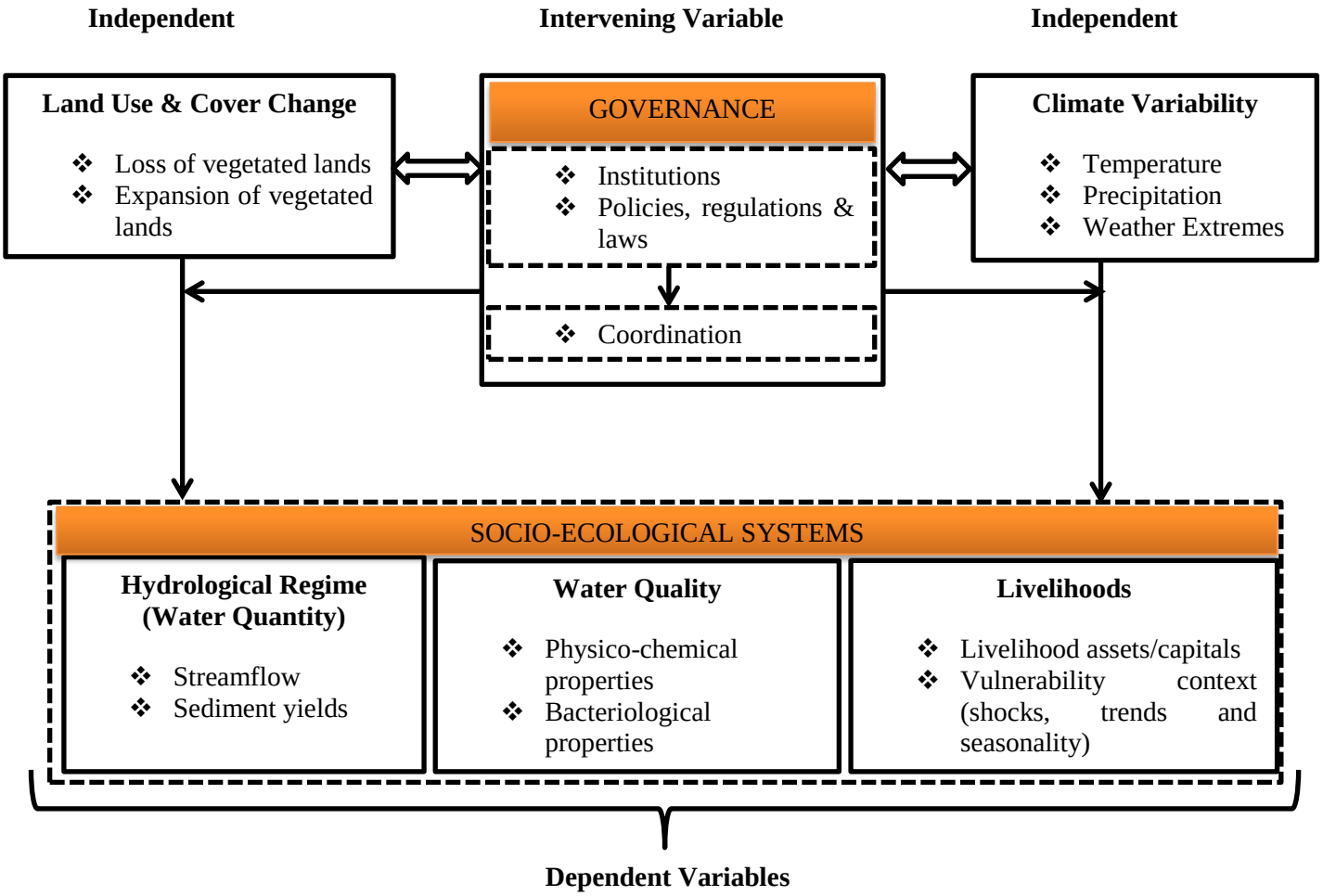


Figure 2.3: Conceptual Framework for Social-Ecological Functioning of the Migori River Watershed (Author, 2022)

2.7 Empirical Review of Methodologies Pertinent to the Study

The research methodologies that have been used in empirical studies related to the specific objectives of the study were examined to identify and select the most suitable and effective methodologies for the current study based on empirical evidence and best practices established in the field.

2.7.1. Remote Sensing and GIS Application

Remote sensing is the science of gathering information about objects, areas, or phenomena through the analysis of data acquired by devices that do not directly contact the subject of investigation (Alawamy et al., 2020). In the context of LULC change analysis, remote sensing plays a crucial role with its strength lying in its broad spatial coverage, long-term imagery collection, and the ability to accurately map LULC distribution over extensive geographical areas (Campbell & Wynne, 2011). It employs various techniques and datasets to evaluate different landscape components/classes and their changes over time in a Geographic Information System (GIS) environment, revealing crucial information about the nature, magnitude, and spatial trends of LULC changes (Onyango et al., 2021). This information is vital for effectively monitoring and managing natural resources (Lillesand et al., 2015). Apart from LULC monitoring, hydrological modeling in SWAT uses LULC maps together with DEM and slope datasets generated directly or indirectly from remote sensed data as critical inputs for simulating hydrological processes in a watershed (Abbaspour, 2015).

Remote sensing relies on different types of satellites of varying capabilities and characteristics to capture and analyze data. One type of satellite commonly used in remote sensing is optical satellites which include Landsat, Sentinel-2, and MODIS (Rai et al., 2018). These satellites utilize sensors that capture visible and infrared light, providing detailed imagery of the Earth's surface and hence are particularly effective in land cover classification and monitoring vegetation health (Taloor et al., 2020). Another type of satellite used in remote sensing is radar satellites with notable examples being Sentinel-1, ALOS PALSAR, and RADARSAT (Zadbagher et al., 2018). Radar satellites employ radar waves that can

penetrate clouds and vegetation, allowing for data acquisition even in unfavorable weather conditions and hence are especially useful for monitoring changes in land surface structure, detecting changes in elevation, and mapping areas prone to flooding or landslides (Zhang et al., 2014; Zadbagher et al., 2018).

In Kenya, remote sensing has been extensively employed using both optical and radar satellites to study LULC changes across diverse terrains including watersheds, river basins, forests, lakes, and water towers (Langat et al., 2021). Researchers have utilized optical satellites such as Landsat and Sentinel-2 to analyze the expansion of urban areas (Onyango & Opiyo, 2021), changes in agricultural practices (Kibet et al., 2021), and the impact on natural resources (Langat et al., 2021). Additionally, radar satellites like Sentinel-1 have been utilized to monitor land surface deformation, identify changes in vegetation cover, and assess the impact of environmental factors on different regions of the country (Greifeneder et al., 2019; Abera et al., 2022). These satellite-based observations have contributed valuable insights into the dynamic land use patterns and supported evidence-based decision-making for sustainable land management in Kenya.

2.7.2. Hydrological Modeling for Water Resources

A hydrological model is a mathematical representation of the hydrological cycle, which includes the movement of water through various pathways in a watershed or river basin (Shukla & Gedam, 2019). It simulates the interactions between rainfall, evapotranspiration, infiltration, surface runoff, groundwater flow, and streamflow (Moriasi et al., 2015). The primary purpose of hydrological models is to understand and predict the behavior of water

resources in a given region, aiding in water resources management, flood forecasting, and ecosystem assessment (Hunink et al., 2013; Zope et al., 2016).

Hydrological modeling works by utilizing mathematical equations and algorithms to simulate the complex processes involved in the hydrological cycle (Karki et al., 2020). These models take into account various factors such as climate data, topography, soil characteristics, land use, and vegetation cover to estimate the water balance and flow dynamics in a watershed (Karki et al., 2020). By inputting these parameters, the model generates predictions of streamflow, groundwater recharge, and other hydrological variables (Chilagane, 2017).

There are several commonly used types of hydrological models, including lumped models, distributed models, and physically-based models (Geremew, 2013). Lumped models represent the entire watershed as a single unit and are relatively simple and computationally efficient (Gashaw et al., 2018). Distributed models divide the watershed into multiple subunits and simulate the hydrological processes in each unit separately (Anaba et al., 2016). Physically-based models incorporate detailed representations of the physical processes involved, considering factors such as soil properties, vegetation dynamics, and land surface characteristics (Ghaffari et al., 2010; Abbaspour, 2015).

One widely used hydrological model is the Soil and Water Assessment Tool (SWAT (Koneti et al., 2018). SWAT is a physically-based, semi-distributed model that integrates hydrological processes with land management practices (Neitsch et al., 2011; Paul, 2016). It is particularly suitable for studying watersheds and their responses to land use and climate changes. SWAT incorporates information on topography, soils, land use, and climate to

simulate the movement of water and various pollutants in a watershed (Gashaw et al., 2018). It can assess the impacts of land management practices, such as agricultural practices and land cover changes, on water resources, sediment yield, and water quality (Milewski et al., 2014; Li et al., 2017). SWAT's versatility, flexibility, and ability to handle large watersheds make it a valuable tool for water resources planning and management (Abbaspour, 2015). The SWAT model has been used in Kenya to study various watersheds, including the Thika River catchment (Kigira, 2010), Sasumua watershed in Central Kenya (Mwangi, 2013), Muringato basin (Muthee et al., 2022), and the Kibwezi Watershed (Ruttoh et al., 2022).

2.7.3. Water Quality Analysis

Water quality is generally defined as the chemical, physical and biological characteristics of water with respect to its suitability for a designated use (Adelagun et al., 2021). These characteristics constitute the parameters for assessing the condition of the water because they usually undergo changes induced by human activities within the catchment area (Sun, 2016), and by the combined actions of interacting natural processes such as geomorphological configuration, hydrological conditions (Michalka, 2008), climatic conditions (Reza, 2010), and weathering processes (Yang, 2010). Water quality assessment usually involves sampling, analysis, and measurement of the physicochemical and biological parameters at temporal scales, and at times spatial scales (Duan et al., 2016). The quantities of the analyzed water quality parameters are then compared with established water quality standards to determine the suitability of water for human consumption or its safety for the ecosystem (CCME, 2017).

The water quality assessment reports are often characterized by large datasets (Bilgin, 2018), thus disseminating vital information regarding water quality to the general public and policy-makers is a challenge for water quality experts (John-Mark, 2006). To address this problem, scientists came up with the water quality index (WQI) which comprehensively summarizes an enormous amount of water quality data into a single numerical value (Reza, 2010; Cristable et al., 2020) used for categorizing the water quality status on a relative scale ranging from very poor to excellent (Gyamfi, 2013), hence providing a simplistic description of the quality of water as clean or polluted (Al-Mashagbah, 2015). This non-technical categorization of the quality of water is easily understood by professionals, decision-makers, and the general public alike (Okab, 2015). Examples of Common WQI include the Weighted Arithmetic Water Quality Index (WA-WQI) (Lumb et al., 2011), Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) (CCME, 2017; Bilgin, 2018), Oregon Water Quality Index (O-WQI) (Al-Ridah, 2020), and the National Sanitation Foundation Water Quality Index (NSF-WQI) (Cristable et al., 2020). Among these WQI indices, the CCME-WQI is internationally well-accepted and universally applicable for evaluating the water quality because of its flexibility (concerning the type and number of variables to be tested, the period of application, and the type of water body) and robustness in reporting water quality problems (Gyamfi, 2013; USGS, 2018).

Besides WQI, multivariate statistical techniques such as analysis of variance (ANOVA), cluster analysis (CA), discriminate analysis (DA) and principal component analysis (PCA) has recently gained popularity for better assessment and understanding of river water quality (Mena-Rivera et al., 2015). These techniques have been widely over the years used by researchers to evaluate the spatio-temporal variations in water quality as well as to identify

possible pollution sources (Sharma et al. 2015), and thus offer an initial step towards remedial approaches to safeguarding public health by the relevant decision-makers (Duan et al., 2016).

2.7.4. Livelihood Indices

Various approaches based on the SLF have been utilized to develop indices for comprehending diverse aspects related to the sustainability of rural livelihoods. The quantification of households' livelihood asset portfolio has become a widely employed approach to assess the socio-economic status of rural communities in developing countries (Abbassi et al., 2020). This approach has led to the development and application of numerous indices globally. For example, Jansen et al. (2006) utilized an index based on quantifying households' asset portfolio to understand the livelihood strategies of rural hillside areas in Honduras. Similarly, in Vietnam, Huang et al. (2021) employed a livelihood capital evaluation indicator system to examine the capital endowment of rural households in tourism regions and identify factors influencing their livelihood choices. Another study by Jaganathan et al. (2019) focused on evaluating the factors impacting the sources of livelihood for sweet potato and paddy growers in the Belagavi district of India, utilizing the rural livelihood sustainable index to quantify livelihood capitals.

Indices based on the vulnerability context of the SLF have been developed to comprehensively assess multiple aspects of rural community livelihood sustainability, with the Livelihood Vulnerability Index (LVI) by Hahn et al. (2009) being a prominent example. The LVI is an indicator-based tool that has been commonly used to evaluate the vulnerability of community/regional livelihoods to climate change impacts. This tool, first applied in two

villages in Mozambique, is a composite index of specific components mapped onto the three IPCC contributing factors to vulnerability; exposure, sensitivity, and adaptive capacity (Hahn et al., 2009). It provides a comprehensive assessment of livelihood vulnerability by incorporating multiple dimensions such as social, economic, and environmental factors, allowing for a more holistic understanding of vulnerability.

Another approach used by other studies is to explore the linkages between livelihoods and poverty through the use of indices. For instance, Ansom and Mckay (2010) study adopted a factor and cluster analysis approach to identifying how different livelihood profiles in rural Rwanda based upon asset portfolios differ with respect to the incidence of poverty and livelihood strategies. Similarly, Berchoux et al. (2019) study in Indian used a Rapid Rural Appraisal (RRA) approach to characterize the collective effects of two levels of livelihood capitals (household capitals and community capitals) on precarious agricultural employment as a measure of chronic rural poverty. Generally, all these indices have been designed to deal with the fundamental needs of the poor, especially to solve food scarcity and starvation.

2.8 Research Gaps

While various studies have examined ecohydrological responses to LULC and climate change interactions in some of the watersheds across the larger Lake Victoria basin in Kenya (such as Ongwenyi et al., 1993; Kathumo et al., 2012; Kaburi & Odera, 2014; Ogembo, 2018), there is no research that focuses on Migori River watershed to account for local patterns of LULC change and climate variability. This has created an information gap that has been acknowledged by some studies previously conducted in Migori County which consequently provided some useful recommendations about bridging it. A study by Olal

(2015) that investigated the effects of urban runoff from the Migori municipality on the concentrations of certain heavy metals in the Migori River, suggested that a hydrological assessment of the contribution of urban runoff to the stream flow regime of the watershed is needed; Sirengo et al. (2018) study that revealed that the land resources in the Migori County are characterized by moderate to high degradation suggested further investigation on how land degradation changes might threaten water resources in the watershed; and Ogola (2018) study that found that high population growth rate in Migori County has put a strain on the county's land resources, proposed that an investigation on how land utilization by the growing human population affects water resources, especially water quality condition of the Migori River.

Furthermore, the influence of LULC and climate change interactions in the watershed on the sustainability of community livelihoods remains unknown. Ogola (2018) observed that the effects of changes in land resources on rural livelihoods especially the farming communities of this region deserve investigation. A review of the literature shows that a research gap exists in our understanding of the implementation dynamics of multi-level governance for watersheds in Kenya under the current devolution framework as no studies have evaluated how this framework has impacted the watershed governance structure. The current study aimed to bridge these knowledge gaps by analyzing the dynamics of ecohydrological processes of the watershed under changing LULC patterns, institutional arrangement and coordination under the current watershed governance structure, and the sustainability of local community livelihoods for the watershed.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

Generally, this chapter describes the research site and outlines the research design, sampling procedures, data collection tools and techniques, data analysis and presentation techniques, and ethical considerations adopted for the execution of this research. Since the study adopted a mixed-method approach to satisfy the data requirements of the general objective of the study, the methodological approaches including data collection and analysis framework deployed for each of the five specific objectives of the study have been presented in distinct sections.

3.2 Description of the Study Area

The Migori River watershed (Figure 3.1) is located within Migori County and covers approximately 2,597km^2 of land area in the Western Kenya region. Migori River originates from Chepalungu Forest in Emuria-Dikiri Sub-county of Narok County, from where it flows 70km through Migori County to Lake Victoria. The entire catchment for the Migori River is found at an altitude of 1500 m above sea level. It enjoys an inland equatorial climate that is heavily influenced by its proximity to Lake Victoria. It receives mean annual rainfall in the range of 700 mm to 1800 mm with two dry and wet seasons. Average temperatures in the region range from 13^{0}C to 24^{0}C depending on the seasons. Due to these climatic conditions, the major crops cultivated in the region include maize, beans, vegetables, tobacco, coffee, sugarcane, and ground nuts. Agricultural production is limited by the occasional drought and flood conditions. In some areas, the waters of Migori River are harvested for irrigation purposes to support crop production during droughts.

The watershed is divided into six agro-ecological areas, ranging from Upper Midland 1-3, which covers sections of Rongo, Uriri, Kuria East and Kuria West Sub-Counties, to Lower Midland 1-5, which covers sections of Rongo, Uriri, Nyatike and Suna East Sub-Counties (Karanja, 2006). In this watershed, there exist three predominant ethnic groups which are distributed along the length of Migori River as follows; the Maasai community (agro-pastoralism) is found in the upstream, the Kuria community (farming) lives in the midstream, and finally the Luo community (farming, mining and fishing) is located downstream.

This watershed's land use is dominated by extensive agricultural and deforestation practices for charcoal production in the upstream, urbanization and agricultural practices - especially tobacco, cotton, maize and sugarcane farming among others- in the midstream and, mining and urban development activities are rampant in the downstream region because of its arid and semi-arid climatic conditions consisting of extensive savanna grasslands.

Geologically, the watershed lies within the Migori Greenstone Belt, which is a system of Archaean rocks containing mineral deposits such as gold, copper, zinc and galena which are being mined artisanally in the region (Odumo et al., 2011). From the foregoing, the major livelihood activities in the watershed include agriculture, mining, fishing, manufacturing, and trading activities (WRMA & JICA, 2014).

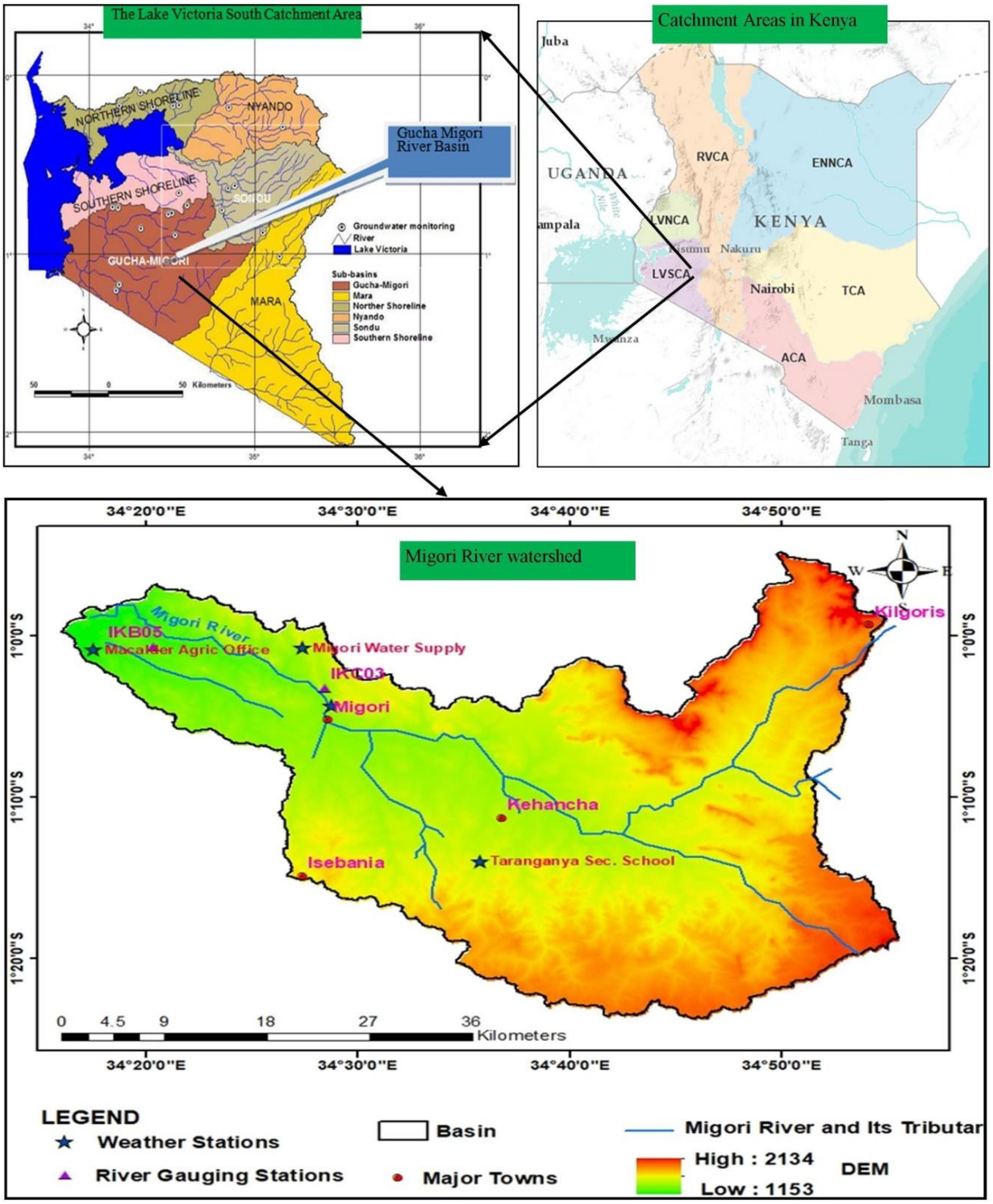


Figure 3.1: Map of Migori River Basin, Migori County

3.3 Research Design and Approach

To address the multifaceted research problem identified in Migori River watershed, this study employed a mixed-method approach that integrated case study and descriptive cross-sectional survey designs, incorporating key informant interviews, GIS-based spatial mapping and modeling, laboratory analysis, questionnaire-based household surveys. A case study design emphasizes detailed qualitative analysis of specific cases while a descriptive cross-sectional survey design focuses on quantitative data collection from a representative sample to describe and analyze a population's characteristics or behaviors (Lewis, 2015). Therefore, combination of these two designs is suitable for the study because it supports the collection of both qualitative and quantitative data from different sources using a range of procedures and methods, analyzing the relationships between variables and making generalizations of the findings (Erute, 2017). Noteworthy, the weaknesses of mixed-method research are the requirement of extra time and financial resources to plan and implement it, and the difficulty in resolving discrepancies arising from interpretation of the results from varied methods (De Silva, 2011). In this study, these weaknesses were offset by the researcher’s possession of adequate time and financial resources for carrying out the study and the working knowledge of various analytical tools and procedures related to qualitative and quantitative research.

Through this mixed-method approach, the study generally investigated the dynamics of ecohydrology, governance, and livelihood systems of Migori River watershed. To do this, a combination of both the quantitative and qualitative data were collected and analyzed. Given that each specific objective of the study required unique sets of data (either quantitative, qualitative or both), the methodology of each of the specific objectives varies. The next sections presents the methodology applied for each the specific objectives of the study.

3.4 Examination of the Influence of Institutional Arrangements of Migori River Watershed Management on Multi-Actor Coordination

3.4.1 Sampling Techniques and Sample Size

To achieve the appropriate sample size from the target population, a two-stage sampling process that involves both purposive and snowball sampling methods was employed. Initially, a stakeholder mapping and analysis based on a desk review of existing press releases, published studies conducted in the watershed, reports, legislation, and policy documents from top governance agencies in the watershed was done. This yielded a list of key stakeholders, who were purposefully chosen as the first batch of key informants. An actor was considered a key stakeholder if it met at least one of these three criteria developed by Blackstock and Richards (2007) to a significant level: (1) assured effective collaboration by demonstrating a strong commitment to the implementation of Integrated Watershed Management (IWM) principles, (2) can influence the formation and implementation of policies, and (3) would be directly impacted by the implementation of any river basin management (RBM) programs.

The list of key stakeholders interviewed was expanded based on a snowball sampling approach of obtaining recommendations of other stakeholders from earlier key informant interviews. This process was repeated until saturation was achieved, that is, no fresh suggestions were offered (Hennink, et al., 2020). Individuals selected as key informants were identified based on their respective positions within the targeted agencies and their responsibilities concerning the management of natural resources within the watershed. A total of 30 actors were contacted for interviews, with 22 agreeing to participate.

3.4.2 Data Collection Instruments

A combination of primary and secondary data was collected for the governance assessment. Primary data on the prevailing institutional arrangement and its causal relationship with the nature and level of coordination among actors involved in the integrated management of the Migori River watershed was collected qualitatively using four semi-structured interview guides tailored for four predefined groups of actors (see Appendix 1). The guides contained open-ended questions that were constructed based on theoretical constructs from relevant literature. The questions in the guides were designed to identify current institutional structures, policies, stakeholder interactions, land and water resources management practices, as well as implementation-related challenges. These topics required in-depth and comprehensive explanations, hence the choice of interview guides. The validity of the interview guides was ensured through the process described in section 3.7.3. To complement the primary data, secondary data was obtained through desk review of collected documents.

3.4.3 Data Collection Procedure

Face-to-face interviews with 22 key informants purposively selected from organizations that are directly involved in the management of the Migori River Watershed were conducted between September and October 2021 using semi-structured interview guides (see Appendix 1). Interviews were conducted for representatives from 6 national government agencies based at the regional/county level namely NEMA, KFS, WRA, LBDA, LVSWWA and KEFRI; 1 intergovernmental agency, the LVBC); 5 Migori County Government Departments namely Water Development and Energy, Environment, Natural Resources and Disaster Management, Agriculture, Livestock and Fisheries, Agricultural Sector

Development Support Programme (ASDSP), and Migori Water and Sanitation Company (MIWASCO); 3 CFAs (namely Agongo, Otacho, and Mirema); 1 WRUA (namely Korondo-Nyasare); and 1 local NGO (Green Life). After obtaining informed consent, permission to audio record the interviews was obtained from the interviewees to supplement note-taking. During the interviews, the questioning took a pyramid approach, with basic beginning questions leading to more complex probing questions as the session progressed (Okok (2015). Data from the initial interviews were used in subsequent interviews to further probe the aspects discussed. The interviews were completed in single sessions that lasted about an hour.

During the interview stage with key informants, documents with relevant information such as press releases, published and unpublished studies conducted in the Migori watershed, maps, reports, master plans, policy documents, and minutes of relevant stakeholder meetings were requested and gathered from various governance actors in the watershed. These documents were examined for details on conservation efforts, technical and scientific data on the environmental state of the Migori River watershed, and documented evidence of interaction and involvement among governance actors. The information from the document review was utilized to augment the discussions of results.

3.4.4 Data Processing, Analysis, and Presentation

To analyze the data, the digital audio recordings were first transcribed into text verbatim. After which the transcriptions were read multiple times to ensure that all common themes and trends were generated and organized. Using ATLAS.ti software, the qualitative data was then analyzed through content analysis, compiled, tallied, and organized into general themes.

The coordination aspect was analyzed in terms of administration plus the six dimensions (sub-activities) of management as defined by the Fayolian theory of management (Corsame, 2016) i.e. communicating, organizing, planning, commanding, executing, and controlling. After this analysis on the nature of coordination, a panel of five experts rated each coordination dimension (as *none*, *low or high*) based on a comparison between the findings on the study area and the baseline indicators using an expert validation questionnaire (see Appendix 2).

3.5 Modeling of the Impacts of LULC Changes on Streamflow and Sediment Yields

3.5.1 SWAT Hydrological Model Description

The impacts of LULC changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 – 2020 were modeled using the Soil Water Assessment Tool (SWAT) model integrated in QGIS software. The model has been extensively used by many researchers around the globe to simulate hydrological and water quality responses of a watershed to varying land management conditions (Milewski et al., 2014; Karki et al., 2020). This is because it is accurate, effective and robust in executing simulations over long periods (Gashaw et al., 2018).

In SWAT model, the whole watershed was initially divided into several sub-watersheds which were further be sub-divided into multiple hydrological response units (HRUs), based on attributes of soil, slope and Land use and land cover (Geremew, 2013). In essence, similar HRUs are assumed to have the same hydrologic attributes (Arnold et al., 2012). The model then simulated the watershed hydrological processes for each HRU using the water balance Equation 1 (Neitsch et al., 2011). The simulated hydrological components and sediment for

the HRUs are summed up for the sub-watersheds, and ultimately to basin level (Neitsch et al., 2011).

$$SW_t = SW_O + \sum_{i=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \quad \text{.....(1)}$$

Whereby;

SW_t = final soil water content (millimeter)

SW_o = initial soil water content (millimeter)

t = the time (days)

R_i = volume of precipitation on day i (millimeter)

Q_i = volume of surface runoff on day i (millimeter)

ET_i = volume of evapotranspiration on day i (millimeter)

P_i = volume of percolation through the soil column to the vadose column on day i (millimeter)

QR_i = volume of return flow on day i (millimeter)

There is a range of key hydrological components that can be simulated by the SWAT model but for this study, the model mainly focused on simulating stream flow (runoff generation and groundwater flow) and sedimentation components. The SWAT model was suitably chosen for this study because of its ability to fill in missing datasets using its weather generator engine system, this is critical because incomplete and missing climate datasets are commonplace in developing nations of which Kenya is part. Moreover, it is capable of delineating large watersheds (Chilagane, 2017). These two key features are lacking in other hydrological models.

3.5.2 SWAT Model Input Data: Collection and Analysis

The SWAT model requires precise information about the LULC change, Digital Elevation Model (DEM), soils, and climate characteristics of the watershed. These data sets were obtained from various sources and analyzed as discussed in the following sub-sections.

(A) Land Use and Land Cover Change Mapping and Analysis Data

(i) Satellite Imagery Data Acquisition and Pre-Processing

A combination of remote sensing and Geographical Information System (GIS) was used to evaluate the trends and pattern of LULC changes in the Migori River watershed between 1980 and 2020 at the recommended 10-year intervals (Alawamy et al., 2020). The study utilizes datasets of multi-temporal and spectral satellite imageries of Landsat 3 Multispectral Scanner (1980), Landsat 4, 5 Thematic Mapper (1990, 2000, and 2010), and Operational Land Satellite - Thematic Infrared Sensor (2020) obtained from the United States Geological Survey (USGS) website. The features of these imageries are summarized in Table 3.1. To minimize phonological variations, all images selected were for the dry month of December; when both the moisture content and cloud coverage in Migori County are at their lowest.

Table 3.1: Features of multi-temporal Landsat imageries

YEAR	Sensor	Path/ Row	Acquisition Date	Resolution (m)	Cloud cover	Season	Source
1980	Land sat 3 MSS	170/60	Dec 1980	30	0	Dry	USGS
1990	Land sat 4,5 TM	170/60	Dec 1990	30	1	Dry	USGS
2000	Land sat 4,5 TM	170/60	Dec 2000	30	1	Dry	USGS
2010	Land sat 4,5 TM	170/60	Dec 2010	30	0	Dry	USGS
2020	Land sat 8 OLI-	170/60	Dec 2020	30	0	Dry	USGS

To heighten visualization and enrich interpretability, the acquired images were exported to ERDAS Imagine software where they were subjected to various standard image pre-processing procedures, including radiometric/atmospheric correction, geometric correction, image mosaicking, image sub-setting, and layer stacking.

(ii) Spatial Data Processing and Analysis

After pre-processing, the corrected images were subjected to a supervised classification process using the Maximum Likelihood Algorithm to define LULC classes. Six classes were designed guided by ancillary data, visual analysis of the locations on Google Earth maps, and ground truthing. The LULC classes of interest were therefore defined as cultivated land, shrub land, grasslands, forests, bare land, built-up areas, water, and wetlands (Table 3.2).

Six ground-truth polygons corresponding to the six defined classes were chosen at random and digitized using aerial photographs and visual inspection of the sites on Google Earth maps. Because each training sample polygon comprised 17 pixels, a total of 102 pixels were used for the six training samples. Following successful image training with the signature editor, the Maximum Likelihood algorithm was run a couple of times to produce class signatures and classify the imageries into meaningful LULC categories. Finally, the ArcGIS software was used to produce cartographically appropriate LULC maps for the years 1980, 1990, 2000, 2010, and 2020.

Table 3.2: Land Use and Land Cover categories used in Migori River watershed

LULC class	Description
Cultivated land	Areas occupied by crops, fruits, and vegetables
Shrub land	Degraded forest land or areas under woody vegetation dominated by young trees and shrubs that are less than 5 meters tall
Grassland	Landscapes covered by herbaceous vegetation and are not cultivated or have less than 10% coverage of shrubs and trees
Forests	Landscapes are mostly made up of mature natural or planted trees, and there are no obvious signs of severe disruption of ecological processes
Bare land	Open rocky or soil surfaces that are devoid of any vegetation
Built-up area	Areas comprising human settlements, transportation, industrial and commercial infrastructure
Water	Water surfaces of rivers, ponds, flood plains, wells, or lake
Wetland	Landscapes that are soaked by water for the majority of the year i.e. swamps

Source: Author, 2022

(iii) Post-processing Analysis of Spatial Data

Accuracy assessment was done through the generation of confusion/error matrices in which the data from LULC classification are compared to the ground-truthing data acquired from fieldwork. This study used 20 ground reference points and reference data extracted from Google Earth images for accuracy assessment. The positions of the ground points were automatically recognized on the classified images and their class values defined to determine the accuracy of a pixel. The statistical components of the confusion matrix namely, producer's accuracy, user's accuracy, overall accuracy, kappa statistics, and overall kappa coefficient was calculated for all the classified LULC images based on the algorithms provided in Congalton and Green (2009).

Change detection analysis was then performed using the change matrix tool. During this automated process, classified LULC data of the initial year under consideration is compared

to the one for the final year under consideration. Once, the areal coverages are computed, the software produces a change detection matrix that shows the net changes for the respective classes over a given period. The data for the 1980, 1990, 2000, 2010, and 2020 obtained from the change matrix is expressed in square kilometers and percentages. Finally, the LULC change-transition matrix through the overlay technique in ArcGIS to estimate the area converted from every LULC category to the other over the period between 1980 and 2020. Moreover, the annual rate of change of each LULC category was computed as percentages using equation 2 proposed by Puyravaud (2003).

$$r = \left(\frac{1}{t_2 - t_1}\right) \times \text{In}\left(\frac{A_2}{A_1}\right) \quad \text{.....(2)}$$

Where r is the annual rate of change for each LULC category (in percentage), and A_2 and A_1 are areas of each LULC category at the end (t_2) and the beginning (t_1), respectively, for the period under review.

(iv) Analysis of Drivers of LULC Changes

In addition to the spatial LULC analyses required for modeling, the study examined the major causes or drivers of LULC changes in the study area for the period under review (1980 to 2020) through analysis of a community perceptions survey carried out among 318 household heads (sampled as described in section 3.7.1) using interviewer-administered semi-structured questionnaires (see sub-section 1 in section B1 of Appendix 5 for the relevant questions). Upon obtaining the descriptive statistics of the survey data from SPSS analysis, the ranking of the LULC change drivers for the watershed based on weighted

average was computed using the Relative Importance Index (RII) equation (3) adopted by earlier studies (Musa et al., 2006; Aziz et al., 2016).

$$RII = \frac{R_n C_1 + R_{n-1} C_2 \ldots + R_1 C_n}{A \times N} \quad \ldots\ldots(3)$$

Where R_n = value of the lowest/last rank e.g. if the lowest/last rank is 5 in the Likert-scale used, then R_n = 5 and R_n−1 = 4; R_1 = value of the highest/first rank in the Likert-scale used, usually 1; C_n = counts/number of observations on lowest/last rank; C_1 = counts/number of observations on highest/first rank; A = the highest value in the overall ranking scale, and N = total number of respondents.

(B) Digital Elevation Model (DEM) Data

DEM is an input of SWAT model required for delineating the basin, and computation of the stream networks and flow accumulation. It is also required for the classification of the slope, which is fundamental for the creation of Hydrological Response Units (HRUs). A 30 m by 30m resolution of the DEM was generated from the from the United States Geological Survey (USGS) website. First, a contour map of the basin was obtained from the (WARMA). This map was then be digitized and loaded in QGIS as a shape file. This was followed by the generation of the Triangulated Irregular Network for the map. The Triangulated Irregular Network is an object for representing the surface and holds surface data. The Triangulated Irregular Network was then transformed into a grid (raster format) for usage in the SWAT model. The data was finally projected to UTM as shown in the study area map (Figure 3.1).

(C) Soils Data

The physical and chemical attributes of various soil types in the watershed constitute a major input of the SWAT model. For this study, the soil map of scale 1:100,000 acquired from the Kenya Soil Survey (KSS) under the Ministry of Agriculture, Livestock, Fisheries and Irrigation was geo-processed in the QGIS platform. The soil classification required for this research was carried out based on the FAO/UNESCO – ISRIC (2003) system and ten major soil types were identified in the Migori River watershed (Figure 3.2). Finally, the soil data was customized to fit the standard requirements of the model before integration with SWAT. The coverage of these soil types is available in Appendix 3.

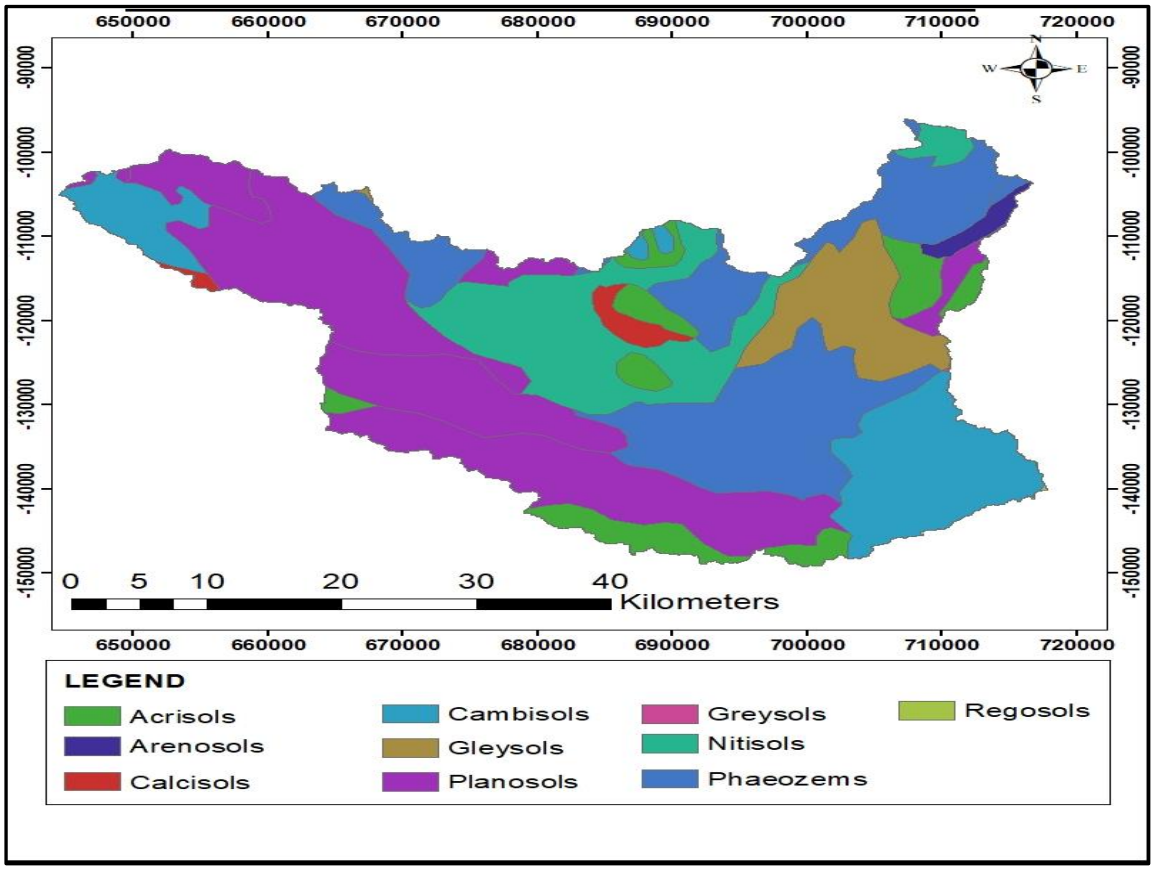


Figure 3.2: Soil map coverage of the Migori River watershed

(D) Hydro-meteorological Data

SWAT model simulation requires weather and stream flow data as one of the major inputs. The long-term weather datasets required to setup the model comprises daily precipitation, temperature (Max and Min), wind speed, solar radiation and relative humidity. The datasets of these variables for the period 1980 – 2020 were acquired from the records of the Kenya Meteorological Department, Nairobi. These records are representations of the weather data collected from the five weather stations located within and around the Migori River watershed namely Muhuru Bay Hydromet Station, Migori Tree and Fruit Nursery, Migori Water Supply, Migori Rainfall Gauging Station, Taranganya Secondary School, and Macalder Agricultural Office as shown in study area map (Figure 3.1). To augment these records, additional weather datasets were obtained from the Lake Victoria South Water Resource Management Authority Office in Kisumu to help fill in missing or incomplete data. In case of further gaps in the meteorological datasets, the weather generator system in SWAT was employed to fill in the missing data.

The calibration and validation of the SWAT model requires measurements of daily discharge therefore the daily discharge data from two stream flow gauging stations on the Migori River, 1KB05 and 1KC03 shown in study area map (Figure 3.1), was gotten from Water Resources Management Authority (WRMA) Kisii regional office. These stations have been in operation since the 1980s and had sufficient data for the modeling period (1980-2020).

3.5.3 SWAT Model Configuration and Simulation Analysis

The initial procedure in SWAT set up and simulation process is watershed delineation using DEM Data which was conducted in ArcSWAT+. This was followed by the characterization

of the hydrological response units (HRUs) based on soil, slope and Land use and land cover datasets, in the GIS interface of the SWAT model. Before simulation was performed in the SWAT model, the datasets were prepared and standardized to conform to SWAT requirements.

The prepared datasets were connected to the SWAT reference database through the generation of lookup tables which incorporates specific watershed parameters into the model. The weather generator was set up to fill in any missing datasets of the required watershed parameters. Once the input data were loaded in the SWAT model, the model parameters including the simulation period (which was set for 40 years - running from 1980 to 2020) was updated and eventually the SWAT model simulation was run (see Appendix 4). In this study, the SWAT simulation analyses were limited to stream flows and sediment yields in the Migori River watershed.

In the SWAT model, the stream flows in the basin were simulated by the curve number (CN-method) (Equation 4-6) (Gashaw et al., 2018) while the sediment yields were estimated by the Modified Universal Soil Loss Equation (MUSLE) (Equation 7) (Karki et al., 2020). During the simulation process, both the stream flows and sediment yields were simulated under varied conditions of LULC for the period 1980 - 2020, but under the same meteorological datasets.

$$Q_{peak} = \frac{\alpha_{tc} \text{ x } Q_{surf} \text{ x } A}{t_{conc}} \quad \text{.....(4)}$$

Where q_{peak} = the peak runoff rate ($m^3\ s^{-1}$), α_{tc}= the fraction of daily precipitation that occur during the time of concentration, Q_{surf} = the runoff volume (mm ha-1), A = the area of sub-catchment (km^2), t_{conc} = the concentration time (hour)

$$Q_{surf} = \frac{(R_a - I_a)^2}{R_a - I_a + S} \qquad \text{For } R_a > I_a,\ Q = 0 \text{ for } R_a \leq I_a \quad \text{.....(5)}$$

Where, Q_s = runoff volume (mm), R_a = precipitation depth for the day (mm), I_a = initial abstraction, and S is obtained using Equation (6):

$$S = 25.4 \text{ x } \left\{\frac{100}{CN} - 10\right\} \text{.....(6)}$$

Where CN= Curve number for the given day. CN is affected by soil permeability and hydrologic group and land use practice, and higher values of CN show higher runoff potential.

$$SedYield = 11.8 \text{ x } \left(Q_{surf}\ x\ q_{peak} \text{ x } A\right)^{0.56} \text{ x C x F x K x LS x P} \quad \text{.....(7)}$$

Where *SedYied* = the sediment yield on a specific day (ton), *Qsurf* = the runoff volume (mm ha-1), q_{peak} = the peak runoff rate ($m^3\ s^{-1}$), *A* = the area of HRU (ha), *C* = the vegetation cover factor, *F* = the coarse fragment factor, *K* = the soil erodibility factor, *LS* = the slope length and slope factor, and *P* = the land management practice factor. The C, K, LS, and P factors are gotten from Universal Soil Loss Equation (USLE).

Finally, the SWAT output data, observed and simulated, for each of these components were collected. The impact of land use and land cover change on stream flows and sediment yields in the Migori River basin were analyzed by comparing the differences between observed and

simulated outputs for the period 1980 - 2020. Basically, in the SWAT model, it is the differences between observed and simulated discharge under varied LULC changes that represent the impacts of LULC changes on the water resources of Migori River Basin. Hence, information on a forty-year hydrological response of Migori River basin to watershed land development effects was simulated and retrieved.

3.5.4 SWAT Model Sensitivity Analysis, Calibration, Validation, and Performance Assessment

In order to standardize and validate the SWAT model, three procedures, i.e. sensitivity and uncertainty analysis, calibration and validation, are often applied to the model. These procedures are necessary for the effective application of the SWAT hydrological model (Abbaspour, 2015), and hence was carried out in this study using the SWAT Calibration and Uncertainty Programs (SWAT-CUP). Information on how they were applied in the SWAT model has been discussed in the following sub-sections.

I. Sensitivity and Uncertainty Analysis

Sensitivity analysis is useful in guiding the model calibration because it is able to detect variables which have greater influence on the outputs of the model (Abbaspour et al., 2013). In this study, sensitivity analysis was conducted to show the extent by which the SWAT model estimates the hydrological components within the Migori River watershed. The Sequential Uncertainty Fitting (SUFI-2) embedded within the SWAT-CUP program was used in calculating parameter sensitivity through the Latin Hypercube (LH) procedure described in Abbaspour (2015). Using SWAT-CUP is highly advantageous since it allows the use of a wide range of various types of variables (Arnold et al., 2012). Sensitivity of the

parameters were determined based on p-values and t-test values, where p-values indicates significance of the sensitivity (values close to 0 have more significance) and t-test measures sensitivity; with most sensitive parameters being those with larger absolute t-test value and a smaller p-value (Abbaspour et al., 2015a). Therefore, parameters with the highest values are the most sensitive.

II. Model Calibration

Calibration is the process of adjusting a set of variables in order to reduce the prediction uncertainty while maximizing the model agreement in relation to a set of empirical datasets (Zeray et al., 2007). In model calibration, the values of input variables for the model are carefully chosen through a comparison of the outputs with the observed data under similar conditions. In this study, the calibration process was automatically conducted in SWAT-CUP program (Abbaspour et al., 2015) by comparing the simulated hydrological outputs generated by the SWAT model with the long term observed datasets in a series of runs. The observed daily stream flow measurements of the watershed recorded by the two gauging stations for the period 1980 – 2020 was used in the calibration process.

III. Model Validation

Validation refers to the process of establishing the capability of a model to produce accurate predictions (Trucano et al., 2006). This study employed the Sequential Uncertainty Fitting (SUFI-2) embedded within the SWAT-CUP program to determine the degree to which it meets the intended purposes. Like the calibration process, observed stream flow data of the

watershed recorded by the two gauging stations for the period 1980 – 2020 was used for the validation process.

The simulation period for both calibration and validation was set for 40 year period - running from 1980 to 2020. This period was chosen because it could have quality data suitable for the computation of the water balance elements. A three year warm up period prior to 1980 was used to let the model parameters to stabilize (Gashaw et al., 2018). During both processes, the values of the model parameter remained constant. The simulated outputs of both calibration and validation were graphically compared with the continuous observed stream flow data.

IV. Model Performance Assessment

Model performance assessment is a measure of the extent to which the simulated outputs marches the observed data (Karki et al., 2020), and it is used to verify the efficiency of the model in simulating hydrological processes (Neitsch et al., 2011). There are numerous criteria for assessing the model efficiency (Moriasi et al., 2015). For this thesis, the goodness of the model fit associated with sediment yield and streamflow was evaluated based on three criteria: Nash–Sutcliffe efficiency (NSE), percent bias (PBIAS), and coefficient of determination (R^2). The values of NSE, PBIAS, and (R^2) were computed using the Equations (8)-(10). The values of NSE, and R^2 between 0 (less accurate) and 1 (more accurate) are generally acceptable while below 0.0 shows that the average observed is a better predictor than the model and is therefore unacceptable (Moriasi et al., 2015).

The determination coefficient (R^2) illustrates the capacity of the model to explain an outcome in the linear regression environment.

$$R^2 = \frac{\sum(X_i - X_{av})\,(Y_i - Y_{av})}{\sqrt{\sum(X_i - X_{av})^2}\sqrt{\sum(Y_i - Y_{av})^2}} \quad \text{.....(8)}$$

NSE illustrates how well the plots of observed data vs. predicted data fits the 1:1 line.

$$\text{NSE} = 1 - \frac{\sum(Y_i - X_i)^2}{\sum(X_i - X_{av})^2} \quad \text{.....(9)}$$

PBIAS indicates to what extent the model is underestimating (indicated by +ve values) or overestimating indicated by -ve values the observations.

$$\text{PBIAS} = \frac{\sum(X_i - Y_i) \text{ x } 100}{\sum X_i} \quad \text{.....(10)}$$

Where, X_i = observed/measured flow value, X_{av} = average of observed/measured flows, Y_i = simulated/predicted flow value, and Y_{av} = average of simulated/predicted flows.

Classification for model performance is as follows (Moriasi et al., 2015):

(i) Better: $0.75<\text{NSE}<1.00$, $0.75<R^2<1.00$, $\text{PBIAS}<\pm 10$

(ii) Good: $0.65<\text{NSE}\leq 0.75$, $0.65< R^2\leq 0.75$, $\pm 10<\text{PBIAS}<\pm 15$

(iii) Satisfactory: $0.50<\text{NSE}\leq 0.65$, $0.50< R^2\leq 0.65 \pm 15<\text{PBIAS}<\pm 25$

(iv) Unsatisfactory: $\text{NSE} \leq 0.50$, $R^2 \leq 0.25$, $\text{PBIAS} > \pm 25$

3.6 Analysis of Water Quality and Associated Household Health Risk Implications

3.6.1 Sampling Procedure and Laboratory Analysis

The water quality of the Migori River was studied monthly for six months (Sep 2021-Feb 2022). Sampling was carried out in the river at the six pre-defined stations (Figure 3.3)

during both the wet season (Sep 2021 to Nov 2021) and the dry season (Dec 2021 to Feb 2022).

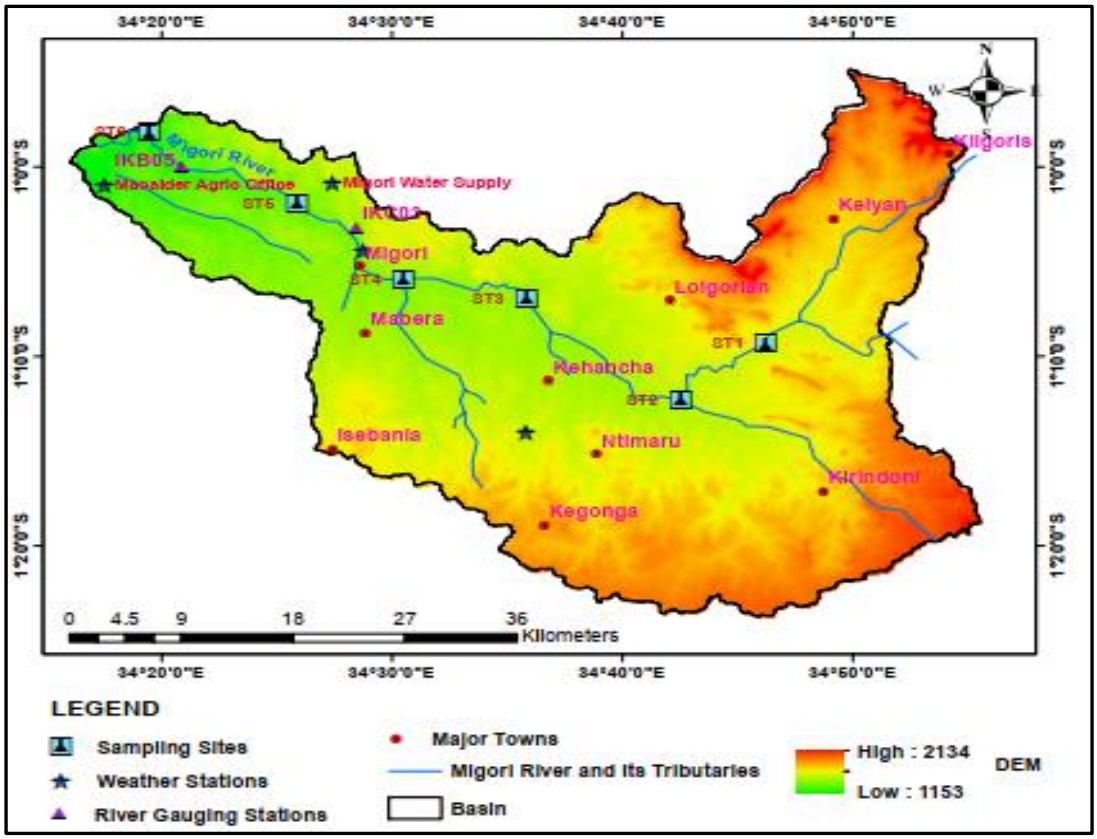


Figure 3.3: Distribution of sampling stations along the Migori River

Sampling occurred between 9 am and 12.00 pm. At each sampling station, triplicate *in-situ* measurements of Dissolved Oxygen concentration (mgL^{-1}), Temperature (ºC), Conductivity (μScm^{-1}), pH, Salinity (ppt), TDS (mgL^{-1}), and Turbidity (NTU) were determined on-site using a handheld Hanna Instruments® Multiparameter Probe (YSI Professional Plus model). Three water samples were then collected at each station, at about 10cm depth from the right, middle and left banks of the river, using 500 ml plastic bottles that had been acid-washed (HCL) and rinsed in distilled water. The collected water samples were then labeled, stored in

a cooler box at 4^{o}C, and transferred to the laboratory at Kenya Marine and Fisheries Research Institute (KMFRI) in Kisumu within five hours of collection. All the samples were then analyzed in the laboratory following the APHA (2017) Standard Methods for the Examination of Water and Wastewater (Table 3.3).

Table 3.3: Studied parameters and their respective standard analytical methods

Water Quality Parameter	**Analytical Method as per APHA (2017)**
Biochemical Oxygen Demand (mgL^{-1})	5-day test
Total Hardness (mgL^{-1})	Ethylene-diamine Tetra-acetic acid (EDTA) Titrimetric Method
Nitrite-nitrogen (μgL^{-1})	Diazotization
Total Nitrogen (μgL^{-1})	Persulphate Digestion
Nitrate-Nitrogen (μgL^{-1})	Cadmium Reduction
Ammonia-Nitrogen (μgL^{-1})	Nessierization spectrophotometric (Nessler)
Total alkalinity (mgL^{-1})	Sulphuric Acid Titration
Total phosphorous (μgL^{-1})	Acid Persulphate Digestion
Soluble Reactive Phosphate (μgL^{-1})	Ascorbic Acid
Silicates (μgL^{-1})	Ammonium Molybdate
Fecal Coliform (cfu $100ml^{-1}$)	Multiple tube fermentation technique

3.6.2 Households River Water Utilization and Health Risk Assessment

The study examined the watershed community's river water usage, perceived water pollution status, indicators, and causes, as well as health implications through analysis of a survey carried out among the proportion of respondents out of the 318 households heads (sampled as described in section 3.7.1) that solely depend on the Migori River water for their household usage using interviewer-administered semi-structured questionnaire (see sub-section 4 in section B1 of Appendix 5 for the relevant questions). The households chosen for the survey were those within 2-5 km from the river as they are the ones who would have easy frequent access to the river for water collection. During the survey, the questionnaires were

only administered to adult female members of the selected households as households in Kenya culturally rely on children or women of child-bearing age (or both) for water collection.

3.6.3 Data Processing, Analysis, and Presentation

I. Statistical Analyses

The datasets for the water quality parameters analyzed were analyzed using SPSS version 24.0. The datasets were first analyzed descriptively to generate mean and standard error values for the various stream sections and seasons. One-way ANOVA was then used to test for significant spatial variations at a *p-value* of ≤0.05 whereas the t-test was used to test for significant seasonal variations at a *p-value* of ≤0.05.

II. Calculation of CCME-Water Quality Index

Following the procedure outlined in CCME (2017) manual, the physicochemical variables to be used in WQI calculation together with their established water quality guidelines (referred to as objectives) were first selected and appropriately arranged in an Excel file. The Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI) values for the various river sections and seasons were obtained by the comparison of the selected physicochemical variables against their established NEMA (2017) guidelines following the procedure outlined in CCME (2017) using equation 11.

$$\mathrm{CCME-WQI} = 100 - \left\{ \frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732} \right\} \quad \text{.....(11)}$$

Where the index equation comprises three components (Equations 12-14):

I. F_1 (*Scope*) – represents the percentage of physicochemical variables for which at least one measure doesn't comply with the prescribed water quality limits.

$$F_1 = \left\{\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right\} \text{X } 100 \quad \text{.....(12)}$$

II. F_2 (*Frequency*) – represents the percentage of individual tests (measurements) that do not comply with their prescribed water quality limits.

$$F_2 = \left\{\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right\} \text{X } 100 \quad \text{..... (13)}$$

III. F3 (*Amplitude*) – represents the quantity by which failed test values do not comply with their prescribed water quality limits. This is computed in three steps:

a. Computation of Excursion. Excursion refers to the number of times by which an individual concentration is greater than (or less than, when the water quality guideline is a minimum) the set guideline. When the water quality guideline must not be exceeded, it is calculated using:

$$Excursions_i = \left\{\frac{Failed\ Test\ Value_i}{Objective_j}\right\} - 1 \quad \text{.....(14a-1)}$$

And when the observed value must not be less than the water quality guideline:

$$Excursions_i = \left\{\frac{Objective_j}{Failed\ Test\ Value_i}\right\} - 1 \quad \text{.....(14a-2)}$$

b. Computation of Normalized Sum of Excursions (nse): The normalized sum of excursions is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests

from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). The nse is computed as:

$$\text{nse} = \left\{\frac{\sum_{i=1}^{n} Excursion_i}{Number\ of\ tests}\right\} \quad \text{.....(14b)}$$

c. Computation of F3 (Amplitude): The F3 is then computed by an asymptotic function that scales the normalized sum of the excursions from water quality guidelines to yield a range from 0 to 100.

$$F_3 = \left\{\frac{nse}{0.1nse+0.01}\right\} \text{.....(14c)}$$

The CCME-WQI is finally calculated using the aforementioned Equation 11. The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the worst water quality and 100 represent the best water quality. The resultant WQI values place water quality into five categories with the following interpretations (Table 3.4).

Table 3.4: CCME WQI categorization schema (CCME, 2017)

Rank	**WQI Value**	**Description**
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

3.7 Analysis of Livelihoods' Sustainability and Associated Vulnerability to Climate Change Impacts

3.7.1 Sample Size and Sampling Procedure

For analysis of the sustainability of community livelihoods and the associated vulnerability to climate change impacts, the study targeted household heads in the three watershed zones: upstream (Kuria West and East Sub-counties), midstream (Suna East and West Sub-counties), and downstream (Nyatike Sub-county). Based on the recent National Population and Housing 2019 Census (KNBS, 2019), the total number of households in Kuria West is 39,781, Kuria East is 17,363, Suna East is 27,302, Suna West is 29,257, and Nyatike is 40,257. An aggregate of these households totaled 153,954, which hence constituted the target population for the livelihoods analysis.

The total sample size for the study was determined from the target population based on Fisher's formula (Equation 15):

$$n = \frac{\mathrm{NZ^2P(1-P)}}{d^2\,(N-1) + Z^2\,P(1-P)} \qquad \text{.....(15)}$$

Where n = required sample size, Z = 95% confidence interval under the normal curve that is 1.96, p = 0.5 (proportion of the population to be included in the sample that is 50%), N = size of population (153,954 households), d = Margin of error or degree of accuracy (0.05).

From this equation (15), a total sample size of 384 households was determined for the survey, which when split equally among the three zones would result in a sample size of 128 households per zone. The actual sample size per zone was however, reduced to 106 households in consideration of the financial constraints. The selection of the 106 respondent

households per each watershed zone was obtained through a multi-stage sampling. In the first stage, clusters samples are based on administrative divisions. In the second stage, sampled villages were purposively chosen based on their proximity to the river, whereby those with households within 2-5 km from the river were chosen as they are the ones whose livelihoods are closely linked to the ecosystem functioning of the river system. In the third stage, a simple random sampling technique was used to select respondent households from the chosen villages.

3.7.2 Data Collection Instruments

Household survey data was collected by 9 trained enumerators (three in each watershed zone), using pre-tested, interviewer-administered semi-structured questionnaire (see Appendix 5). The household questionnaire consisted of several sections intended to get information on livelihoods indicators outlined in Table 3.5 and 3.6, as well as on drivers of LULC changes (described in section 3.5.2, I, a), and household health risk associated with community usage of the river water (described in section 3.6.2). The questionnaire was transformed into a digital format on *Kobo Toolbox*, an open-source mobile-data collection software. The digital questionnaire was then loaded into the *Kobo Collect* (a free android application that allows users to collect and store data offline in real-time for later transmission to a central server) on the smartphones of the enlisted enumerators.

3.7.3 Validity and Reliability of Data Collection Instruments

To ensure reliability of the questionnaire, the study adopted a test re-test method in pre-testing whereby a repeat pre-test was conducted after one week among 35 household heads from Awendo Sub-county of Migori County (an area that was not included in the actual data

collection for the main study), and Cohen's kappa statistic was used to measure the level of agreement of the results from the two pre-tests. Kappa coefficients were computed for categorical variables and intra-class correlation coefficients for continuous variables. Since the Kappa coefficients obtained after comparison were above 0.78 and intra-class coefficients ranged between 0.95 – 1.00, indicating a moderate to excellent reliability of the questionnaire based on the criteria by Landis and Koch (1977), all the questions were retained. To ensure validity, the questionnaire (and the interview guides stated in section 3.4.2) were shared and discussed with experts from relevant government departments/agencies, and the study supervisors. The feedback from these experts and pre-testing results were used to make necessary adjustments in those instruments including eliminating inadequacies, irrelevance and ambiguities to ensure the questions were able to test what was intended.

3.7.4 Data Collection Procedure

Prior to the survey, village elders and local administration officials were consulted to explain the purpose of the study, understand the local livelihood realities (which helped in developing indicators and questionnaire items), and obtain permission to visit the selected households. During the actual survey, the digital household questionnaire contained in the *Kobo Collect* app was administered to household heads (or other senior members of the selected households) by the enumerators at the respondents' houses and farms, upon obtaining verbal consent. Cultural norms dictated that the male be interviewed as the head of the household unless absent then the spouse or adult (over 18 years) family member who understand the family and area well. Each interview lasted about 35 minutes on average.

3.7.5 Data Processing, Analysis and Presentation

The collected household survey datasets were cleaned, edited, coded, and organized in MS Excel, then analyzed descriptively using SPSS version 24.0. The livelihood sustainability and vulnerability were analyzed using the Livelihood Sustainability Index (LSI) and the Livelihood Vulnerability Index (LVI) framed within the Intergovernmental Panel on Climate Change (IPCC) vulnerability framework (LVI-IPCC), respectively, as discussed in the following sections.

I. Livelihood Sustainability Index (LSI) Calculation

Analysis of the sustainability of household livelihoods in the three zones of the Migori River watershed was conducted based on Livelihood Sustainability Index developed by DFID based on the Sustainable Livelihood Framework. This framework has been widely applied as an analytical tool for livelihood status and has been found to be highly effective by various previous studies (Wang et al., 2015; Li et al., 2020; Etana et al., 2021). Since LSI uses indicators to measure the livelihood assets, a set of indicators under each livelihood asset (natural capital, financial capital, human capital, physical capital, and social capital) were developed based on the realities of livelihood conditions in the watershed as identified through reconnaissance field survey, and a thorough literature review to determine the functional linkages. The indicators considered under each livelihood capital, their sources, and their scales of measurement are shown in Table 3.5.

Table 3.5: Indicators for livelihood capital of rural households and their index measurement

Livelihood Capital	Indicators	Source	Measurement Categories and Weighting
Natural Capital	Land holding size	Mumuni & Oladele (2016)	In acres
	Land fertility level	Mumuni & Oladele (2016)	Low = 0.33; moderate = 0.66; & high = 1
	Annual production	Siraw et al. (2018)	In Kilograms
	Commercial agriculture (cash crops)	Siraw et al. (2018)	Yes = 1 and No = 0
	Livestock possession size	Siraw et al. (2018)	No. of heads
	Access to grazing pasture	Saini et al. (2014)	Yes = 1 and No = 0
	Distance to portable water	Siraw et al. (2018)	Walking duration (in minutes)
	Water quality of household drinking water point	Li et al. (2020)	Low= 0.33,moderate = 0.66 & high = 1
	Access to tangible forest resources	Ahmed et al. (2021)	Yes = 1 and No = 0
	Access to fishery resources	Ahmed et al. (2021)	Yes = 1 and No = 0
Human Capital	Educational attainment of household head	Siraw et al. (2018)	No formal education = 0; primary = 0.33; secondary = 0.66; tertiary (college/university) =1
	Watershed conservation and development training	Siraw et al. (2018)	Yes = 1 and No = 0
	Labor force size	Li et al. (2020)	No. of family laborers (healthy adults)
	Technical skill level of laborers	Mumuni & Oladele (2016)	Low= 0.33,moderate = 0.66 & high = 1
	Daily nutritional intake level	Gupta & Sharma (2017)	Low (<3 meals per day) = 0.33; normal (3 meals per day) = 0.66; & high (> 3 meals per day) = 1
	General health status of the household	Gupta & Sharma (2017)	Low (half of HH members suffer from chronic illnesses) = 0.33; moderate (few HH members suffer from chronic illnesses) = 0.66; & high (no HH members suffer chronic illnesses) = 1
	Distance to the nearest medical facility	Hahn et al. (2009)	Walking duration (in minutes)
Financial Capital	Participation in off-farm activities	Siraw et al. (2018)	Yes = 1 and No = 0
	Participation in non-farm activities	Siraw et al. (2018)	Yes = 1 and No = 0
	Household monthly income	Siraw et al. (2018)	Amount in Kshs.
	Access to credit/loan services from lending institutions	Saini et al. (2014)	Yes = 1 and No = 0
	Ownership of savings accounts in financial institutions	Saini et al. (2014)	Yes = 1 and No = 0
	Annual household savings	Siraw et al. (2018)	Amount in Kshs.
	The financial value of available livestock	Li et al. (2020)	Amount in Kshs.
	The financial value of current standing crop	Li et al. (2020)	Amount in Kshs.
Physical Capital	Ownership of any transport means (bicycle, motorcycle or car)	Saini et al. (2014)	Yes = 1 and No = 0
	Ownership of any functioning communication devices (cell phone, radio, or TV)	Siraw et al. (2018)	Yes = 1 and No = 0

	House roof type	Siraw et al. (2018)	Iron roofing = 1 and Grass-thatch = 0
	Housing quality	Li et al. (2020)	Hut = 0.33, mud-walled house = 0.66 & brick-walled house = 1
	Possession of sanitary toilet	Abbassi et al. (2020)	Yes = 1 and No = 0
	Household cooking fuel	Chen et al. (2013)	Crop straws/cow dung = 0.25; Fire wood/charcoal = 0.5; LPG gas = 0.75; Electrical power = 1
	Household light source	Chen et al. (2013)	Candle = 0.25; Kerosene = 0.5; Solar power = 0.75; Electricity = 1
	Ownership of full farm equipment	Siraw et al. (2018)	Yes = 1 and No = 0
	Ownership of irrigation equipment (e.g. water pumps)	Mumuni & Oladele (2016)	Yes = 1 and No = 0
	Fertilizer use	Siraw et al. (2018)	Yes = 1 and No = 0
	Herbicides/pesticides use	Siraw et al. (2018)	Yes = 1 and No = 0
	Compost manure application	Siraw et al. (2018)	Yes = 1 and No = 0
	Improved seeds use	Siraw et al. (2018)	Yes = 1 and No = 0
	Possession of furniture (table, chair, bed)	Siraw et al. (2018)	Yes = 1 and No = 0
	Possession of a silo/storage facilities	Mumuni & Oladele (2016)	Yes = 1 and No = 0
Social Capital	Mutual trust and reliability of relatives	Ahmed et al. (2020)	High = 1 and Low = 0
	Support from the local administration	Siraw et al. (2018)	Yes = 1 and No = 0
	Relationship with neighbors	Ahmed et al. (2021)	Worst = 0.25; Bad = 0.5; Good = 0.75; Very good = 1
	Extent of trust on community social relations	Gupta & Sharma (2017)	Low = 0.33,moderate = 0.66 & high = 1
	Membership in social organizations	Siraw et al. (2018)	Yes = 1 and No = 0
	Membership in WRUA/CFA	Siraw et al. (2018)	Yes = 1 and No = 0
	Participation in community barazas	Saini et al. (2014)	Yes = 1 and No = 0

In creating an index that could capture all livelihood assets of the watershed households, different scaling and indexing approaches were used to make them comparable and enable purposeful interpretation (see Table 3.5). All the indicators were evaluated using rating scale methods with varying weights: for example, low, moderate, and high were interpreted as 0.33, 0.66, and 1 respectively; and two answer questions (yes or no responses) were weighted Yes=1 and No=0 (Table 3.5). This weightage approach was based on the Muangkaew and Shivakoti (2005) indexing, where critical values are chosen to represent different degrees. The rest of the indicators were quantified in measurement units that were suitable for them (Table 3.5).

To analyze the LSI for each of the three watershed zones, five major steps were followed. First, the weighting for each of the indicators with assigned weights was calculated depending on the design features of the questionnaire to obtain single values as follows: for example, indicators with two answer choices (Yes and No), the final indicator value (I) = Yes% x 1 + No% x 0; indicators with three answer choices e.g. erosion level (high, moderate, and low), the final indicator value (I) = High% x 1 + Moderate% x 0.66 + Low% x 0.33; and the same procedure was followed for indicators with four or more answer choices (Table 3.5). Indicators without assigned weights such as those in the form of counts or ratios or averages, for example annual income, remain with their original values.

Secondly, since each indicator is measured on a different scale, standardization was necessary before the calculation of the livelihood indices (Phanxay et al. 2015). Therefore, the values of all the indicators were standardized to a scale between 0 and 1 using equation (16).

$$X_i = \left\{\frac{S_z - S_{min}}{S_{max} - S_{min}}\right\} \quad \text{.....(16)}$$

Where, X_i is the standardized value of the indicator; S_z is the actual value of the same indicator; and S_{min} and S_{max} are the minimum and maximum values, respectively, of the same indicator.

Third, after standardization of all indicators, the indicators under each livelihood capital were averaged using Equation (17) to obtain the value of each type of livelihood capital for the respective watershed zones.

$$LC = \left\{\frac{\sum_{i=1}^{n} X_i}{n}\right\} \quad \text{.....(17)}$$

Where, LC is the value of one of the five types of livelihood capitals (natural capital, financial capital, human capital, physical capital, and social capital) for each watershed zone; X_i is the standardized value of the indicator, that makes up each type of livelihood capital; and n is the total number of indicators in each type of livelihood capital.

Fourth, the overall livelihood asset score for each watershed zone was then calculated by averaging the values of the five livelihood capitals as follows using Equation 18:

$$LA = \left\{\frac{NC + FC + HC + PC + SC}{5}\right\} \quad \text{.....(18)}$$

Where, LA represents the livelihood asset score for each watershed zone; NC, FC, HC, PC, and SC are the respective values for natural capital, financial capital, human capital, physical capital, and social capital. In order to compare the mean differences in access to livelihood

capital assets of the three watershed zones, the group comparison method using one-way ANOVA was applied following Donohue and Biggs (2015) and Siraw et al. (2018). The livelihood asset pentagon was drawn to illustrate the level of access to the capital assets among the watershed zones.

Finally, the LA scores for each watershed zone were transformed into percentages (by multiplying by 100) to generate the livelihood sustainability index which was then meaningfully interpreted using the rating scale system applied by Etana et al. (2021). This LSI scale ranges from 0% (Least sustainability) to 100% (Highest sustainability), and livelihood sustainability is classified as low (when LSI ranges from 0–33%), medium/moderate (when LSI ranges from 34–66%), and high (when LSI ranges from 67–100%).

II. Livelihood Vulnerability Index (LVI-IPCC) Calculation

The Livelihood Vulnerability Index integrated with the IPCC's vulnerability framework (LVI-IPCC) as developed by Hahn et al. (2009) was adopted in assessing the vulnerability of households in the three zones of the watershed. This framework has been applied by previous studies (Shah et al., 2013; Tewari & Bhowmick, 2014; Minh et al., 2019; Zhang & Fang, 2020). The LVI-IPCC comprises eight major components (i.e., socio-demographic profile, livelihood strategies, social networks, health, food, water, natural disasters, and climate variability) distributed across the three dimensions of vulnerability (i.e., exposure, adaptive capacity, and sensitivity). Each of the eight major components of the LVI-IPCC is comprised of sub-components or indicators, totaling 47 (Table 3.6). These indicators were developed based on the literature review, and included some of the initial 29 indicators

developed by Hahn et al. (2009), which were adjusted and customized to reflect the local realities of the watershed. The indicators considered under each major component, the source of information, their measurement scale, and their functional relationship with vulnerability are shown in Table 3.6.

The LVI-IPCC calculation is based on a balanced weighted-average approach, where each indicator contributes equally to the overall index (Hahn et al., 2009; Simane et al., 2016). To analyze the LVI-IPCC for the three watershed zones, five major steps were followed. First, the raw data of the indicators were transformed into appropriate numeric units of measurement such as count, ratios, indices and percentages. Second, since each indicator is measured on a different scale, the data of all the indicators were standardized to a scale between 0 and 1 using either equation (20) or (21) (Hahn et al., 2009). Equation (19) was used where the indicator has a positive relationship with vulnerability i.e. vulnerability increases with the increase in the value of indicators while equation (20) was applied where the indicator has a negative relationship with vulnerability i.e. vulnerability will decrease with an increase in the values of indicators.

$$IndexS_z = \left\{\frac{S_z - S_{min}}{S_{max} - S_{min}}\right\} \quad \text{.....(19)}$$

$$IndexS_z = \left\{\frac{S_{max} - S_z}{S_{max} - S_{min}}\right\} \quad \text{.....(20)}$$

Where, $IndexS_z$ is the standardized value of the indicator for households in watershed zone z; S_z is the actual value of the same indicator; and S_{min} and S_{max} are the minimum and maximum values, respectively, of the same indicator.

Table 3.6: Vulnerability dimensions, major components, indicators and relationships

IPCC Vulnerability Dimensions	Major Components	Indicators	Functional Relationship to vulnerability	Source
Adaptive Capacity	Socio-demographic Profile (SDP)	% of female-headed Household Heads (HHs)	Positive (high percentage increases vulnerability)	DHS (2006); Hahn et al. (2009)
		Dependency ratio of HHs	Positive (high ratio increases vulnerability)	DHS (2006); Hahn et al. (2009)
		The average age of household heads	Positive (old ages increases vulnerability)	Toufique and Yunus (2013)
		% of HHs who have not gone beyond primary education	Positive (higher education level of households head decrease vulnerability)	DHS (2006); Hahn et al. (2009)
		% of HHs with more than four members	Positive (higher numbers of family members increases vulnerability)	Campbell (2013)
		% of HHs with orphans	Positive (higher numbers of orphans increases vulnerability)	Adu et al. (2018)
		% of HHs where members had any informal skill	Negative (higher numbers of skilled family members reduces vulnerability)	Cutter et al. (2003)
		% of HHs with members needing dependent care	Positive (high % leads to high vulnerability)	Adu et al. (2018)
	Livelihood strategies	% of HHs with family members working in a different community/county	Negative (the high % lowers vulnerability)	World Bank (1998)
		% of HHs solely dependent on agriculture and livestock as their only source of income	Positive (higher the numbers, higher is the vulnerability)	Hahn et al. (2009)
		Average agricultural livelihood diversification index	Negative (more agricultural livelihoods reduce vulnerability)	DHS (2006); Hahn et al. (2009)
		% of HHs who took a loan in the past 5 years	Negative (higher %, lower the vulnerability)	Corbett (1988); Hahn et al. (2009)
		Income diversification index	Negative (more income sources reduce vulnerability)	Hahn et al. (2009)
		Natural resource and livestock index	Negative (more natural resources and livestock livelihoods reduce vulnerability)	Toufique and Yunus (2013)
	Social networks	Average Receive: Give ratio	Negative (lower ratio leads to higher vulnerability)	DHS (2006); Hahn et al. (2009)
		Average Borrow: Lend Money ratio	Negative (more sources of lending money reduce vulnerability)	World Bank (1998); DHS (2006); Hahn et al. (2009)
		% of HHs that have not asked their local government for any assistance in the past12 months	Negative (more assistance reduces vulnerability)	WHO/RBM (2003); Hahn et al. (2009)
		Availability of amenities (average no. of types of amenities)	Negative (high availability reduces vulnerability)	Toufique and Yunus (2013)
		% of HHs with membership in social groups	Negative (higher % reduce vulnerability)	Panthi et al., (2016)
		% of HHs that have received or attended training	Negative (more training reduce vulnerability)	Piya et al. (2016)
		% of HHs owning communication device	Negative (higher % reduce vulnerability)	Panthi et al., (2016)
Sensitivity	Health	Average time to reach the nearest health facility (on foot)	Positive (longer distance increases vulnerability)	Hahn et al. (2009)
		% of HHs with a family member with chronic illness	Positive (high % leads to high is the vulnerability)	Hahn et al. (2009)
		% of HHs where a family member had to miss work or school in the past 6 months due to illness	Positive (high % leads to high is the vulnerability)	World Health Organization/Rollback Malaria (2003); Hahn et al. (2009)

		% of HHs without sanitary toilet	Positive (high % leads to high vulnerability)	Madhav (2010); Toufique and Yunus (2013)
	Food	% of HHs dependent on the family farms for food	Positive (high % leads to high vulnerability)	Hahn et al., (2009)
		Average crop diversity index	Positive (high index leads to high vulnerability)	Campbell (2013)
		On average number of months, households struggle to find food/ % of HHs who report at least one month of food insecurity per year	Positive (the higher the number of months, the higher the vulnerability)	Hahn et al. (2009)
		% of HHs that do not save crops	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs that do not save seeds	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
	Water	% of HHs using unprotected water source	Positive (the higher the % using unsafe drinking water, the higher the vulnerability	DHS (2006); Hahn et al. (2009)
		Time to travel to the source of natural water	Positive (longer distance leads to higher vulnerability)	Toufique and Yunus (2013)
		% of HHs that have to go far to fetch water (above 5 km)	Positive (longer distance leads to higher vulnerability)	IIPS and ORC Macro (2007)
		% of HHs that do not have a consistent water supply	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs reporting water conflicts in the previous years	Positive (high % leads to high vulnerability)	Azene et al. (2018)
		The inverse of the average number of liters of water stored per household	Negative (higher liters stored lowers vulnerability)	Hahn et al. (2009)
Exposure	Natural disasters	Average frequencies of flood events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		Average frequencies of drought events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		Average frequencies of land degradation events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		% of HHs with an injury or death as a result of natural disasters in the last 10 years	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs that do not receive a warning about the pending natural hazard	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs with an injury or death to their livestock as a result of natural disasters in the last 10 years	Positive (high % leads to high vulnerability)	Adu et al. (2018)
		% of HHs with losses to physical assets (homestead/agricultural. equipment/ machinery) due to natural disasters	Positive (high % leads to high vulnerability)	Adu et al. (2018)
		% of HHs with crop failure as a result of natural disasters in the last 10 years	More reflects high exposure	Campbell (2013)
	Climate variability	% of HHs that perceived rising trend in daily temperature for the last 10 years	More reflects high exposure	Hahn et al. (2009)
		% of HHs that perceived annual temperature changes for the last 10 years	More reflects high exposure	Hahn et al. (2009)
		% of HHs who have experienced annual rainfall changes for the last 10 years	More reflects high exposure	Hahn et al. (2009)

Third, after the standardization of all indicators, the indicators were averaged using Equation (21) to obtain the index of each major component for the respective watershed zones.

$$M_c = \left\{\frac{\sum_{i=1}^{n} IndexS_{zi}}{n}\right\} \quad \text{.....(21)}$$

Where, M_c is one of the eight major components for each watershed zone; $IndexS_{zi}$ represents the indicators indexed by i that make up each major component; and n is the number of indicators in each major component. The weights of each major component are determined by the number of indicators that make up each major component and are incorporated to make sure that all indicators contribute equally to the final LVI-IPCC (Hahn et al., 2009).

Fourth, once the values of each major component for each watershed zone were obtained and their weights determined, they were combined under their respective vulnerability categorization, exposure (natural disasters and climate variability), sensitivity (health, food, and water), and adaptive capacity (socio-demographic profile, livelihood strategies, and social networks).

The values for each vulnerability categorization for every watershed zone were then calculated based on the weighted averages of their respective major components using equations 22a-22c:

$$Exposure_z = \left\{\frac{W_{nd}ND + W_{cv}CV}{W_{nd} + W_{cv}}\right\} \quad \text{.....(22a)}$$

Where, W_{nd} and W_{cv} are the weights for natural disasters and climate variability, respectively; and $Exposure_z$ (exposure score for the studied watershed zone).

$$Sensitivity_z = \left\{\frac{W_h H + W_f F + W_w W}{W_h + W_f + W_w}\right\} \quad \text{.....(22b)}$$

Where, W_h, $W_{f,}$ and W_w are the weights for health, food, and water, respectively; and $Sensitivity_z$ (sensitivity score for the studied watershed zone).

$$Adaptive\ Capacity_z = \left\{\frac{W_{sdp}SDP + W_{ls}LS + W_{sn}SN}{W_{sdp} + W_{ls} + W_{sn}}\right\} \quad \text{.....(22c)}$$

Where, W_{sdp}, $W_{ls,}$ and W_{sn} are the weights for socio-demographic profile, livelihood strategies, and social networks, respectively; and Adaptive $Capacity_z$ (adaptive capacity score for the studied watershed zone).

Finally, the three vulnerability contributing factors were combined using equation (23) to calculate the LVI-IPCC score for each watershed zone.

$$LVI\text{-}IPCC_z = (Exposure_z - Adaptive\ Capacity_z) * Sensitivity_z \quad \text{.....(23)}$$

Where, LVI-$IPCC_z$ is the LVI for the studied watershed zone, $Exposure_z$ (weighted average of natural disasters and climate variability), $Sensitivity_z$ (weighted average of the heath, food, and water), and Adaptive $Capacity_z$ (weighted average of the socio-demographic, livelihood strategies, and social networks). Upon obtaining the value for LVI-IPCC, the rating system shown in Table 3.7 was used in classifying the livelihood vulnerability of the three watershed zones. This rating system has a scale ranging from 1 (indicating most vulnerability) to -1 (indicating least vulnerability) based on IPCC (2014).

Table 3.7: Vulnerability Classification scheme for LVI-IPCC scores

Vulnerability Classification	**Overall LVI-IPCC Values**
Very high	0.61-1
High	0.21-0.60
Moderate	0.20-(-0.19)
Less	(-0.20)-(-0.60)
Very less	(-0.61)-(-1)

Noteworthy, a comparison of the vulnerability level of three contributing factors (exposure, sensitivity, and adaptive capacity), their respective major components and composite indicators across watershed zones is based on their index scores where higher scores represents higher vulnerability and vice versa.

3.8 Logistical and Ethical Considerations

Before the commencement of the study, research permits were obtained from Kenyatta University Graduate School (Appendix 7), the National Commission for Science, Technology, and Innovation (NACOSTI) (Appendix 8), Migori County Commissioner (Appendix 9), and the relevant department of Migori County Government. Participation in the study was entirely optional, with key informants and respondents having the option to leave at any time without offering explanations. Before agreeing to take part in the interviews, those who opted to do so were asked to carefully read and sign the consent form. Interviews with key informants were conducted discretely at their workstations to maintain confidentiality. The scholar, along with the rest of the study team, ensured that the information gathered is kept safe and secure from unwanted access. Both during the study and publication of the findings, no personal data about any participant was revealed.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents analyses and discussions of the study findings, and a brief reflection on theories, methods and approaches. Initially, the chapter is organized per the four study objectives as follows; Sections 4.2, 4.3, 4.4, and 4.5 respectively presents analyses and discussions on the institutional arrangements in the management of Migori River watershed and their influence on the nature and level of coordination among the actors, impacts of land use and land cover changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 - 2020, the spatio-seasonal variations of water quality parameters of the Migori River and associated household health risk implications in Migori River watershed, and the level of sustainability of community livelihoods in the Migori River watershed and its associated vulnerability to climate change impacts. Lastly, the reflection on theories, methods and approaches is presented in section 4.6.

4.2 Assessment of the Institutional Arrangement and Coordination in the Governance Framework of Migori River Watershed

The analysis of the governance framework for the watershed is composed of five sections. The first section presents analyses and discussions on the institutional arrangement in the management of the Migori watershed detailing the roles and responsibilities of the actors, the second presents analysis on the nature of coordination among the actors involved in the RBM of the watershed, the third focuses on the level of coordination between actors, the forth discusses the influence of formal and informal rules of the institutional arrangement on coordination of actors, and the fifth generally contextualizes the findings within the theoretical constructs.

4.2.1 Institutional Arrangements for the Management of Migori River Watershed

There are diverse set of actors involved in the management of natural resources of the watershed. These actors have been classified into two; permanent actors (government actors and river basin organizations) referring to actors whose RBM mandates are defined in the existing legal framework, and non-permanent actors (hereafter referred to as the external support agencies) referring to actors whose RBM mandates are not defined in the legal framework. The interactions between the permanent actors are summarized in Figure 4.1.

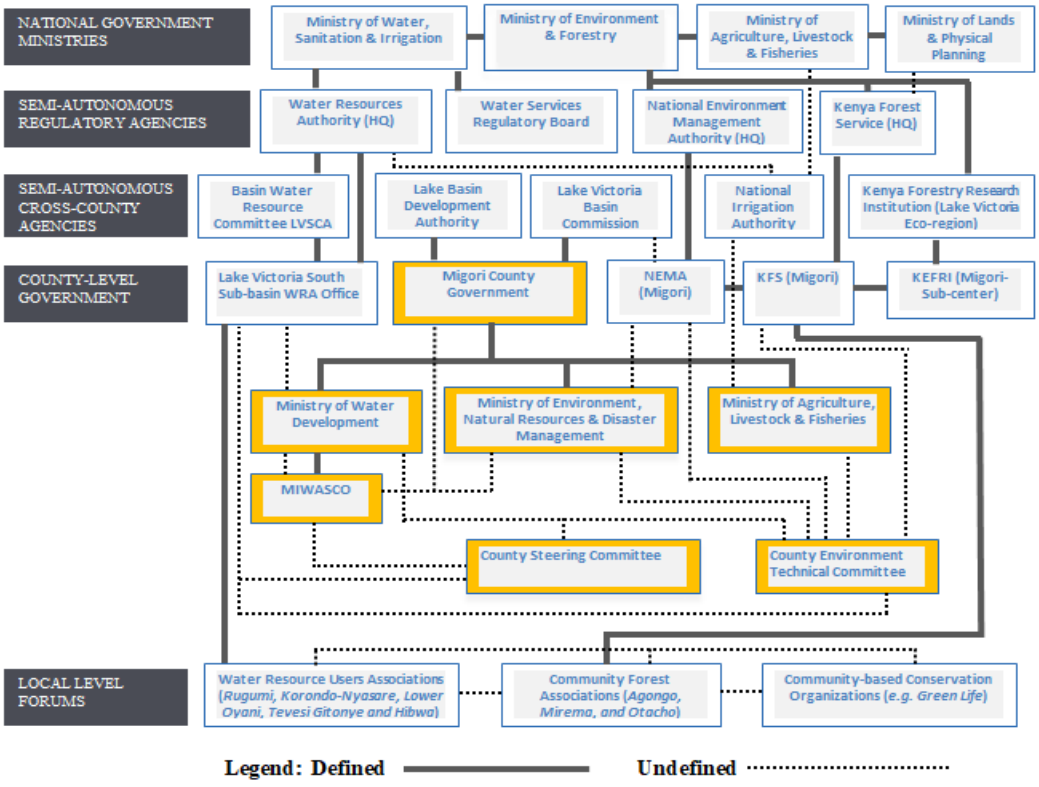


Figure 4.1: Governance interactions between permanent actors in Migori River watershed

(i) Government Actors

Key informant interviews revealed that there are many government agencies with different mandates, roles, and responsibilities involved in the river basin management (RBM) of the watershed (Figure 4.1 and Table 4.1).

Table 4.1: Government actors involved in natural resource management in Migori River watershed

Actor	Governance Level	Establishment	Mandate relevant to RBM	Role and Responsibilities in Migori River Watershed
Kenya Government Ministries: environment, water, agriculture and land	National level	Established in 2011 under The Constitution of Kenya 2010.	Formulation of policies, strategies, and legislation; sectoral leadership and coordination; and financing.	Empowers their respective state agencies operating within the watershed to carry out their statutory prescribed mandates including sectoral policy formulation and implementation, by providing financial and capacity-building support.
County Government of Migori: Departments of Environment, Natural Resources and Disaster Management; Agriculture, Livestock, and Fisheries; Water Development	County-level	Established in 2013 under the County Government Act 2012 which operationalized the devolution provision outlined in the Constitution of Kenya 2010.	Implementation of constitutional obligations (i.e., development and implementation of legislation and county-level policies) and specific national government policies on environmental conservation, natural resources management, water management, land planning, and climate change.	• The Department of Agriculture promotes soil and water conservation by providing farm inputs and extension services to farmers, educating farmers on climate-smart agriculture, regulating agricultural pollution of the rivers and streams, and executing climate change mitigation projects. • The Department of Environment is developing county policies and laws on solid waste management, climate change mitigation, community forest conservation, and the management of artisanal mining. It also implements river bank conservation measures; farmer training on best practices of conservation agriculture; management of mining operations, surface runoff, open dumps, and commercial effluents in the vicinity of riparian zones. • The Department of Water is involved in financing and developments of pans and boreholes; spring protection through fencing; and financing of capacity building for MIWASCO.
Water Resources Authority (WRA)	National level with a regional station in Kisii for the Migori River watershed	WRA is a state agency that was established in 2003 under the Water Act 2002, now repealed by the Water Act, 2016.	Sustainable protection, management, and conservation of water catchment areas	Protection, management, and conservation of the Migori River watershed; management of water abstractions; water quality monitoring; water permits issuance; resolution of water-related conflicts; collection of water resources data, and provision of technical assistance to WRUAs.
National Environment Management Authority (NEMA)	National level with county-level station based in Migori	NEMA is a state agency established under the EMCA Act No. 8 of 1999, revised in 2015.	NEMA is mandated to provide general guidance, coordination, supervision, and management of the environmental sector	Evaluation and approval of EIAs and EAs; implementation of climate change adaptation programs; provision of technical assistance to other agencies involved in environmental projects; conducting environmental sensitization; and pollution monitoring

Actor	Governance Level	Establishment	Mandate relevant to RBM	Role and responsibilities in Migori River watershed
Kenya Forest Service (KFS)	National level with county-level station based in Migori	KFS is a state agency that was established in 2007 under the Forest Act 2005, now repealed by the Forest Conservation and Management Act 2016.	Overseeing sustainable conservation, management and utilization of all forests in Kenya including water catchment areas.	Afforestation and reforestation, protection of gazetted forests from deforestation; regulating planting of certain exotic trees along riparian zones; promotion of sustainable utilization of forest resources; and providing technical assistance to CFAs and Migori County Government in the management of community forests.
Water Service Providers (E.g. MIWASCO	County level	WSPs are established under the Water Act 2016.	Water supply and sanitation in the county	The WSPs are involved in some limited conservation measures, including river bank protection to improve water quality.
Kenya Forestry Research Institute (KEFRI)	National level with county-level station based in Migori	KEFRI was established in 1986 by an Act of Parliament (Cap 250)	Undertaking forestry research in Kenya.	KEFRI is engaged in research and development of better tree species which are then distributed to stakeholders for planting within the watershed.
National Irrigation Authority	National level with regional station	NIA was established under the Irrigation Act 2019	Developing, managing and regulating irrigation services	NIA developed the Lower Kuja Irrigation scheme and they are co-managing it with the Migori County Government and providing technical support.
Lake Basin Development Authority (LBDA)	Regional level	The LBDA was established in 1979 through Cap 442 of the laws of Kenya	Catalyse socio-economic development in the Lake Victoria basin through sustainable use and management of natural resources	Within Migori County, LBDA is spearheading the planning, implementation and monitoring of various projects on environmental conservation, water provision and supply, green energy development and promotion, and capacity building for institutions and groups on sustainable conservation agriculture.
Lake Victoria Basin Commission (LVBC)	Intergovernmental level	LVBC is an institution of the EAC established in 2001 under the LVBC Protocol, ratified in 2004 by EAC partner states	Coordination and promotion of interventions of various actors within the Lake Victoria Basin region to spur sustainable development	In Migori sub-basin region, the LVBC is undertaking the management and conservation of aquatic resources including fisheries resources, promoting access to clean water and sanitation, implementing climate change projects
Lake Victoria South Water Works Development Agency (LVSWWA)	Regional level	The LVSWWA was established in 2004 under the Water Act 2002, now repealed by the Water Act, 2016.	Ensuring efficient and economical provision of water and sanitation services through the development of water and sanitation infrastructure.	Implementation of projects on wastewater treatment which has a bearing on management of water quality of water sources.

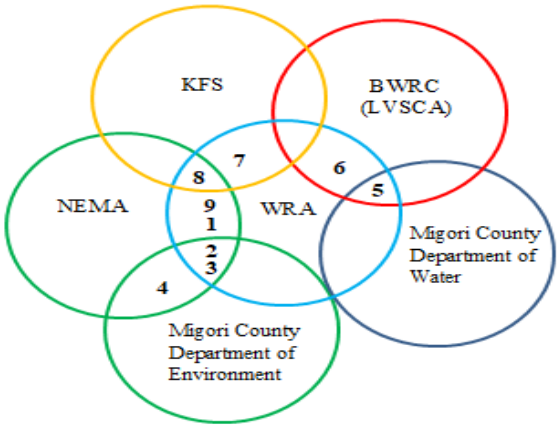
Hierarchically, the national government ministries with roles and responsibilities in line with the RBM of the watershed sit at the top of decision-making in the watershed governance structure. The second level in the hierarchy of governance comprises the semi-autonomous regulatory agencies (SARAs) headquartered in Kenya's capital, which are empowered by their respective line ministries to carry out their statutory prescribed mandates. The SARAs have lower-level agencies operating at the county level and have major and direct roles in the management of watershed resources in the catchment. These county-level agencies of SARAs constitute the third level of watershed governance and in the order of influence, they include Water Resources Authority (WRA) who are in charge of water resources management; National Environmental Management Authority (NEMA) in charge of the coordination of environmental management; and Kenya Forestry Service (KFS) in charge of forest management. This third governance level also includes the county government actors, in this case the Migori County Government, which are tasked with the management of specific natural resources in their jurisdiction. Operating at the cross-country level are some government agencies with limited-but-direct roles in managing water or natural resources in the catchment and always have to obtain licenses for their planned operations in the watershed from WRA, NEMA, or the County Government.

These actors requiring licenses for their programs include Lake Basin Development Authority (LBDA), Lake Victoria Basin Commission (LVBC), and Lake Victoria South Water Works Development Agency (LVSWWDA); but obtaining these permits often involve unnecessary delays arising from late review and verification of the project documentation. There are other key government actors that are not directly related to catchment management but are regarded to play part such as the Ministry of Interior and Coordination of National Government with officials acting at the county-level which not only offers security to government officials whenever conflicts emerge within the watershed but also assist in

mobilizing the public for participation in conservation efforts organized by the relevant government agencies or ESAs.

The mandate of each government actor involved in RBM for Migori River watershed is provided for in their respective acts, defining the roles and responsibilities. However, some roles and responsibilities of various RBM actors within the watershed are duplicated, overlapping or conflicting, which is summarized in the Venn diagram (Figure 4.2).

The issuance of effluent discharge permits is performed by both NEMA and WRA at the same time. This is because section 108 of the Water Act 2016 gives WRA the responsibility of issuing permits for effluent discharge, and at the same time section 75 of EMCA Act 1999 and its subsequent amendment of 2015 gives NEMA the responsibility of issuing permits for effluent discharge.



Key:

1. Issuance of effluent discharge permits
2. Coordination of actors dealing with environmental and water resources management
3. Catchment protection & management function
4. Enforcement of environmental regulations
5. Establishment and management of WRUAs
6. Collection of data on quality and quantity of catchment water resources
7. Permitting abstractions at key water sources in forests
8. Regulating logging within a gazetted forest; deforestation or planting of certain exotic trees along key riparian zones on non-public lands; and afforestation or re-forestation of mountainous regions and hilltops
9. Setting and regulating water quality standards

Figure 4.2: Overlapping roles and responsibilities of government actors in Migori River Watershed

The function of coordination of actors dealing with environmental and water resources management within the watershed is an overlapping role performed by NEMA, WRA, and Migori County Department of Environment. NEMA is legally mandated to supervise and coordinate all environmental management operations (including activities related to water resource conservation and management) conducted by other actors under section 9(1) of the EMCA Act 1999 whereas WRA is mandated, under section 12(b) of the Water Act 2016, to regulate the utilization and management of water resources which involve coordinating the activities of actors involved in the utilization and management of water resources. The Migori County Government, on the other hand under section 30(a) of EMCA Act 1999, is given the responsibility of properly managing the environment within the county (a function that includes coordinating the actors involved in environmental management in the county) through the County Environment Committee headed by the CEC in charge of environment ministry at the county provided for under section 29(2) of EMCA Act 1999.

The function of catchment protection and management is duplicated among NEMA, WRA, and Migori County Department of Environment. Section 44 and 47 of EMCA Act 1999 empowers NEMA to develop, regulate and implement measures for the sustainable protection of water catchment areas; and section 22 authorizes WRA to be responsible for the protection of catchment areas. Even though the county government does not have any legal standing to perform this function under the Water Act 2016, empirical findings from the interviews indicated that the Migori County Government has been performing some aspects of this function by claiming authorization from section 30(a) of EMCA Act 1999 which authorizes it to be responsible for proper management of the environment within their jurisdiction which includes the Migori River watershed. The KFS, under section 8(j) of the Forest Conservation and Management Act 2016, is also given the responsibility of managing catchment areas in terms of water and soil conservation among other ecological services.

The establishment and management of WRUAs is also a conflicting role as both WRA, BWRC for the LVSCA, and Migori County Department of Water claim responsibility for it. Under the Water Act 2016, WRA is given the express authority to oversee the establishment of both BWRCs and WRUAs and regulate their activities under section 29(1) whereas the BWRC is required to facilitate the establishment and operation of WRUAs. Despite the lack of legal backing for the performance of this function by the county governments, findings from interviews indicated that, the Migori County Department of Water (through the MIWASCO) has been actively involved in the formation of WRUAs without consulting both WRA and the BWRC for the Lake Victoria South Catchment Area.

Under the Water Act 2016, collection of data on the quality and quantity of catchment water resources is a function that has been granted to WRA under section 13(2b) and the Basin Water Resource Committee under section 27(e). From the interviews, it was observed that both agencies have been actively involved in the collection of water quality datasets and river discharge datasets for the Migori River watershed, a situation that represents a duplication of efforts and wastage of resources since there is no data collection and sharing protocol between these two bodies. Each agency uses their collected datasets in designing their management programs or advising the county government departments.

Permits for water abstractions at key water sources in forests are a conflicting role being carried out by both WRA and KFS based on their respective legal mandate. Under section 12(d) of the Water Act 2016, WRA has the express authority to issue and enforce permits for all water abstractions, including at key water sources in the forests. On the other hand, the Forests (Fees and Charges) Rules, 2016, stipulate that water abstraction at key sources within the forest can only happen with authorization for KFS. The Rules gives the Cabinet Secretary the power to establish the fees payable for the approval of water abstraction applications.

The functions of regulating logging within a gazetted forest; deforestation or planting of certain exotic trees along key riparian zones on non-public lands; and afforestation or reforestation of mountainous regions is overlapping roles between KFS and NEMA. The KFS under section 56 of the Forest Conservation and Management Act 2016 is mandated to authorize all forest conservation or forest resource utilization activities including logging within gazetted forests and private lands through permits and licenses. However, NEMA is authorized to regulate deforestation or planting of certain exotic trees along key riparian zones on non-public lands under section 42(1d) and regulate afforestation or reforestation of mountainous regions under section 46 of EMCA Act 1999, but lacks the legal mandate to regulate logging activities inside gazetted forests. The interviews indicated that both NEMA and KFS are involved in regulating all these three functions in some form. However, since NEMA and KFS stations in Migori County involved in the RBM of the study area have a close working relationship, this overlapping role doesn't present a conflict as they mutually agreed to bestow the regulation and enforcement of this function solely to NEMA.

The function of establishing and regulating water quality standards is a role performed by both NEMA and WRA. The conflicting role of setting and regulating water quality standards for water resources for various uses is allocated to NEMA under section 71 of the EMCA Act of 1999, and at the same time allocated to WRA under section 20 of the Water Act 2016. The interviews showed that this overlap doesn't affect the water service providers since they are legally required to only follow the standards set by their regulator which is WRA. However, it affects the industries, companies, and facilities that discharge effluents into the environment as they would get conflicted on what standards to adhere to because they are regulated by both NEMA and WRA through the issuance of effluent discharge permits, another overlapping function.

(ii) River basin organizations (RBOs)

These are specialized entities that are involved in managing water resources at the sub-basin level. In the watershed, there are 2 major types of RBOs, namely Water Resource Users Associations (WRUAs) and Community Forest Associations (CFAs). WRUAs comprise landowners, water users, and other relevant stakeholders, and operate at a sub-basin level. WRUAs are mandated by the Water Act 2016 to undertake river bank protection; establishment of tree nurseries for donating to landowners for planting on their farms; community sensitization and training on soil and water conservation measures; and advising Water Resources Authority on water allocation. However, only three WRUAs are active and operating within the watershed despite 16 having been registered in recent years since 2010 when the county government was established under devolution in 2010 constitution. The inactive WRUAs were formed by people who were interested with getting some funds from the government, but when they noticed that government support was only little and comes with strict accountability they abandoned the whole WRUAs.

The three WRUAs of Hibwa (founded in 2012), Korondo-Nyasare (founded in 2006), and Lugumi (founded in 2016) are spread over the watershed representing the upstream, midstream, and downstream sections of the watershed respectively. In terms of current membership, Hibwa has 282, Korondo-Nyasare has 350 and Lugumi has 526. In line with their constitutions, payments from membership registrations and monthly subscription fees cover their operating expenses. The registration fee is Kshs 100 paid by each member joining a WRUA. The second funding source is monthly contribution of 250sh paid by each registered member. So, it's these small collections that go towards financing limited watershed activities like establishment of tree nurseries and facilitating community sensitization campaigns. The WRUAs are managed by five-member executive committees

and sub-committees of varying membership in charge of Procurement, Finance, Livelihood, Monitoring, and Climate Change. The committee members are elected every three years in line with organization's constitutions.

Besides WRUAs, the watershed has three Community Forest Associations (CFAs) mandated by the Forest Act 2016 to participate in the co-management of forests. These are Otacho founded in 2009, Agongo founded in 2016, and Mirema founded in 2018 with memberships of 68, 41, and 96 respectively. The memberships of CFA are very low compared to WRUAs. Concerning the nature of operations, the management plans for the Mirema CFA for instance, organizes the members into 12 user groups, each of which carries out enrichment planting on degraded forest sections, and farmer nurturing and management of indigenous trees in their respective forest blocks. In turn, the user groups are allowed to conduct income-generating activities including beekeeping and agricultural production through small-scale crop farming within the forests, the establishment of nurseries and sale of tree seedlings.

Like WRUAs, CFAs operate based on their constitutions, which dictate how they choose leaders i.e. the executive committee. For instance, for Otacho CFA, it was noted that their constitution provides for holding elections for the committee members every three years, and that for one to be selected in a leadership position one must be living adjacent to the forest block where the CFA operates, and must be an active participant of the group's operations. Educational achievement, however, is not part of the guidelines but essentially the members would often tend to choose those they perceive to have enough education to be able to engage with government officials and even donors. Also like WRUAs, CFAs operational costs for management or conservation activities draw from payments from membership registrations and monthly subscription fees. The CFAs receive capacity-building assistance from NGOs which primarily finance and organize trainings for the members on forest

conservation issues, new improved methods of farming, and soil erosion prevention. The knowledge gained by the members has greatly benefited the local communities, who have been regularly sensitized on tree nursery establishment, beekeeping activities including marketing, and participation in forest management among others, through barazas or at the invitation by some community members.

(iii) External Support Agencies (ESAs)

The ESAs encompass an agglomeration of private entities, academic institutions, NGOs, and donor agencies that are not necessarily located within the watershed, but provide some form of capacity building, technical, or financial assistance to organizations directly involved in or concerned with ecological conservation of watershed resources or socio-economic empowerment of local communities residing within the Migori River watershed.

There were about 30 ESAs that are directly or indirectly working towards ecological conservation or socio-economic empowerment of communities in the watershed. Some ESAs like NGOs, national or international, must often obtain necessary approvals from the NGO Coordination Board before they can be allowed to operate within the country, including in Migori County where the watershed is located. The findings on key ESAs are summarized in Table 4.2.

The interviews with experts indicated that ESAs operating within the watershed play a significant role in the formulation of county policies; advocacy for water rights; research and development of best practices for water supply and sanitation; and financing of community-based climate resilient interventions, socio-economic empowerment programs, afforestation projects, and flood mitigation interventions.

Table 4.2: External support agencies involved in natural resource the management in Migori River watershed

Name of ESA	Organization Type	Establishment	Motivation for creation	The focus of actions in the Migori River Watershed
World Vision International	International NGO	Founded in 1950 in the USA	Promotion of sustainable community-based development	Implementing community-based Re-greening Africa Project
British American Tobacco	International NGO	Founded in 1902 in Britain	Production and sale of tobacco	Funding afforestation programs
Japan International Cooperation Agency	International NGO	Founded in 1974 in Japan	Promotion of socio-economic development in developing world	Carrying out technical studies and surveys
One Vision Kenya	National NGO	Founded in 2012 in Kenya	Promotion of sustainable utilization and management of natural resources	Community-based climate resilient interventions, community environmental education
Ecology Without Borders	International NGO	Founded in March 2009 in Slovenia	Provision of technical assistance to communities towards restoration, protection, and conservation of ecosystems	Community socioeconomic empowerment programs, and green energy initiatives
Kenya Red Cross Society	National NGO	Founded in 1965 in Kenya	Provision of humanitarian assistance to communities	Flood mitigation interventions on the downstream of Migori River
Send a Cow	International NGO	Founded in 1988 in the UK	Transform rural community livelihoods to promote the protection of the planet	Livelihood support programs, spring protection, agroforestry promotion
Rural Aids Prevention and Development Organization (RAPADO)	National NGO	Founded in 2004 in Kenya	Building stronger communities through AIDS prevention	Establishment and management of community tree nurseries
Hands in Hand International	International NGO	Founded in 1980 in the UK	Promotion of socio-economic empowerment of the impoverished and marginalized communities	Climate-smart agriculture projects
Public Universities	Government Agency	Varied	Centres of higher education	Research ventures on various natural resource management aspects including ecosystems conservation, aquaculture, and socio-economic surveys
Local Banks	Private Businesses	Varied	Provision of banking and financial services	Funding community environmental initiatives e.g. riparian conservation
Development Partners (World Bank, African Development Bank, EU Investment Bank, DANIDA, USAID, GIZ, KFW Development Bank	Multinational NGOs	Varied	Provision of financial services globally	Financing of community smart agriculture projects and climate change initiatives

NGO efforts have been very effective in addressing ecological conservation issues in the watershed and this is largely because they have established strong informal networks and financial resources that enable them to work directly with the people in actually achieving their goals be it conservation or community livelihood projects.

The main private entities involved in watershed resources management in the watershed are banks that provide funding to community environmental initiatives such as riparian conservation organized by government actors. Usually, such initiatives are always multiagency and are often conducted during special occasions. For example, during the international forest day or environment day or water day, the banks collaborate with British American Tobacco (BAT), World Vision, Vector Link, KFS and other government agencies on the procurement and planting of indigenous trees and bamboo trees on riparian banks and degraded sections of the watershed. Academic institutions within the larger Lake Victoria basin have been actively collaborating with various actors in conducting techno-scientific research in the watershed, and knowledge dissemination. For instance, two public universities, Kisii and Maseno, have been actively working towards ecosystems conservation or promotion of sustainable livelihoods in the watershed.

4.2.2 Nature of Coordination in the Management of Migori Watershed

The nature of coordination was analyzed in terms of administration plus the six dimensions (sub-activities) of management as defined by the Fayolian theory of management (Corsame, 2016) i.e. communicating, organizing, planning, commanding, executing, and controlling. Table 4.3 and Figure 4.3 summarizes on the nature of coordination as rated by a panel of experts.

Table 4.3: Nature of Coordination in the integrated management of Migori River watershed

Variables	Indicator(s)	Findings and Analysis
Administration	Existence of a single coordinating body for RBM and how coordination is performed	• No single coordinating body is available; County Environment Technical Committee exists but it's been non-operational • No lead agency in joint programs/projects • Coordination is on a per-need basis
	Stakeholder networks (existence of partnership agreements between and/or among actors)	• MoUs for long term cooperation only exist between a few government agencies collaborating • MoUs for short term cooperation only exist between a few government agencies collaborating with ESAs • Only MoUs involving NGOs are documented, with a few of them having penalties for non-compliance
Communicating	Presence of communication channels among actors	• National-government-level agencies hold meetings on RBM with stakeholders quarterly • County-government departments hold meetings with stakeholders on a per-need basis on RBM projects • River Basin Organizations and ESAs hold meetings with stakeholders on a per-need basis, depending on the activities of the RBM projects
	Presence and frequency of information sharing among actors	• Data sharing between national government agencies exist, though it's on a per-need basis & takes a long due to bureaucratic procedures • Data sharing between national and county government agencies are highly inefficient and almost non-existent due to the lack of established legal mechanisms • Data sharing between government agencies and ESAs exist but it is hindered by long and ineffective bureaucratic procedures
Organizing	Presence of a mechanism to distribute authority, roles, and responsibilities among actors	• No single coordinating body but most collaborating actors have some level of distribution of roles among them • Intergovernmental agencies, cross-county agencies, ESAs, and RBOs focus on their jurisdictions/interests
Planning	Existence of a common master plan and joint participation of all actors in the development of the master plan	• No common RBM master plan for all actors due to lack of clear coordination mechanisms • County departments (water, agriculture, and environment) and external support agencies (donors & NGOs) have joint master plans for projects • National government actors often focus on their own strategic plans/management plans • Joint planning between collaborating actors often face delays in reaching agreements owing to political squabbling as well as other concerns • RBOs awaiting coordination from other agencies • Coordination on planning is on a per-need basis, depending on the RBM activities proposed
	The existence of a synchronized schedule of operations conducted by various actors	• Master plans between county departments and external support agencies (donors & NGOs) have synchronized schedule of activities to be performed by various actors

Variables	Indicator(s)	Findings and Analysis
Commanding	Existence of a central authority that provides order and direction based on strategic management plans	• No common strategic RBM plans • No single coordinating body is available; County Environment Technical Committee exists but its non-operational • No lead agency in joint RBM programs • Not all agreements (MoUs)/processes are documented and enforceable
Executing	Cooperation and collaboration among actors in the implementation of management plans/projects	• Each state agency implements and monitors its projects, and there are limited opportunities for collaboration • Collaborations during implementation are on a per-need basis and sometimes affected by conflicting roles • Challenges and delays faced on some RBM projects due to jurisdictional issues and delay in permit acquisition from NEMA and WRA
Controlling	Existence and effectiveness of authority that enforces compliance among actors, monitoring and providing feedback	• Each agency implements and monitors its projects; no synchrony • In the case of joint programs, no single authority ensures compliance of actors with the implementation of management plans or projects • No penalties for actors which don't implement mutually agreed project activities • Lack of control of activities in the watershed due to jurisdictional challenges

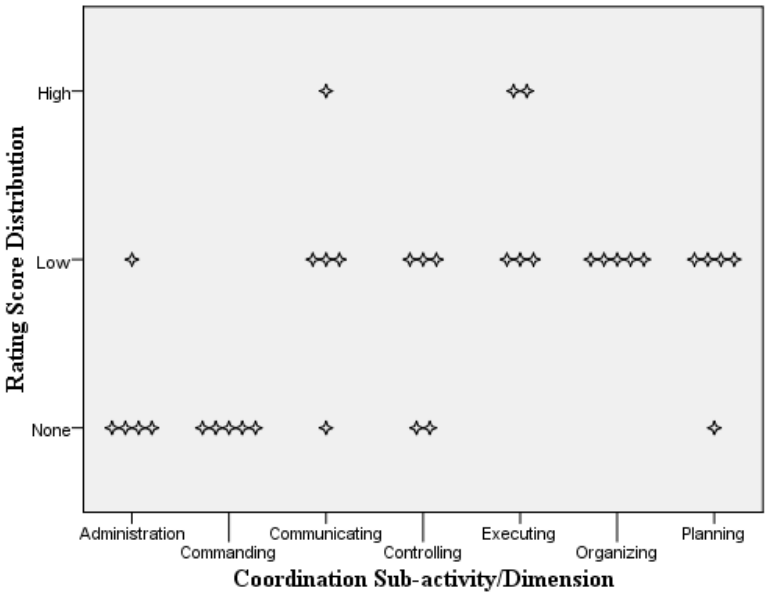


Figure 4.3: Distribution of rating scores of coordination dimensions for the Migori River watershed

Key: *None* is where sub-activity is non-existent, *Low* is where sub-activity exists but not all-encompassing, and *High* is where activity exist and all-encompassing.

The performance per coordination dimension (Figure 4.3) shows that administration and commanding dimensions are rated “none”, indicating that the findings on these two coordination sub-activities don’t measure up to the baseline indictors. The rest of the coordination sub-activities, i.e., communicating, controlling, executing, organizing and planning, are rated “low”, indicating that findings on those sub-activities suggest that they exist but their degree of performance doesn’t cover all aspects of the baseline indicators.

(i) Administration (coordinating body and stakeholder networks)

The administration of the RBM was evaluated in terms of the existence of a single coordinating body for RBM and the stakeholder networks i.e., the existence of partnership agreements between or among actors. Concerning coordinating body, the respondents had diverse ideas about who exactly coordinates RBM in the Migori River watershed. Three actors were cited by respondents to be the coordinating agencies, i.e., NEMA, WRA, and the County Environment Technical Committee (CETC). In water resource management, the principal agency, WRA, was identified as the coordinating body. It was criticized for lack of formal coordination meetings among the many stakeholders during planning or project implementation. Moreover, NEMA was cited as a coordinating body since it is obligated by law to supervise all environmental regulations. However, NEMA was also criticized for inactive participation in environmental issues other than reviewing and approving EIAs/EAs. Out of these three agencies, most respondents stated that the County Environment Technical Committee should be in charge of coordinating because it was designed to bring together all the key agencies related to the water/environmental management. However, the informally instituted Committee is dysfunctional due to constant supremacy wrangles between NEMA and WRA perpetrated by overlapping/conflicting roles and unclear/lack of regulation on the overall coordinator of river basin management programs; WRA is in charge of managing

water resources and their catchments but the water resources and their catchments are part of the natural resources and environment which NEMA is mandated to manage. Based on these findings, the existence of a single lead agency in charge of coordinating RBM activities is lacking. Due to the lack of a single coordinating body, coordination between national government agencies, Migori county government departments and the ESAs is on a per-need basis.

The study also evaluated the stakeholder networks, indicated by the presence of a memorandum of understanding (MoU) between actors, which facilitate coordination in RBM for Migori River watershed. The interviews revealed that MoUs for long-term cooperation are only available between collaborating government agencies while those between government agencies and ESAs (NGOs) are short-term in nature. These MoUs outline the processes and mechanisms for collaboration, including the allocation of roles and responsibilities among the parties involved. For instance, one MoU that brought together WRUAs, WRA, and KFS in a partnership, allocated responsibilities among parties as follows: WRA was tasked with performing abstraction surveys, riparian marking, and developing Sub-catchment Management Plans for WRUAs, KFS was tasked with providing suitable tree species for planting in riparian regions, and WRUAs were tasked with conducting tree planting along river banks, and community sensitization on soil and water conservation measures. The validity of MoUs between government agencies themselves, and those between government agencies and ESAs were varied in nature. Partnerships between government agencies are long-term and last beyond 5 years while those between ESAs and government agencies are usually short-term and their validity is often aligned with the timelines of the joint project under implementation. The actors formally collaborating with others through different MoUs believe that MoUs have been highly efficient and productive agreement tools for RBM as they support cordial and synchronized working relationships

while reducing potential problems between the parties involved. A written agreement clarifies responsibilities and roles and strengthens each party's dedication to their obligations.

Apart from formal agreements of MoUs, the actors in the Migori river watershed also utilize informal agreements to guide their collaborations on various RBM activities. Even though the usage of informal agreements are rare among actors from the government side and ESAs, the interviews showed that nearly all RBOs (WRUAs and CFAs) use informal agreements on collaborations and they don't usually have formal MoUs with their collaborators. However, the effectiveness of both formal and informal stakeholder networks on RBM for the watershed was found to be similar. For instance, the collaborations between WRUAs and WRA and CFAs and KFS are effective despite being grounded on informal agreements. Also, findings showed that the WRUAs in Migori County, through informal agreements, have successfully formed an umbrella WRUA called Migori County WRUAs which has provided them a better platform for lobbying for financial and technical support from donors. As with any agreements, both the formal and informal working agreements among actors in the watershed faced the challenge of non-compliance from the concerned parties. Findings indicated that most MoUs between government agencies are soft on enforcement of penalties as compared to those that involve NGOs which are often well-documented and involve strict penalties for non-complying signatory. For instance, it was found that World Vision's MoUs with other government agencies contain penalties for non-compliance including blacklisting of some stakeholders from future participation in projects and legal redress in courts.

Generally, administration sub-activity was found to be non-existent, meaning the findings are not at par with the baseline indicators for RBM administration. Of importance is the lack of a coordinating body for facilitating the administration process.

(ii) Communicating

Communication channels, as pointed out by 19 out of 22 respondents, are present among and between stakeholders in the Watershed. Findings showed that the national-government-level agencies (such as NEMA, WRA) hold meetings on RBM with stakeholders quarterly while Migori County Government departments and river basin organizations (WRUAs and CFAs) hold meetings with stakeholders on a per-need basis on RBM projects. Coordination meetings between national-government-level agencies and other stakeholders seem to be happening as a matter of legal obligation rather than appreciation of the importance of information sharing on RBM activities and projects. For instance, WRA often convenes yearly stakeholder workshops to coordinate the sub-basin area's execution of the Catchment Management Strategy, in accordance with the WRM Rules 2007; although it is quite challenging to have all the relevant RBM actors involved. Most respondents cited a coordination lapse due to a lack of explicit and regular coordination platforms or channels for feedback and conversational engagement.

Before actually issuing licenses, NEMA engages with key stakeholders, including other state agencies and the general public, through EIA process. However, the majority of interviewees expressed dissatisfaction with the lack of coordination meetings or visibility on the ground. To this, an informant from NEMA responded that they normally call for *barazas* (public meetings where important matters affecting the community are discussed) and workshops within the county whenever there’s a need for education and sensitization of stakeholders on new policies/regulations or to address environmental-related contentious issues between organizations and the public.

Apart from coordination meetings, communication channels utilized by the actors include memos, phone calls, emails, and office physical visits; these types of communication

channels are often focused on following up on commitments owed by one organization to the other. For instance, the Migori County Governments usually write to NEMA requesting permits for some of their environmental activities like solid waste management. Information sharing among actors was established from the interviews to be on a per-need basis and ineffective, as most respondents reported being unaware of what their counterparts was doing in terms of river basin management activities. Just a few respondents reported sharing information with other stakeholders via the distribution of brochures, the circulation of yearly work plans, provision of extension services, as well as through public forums and social media platforms. This was found to be happening between national government agencies; information sharing between national and county government agencies is rare and almost non-existent due to a lack of established legal mechanisms for sharing of RBM-related information between the two levels of government.

Even though sufficient communication efforts between ESAs and the state agencies were observed since 15 out of 22 ESAs engage state agencies based on MoUs, information sharing between the two levels received “low” expert ranking. Interviewees from government agencies indicated that their communication with ESAs are mostly to satisfy legal requirements such as in the issuance of licenses for some activities to be done by the ESAs, provision of information required by ESAs to finance some of their development projects, or updates on the progress project activities. However, the ESAs complained about the bureaucratic nature of the communication process between them and the state agencies, as they are often required to seek approval from the SARAs headquartered in the country’s capital before engaging the head of the state agency at the county-level about some possible collaboration ventures; a process which sometimes is responsive or has late responses from the government’s side. In responding to this criticism, a government respondent voiced concern about ESA's lack of trust in state agencies as a hurdle to effective communication

between them. Findings indicate that ESAs are often hesitant to share their plans with certain government agencies possibly to hide their sensitive financial information upon which corrupt government officials can use in asking for kickbacks to approve/license project implementation.

Communication was rated low because of inconsistent flow of information among stakeholders. For example, government organizations usually hold consultation meetings every quarter, maybe at the beginning or the end, but these are never all-encompassing as some stakeholders are left out. There are no clear mechanisms on which actor to invite and when, and so there are no clear guidelines for information flow.

(iii) Organizing

Organizing, as a key dimension of coordination, is a process of distributing authority, roles, and responsibilities among stakeholders involved in RBM activities. The distribution of RBM roles is a function that requires a single coordinating authority for the watershed. Despite the lack of a single coordinating body, respondents reported that their organization generally enjoys a cordial working relationship with at least three organizations. The findings indicated that these relationships, however, vary depending on the organization and the function it performs in the RBM. The study noticed a close working relationship between stakeholders who are directly involved in water resources management and those who belong to common networks. For instance, one respondent indicated that; *"...the governance landscape functions like a market system…if you are interested in a particular area, you align closely with those organizations that share your interest be it in the governmental sphere or the private sector. When you find an organization which shares your interests, you agree on a working framework for collaborations on that particular shared interest. That's now where MoUs come in..."* The ESAs tend to collaborate more closely together than the

other stakeholders in the watershed. Furthermore, national government actors had closer relationships among themselves than they are with the Migori County departments or with private-sector entities. This can be seen in the number of consultative meetings held as well as on the number of joint projects implemented since 2015.

Concerning the distribution of roles and responsibilities among RBM stakeholders, interviews with representatives of stakeholder agencies revealed that state agencies have well-defined and distinct functions in the RBM, which are outlined on their respective legal basis. Heads of state agencies were aware of the roles and responsibilities of their respective agencies as it relates to RBM. For instance, WRA is tasked with water resources management, NEMA is responsible for the coordination of environmental management, KFS deals with forest management and the Migori County Government has distinct but limited roles in the management of specific natural resources (including certain streams and community forests) in its area of jurisdiction. Each state agency, therefore, has a well-organized role in the RBM in the watershed, and the management approach is based on mandate per agency. Findings revealed that a County Environment Technical Committee had been informally established to coordinates interactions between national government actors and Migori county government departments in order to improve working relationships between stakeholders and consequently effective watershed conservation.

The ESAs (NGOs and private entities) on the other hand, lack established standards, procedures, or policies that define their roles concerning RBM; hence the majority of them appear to be working on duplicative or similarly related programs in the same watershed. For example, World Vision, One Vision Kenya and Ecology without Borders are all implementing community-based climate resilient interventions within the watershed. The

working relationships between ESAs and state actors are based mostly on temporary formal or informal partnerships on various RBM projects and often last for the duration of the projects concerned. The RBOs (WRUAs and CFAs), are all involved in their respective community-based environmental management programs as defined by law hence undertake similar activities. For instance, all WRUAs in the watershed are involved in tree planting and nurturing, forest patrols to deter illegal activities; and small-scale forest farming.

The organizing as a sub-activity was also rated low, generally because all agencies involved in the catchment have distinct mandated roles and responsibilities on which they normally focus and collaboration is on a per-need basis due to the lack of a single coordinating body that could distribute of RBM roles based on a common plan.

(iv) Planning

Planning is concerned with the preparation of an action plan to be carried out; encompassing the timelines, schedule of actions, and resource allocation. In evaluating the level of planning, the study examined the existence of a common master plan and joint participation of all actors in the development of the master plan, as well as the existence of a synchronized schedule of operations conducted by various actors. Findings indicated that there is no common RBM master plan that engages all actors due to a lack of clear coordination mechanisms. All the national government level actors develop and implement their own strategic plans/management plans for their RBM activities in the watershed. According to the interviews, these state agencies are semi-autonomous and have their strategic plans to guide the achievement of organizational goals. For instance, WRA annually develops a catchment management strategy for the watershed and implements it based on their schedule and knowledge. The major reason for a separate plan preparation

per state agency was alluded to by one respondent among the state actors who indicated that; *"...each agency just works with its separate organizational plan aligned with the directives and funding from their own ministry. So, even the execution and monitoring of these plans are also bound by their respective ministry's directives and funding."*

Although the state agencies prepare their plans, interviews established that few of them usually make an effort of sharing their plans with other stakeholders with whom they have close collaborations. Government agencies were found to be reluctant to invite the relevant stakeholders to participate in the development of their plans majorly because most of them feel that outsiders may not quite understand the objectives to be achieved or the funding implications for their organization.

The situation was however different from ESAs where findings revealed that ESAs usually invite other stakeholders to participate in the development of their strategic plans for the RBM. Moreover, the ESA respondents stated that they are quite generous in sharing their plans with other stakeholders, including the ones that are never friendly to their programs. This sentiment was, however, refuted by state agencies which in the contrast, implied that ESAs are often unwilling to share their plans possibly to hide sensitive financial information contained in those plans from government agencies.

The interviews showed that most external support agencies (donors & NGOs) have joint master plans for projects with Migori County Government departments (water, agriculture, and environment). These plans (especially for community-based conservation or livelihood programs) have a synchronized schedule of activities to be performed by various actors involved in the project. However, it was observed that joint planning between collaborating

actors often faces delays in reaching agreements owing to political squabbling as well as other concerns. The ESAs involved in planning listed seminars, meetings, and workshops as venues for interacting with other stakeholders to share their goals and discuss their projects. The RBOs often involve their key stakeholders in their planning but the invitations for collaboration on plans usually come from other agencies on a per-need basis. For instance, WRUAs often develop the Sub-Catchment Management Plans in collaboration with WRA, but the invitation for that collaboration is undertaken by WRA.

All the interviewed respondents indicated the need for joint planning among actors. It is for this reason that the CETC was formed as a forum where various actors can share plans and collaborate on projects. However, despite the representation of all stakeholders in the Committee, the development of a joint master plan for RBM activities in the watershed has never been successful. This is attributed to infrequent meetings and a lack of responsiveness from the committee members. For example, during the financial year of 2020/2021, only 2 meetings were held out of the 6 meetings that had been scheduled. Generally, planning as a coordination sub-activity received low rating, since there is no common RBM master plan that engages all actors due to a lack of clear coordination mechanisms. The low level of joint planning was attributed to the fact that planning requires funds and the fragmented agencies of various ministries usually have separate budgets which they are often unwilling to commit to collaborative efforts due to their limited nature.

(v) Commanding

Commanding is a key coordination sub-activity that refers to the operationalization of a management plan, which encompasses negotiations among parties involved in the operations and decision-making process. Findings indicate that with no common master

plan, each actor in the RBM of the Migori River watershed performs its responsibilities independently and that there is no single central authority that orders and directs the operations of all the stakeholders based on some joint strategic management plans. A respondent from one of the county departments, notes that; *"The executing agency is usually the lead agency for a particular project."* The County Environment Technical Committee which should be capable of filling this role based on the nature of its leadership and management structure was found to be dysfunctional due to jurisdictional wrangles between agencies.

The interviews showed that every actor has its autonomous management and organizational structure responsible for its decision-making, planning, and implementation of RBM activities and is not swayed by other actors other than the parent ministries whose responsibilities are limited to only policymaking. However, when two or more actors are formally collaborating, the MoUs usually outline the authority to be tasked with directing the joint activities of the alliance, but only for a particular program and period. For instance, an MoU (provided to the researcher) that brought together WRUAs, WRA, and KFS in a partnership, defined WRA as the central authority that directs the actions of other actors even though all the other actors have equal contributions to the execution of various riparian conservation projects. The interviews revealed that not all agreements (MoUs)/processes are documented and enforceable, and this sometimes undermines the commanding of processes in joint RBM projects. The commanding a sub-activity was rated as non-existent, because without a single basin-wide master plan and a single body overseeing its development and implementation, commanding is irrelevant.

(vi) Executing

Executing as sub-activity of coordination entails the implementation of a management plan by the stakeholders, either individually or collectively. In the study, the cooperation and collaboration among actors in the implementation of management plans/projects were evaluated. During the empirical investigation, interviewees were asked to characterize their project implementation process and whether they develop partnerships or collaborations to implement them. The findings indicated that each state agency implements and monitors its projects through its personnel, and there are fewer projects for any collaboration. ESAs on the other hand appear to be making efforts to forge collaborations and partnerships among themselves and with the government stakeholders. These collaborations during the implementation of RBM projects are on a per-need basis. However, not all ESAs implement their programs in collaboration with stakeholders, and those that collaborate with others do not always do so for all of their programs.

The findings also showed that collaboration between two or more actors occurs through technical or financial assistance. For instance, WRA has a MoU with Water Sector Trust Fund whereby the WSTF provides funds to WRA to finance WRUA activities. Also, the WRUAs have an informal agreement with WRA whereby WRA provides technical support to WRUAs in the development of Sub-catchment Management Plans. Generally, executing as sub-activity is rated low, due to inadequacy of partnerships in the execution of watershed activities which is attributed to the unwillingness of most of stakeholders to enter into partnerships and preference to execute their projects independently as they perceive collaboration as inconveniencing and a waste of time while others seem afraid of being outshined by their collaborators or even losing recognition of their work by other actors and the community to their partners.

(vii) Controlling

Okok (2015) describes controlling as the coordination sub-activity that is concerned with the mechanisms for monitoring and evaluation of the executed projects. In this study, the existence and effectiveness of authority that enforces compliance among actors, monitoring and providing feedback on implemented programs were evaluated. Findings indicates that since there is no lead agency for RBM, each agency implements and monitors its projects, and there is no form of synchrony of RBM activities implemented in the Migori River watershed. In the case of multi-agency joint programs, no single authority holistically ensures compliance of actors with the implementation of management plans/projects and provides feedback on the progress of those projects. Moreover, there are no penalties for agencies that do not implement agreed project activities. Nonetheless, the interviews indicated that all stakeholders use their internal mechanisms for guaranteeing conformity of project activities, monitoring, and evaluation. Generally, controlling as a sub-activity of coordination was rated low, due to the low level of monitoring and evaluation of RBM programs.

4.2.3 Levels of Coordination in the Management of Migori Watershed

In analyzing the level of coordination between stakeholders, a distinction was made between the mechanisms in the horizontal and vertical dimensions, as summarized in Table 4.4. Analysis of combination of interviews and secondary materials were used in evaluating the horizontal and vertical dimensions of coordination.

On the vertical dimension, the study evaluated presence and nature of hierarchical interactions between the two levels of government brought by devolution i.e., national government level actors and county government level actors. Based on the current legal framework related to catchment areas in Kenya, RBM begins at the top national level where

the national government ministries with roles and responsibilities in line with the management of catchment resources (i.e., Environment and Forestry; Water, Sanitation and Irrigation; Agriculture, Livestock, and Fisheries; Lands and Physical Planning) are tasked with policy formulation.

Table 4.4: Levels of Coordination in the integrated management of Migori River watershed

Variables	**Indicator(s)**	**Findings and Analysis**
Horizontal coordination	Existence and nature of interactions between sectors (environment, water and agriculture) or government & NGOs of the same level	• Horizontal coordination is provided for in the Water Act 2016 which requires consultation with other stakeholders when carrying out different activities at the sub-basin level but no procedures for reporting • National level actors (ministries, semi-autonomous agencies headquartered in Nairobi, and multinational NGOs) from water and environment sectors have effective mechanisms for horizontal consultation and reporting on catchment resources management. • Locally, most national government level actors (KFS, KEFRI, LBDA, & LVSWWA) conduct consultations with stakeholders despite lack of legal basis for horizontal reporting.
Vertical coordination	Existence and nature of interactions between national government level actors and county government level actors	• The current legal framework for RBM still emphasizes top-down bureaucratic decision-making structure • No clear coordination mechanisms between county departments and national government level actors due to legal ambiguity • County departments and national government level actors informally established the County Environment Technical Committee to act as a bridge for vertical reporting between the two levels, however it's non-operational.

These ministries' policies empower their national-level semi-autonomous state agencies (WRA, NEMA, KFS, NLC), headquartered in Nairobi, to carry out their statutory prescribed mandates. The national-level semi-autonomous state agencies provide operational directions to their lower level agencies distributed county-wise or regionally across the country, including in Migori County. It is these county-level semi-autonomous state agencies that directly interact at the local level with Migori County Government departments through consultations and partnerships. Findings showed that respondents believe that a clear

coordination mechanism between county-level semi-autonomous state agencies and Migori county departments (each with a hierarchical governance structure) on RBM matters is still lacking due to legal ambiguity – no regulations that guides interactions between two levels of government on RBM issues. At the lowest level of this multilevel governance arrangement are the RBOs, especially WRUAs and CFAs which are community-based RBM entities operating at sub-basin level. From the interviews, most respondents claimed that this hierarchical coordination is inefficient, highlighting convoluted processes in bureaucracies that impede effective collaboration for better RBM for the watershed.

On the horizontal dimension, the study evaluated the presence and nature of interactions between sectors (environment, water and agriculture) or government & NGOs of the same level. Horizontal coordination is provided for in the Water Act 2016 which requires consultation with other stakeholders when carrying out different activities at the sub-basin level. Interviews with respondents from county-level semi-autonomous state agencies indicated that national players (ministries and multinational NGOs) from water and environment sectors have effective mechanisms for horizontal consultation on catchment resources management. Locally, in Migori River watershed, most national government level actors (KFS, WRA, KEFRI, LBDA, and LVSWWA) stated that they normally consult with stakeholders, but there are no procedures or provisions in the legislation for horizontal reporting. Hence, the weak horizontal interaction among some RBM actors in Migori River watershed is generally attributed to lack of legal mechanisms for horizontal reporting.

4.2.4 The Influence of Formal and Informal Rules of the Institutional Arrangement on Coordination of Actors

(i) The Influence of Formal Rules (Policy and Legal Framework) on Coordination of Actors

The regulatory framework governing RBM for Migori River watershed comprises many policies and legislations implemented at both the national and county government levels, with the goal of protecting the environment and improving livelihoods. Per the results, there are various ways in which the regulatory framework influences the coordination capacity in RBM. This is consistent with Ghorbani (2010) that described regulatory structure as an instrument that shapes the actors' behavior.

First, the regulatory framework governing RBM has created a multi-level governance structure (national and county government) with institutions undertaking various roles in the management of natural resources in the Migori River watershed. However, this multi-level governance lacks clearly-defined mechanisms for collaboration, cooperation and accountability between national-government actors and county-government actors, and amongst actors. Consequently, both national government actors and county government actors exercise caution when carrying out their responsibilities in order to prevent overstepping their bounds or causing a disagreement with another actor. This situation could potentially make the actors to play it safe so as not to violate any current or recently developed regulations, hence causing inefficiency in management of some watershed issues.

The regulatory framework contains some conflicts/overlaps which undermine the collaboration between stakeholders. The primary legislation concerned with RBM, namely, the Water Act 2016, EMCA Act 2015, and the Forest Conservation and Management Act 2016 contain provisions that conflicts with each other. For instance, empirical investigation

revealed that the establishment and regulation of water quality standards is provided for in both section 71 of the EMCA Act of 2016 and section 20 of the Water Act 2016, while regulation of deforestation or planting of certain exotic trees along key riparian zones on non-public lands as well as afforestation or re-forestation of mountainous regions are all provided for by both section 56 of the Forest Conservation and Management Act 2016 and section 46 of EMCA Act 2016. These conflicting legislative issues has caused confusion which undermines the effective implementation of RBM programs and activities.

The regulatory framework contains provisions that support inclusion of all actors in the RBM in line with the IWRM principles. The primary RBM legislations applied in Migori River watershed (the Water Act 2016, EMCA Act 2015, and the Forest Conservation and Management Act 2016) all provide for gender mainstreaming, and inclusion of special interest groups (such as those living with HIV/AIDS or disabilities) and marginalized communities. For instance, all the WRUAs and CFAs are mandated to include women, and people living with disabilities before they can be registered. This has led to greater inclusion and meaningful participation of actors in the RBM for Migori River watershed.

Notwithstanding the presence of a robust regulatory framework for RBM activities, findings indicate insufficiency in the enforcement of legislations, policies, and regulations, particularly those pertaining to the protection of water resources from pollution and riparian areas from encroachment. From the interviews, it was revealed that weak enforcement of the Water Act 2016, EMCA Act 2015, and the Forest Conservation and Management Act 2016 has contributed to the pollution of the Migori River. The weak enforcement was attributed to the lack of well-established collaboration linkages between state agencies and the law enforcement agencies. Findings also showed that the presence of conflicting legislative provisions (such as that on the allowable riparian distance from nearby farms which varies

between lead agencies) and misinterpretation of the mandates have contributed to the weak enforcement of conservation provisions including prevention of farming near river banks.

(ii) The Influence of Informal Rules on Coordination of Actors

Apart from formal rules, the vertical dimension of coordination in the Migori River watershed is characterized by informal rules - the norms, relationships and political culture surrounding the interactions between organizations (Ghorbani, 2010). These rules are defined by existence of a strict bureaucratic system and robust unidirectional top-down interactions. For instance, findings indicated that inter-agency relationship is confined to top-level administrators and limited to understanding of the mandates of other agencies. This was found to constrain the flexibility of lower cadre officials from effectively coordinating with other actors on RBM matters in the watershed. Olsen (2006) states that the fundamental issue with the vertical governance configuration are that the distribution of authority is irregular and lopsided, with most decision-making responsibilities resting with the agency's leaders. Therefore each actor concentrates only within their mandates and communicating with other stakeholders only when highly necessary.

Political interference has a double-sided impact of RBM; it can function both as an incentive and stumbling block to coordination. Interviews show that political good will is needed for swift and better collaboration between actors on RBM issues. For instance, the study established that coordination attributes such as communication, joint planning, and monitoring and evaluation is improved among stakeholders who enjoy strong political goodwill.

4.2.5 Contextualization of the Findings within the Theoretical Constructs

With most coordination sub-activities rated low, the governance system of the Migori River watershed is characterized by certain coordination failures which are linked to coordination neglect, explainable from the perspective of network governance theories and theories that underpin motivation for coordination. The first aspect of coordination failure in the governance of the study area revolves around the institutional arrangement, whereby diverse mandates, distinct but sometimes confusing/conflicting RBM roles, and independent nature of state institutions have contributed to weak relationships among actors (Hoffmann et al., 2012). This is explainable using two theories underpinning motivation for coordination; *exchange theory* and *transaction cost theory*. The *exchange theory* posits that entities are driven to coordinate, either vertically or horizontally, because of their reliance on others for resources to accomplish their objectives while the *transaction cost theory* posits that entities are driven to coordinate, either vertically or horizontally, to reduce internal and external transaction costs (Hoffmann et al., 2012; Okok, 2015). Jointly, the two theories explain that interactions between entities are motivated by the desire to exchange resources to achieve their objectives. Meaning entities are not completely independent; they must rely on other entities in the system for resources to achieve their objectives (Mercado, 2018). The fact that governmental actors in the study area have separate mandates and possess necessary resources to develop, implement, and oversee their programs have made these actors act independently, overlooking critical inputs from non-state actors along with interconnections across government ministries. The lack of notion of interdependence among these government agencies does not inspire them to seek collaborations with other actors in performing RBM functions hence weakening coordination in the watershed.

The inadequate coordination among actors in the watershed is a case of coordination neglect attributable to the theoretical concepts of *partition focus* and *component focus* whereby; in partition focus concept the actors tend to be more concerned with the process of partitioned function than with the process of integration and in component focus, the actors tend to concentrate on the individual component while evaluating issues or formulating solutions rather than the entire system (Heath & Staudenmayer, 2000). This means that due to decentralization, actors in the watershed tend to function within their institutional mandates and jurisdiction, and they concentrate on the tasks themselves - especially the division of responsibilities—rather than the entire system (Mercado, 2018). In this situation, the integration and harmonization of these tasks are sometimes neglected. One empirical manifestation of this behavior can be found in the case of county-level agencies that strive to operate within their geographical jurisdiction to avoid infringing on the mandates for other government bodies such as NEMA and WRA. Another example is seen in the case of RBOs, which often wait for a lead agency, like KFS or WRA, to make the initial move in collaborating with them on RBM activities.

Another critical cause of coordination neglect in the Migori River watershed governance is inadequate communication, whereby the actors lack sufficient opportunities for interactions (Heath & Staudenmayer, 2000 as cited by Okok, 2015). In the study area, the barriers to effective communication among actors could be related to the lack of a proper forum for effective coordination, confusion about which entity to cooperate with, and a sluggish willingness to collaborate because of long and inefficient bureaucratic processes. From the empirical findings, the watershed lacks a single coordinating body that would provide a central forum through which all the actors might interact led to poor coordination. Evidently, many actors have been collaborating with some other stakeholders on a per-need basis; however, because there is no lead agency overseeing and managing the network of

interactions, confusion has arisen, and gaps in organizing, planning, execution, and monitoring of RBM programs have transpired. Inadequate communication contributes to poor coordination. This case of coordination neglect is also attributable to the framework of decentralization which lacks well-defined mechanisms for horizontal coordination leading stakeholders into concentrating on specific mandates and individual elements-partition focus and component focus. Sehested and Groth (2012) argue that to strengthen horizontal coordination in pluricentric (multi-actor) governance, the fragmented structures should be glued using formal regulations, schedules, plans, and standard procedures. These formalized regulations and procedures are necessary tools for influencing the behaviour of the stakeholders (Ghorbani, 2010).

The network management theory postulates that coordination failure is frequently caused by the absence of incentives for a combined action among actors (Corsame, 2016). Empirical evidence of this phenomenon was observed in the management of the Migori River watershed, wherein the collaborating actors/sectors do not always consider their collaborators in their management plans. This behavior discourages effective collaboration/coordination among actors involved in the study area. In addressing this situation, the network model focuses on the institutional structure, harmonizing diverse aims and priorities to develop an integrated approach. Such integration of independent actors incentivizes horizontal coordination (Sehested & Groth, 2012). The network management theory emphasizes the importance of enhancing the environment in which stakeholders interact by arguing that since the institutional framework of a network influences the nature and level of coordination among stakeholders, modification of the institutional design, through changing of formal and informal regulations, and processes, will bring about sustainable interaction of actors (Klijn & Koppenjan, 2007). Further, Klijn and Koppenjan (2012) assert that besides facilitating

interactions among actors, modification of the institutional design can also establish clear and well-defined channels of engagement between actors.

Another source of coordination failure in the study area is institutional complexity, defined as antagonism in the institutional arrangements created by conflicting and incompatible institutional logics (McPherson & Sauder, 2013; Qiu et al., 2019). The impasse between NEMA and WRA arising from conflicting/overlapping roles is a perfect example of this phenomenon happening in the network. Notably, findings noted many instances of conflicting/overlapping roles between actors in the Migori River watershed. The institutional complexity happening in the governance of the study area emanates from confusing legal frameworks or misinterpretation of the mandates by the actors (decision-makers). This is consistent with the study of Klijn and Koppenjan (2014) which observes that network regulations derived from national laws, sectoral policies, or professional groups sometimes compete against each other, and therefore if a set of regulations increases, they could become ambiguous, obscure, and difficult to understand, resulting in complexity in the governance setup rather than predictability. Interactions among actors are quite challenging in a system where the actors are guided by varied or even conflicting rules and standards of practice. Additionally, collaborations on projects are quite challenging when the stakeholders are compelled to modify their institutionalized practices to embrace new ones required for collective action on joint projects (Qiu et al., 2019). Previous studies agree that institutional conflicts create barriers to effective coordination in a complex institutional environment because they can either lead to total paralyzation of the system functioning (Pache & Santos, 2013) or cause the decision-makers (actors) to delay compliance/avoid cooperation (Raaijmakers et al., 2015). Solving the institutional complexity in the study area would require interventions in the institutional design of the system, changing formal and informal regulations and processes.

Another source of coordination failure is fact that findings indicated that the vertical coordination is more pronounced than horizontal coordination in the Migori River watershed. This is in line with the organizational theory which explains that a system possessing a powerful vertical coordination structure will have an eroded horizontal coordination structure (Sienkiewicz-Małyjurek, 2017). As Olsen (2006) puts it, the major issue with the vertical coordination structure is that power is unequally distributed and lopsided, with the greatest decision-making powers resting with the agency's top-most leaders. This situation can make the system vulnerable to political interference whereby the top-most leaders are inclined to bow down to political pressure in terms of project initiation and implementation within the watershed. Political interference has a double-sided impact of RBM; it can function both as an incentive and stumbling block to coordination. Interviews show that political good will is needed for swift and better collaboration between actors on RBM issues. For instance, the study established that coordination attributes such as communication, joint planning, and monitoring and evaluation is improved among stakeholders who enjoy strong political goodwill.

4.3 Modeling of the Impacts of Land Use and Land Cover Changes on Streamflow and Sediment Yields in Migori River Watershed between 1980 and 2020

This section presents results on the hydrological response of the Migori River watershed to LULC changes between 1980 and 2020 as estimated using the SWAT model. It consists of sub-sections presenting results on the spatial analysis of trends of LULC change, watershed community perceptions regarding trends of the LULC changes, drivers of LULC changes analyzed based on index-based ranking of 318 households' survey data, and the simulated changes in the water balance components and the sediment regime in the watershed as a result of LULC changes.

4.3.1 Land Use and Land Cover Change Dynamics from 1980 to 2020

LULC changes have been investigated for the years 1980, 1990, 2000, 2010, and 2020 using three-generation Landsat time-series data considering eight different classes, namely cultivated land, shrub land, grasslands, forests, bare land, built-up areas, water, and wetlands. The classified LULC maps for the corresponding years, showing the spatial representation of these LULC types, are shown in Figure 4.4.

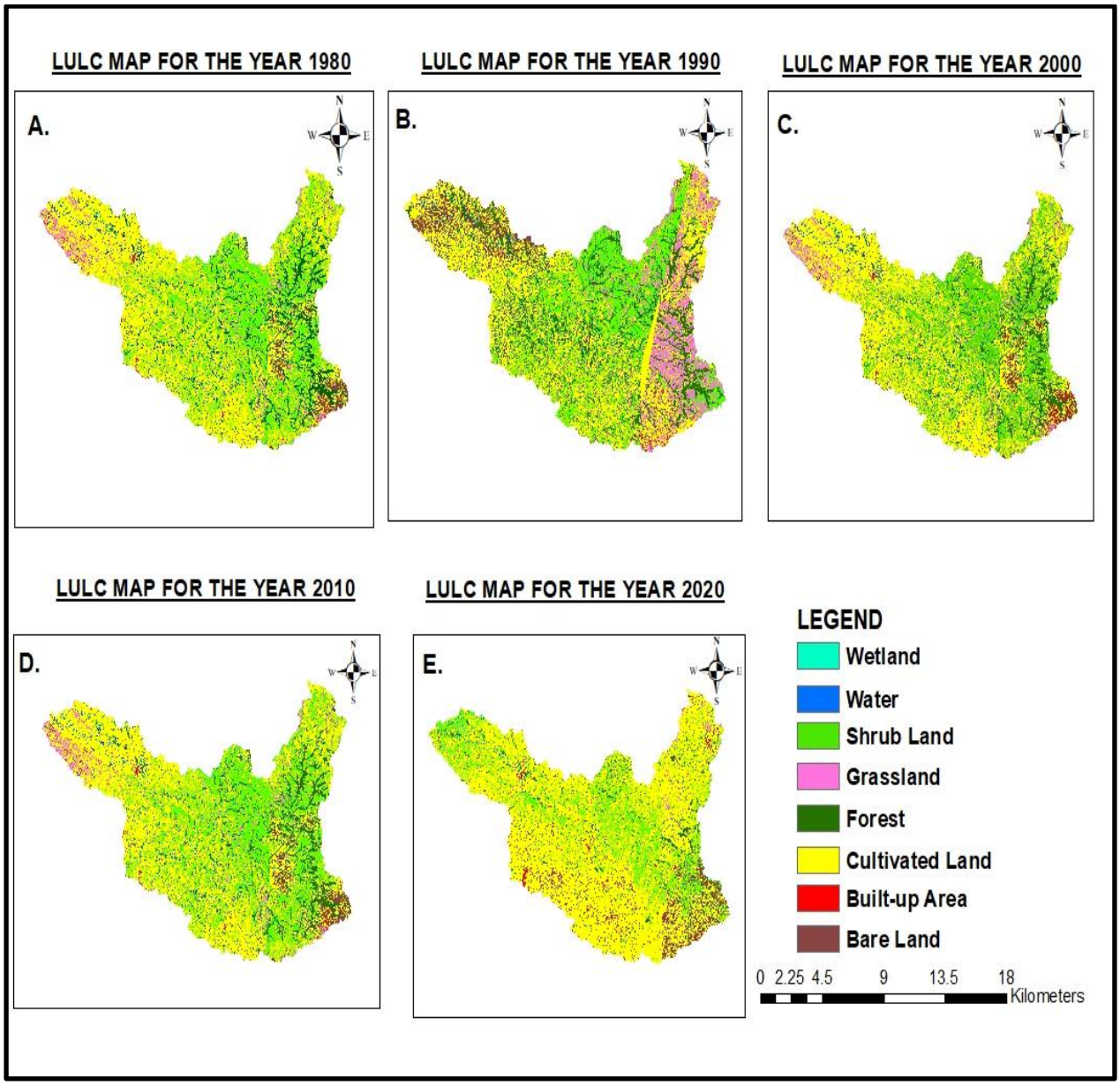


Figure 4.4: Land use and land cover maps of Migori River watershed (1980 – 2020)

(A) Overall trend analysis of LULC changes (1980-2020)

The proportionate coverage area of each of the eight classes extracted in the watershed from 1980 to 2020 of LULC change trends is summarized in Table 4.5 and Figure 4.5. Table 4.5 indicates that shrub land, grassland, forests, water, and wetland shrunk while cultivated land, bare land, and built-up area expanded over the past 40 years in the watershed. The cultivated land was the most dominant LULC class in the watershed in 1980, accounting for approximately 51.86% of the total landscape; but it has since then increased by about 347.42 km^2 (8.69km^2/year). Since the 1980s, cultivated land initially fell sharply in 1990 before taking a steady increasing trend over the following decades. While the cause of the decline in cultivated land in 1990 is unknown, the trend of farmland expansion over the years could be attributed to the high rate of population increase (UN Department of Economic and Social Affairs, 2019); which might have increased the demand for food and consequently resulted in the conversion of other natural landscapes like grasslands, wetlands and forests and shrub lands into farmlands. Bare land accounted for 2% of the watershed in 1980 but has since risen by 132.28% (0.1km^2/year). This is a reflection of the effect of increased unsustainable utilization of grasslands and forests through overgrazing and deforestation. This is consistent with the conclusions of Hassen and Assen (2018) about land-use change in the Lake Tana watershed in Ethiopia. The built-up area constituted less than 3% of the watershed in 1980 but has since expanded by 461.20% (0.6km^2/year). This exponential expansion demonstrates the rapid rate of conversion of natural landscapes into settlement areas to accommodate the ever-burgeoning population.

Forest cover in the watershed seems to have declined by about 52.90% (1.48km^2/year) notwithstanding the forest conservation efforts since the 1980s championed by the Permanent Presidential Commission on Soil Conservation and Afforestation. This can be attributed to

the expansion of rural and urban settlements and farmlands, weak enforcement of conservation laws, and increased demand for timber as raw materials for construction and fuel wood for household usage. Although grasslands exhibited an irregular pattern of spatio-temporal changes across the five reference periods, it has experienced a decline of approximately 84.86% (1.48km^2/year) over the past 40 years. This substantial decline in grasslands is an indication of the increasing demand for agricultural lands and the development of forests in some of the grasslands. Moreover, the irregular pattern of changes observed in grasslands from 1980 to 2020 can be attributed to the destruction by constant incidences of fire outbreaks that usually occur in the area during periods of droughts (Odeny, 2015) or by the droughts themselves (Oyugi, 2016). The entire Migori County where the watershed lies is a drought prone region characterized by unreliable rainfalls, poorly distributed throughout the year and constantly fluctuating temperatures (Oyugi, 2016), and has been known to be constantly threatened by fire outbreaks, following prolonged drought conditions (Odeny, 2015). The frequent destruction of grasslands by both fire or drought incidences and the successive regenerations contributes to the irregular pattern of spatio-temporal changes over time.

Similar to grasslands, the patterns of spatio-temporal changes in shrub lands showed that it has declined by 40.63% (5.90km^2/year) over the four-decade period, which was largely attributed to the conversion to cultivated lands and settlements due to population pressure. Since 1980, water declined by 82.03% (0.98km^2/year) while the wetlands shrunk by 38.44% (0.1km^2/year). This declining trend in areas under water and wetlands could be attributed to the emergence and growth of aquatic vegetation and invasive species in these areas, frequent occurrence of droughts in the area (Magige, 2014), and probably the depletion of water through domestic usage, canal irrigation, and livestock watering. Further, the decline

suggests the existence of unsustainable land management practices like the reclamation of these lands to create spaces for agriculture and settlement, coupled with mining in the area.

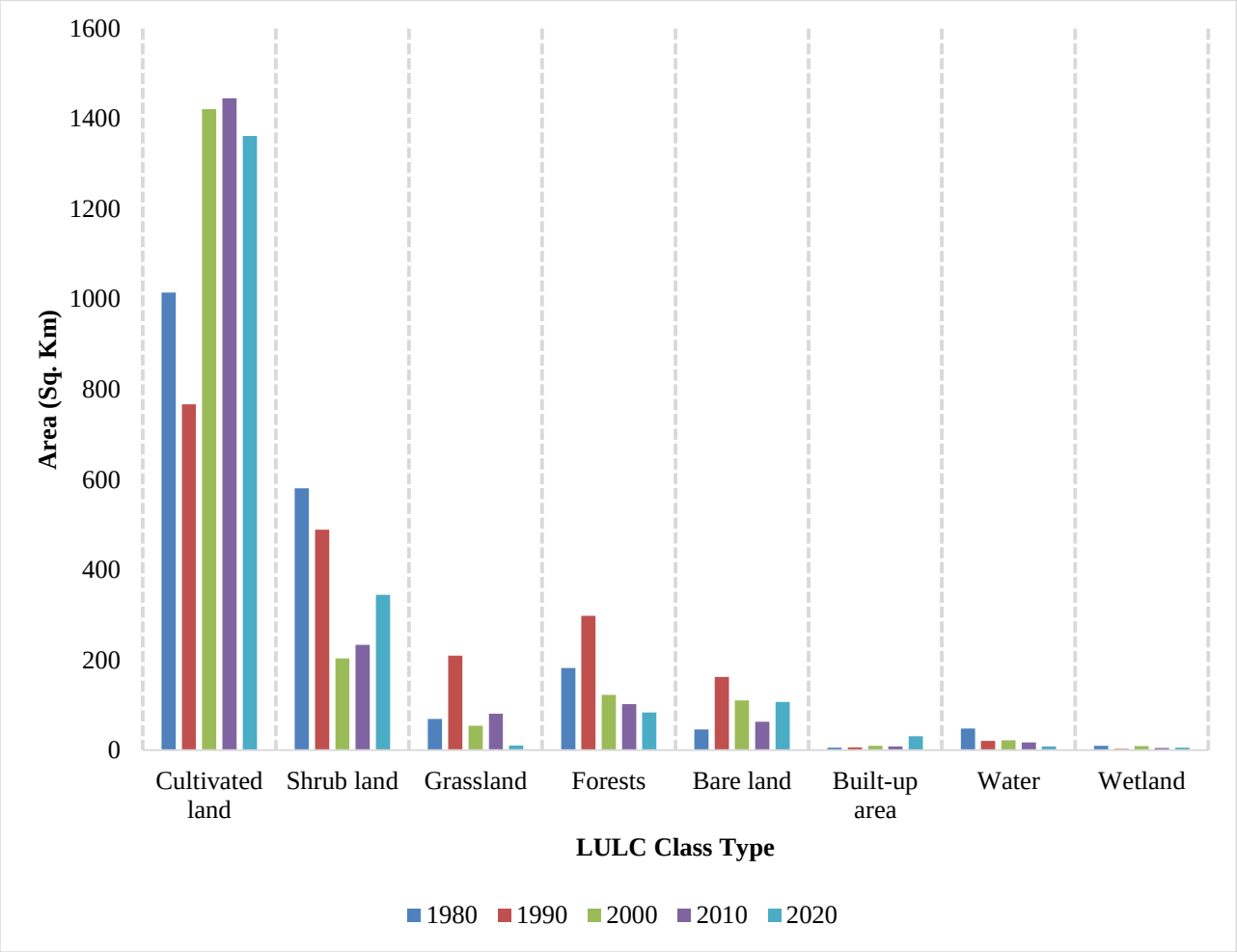


Figure 4.5: Trends of LULC changes in Migori River watershed from 1980 to 2020

(B) Decadal trend analysis of LULC changes

A decade-by-decade analysis of the rates of change in LULC between 1980 and 2020 in the watershed revealed specific net changes in the form of gains and losses for each class during the 1st period (1980–1990), 2nd period (1990–2000), 3rd period (2000-2010) and 4th period (2010-2020) as shown in Table 4.6 and Figure 4.6.

Table 4.5: Land Use and Land Cover patterns of Migori River Watershed between 1980 and 2020

LULC type	1980		1990		2000		2010		2020	
	Area (km^2)	%	Area (km^2)	(%)	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Cultivated land	1014.36	51.86	766.54	39.19	1421.17	72.66	1445.28	73.89	1361.78	69.62
Shrub land	580.81	29.69	488.67	24.98	203.38	10.40	233.70	11.95	344.84	17.63
Grassland	69.69	3.56	209.79	10.73	54.58	2.79	80.87	4.13	10.55	0.54
Forests	182.15	9.32	298.19	15.25	122.98	6.60	102.07	5.22	83.79	4.28
Bare land	46.04	2.35	162.31	8.30	110.25	5.64	63.25	3.23	123.02	5.57
Built-up area	5.49	0.28	6.50	0.33	9.83	0.50	8.27	0.43	30.81	1.58
Water	47.87	2.45	21.01	1.07	22.15	1.13	17.23	0.88	8.60	0.44
Wetland	9.97	0.49	2.95	0.15	8.93	0.46	5.34	0.27	5.91	0.34
Total	1955.98	100	1955.98	100	1955.98	100	1955.98	100	1955.98	100

Table 4.6: Rate of change in Land Use and Land Cover between 1980 and 2020 in Migori River watershed

LULC Type	1980 - 1990		1990 - 2000		2000 - 2010		2010 - 2020		1980 - 2020		
	Area (km^2)	% Change	Area (km^2)	% Change	Area (km^2)	% Change	Area (km^2)	% Change	Area (km^2)	% change	Annual Rate of Change (km^2/year)
Cultivated land	-247.82	-24.43	654.63	85.40	24.11	1.69	-83.5	-5.78	347.42	34.25	8.69
Shrub land	-92.14	-15.86	-285.29	-58.38	30.32	14.91	111.14	47.56	-235.97	-40.63	-5.90
Grassland	140.10	201.03	-155.21	-73.98	26.29	48.17	-70.32	-86.95	-59.14	-84.86	-1.48
Forests	116.04	63.71	-175.21	-58.76	-20.91	-17.00	-18.28	-17.91	-98.36	-52.90	-2.46
Bare land	116.27	252	-52.06	-32.07	-47	-42.63	43.74	69.15	60.95	132.38	1.52
Built-up area	1.01	18.40	3.33	51.23	-1.56	-15.87	22.54	272.55	25.32	461.20	0.63
Water	-26.86	-56.11	1.14	5.43	-4.92	-22.21	-8.63	-50.09	-39.27	-82.03	-0.98
Wetland	-6.65	-69.27	5.98	202.71	-3.59	-40.20	0.57	10.67	-3.69	-38.44	-0.09

(i) The Pattern of LULC Changes Between 1980 and 1990

From 1980 to 1990, the watershed experienced considerable fluctuations – net positive and negative changes - in the LULC coverage (Table 4.6 and Figure 4.6). Spatial analysis indicated that cultivated land was dominant LULC in the watershed in 1980, covering around 1014.36 km^2 (51.86%) of the entire land area (Table 4.5). However, it decreased to 766.54 km^2 (39.19%) in 1990, resulting in a net loss in coverage of about 24.43% over that decade (Table 4.6). Shrub lands, water, and wetlands also showed negative/decreasing trends during this decade, with net losses of 15.86%, 56.11%, and 69.27% from their original coverage, respectively (Table 4.6). On the contrary, the remaining LULC categories experienced increasing trends from 1980 to 1990 i.e. there is an increase in grasslands by 201.03%, forests by 63.71%, bare land by 252.00%, and built-up area by 18.40%. These findings imply that, during this era, the land areas under cultivation, shrubs, water, and wetlands shrunk because they became bare, got covered by grasslands and forests, or were converted to settlements for the growing population. This phenomenon could be attributed to a government policy by the new government in the early 1980s which established the Permanent Presidential Commission on Soil Conservation and Afforestation (PPCSCA) in 1981 to champion environmental conservation efforts in the entire country (Nasong'o, 2017). This policy instituted protective and preservation measures for natural forests and grasslands, with farmlands inside forested areas being reclaimed by the government, leading to encroachment of wetlands and shrub lands due to increased demand for new farmlands and settlement areas (Nasong'o, 2017).

(ii) The Pattern of LULC Changes Between 1990 and 2000

In this decade, the LULC categories of cultivated land, water, and wetlands, which had recorded net losses during the previous decade showed substantial gains in their land coverage whereas those of grasslands, forests, bare land, that had registered substantial net gains recorded net losses (Table 4.6 and Figure 4.6). Cultivated land increased by 85.40%, water rose by 5.43% and wetlands grew twofold (202.2%). Conversely, grasslands reduced by 73.98%, forests by 58.76% and bare land by 32.07%. During the same period, shrub land continued to show a negative trend with a 58.38% net loss while built-up lands continued to experience a positive trend with a net gain of 51.23%. These environmental transformations could generally be attributed to the high rate of population growth observed in Kenya from the late 1980s towards the new millennium, which was estimated to be between 3.20-3.60% per annum (UN Department of Economic and Social Affairs, 2019). During the same period, the population growth rate of the entire Lake Victoria basin, under which the watershed is located, was touted to be among the highest in the country at 2.85% per year (Rakama et al., 2017). This massive population growth might have led to the conversion of bare lands to settlement areas or farms; and the destruction of forests and grasslands in the quest for new croplands or settlement areas, raw materials for construction works, and fuel wood for domestic consumption.

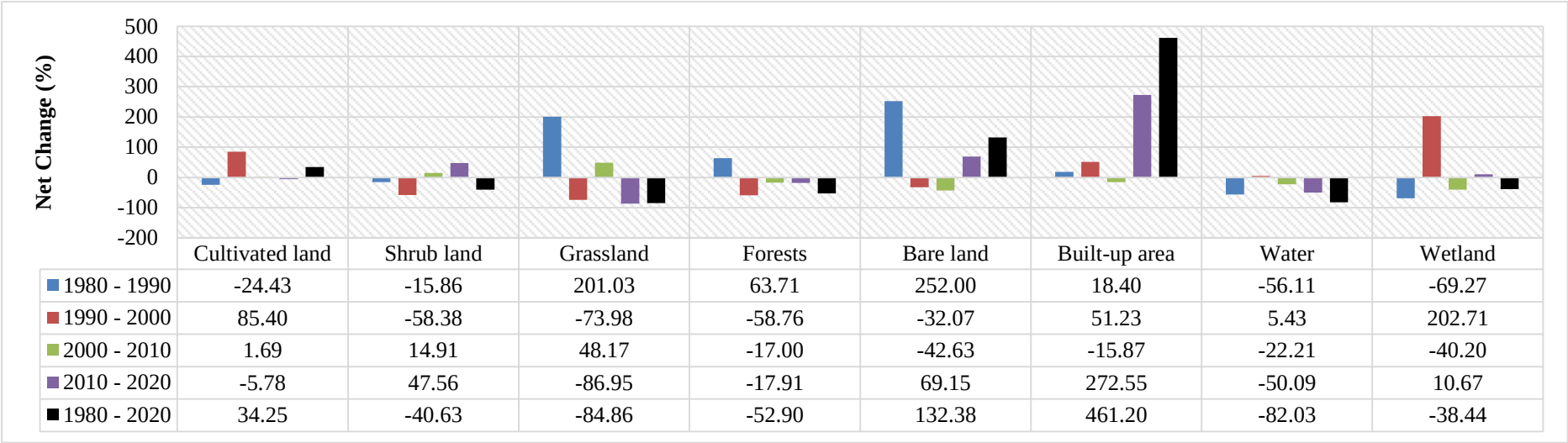
(iii) The Pattern of LULC Changes Between 2000 and 2010

Table 4.6 and Figure 4.6 reveal that five of the LULC categories recorded net losses with two recording net gains. Forests, bare land, water, wetland, and built-up registered net losses of 17.00%, 42.63%, 22.21%, 40.20%, and 15.87% respectively; whereas shrub land and

grassland grew by 14.91% and 48.17% respectively. Unlike the previous decades, cultivated land remained relatively constant during this decade (2000-2010), only rising by 1.69%.Generally, the transformations suggest that during this period grasslands and shrub lands expanded largely at the expense of other natural landscapes - forests, bare land, water, and wetlands - due to the existence of unsustainable land management practices. The built-up area lost a small portion as cultivated lands saw little change in their coverage; which indicates no acquisition of new lands for settlement or farming. These occurrences could be attributed to the coming to power of a new regime that oversaw policies that not only spurred strong economic development and created employment opportunities in urban areas of the country, but also enacted new conservation laws and policies like the Environmental Management and Coordination Act of 1999 and Forest Act of 2005, that may have impacted land management approaches causing an uncoordinated transition from old practices.

(iv) The Pattern Of LULC Changes Between 2010 and 2020

Between 2010 and 2020, grasslands declined by 86.95%, forests by 17.91%, and water by 50.09% unlike other categories that increased - shrub land by 47.56%, bare land by 69.15%, built-up area by 272.55%, and wetlands by 10.67%, with cultivated land remaining fairly constant (Table 4.6). The substantial expansion of bare lands and shrub lands is a reflection of the effect of unsustainable utilization of grasslands and forests through overgrazing and deforestation respectively. Moreover, the substantial increment of the built-up areas reflects the high rate of conversion of natural landscapes like forests and grasslands into settlement areas for the burgeoning population. Of the four epochs, this period stands out as the one under which the environment of the watershed suffered considerable negative transformation.



	Cultivated land	Shrub land	Grassland	Forests	Bare land	Built-up area	Water	Wetland
1980 - 1990	-24.43	-15.86	201.03	63.71	252.00	18.40	-56.11	-69.27
1990 - 2000	85.40	-58.38	-73.98	-58.76	-32.07	51.23	5.43	202.71
2000 - 2010	1.69	14.91	48.17	-17.00	-42.63	-15.87	-22.21	-40.20
2010 - 2020	-5.78	47.56	-86.95	-17.91	69.15	272.55	-50.09	10.67
1980 - 2020	34.25	-40.63	-84.86	-52.90	132.38	461.20	-82.03	-38.44

Figure 4.6: LULC decadal net changes in the Migori River watershed for the period of 1980 – 2020

Table 4.7: Land Use/Land Cover change matrix of Migori River watershed from 1980 to 2020

1980	**2020**								
	Cultivated land	Shrub land	Grassland	Forests	Bare land	Built-up area	Water	Wetland	**Total (1980)**
Cultivated land	***756.84***	155.56	1.18	31.76	44.85	18.16	2.52	3.49	**1014.36**
Shrub land	384.03	***118.09***	5.44	14.92	50.66	6.69	0.55	0.43	**580.81**
Grassland	47.8	12.63	***2.84***	0.89	3.11	1.47	0.16	0.79	**69.69**
Forests	100.1	38.39	0.31	***29.08***	12.05	0.96	1.11	0.15	**182.15**
Bare land	26.87	7.61	0.28	0.34	***10.4***	0.47	0.05	0.02	**46.04**
Built-up area	12.61	1.78	0.15	0.29	0.94	**2.34**	0.22	0.07	**15.49**
Water	26.93	8.95	0.01	5.73	0.89	0.62	***3.85***	0.89	**47.87**
Wetland	6.6	1.83	0.34	0.78	0.12	0.1	0.14	***0.06***	**9.97**
Total (2020)	**1361.78**	**344.84**	**10.55**	**83.79**	**123.02**	**30.81**	**8.6**	**5.91**	**1955.98**

Note: The bold and italicized entries along the diagonal represent the LULC areal coverages that remained unchanged between 1980 and 2020

(C) Land use and land cover transition matrix

Table 4.7 above present the cross-tabulation change matrix illustrating how the coverages of various LULC classes have changed over time from one class to another from 1980 to 2020. Conversions of one LULC to the other occurred across the entire watershed. Results show that during the period between 1980 and 2020, 81.41% of built-up areas (12.61km2), 74.34% of cultivated land (756.84km2), 56.26% of water (26.93km2), 22.59% of bare land (10.40km2), 20.33% of shrub lands (118.09km2), 15.96% of forests (29.08km2), 4.08% of grasslands (2.84km2), and 0.60% of wetlands (0.06km2) remained unchanged. This demonstrates that while the original areas of built-up lands, cultivated lands, and water remained largely unchanged, the rest of the LULC categories experienced high conversion with over 80% of their total land areas converted to other LULC classes. A large portion of cultivated land was converted to shrub land (15.30%) whereas that of bare land became cultivated land (58.36%). Also, majority of shrub lands turned into cultivated land (66.12%) whilst major sections covered by grasslands became either cultivated land (68.59%) or shrub land (18.12%). Forests lost a large part of their coverage to cultivated land (54.95%) as water and wetland lost large chunks to shrub land (18.70%) and cultivated land (66.20%) respectively. Although the original built-up areas remained largely unchanged, 18.16km^2 and 6.69 km^2 were gained from cultivated land and shrub land respectively.

(D) Accuracy assessment of the land use and land cover classification

The classified imageries have overall accuracy of over 86% (See Appendix 6). Since an overall accuracy of over 80% is acceptable and recommended (Wickham et al., 2006; Turan & Günlü, 2010), the LULC classification is thus acceptable and hence reliable. Furthermore, the overall kappa coefficient for all the classified images ranged between 0.77 and 0.81,

which when compared to the Landis and Koch (1977) ratings shows that the classification carried out for the study has a strong agreement with the ground-truthing reference data. The kappa coefficient is a measurement of the precision or agreement between data from classified imageries and data from ground reference locations (Ikiel et al., 2013). Although there are small differences in producer and user accuracies of specific LULC categories, the classification registered high overall accuracy (Appendix 6). These accuracy assessment results lay the groundwork for subsequent examination of LULC modifications.

4.3.2 Watershed Community's Perceptions of Trends of LULC Changes

To generate a broad understanding of the changing situation in the watershed, the findings of the spatial analysis of LULC trends were triangulated with a survey of watershed communities' perceptions of trends and drivers of LULC changes. A summary of the socio-economic characteristics of the survey respondents is presented in Table 4.8. The age of the participants range from 21- 83 years, with an average of 38.6. Approximately 57.8% lived in the watershed throughout the period under review for LULC changes. The majority (77%) are married, 71.7% of the households are male-headed while 28.3% are female-headed. Household sizes in the watershed range from 1-12 persons, with an average of 6.1. About 84.3% own land and 15.7% being landless, with landholding size ranging from 0.5-9 acres, with an average of 2.91 acres. Regarding educational attainment, 72.1% are literate - 23%, 25.5%, and 23.6% - had attained primary education, secondary education, and college education, respectively, with 27.9% having no formal schooling.

Approximately 80% of the surveyed households were involved in crop farming and a fifth of the participants (20%) were engaged in various off-farm and non-farm activities. The

average household income of the participants was USD 498.72 (Kshs 57,552.29) per annum. Agriculture is ranked as an important source of income for households in the watershed, followed by non-farm activities such as employment in non-farm sectors like healthcare education, mining, and tourism, which are ranked second, then off-farm self-employment activities such as processing, packaging, transport or sale of farm produce, and lastly remittances.

Table 4.8: Summarized attributes of the sampled household in the study area (N = 318)

Household Characteristic	**Value**
The average age of household heads (years)	38.6
Male-headed households (%)	71.7
Marital status (married, %)	77.7
Education (literate, %)	72.1
Occupation (Farming, %)	80
Average household size (no)	6.1
Average landholding size (acres)	2.91
Average household income (Kshs/year*)	57,552.29
Income sources (agriculture, rank)	1
Household cooking stove (three-stone open fire, %)	93.5

*Key: * The exchange rate for Kshs at the time of the study was 1 USD = 115.40*

The study observed significant differences (at $p < 0.05$) among the surveyed households' perceptions of LULC trends in the watershed. The study participants perceived that farmlands have significantly expanded (at $p < 0.05$) in the watershed while forests and vegetation cover have significantly declined (at $p < 0.05$) over the years under review, confirming the findings of the spatial analyses of section 4.3.1. 60.5% and 75.8% of watershed communities perceived that farmlands and forests had expanded and shrunk respectively (Figure 4.7); these perceptions were consistent with the spatial analysis and indicate the intensive conversion of forests to farmlands over the years. Nearly two-thirds of the households (65.2%) perceived that the distance to natural water sources didn't change

from 1980 to 2020. Also, the distances to infrastructures like health facilities and major roads largely remained unchanged over the same period whereas distances to commercial centers and markets, portable drinking water, and education centers were perceived to have significantly decreased over the same period (at $p < 0.05$). These show that the accelerated urban development observed in the spatial analysis prioritized the expansion of residential areas for commercial, settlement and academic purposes at the expense of health centers and road networks.

In general, the study observed that the watershed communities are sufficiently aware of changes in natural resources and changes related to infrastructure development. This local attention to LULC changes including infrastructure development can provide valuable input for government strategies to execute a suitable spatial plan for the watershed. Combining LULC maps with local perceptions of LULC changes enables enhanced interpretation of the land use information, which can help the government to develop spatial plan that considers socio-economic and ecological circumstances and engages local people in decision-making.

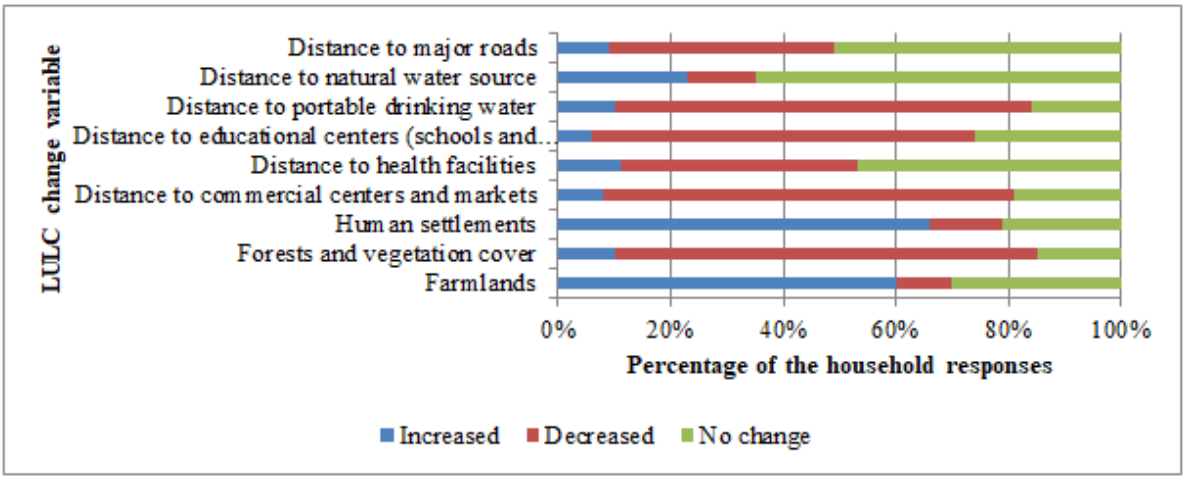


Figure 4.7: Survey participants' perceptions of LULC trends in the Migori River watershed

4.3.3 Drivers of Land Use Land Cover Changes in the Migori River Watershed

The survey identified 11 major proximate drivers of LULC change in the watershed (Table 4.9); these are factors linked to human undertakings that directly transform the land cover (Lambin et al., 2001). Fuel wood collection, timber/poles production, shifting cultivation, agricultural expansion, and charcoal production were the top five ranked proximate drivers of LULC changes in the watershed, with fuel wood collection and timber/poles production ranking first and second respectively. Other notable factors included settlements and artisanal mining (Table 4.9).

Table 4.9: Perceived proximate drivers of LULC changes in the Migori River watershed

LULC Proximate Driver	Distribution of Respondents per Rank					Weight	Index	Rank
	1	2	3	4	5			
Firewood collection	139	114	38	11	16	1303	0.819	1
Timber or poles production	118	86	94	13	7	1249	0.786	2
Shifting cultivation	57	49	128	64	20	1013	0.637	3
Agriculture expansion	45	53	78	89	53	902	0.567	4
Charcoal production	21	35	95	132	35	829	0.521	5
Rural infrastructure expansion	14	34	48	201	21	773	0.486	6
Settlements	9	17	113	43	136	674	0.424	7
Brick production	2	10	56	167	83	635	0.399	8
Artisanal gold mining	0	2	35	205	76	599	0.377	9
Unplanned urban expansion	3	13	16	62	224	463	0.291	10
Bush fires	0	0	0	60	258	378	0.238	11

Note: Ranking of the drivers is based on the Relative Importance Index (RII) equation (3) described in section 3.5.2

Concerning the underlying drivers, that is the forces that indirectly prompt the proximate causes (Geist & Lambin, 2002), the survey participants perceived population growth and poverty as the two main drivers of LULC change in the watershed, followed by limited access to alternative sources of energy, demand for timber, and lack of law enforcement (Table 4.10). Approximately 95% of survey participants agreed that the population of the

area has increased over the period under review, which corroborated with population data that indicate that the population of the Migori County where the watershed is situated has grown by 180% between 1980 and 2019 (Figure 4.8). Previous studies in the larger Lake Victoria basin, which encompasses the Migori River watershed, had also identified population pressure as one of the drivers of landscape alterations (Odada et al., 2009; Onyango et al., 2021). In the developing world, population growth and high poverty levels have also been identified to be the main indirect drivers of LULC changes (Ariti et al., 2015; Mekuyie et al., 2018).

Table 4.10: Perceived underlying drivers of LULC changes in the Migori River watershed

LULC Underlying Driver	Distribution of Respondents Per Rank					Weight	Index	Rank
	1	2	3	4	5			
Population growth	272	25	5	12	4	1503	0.945	1
Poverty	162	106	31	18	1	1364	0.858	2
Poor access to alternative-energy supply	38	47	192	24	17	1019	0.641	3
Demand for timber	35	48	79	105	51	865	0.544	4
Lack of law enforcement	34	15	95	136	38	825	0.519	5
High cost of agriculture inputs	23	29	48	186	32	779	0.490	6
Weak government policies	10	13	111	37	147	656	0.413	7
Natural conditions	5	0	28	199	86	593	0.373	8
Urbanization	1	5	19	177	116	552	0.347	9
Political interferences	0	1	1	24	292	347	0.218	10

Note: Ranking of the drivers is based on the Relative Importance Index (RII) equation (3) described in section 3.5.2

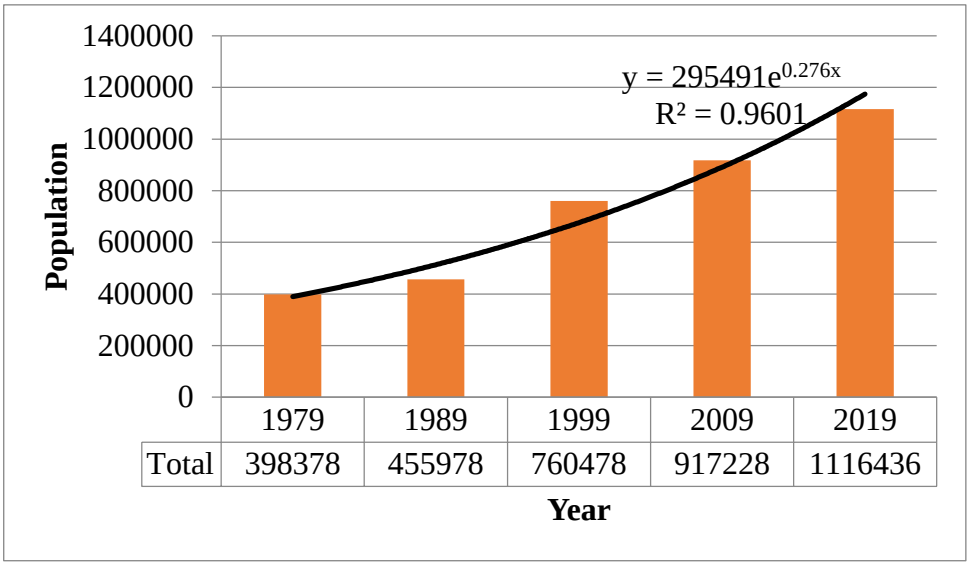


Figure 4.8: Population Growth in Kenyan Lake Victoria Basin, 1979 - 2019

Generally, the top 5 proximate causes of LULC changes in the watershed i.e., fuel wood collection, timber/poles production, shifting cultivation, agricultural expansion, and charcoal production, are triggered by population pressure and high poverty levels. Due to the high poverty levels, about 93% of the watershed households use three-stone open fire for cooking resulting in increased utilization of fuel wood which not only causes indoor air pollution but also accelerates deforestation. Association between poverty and usage of three-stone open fire has been established in the western Kenya region by Njenga et al. (2017). Also, poverty has made watershed communities to be involved in charcoal burning as a source of income; they seem to burn the charcoal and sell it in urban areas rather than use it in their households. The overdependence of rural communities on fuel wood and urban dwellers on charcoal has been widely documented in Kenya by previous studies (Kituyi, 2004; Njenga et al., 2017).

Timber/poles production was identified as one of the drivers because it is used by the rural communities for constructing settlements for the ever-burgeoning population. The high

utilization of fuel wood, charcoal, and timber/poles for construction in this region explains the decline in forest cover between 1980 and 2020. Overall, the findings imply that the watershed community derives its income from shifting cultivation and the extraction and sale of forest products like poles, lumber, firewood, and charcoal and that they are also driven to clear forested areas for additional farmlands or settlement areas to accommodate the growing population.

4.3.4 Hydrological Response to Land Use and Land Cover Changes in the Migori River Watershed between 1980 and 2020

The hydrological response of the Migori River watershed to LULC changes between 1980 and 2020 was simulated using the SWAT model in a complex process that begins with model parameter sensitivity analysis and model calibration and validation before simulation of the changes in the water balance components and the sediment regime for the period under review.

(i) Parameter Sensitivity Analysis

During the calibration process, sensitivity analysis carried out on 18 flow parameters on monthly time steps with river gauged data indicated that 12 parameters were the most important or sensitive for flow simulation in the Migori River watershed (Table 4.11). This means that these 12 variables hold significant influence in regulating the streamflow in this area, and were therefore used in calibrating and validating the model. The sensitivity ranking revealed that Curve number (CN2) and Alpha factor (ALPHA_BF) were the two most sensitive variables for streamflow prediction, an indication that streamflow in the watershed was majorly controlled by runoff and base flow (ground water flow) processes. The Migori

River watershed lies within a region associated with volcanic geological configuration favorable to ground water recharges.

Table 4.11: List of sensitive parameters and fitted values of flow calibration for Migori River watershed

Rank	Parameter Name	Description	Range	Fitted Value
1	R__CN2.mgt	SCS runoff curve number factor	-0.2 - 0.2	-0.282
2	V__ALPHA_BF.gw	Base flow alpha factor	0.0 - 1.0	0.047
3	V__GW_DELAY.gw	Groundwater delay time (days)	30 - 450	136.15
4	V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	0 - 5000	4.092
5	R__ESCO.hru	Plant uptake compensation factor	0 - 1	0.737
6	V__EPCO.hru	Plant uptake compensation factor	0 - 1	0.261
7	V__OV_N.hru	Manning's "n" value for overland flow	0.01 - 1	0.12
8	R__RCHRG_DP.gw	Deep aquifer percolation fraction	0 - 1	0.39
9	V__GW_REVAP.gw	Groundwater "revap" coefficient	0.02 - 0.2	0.123
10	V__SURLAG.bsn	Surface runoff lag time	0.05 - 25	8.115
11	V__CH_N2.rte	Manning's "n" value for the main channel	0 - 1	-0.112
12	V__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	0 - 150	55

(ii) SWAT Model Calibration and Validation of Stream Flow

During the calibration period (1981-2009), the observed and simulated mean monthly stream flow for Migori River at the main gauging outlet were 227.8 and 225.2 m^3/s, respectively (Figure 4.9, Table 4.12); whereas during the validation period (2010-2020), the observed and simulated mean monthly stream flow were 231.9 and 226.7 m^3/s, respectively (Figure 4.10, Table 4.12). The simulated mean monthly flows showed a good agreement with the observed mean monthly flows in both calibration and validation periods as indicated by the statistical values of R^2, NSE and PBIAS for both periods (Table 4.12), falling above the satisfactory

range in the model evaluation criteria by Moriasi et al. (2015) recommended by SWAT model developer.

However, the PBIAS values of -16.2% for the calibration and -29.8% for the validation (Table 4.12), although within the <±10 range for above average model, shows that the model might have overestimated the flows for certain years in both the calibration and validation periods. This may be attributable to some extreme precipitation events in the watershed or errors inherited from data inputs like LULC maps and soil maps, which were obtained from different sources. The observed mean monthly flows in both the calibration and validation periods for Migori River were comparatively higher than simulated flows.

Generally, the calibration and validation results show that the simulated and observed mean monthly flows were consistent (Figure 4.9 and 4.10) and not significantly different between the two periods; and that the model has above average performance which indicates that the biophysical processes controlling stream flows in the study area were sufficiently captured by the model. Thus the model was considered sufficient for estimating the effects of various LULC scenarios on the water balance of Migori River watershed.

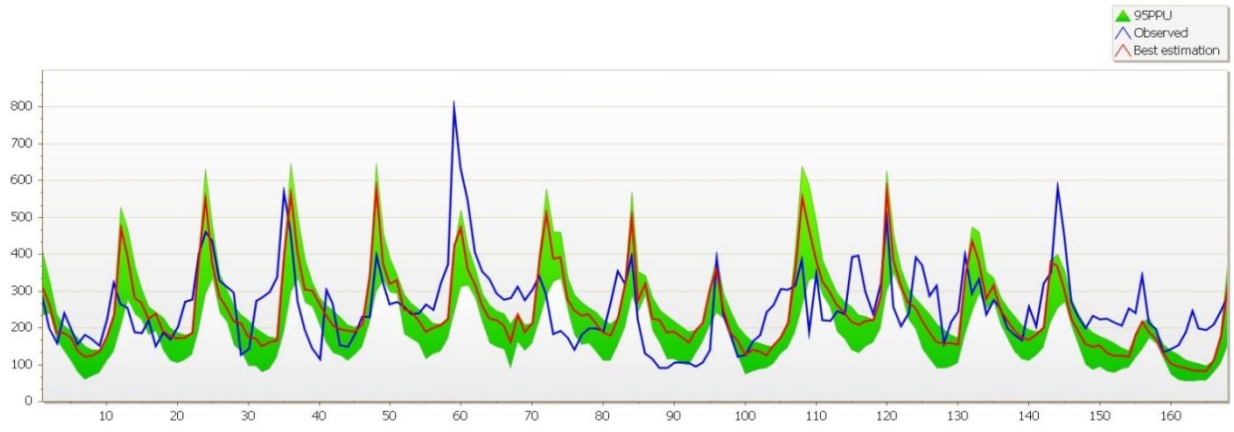


Figure 4.9: Calibration hydrograph for Migori River watershed at the main outlet

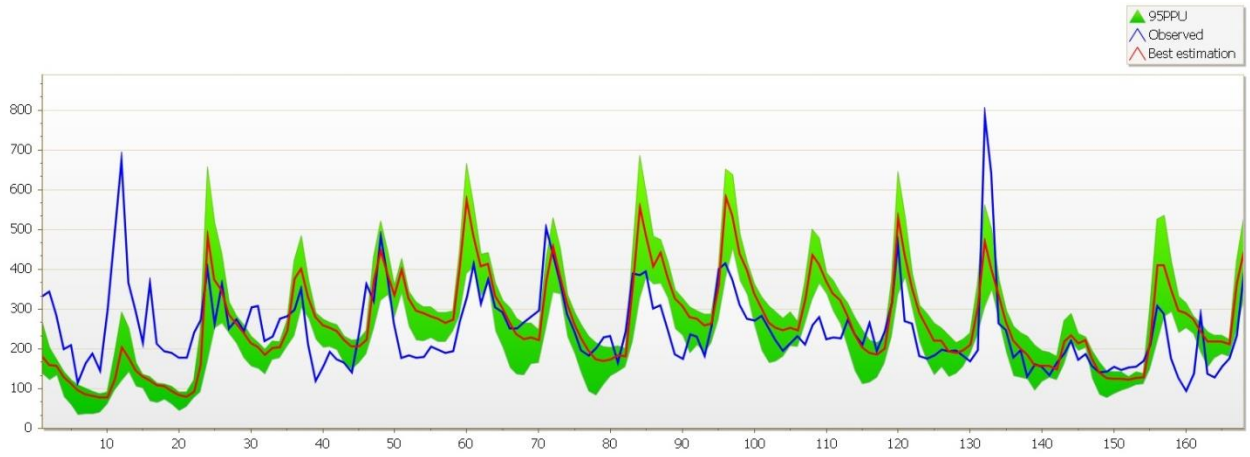


Figure 4.10: Validation hydrograph for Migori River watershed at the main outlet

Table 4.12: Evaluation results for calibration and validation of the model output

Period	Mean monthly stream flow (m^3/s)		Evaluation statistics		
	Observed	Simulated	R2	NSE	PBIAS (%)
Calibration	227.8	225.2	0.73	0.79	-16.2
Validation	231.9	226.7	0.67	0.71	-29.8

(iii) Trends of Changes in Water Balance and Sediments Yields due to LULC Changes

As demonstrated by the results of the evaluation of the impacts of LULC changes on the major hydrological components in the Migori River watershed (Table 4.13 and Figure 4.11), the hydrology of the watershed has been changing over the years with changes in LULC. The results show that the changes in LULC between 1980 and 2020 has contributed to the decline of annual actual evapotranspiration by 2.83% (-14.63 mm), annual potential evapotranspiration by 5.38% (-95.29 mm), and annual ground water recharge 19.06% (-18.41 mm); whereas annual surface runoff, water yield and sediment yields due to soil erosion have increased over the same period by 32.57% (+16.75 mm), 4.82% (+8.75 mm) and 84.58% (+7.57 tons/ha/year), respectively.

These results demonstrate that the LULC changes in the watershed, has considerably influenced its hydrological response. Increase in surface runoff and sediment yields coupled with a decrease in actual and potential evapotranspiration and ground water recharge indicate increase in agricultural lands and built-up areas at the expense of vegetation cover for forests and shrub lands. Evaluation of the LULC change from 1980 to 2020 by this study shows that vegetation cover within the watershed has considerably reduced because of destruction of natural landscapes (particularly shrub land, grassland, and forests) at the expense of agricultural expansion, human settlement and infrastructural developments. Over the period under review, spatial analysis of this study showed that shrub land declined by 40.63% (-235.97 km^2), grassland by 84.86% (-59.14 km^2), and forests by 52.90% (-98.36 km^2); whereas cultivated land, bare land, and built-up area expanded by 34.25% (+347.42 km^2), 132.28% (+60.95 km^2) and 461.20% (+25.32 km^2), respectively.

Over the 40 year period, the expansion of cultivated lands and bare lands by displacing shrub lands, grasslands, and forests led to an increased erosion of the soil surface by precipitation events which consequently caused the increased sedimentation and a reduction in ground water recharge to the aquifers. Previous studies show that reduced vegetation cover causes increased sediment and runoff generation (Balthazar et al., 2015; Gyamfi et al., 2016), and hence reduced infiltration in the ground (Kashaigili, 2008; Shukla & Gedam, 2019). Chaves et al. (2008) indicates that removal of the vegetation cover impacts the watershed water budget because it removes the organic and humus matter required to improve the soil structure to prevent erosion while promote infiltration rates.

Additionally, this conversion of the natural landscapes containing vegetation cover (shrub land, grassland, and forests) to other land uses like built-up areas in the watershed contributed to the increased generation of annual surface runoff and reduced actual (and potential) evapotranspiration, which consequently led to increased water yield for the watershed. Loss of vegetation cover is directly linked to an increase in water yield as the degree of surface flow overcomes that of base flow (Kashaigili, 2008), and it is also known to reduce the transpiration rate (Shukla & Gedam, 2019). The reduction in evapotranspiration in the watershed can also be partially attributed to the decline of the area covered by water bodies. This study established that over the period under review, area occupied by water decreased by 82.03% (-39.27 km^2) while wetlands shrunk by 38.44% (-3.69 km^2). The expansion of built-up areas within the watershed increases the water yield since the infrastructural constructions like roads and buildings elevates the runoff coefficient which consequently leads to elevated streamflow rates.

Table 4.13: Estimated Mean annual hydrological summaries for the Migori River watershed

Parameter	**Year**					
	1980	**1990**	**2000**	**2010**	**2020**	**1980-2020**
SURQ	51.42	53.89	52.94	57.97	68.17	16.75
ET	517.48	514.01	510.74	504.56	502.85	-14.63
PET	1771.11	1732.39	1709.43	1688.35	1675.82	-95.29
GWQ	96.61	96.27	91.05	82.88	78.2	-18.41
Water yield (mm)	181.26	185.53	187.67	187.98	190.01	8.75
Sediment yield (t/h)	8.95	8.87	13.06	15.51	16.52	7.57

Where: SurQ: Surface runoff contribution to streamflow (mm); PET: Potential evapotranspiration (mm); ET: Real evapotranspiration (mm); GwQ: Groundwater contribution to streamflow (mm/day)

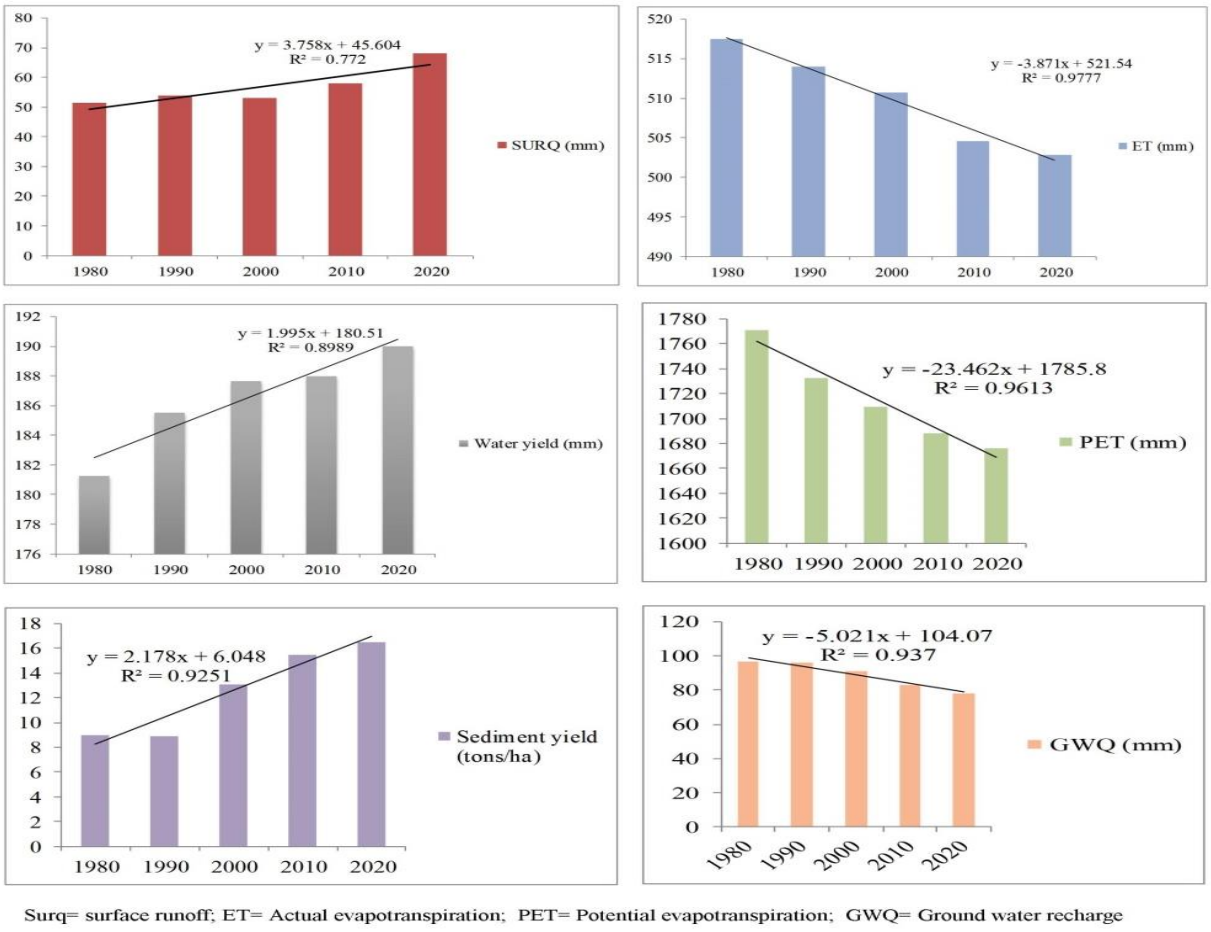


Figure 4.11: Trends of changes in water balance and sediments yields due to LULC changes

The increase in surface runoff and sedimentation established in this study explains the frequent flooding events that have been reported in the low-lying downstream area of this watershed over the years (Ndetei, 2006; JICA &WRA, 2014; Owuonda, 2016). This is because the large volumes of generated surface runoff frequently flow to the river with a reduced depth due to heavy sedimentation, causing the excess water to busts the banks and become floods (Figure 4.12). These floods have been increasing in frequency over the years and have often led to destruction of crops, degradation of farmlands, loss or injury of livestock and displacement of people in Nyatike area (Figure 4.12).

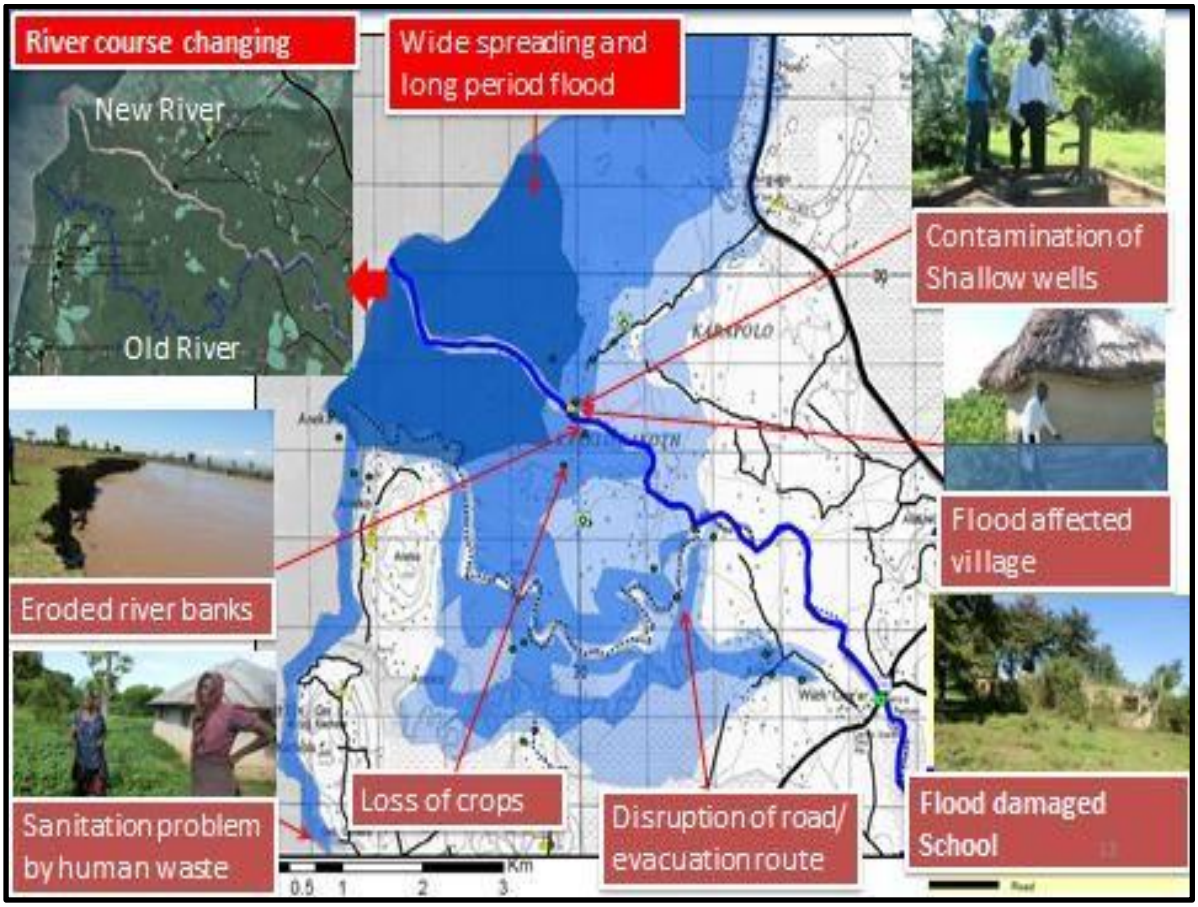


Figure 4.12: Flood Characteristics and records of damage in the downstream area of Migori River watershed (JICA &WRA, 2014)

The findings of this study are consistent with previous published studies modeling the impacts of LULC changes on stream flow and sediment yields in various watersheds in Kenya using the SWAT model. These studies tend to show an increase in streamflow and sediment yields and a decrease in ground water recharge due to LULC changes, an indication that the hydrological processes of various watersheds in the country are influenced by nearly similar changes in LULC. A hydrological modeling study of Thika River catchment in Kenya by Kigira (2010) revealed that sedimentation increased in the watershed due to the expansion of cultivation on hilly areas. A study in in Sasumua watershed, in Central Kenya by Mwangi (2013) indicated that because of the conversion of forests to farmlands and

pasturelands, the mean annual surface runoff and sediment yield increased by 44% and 53% respectively; whereas the baseflow reduced by 10%. In the study of Upper Tana River catchment, also in Central Kenya, by Hunink et al. (2013) reported that a 25% increase in sediment yield occurred due to expansion of built-up area in the watershed, especially roads and settlements.

4.4 The Spatio-seasonal Variations of Water Quality Parameters of the Migori River and Associated Household Health Risk Implications in Migori River Watershed

Monitoring of water quality of the Migori River was undertaken to provide objective evidence of how the combined actions of biophysical processes and human activities potentially pose health risks to households in the watershed. This section presents analyses and discussions on the spatio-seasonal variations in water quality parameters (physico-chemical and bacteriological properties) of the Migori River as analyzed through multivariate statistical techniques, the overall river drinking water quality status based on the Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI), and the potential public health risk associated with river water usage analyzed based on household health risk survey data.

4.4.1 Spatio-seasonal Variations in the Physico-chemical and Bacteriological Properties of Migori River Water

The spatial and seasonal variations of monitored physicochemical and bacteriological parameters in the surface waters of the Migori River are shown in Tables 4.14 and 4.15, respectively.

Table 4.14: Spatial variation of water quality parameters (Mean ± S.E) in the three stream sections of Migori River compared against established standards

Parameter	Water Quality Standards		Site-Specific Measurements Mean (± S.E)			
	NEMA	WHO	Upstream	Midstream	Downstream	Total (Stream)
Temperature (°C)	25.00	25.00	25.28 (0.49)[a]	24.84 (0.51)[a]	25.59 (0.41)[a]	25.24 (0.28)
DO (mgL^{-1})	8.00	7.00	7.89 (0.13)[a]	8.28 (0.09)[b]	8.68 (0.16)[c]	8.28 (0.11)
BOD (mgL^{-1})	5.00	5.00	10.80 (0.78)[a]	15.01 (0.93)[b]	18.06 (1.09)[c]	14.62 (0.73)
pH	6.5-8.5	6.5-8.5	8.16 (0.10)[a]	8.59 (0.15)[a]	8.53 (0.12)[a]	8.43 (0.07)
EC (μScm^{-1})	250.00	1500.00	176.64 (14.12)[a]	157.62 (13.58)[a]	174.40 (13.00)[a]	169.55 (7.74)
Salinity (mgL^{-1})	0.04	0.04	0.08 (0.02)[a]	0.07 (0.01)[a]	0.07 (0.1)[a]	0.07 (0.01)
Total Alkalinity (mgL^{-1})	500.00	500.00	55.18 (4.36)[a]	51.02 (3.86)[a]	53.99 (3.89)[a]	53.40 (2.29)
Total Hardness (mgL^{-1})	500.00	500.00	53.67 (3.66)[a]	50.02 (4.12)[a]	55.92 (3.30)[a]	53.20 (2.12)
TDS (mgL^{-1})	1500.00	1200.00	111.22 (10.19)[a]	101.14 (8.79)[a]	108.40 (9.27)[a]	106.92 (5.24)
Turb (NTU)	5.00	5.00	193.03 (44.18)[a]	238.47 (47.31)[a]	316.45 (69.04)[a]	249.32 (31.82)
TP (μgL^{-1})	2000.00	2000.00	156.33 (8.59)[a]	166.53 (15.41)[a]	191.74 (17.05)[a]	171.53 (8.33)
TN (μgL^{-1})	2000.00	2000.00	1035.66 (64.35)[a]	984.82 (107.40)[a]	1293.25 (125.22)[a]	1104.58 (61.69)
NO3−N (μgL^{-1})	10000.00	10000.00	213.05 (39.54)[a]	127.47 (20.32)[a]	148.11 (12.51)[a]	162.87 (16.17)
NO2−N (μgL^{-1})	3000.00	1000.00	19.49 (1.54)[a]	20.01 (1.28)[a]	17.67 (1.05)[a]	19.05 (0.75)
NH3−N (μgL^{-1})	500.00	500.00	37.73 (6.33)[a]	33.63 (6.79)[a]	28.53 (3.77)[a]	33.30 (3.30)
SRP(μgL^{-1})	NS	NS	40.56 (5.53)[a]	39.92 (7.01)[a]	40.13 (4.40)[a]	40.20 (3.22)
SiO_2 (μgL^{-1})	NS	NS	33.21 (2.93)[a]	31.43 (3.23)[a]	32.47 (2.86)[a]	32.37 (1.69)
FC Counts (cfu/100ml)	Nil (0)	Nil (0)	307.51 (36.17)[a]	596.63 (65.14)[b]	632.55 (31.28)[c]	512.23 (35.90)

Note: Mean values in the same row that do not share a superscript letter are significantly different ($p<0.05$).

Key: DO*: dissolved oxygen;* BOD: *biological oxygen demand;* EC: *electrical conductivity;* TDS: *total dissolved solids:* Turb: *turbidity;* TP: *total phosphate;* TN: *total nitrogen;* NO_3−N: *nitrate-nitrogen,* NO_2−N: *nitrate-nitrogen;* NH_3−N: *ammonia-nitrogen;* SRP: *soluble reactive phosphorus;* FC: *fecal coliforms*

Table 4.15: Seasonal variation of water quality parameters (Mean ± S.E) in the two seasons of Migori River System in comparison with established standards

Parameter	Water Quality Standards		Season-specific Measurements Mean (± S.E)		
	NEMA	WHO	Wet Season	Dry Season	Overall Sampling Period
Temperature (°C)	25.00	25.00	24.12 (0.39)[a]	26.35 (0.17)[b]	25.24 (0.28)
DO (mgL^{-1})	8.00	7.00	8.49 (0.14)[a]	8.08 (0.10)[a]	8.28 (0.11)
BOD-5 (mgL^{-1})	5.00	5.00	17.34 (0.92)[a]	11.91 (0.68)[a]	14.62 (0.73)
pH	6.5-8.5	6.5-8.5	8.54 (0.08)[a]	8.32 (0.10)[a]	8.43 (0.07)
EC (μScm^{-1})	250.00	1500.00	141.28 (11.81)[a]	197.83 (3.66)[b]	169.55 (7.74)
Salinity (mgL^{-1})	0.04	0.04	0.06 (0.00)[a]	0.09 (0.00)[b]	0.07 (0.01)
Total Alkalinity (mgL^{-1})	500.00	500.00	44.50 (3.24)[a]	62.29(1.29)[b]	53.40 (2.29)
Total Hardness (mgL^{-1})	500.00	500.00	43.78 (2.71)[a]	62.62 (0.84)[b]	53.20 (2.12)
TDS (mgL^{-1})	1500.00	1200.00	87.33 (8.14)[a]	126.51 (2.42)[b]	106.92 (5.24)
Turb (NTU)	5.00	5.00	351.42 (52.92)[a]	147.21 (11.93)[b]	249.32 (31.82)
TP (μgL^{-1})	2000.00	2000.00	184.92 (7.37)[a]	158.15 (14.50)[b]	171.53 (8.33)
TN (μgL^{-1})	2000.00	2000.00	1264.73 (55.88)[a]	944.42 (97.63)[b]	1104.58 (61.69)
NO3−N (μgL^{-1})	10000.00	10000.00	210.00 (27.82)[a]	115.75 (6.45)[b]	162.87 (16.17)
NO2−N (μgL^{-1})	3000.00	1000.00	20.63 (1.22)[a]	17.48 (0.73)[b]	19.05 (0.75)
NH3−N (μgL^{-1})	500.00	500.00	46.95 (4.76)[a]	19.65 (0.64)[b]	33.30 (3.30)
SRP(μgL^{-1})	NS	NS	52.10 (4.88)[a]	28.30 (1.52)[b]	40.20 (3.22)
SiO_2 (μgL^{-1})	NS	NS	29.32 (3.07)[a]	35.42 (1.12)[b]	32.37 (1.69)
FC Counts (cfu/100ml)	Nil (0)	Nil (0)	540.50 (43.94)[a]	483.96 (57.30)[a]	512.23 (35.90)

Note: Mean seasonal values in the same row that do not share a superscript letter are significantly different ($p<0.05$).

Key: DO*: dissolved oxygen;* BOD: *biological oxygen demand;* EC: *electrical conductivity;* TDS: *total dissolved solids:* Turb: *turbidity;* TP: *total phosphate;* TN: *total nitrogen;* NO_3−N: *nitrate-nitrogen,* NO_2−N: *nitrate-nitrogen;* NH_3−N: *ammonia-nitrogen;* SRP: *soluble reactive phosphorus;* FC: *fecal coliforms*

(i) Temperature

With an overall mean of 25.24°C, the mean water temp in the river varied between 24.84°C and 25.59°C recorded upstream and downstream, respectively, with ANOVA (at $p<0.05$) revealing no significant differences between the three sections of the river ($F(2, 33) = 0.579$, $p = 0.566$). Since water temperature is regulated by the geographical location of the river and the local climatic conditions (Mathew et al., 2017), the upstream waters of the river are cooler than the downstream waters because of variation in altitude and vegetation cover. The upstream has dense riparian vegetation which cools the passing water while the downstream has sparse vegetation exposing it to direct insolation. Based on T-test results ($t(34) = -5.212$, $p = 0.000$), the mean temperature of the dry season (26.35°C) was significantly higher than that of the wet season (24.12°C), which might be due to the dry season being characterized by reduced precipitation and less cloud cover facilitating intense insolation to directly reach the waters of the river. These findings are consistent with those of Musyimi et al. (2017). Water temperature for various stations and seasons was within the acceptable drinking water standards recommended in the NEMA (2017) and WHO (2017).

(ii) Dissolved Oxygen (DO)

Dissolved oxygen (DO) is the concentration of oxygen in the water column and is influenced by the level of temperatures, photosynthetic activity, and water flow velocity which regulates the aeration, and decomposition of organic materials (Musyimi et al., 2017). The mean DO varied from 7.89 mgL^{-1} registered by the upstream to 8.68 mgL^{-1} registered by the downstream, with ANOVA (at $p<0.05$) revealing that significant differences exist between the three sections of the river ($F(2, 33) = 8.498$, $p = 0.000$). The DO level is highest

downstream compared to the other two zones probably because its higher temperatures influenced greater solubility of oxygen in the water column. With no significant difference (at $p<0.05$) between the means of the two seasons ($t(34) = 2.347$, $p = 0.191$), the mean DO for the wet season (8.49 mgL^{-1}) was slightly higher than that of the dry season (8.08 mgL^{-1}); which could be attributed to increased atmospheric diffusion of oxygen by fast-flowing water during rainy periods, allowing greater aeration (Langat, 2009). With an overall mean of 8.28 mgL^{-1}, the DO levels recorded in the river were within the acceptable limits recommended by NEMA (2017) and the WHO (2017).

(iii) Biological Oxygen Demand (BOD)

BOD signifies the amount of DO required by aerobic microbes to break down organic materials in a water sample (Woldeab et al., 2018); hence it is influenced by the same factors as DO. While the mean BOD spatially varied from 10.80 mgL^{-1} registered in upstream to 18.06 mgL^{-1} registered in downstream, ANOVA (at $p<0.05$) revealed that significant differences exist between the three sections of the river ($F(2, 33) = 15.009$, $p = 0.000$). The BOD levels were generally low at the upstream stations and gradually increased toward the downstream stations due to increased loading of organic matter from domestic wastes and industrial effluents downstream through runoff from the upper reaches of the river. BOD concentration of the wet season (17.34 mgL^{-1}) was higher than that of the dry season (11.91 mgL^{-1}) because high amounts of runoff during the wet season collect huge amounts of organic material and deposit them in the river (Sanchez et al., 2020), this variation was not significant as revealed by the T-test ($t(34) = 4.727$, $p = 0.195$). The BOD values recorded at various stations and seasons exceeded the permissible limit of 5 mgL^{-1} recommended by NEMA (2017) and WHO (2017).

(iv) pH

With an average pH level of 8.43, the waters of the Migori River can be described as slightly basic. This weak alkalinity comes from the carbonate-rich rocks and soils in which the river flows through. The pH results were uniform throughout this study, with no significant differences among the three river sections ($F(2, 33) = 8.159$, $p = 0.010$) and seasons ($t(34) = 1.736$, $p = 0.377$) as revealed by ANOVA (at $p<0.05$) and T-test (at $p<0.05$) respectively, which is an indication that there is more or less the same level of chemical disruption across the river length (Sanchez et al., 2020). The study observed a slightly higher pH during the wet season compared to the dry season which could probably be a result of increased photosynthetic activity in the wet season which depleted the CO_2 concentration in the water column and hence raised the pH slightly. It could also be attributed to increased levels of alkaline-based detergents washed off by runoff during the wet season. Every pH value observed in the river was within the maximum permissible range of 6.5-8.5 recommended by NEMA (2017) and WHO (2017).

(v) Electrical Conductivity (EC), Salinity, and TDS

The EC and TDS measure the salinity of river water, which also refers to any minerals, salts, metals, anions, or cations dissolved in river water (WHO, 2008; Opiyo, 2019). The EC, salinity, and TDS levels exhibited similar spatial and seasonal variability in the river because all three variables are governed by the weathering of the geological configuration of the watershed, soil type, prevailing climatic conditions, and the intensity of anthropogenic activities occurring within the catchment (Ansa-Asare & Asante, 1996; Stevenson et al., 2010). The mean values of EC ranged from 157.62 μScm^{-1} of midstream to 176.60 μScm^{-1}

of upstream (overall mean of 169.55 µScm^{-1}), and salinity ranged from 0.07 mgL^{-1} of both the midstream and downstream to 0.08 mgL^{-1} of upstream (overall mean of 0.07 mgL^{-1}), while TDS varied from 101.14 mgL^{-1} of midstream to 111.22 mgL^{-1} of upstream (overall mean of 106.92 mgL^{-1}). The lack of significant spatial differences in the levels of EC ($F(2, 33) = 0.586$, $p = 0.562$), salinity ($F(2, 33) = 0.303$, $p = 0.740$), and TDS ($F(2, 33) = 0.304$, $p = 0.739$) across the three sections of the river length implies that the erosion and weathering of dissolved minerals from the watershed are more or less uniform throughout the river length owing to the uniform geological characteristics of the watershed.

T-test results on the seasonal levels of EC ($t(34) = -4.574$, $p = 0.000$), salinity ($t(34) = -5.586$, $p = 0.000$), and TDS ($t(34) = -4.612$, $p = 0.000$) showed that they were significantly higher during the dry season compared to the wet season (Table 4.15), and this is because the dry season is characterized by high evaporation rates and no dilution effect whereas the wet season experiences dilution of dissolved minerals by the voluminous water brought about by the rains (Woldeab et al., 2018). Despite the similarity in spatio-seasonal variability, the levels of EC and TDS in the river were within the maximum permissible limits for drinking water while salinity exceeded its maximum permissible limit for drinking water standards (Tables 4.14 & 4.15). Noteworthy, the EC is a measure of the concentration of dissolved sodium and nitrate ions, salinity measures dissolved chloride (salts) in the water, and TDS measures the amount of organic materials and inorganic salts available in the water column (WHO, 2008; Chergui et al., 2013).

(vi) Total Alkalinity (TA) and Total Hardness (TH)

The total alkalinity (TA) level is dependent on the concentration of carbonates, bicarbonates, and hydroxides in the water whereas the total hardness (TH) level is dependent on the concentration of dissolved cations (magnesium and calcium) and anions (chloride, carbonate, bicarbonate, and sulphates) in the water (USGS, 2018). The source of these ions in water is deposits of limestone or gypsum minerals (EPA, 2020). In this study, the mean values of TA oscillated around 50 mgL^{-1} across the river length with an overall mean of 53.40 mgL^{-1} and no significant differences between the upstream, midstream, and downstream sections ($F(2, 33) = 0.282$, $p = 0.756$) per ANOVA (at $p<0.05$); whereas those of TH varied between 50.00 mgL^{-1} of upstream and 57.83 mgL^{-1} of downstream with an overall mean of 52.59 mgL^{-1} and also no significant differences between the three sections of the river ($F(2, 33) = 0.644$, $p = 0.531$) per ANOVA (at $p<0.05$) results. These results indicate that TA and TH levels are relatively uniform across the river length, implying that the erosion and weathering of limestone minerals from the catchment's geology to the river have been occurring at roughly uniform rates.

However, on a seasonal scale, the levels of TA and TH were significantly higher in the dry season than in the wet season (at $p<0.05$), which could be attributed to the accumulation of large amounts of limestone minerals by high evaporation rates during the dry season and the effect of water dilution during the wet season by the large amounts of rainfall. The dry season mean TA of 62.29 mgL^{-1} was significantly higher than the wet season mean TA of 44.50 mgL^{-1} ($t(34) = -5.097$, $p = 0.000$) whereas the dry season mean TH of 62.62 mgL^{-1} was significantly higher than the wet season mean TH of 43.78 mgL^{-1} ($t(34) = -6.637$, $p =$

0.000). These low levels in the wet season could also be as a result of the floods of high velocity generated by the surface runoff limiting the amount of contact time between the water and the parent rock, which consequently reduces weathering and hence low levels of TA and TH. Generally, the results of the study suggested that the observed TA and TH levels in the river were within the maximum permissible limits for drinking water set by NEMA (2017) and WHO (2017) (Tables 4.14 & 4.15).

(vii) Turbidity (Turb)

Turbidity measures the relative cloudiness or clarity of water caused by suspended particulates that are normally imperceptible to the human eye (USGS, 2018). While ANOVA (at $p<0.05$) revealed no significant differences in the mean turbidity between the three sections of the river ($F(2, 33) = 1.305$, $p = 0.284$), the mean turbidity varied from 193.03 NTU recorded upstream to 316.45 NTU recorded downstream (overall mean of 249.32 NTU), and exhibited a general increasing trend from the upstream stations to the downstream stations; an indication that high amounts of sediments eroded from the upper reaches of the catchment end up downstream through runoff. With respect to seasons, the T-test (at $p<0.05$) showed that the wet season mean turbidity of 351.42 NTU was significantly higher than the dry season mean turbidity of 147.21 NTU ($t(34) = 3.764$, $p = 0.000$); this can be due to heavy sedimentation resulting from the deposition of high amounts of suspended solids by the surface runoff brought by the rains of the wet season ($t(34) = 3.764$, $p = 0.000$). The results depicted that the level of turbidity in the river at any station or season exceeds the permissible limit of 5 NTU recommended by NEMA (2017) and WHO (2017) for drinking water.

(viii) Nutrients concentration

Nutrients are vital parameters of water quality, which depict the status of pollution and anthropogenic load in river water (Suthar et al., 2010). The mean levels of all the phosphoric nutrients (TP and SRP) and nitrogenous nutrients (NO_3-N, NO_2-N, NH_3-N, and TN) analyzed from the water samples of the Migori River were within their respective maximum permissible limits for drinking water (Tables 4.14 and 4.15), which implies that the usage of phosphatic and nitrogen-based fertilizers in farms of the watershed is low level, and therefore has not impacted the water quality. All these nutrient forms enter the water from a variety of sources: runoff from non-point sources (fertilized agricultural lands, animal excreta, mining sites, and residential areas), effluents from point sources (such as wastewater treatment facilities, factories, and malfunctioning septic systems), and fixation by micro-organisms and lightning (EPA, 2020).

Although there were no significant spatial variations in the mean values of the nutrients analyzed (at $p<0.05$), the concentration of phosphatic nutrients, TP (with an overall mean of 171.53 μgL^{-1}), and SRP (with an overall mean of 40.20 μgL^{-1}), were highest in the downstream and gradually decreased toward the upstream stations (Table 4.14 and 4.15). This demonstrates that the downstream receives enormous phosphate nutrients loads eroded by runoff from various sources in the river basin, including fertilized agricultural lands, waste streams from residential settlements, mining activities, and inflowing tributaries. On the contrary, the concentrations of nitrogen-based nutrients (NO_3, NO_2, and NH_3 with exception of TN) were highest in the upstream and gradually decreased toward the downstream stations (Table 4.14). This shows the intensity of usage of nitrogen-based

fertilizer on the upper reaches of the watershed. These spatial variations are related to the closeness of the sampling stations to the river banks, the intensity of agricultural practices nearby, and the density of the riparian vegetation cover. The concentrations of both phosphoric (with exception of TP) and nitrogenous nutrients analyzed for Migori River were significantly higher during the wet season than the dry season at $p<0.05$ (Table 4.15), because in the wet season the surface runoff generated from the rains drains huge volumes of phosphatic and nitrogen-based pollutants from agricultural farms, industrial effluents, animal excreta, mining sites, and residential areas to the river.

(ix) Silicates (SiO_2)

Silicates (SiO_2) in river waters originate from the physical and chemical weathering of silicate minerals from the lithology of the catchment and can be beneficial to humans or cause water quality and treatment problems (EPA, 2020). In this study, with very slight differences in the mean values, the SiO_2 concentrations in various sections were constantly oscillating around 30 μgL^{-1} across the river length during the entire sampling period, and ANOVA (at $p<0.05$) revealed no significant differences between the three sections of the river ($F(2, 33) = 0.088$, $p = 0.915$). This trend implies that the rate of physical and chemical weathering of silicate minerals from the lithology of the river basin has been fairly uniform across the river length.

T-test results at $p<0.05$ ($t(34) = -1.865$, $p = 0.000$) indicated that silicate levels during the dry season (35.42 μgL^{-1}) were significantly higher than in the wet season (29.32 μgL^{-1}), which is an unusual occurrence because silicates are normally higher in the wet season than in the dry season because the rainfall-runoff dissolves high amounts of silicate minerals from

the entire watershed and deposits them in the rivers. Nonetheless, the low silicates observed during the wet season could be attributed to high silica utilization by planktonic organisms especially the diatoms (Bacillariophyceae family) which have been known to utilize silica for building their cell walls to be photosynthetic (Patil et al., 2013).

(x) Bacteriological characteristics (Fecal Coliform Counts)

A fecal coliform is a group of bacteria originating from fecal matter as they specifically reside in the intestines of warm-blooded animals, and although not normally pathogenic on their own, they can indicate the presence of other pathogens (disease-producing bacteria or viruses) in river water (Sanchez et al., 2020). The overall mean count of FC in the river water was 512.23 cfu/100ml, which far exceeded the maximum permissible limit of zero/100ml recommended by NEMA (2017) and WHO (2017); which indicates that the waters of Migori River are contaminated with fecal matter and thus may contain disease-causing pathogens. The high concentration of FC in the river is attributable to the presence of several households along the stretch of the river which dispose of animal and human feces, animal carcasses, and decomposing food wastes in the river.

The mean FC in the downstream (632.55 cfu $100ml^{-1}$) was higher than that of the upstream (307.51 cfu $100ml^{-1}$), and the mean values exhibited a general increasing trend from the upstream stations to the downstream stations although ANOVA (at $p<0.05$) revealed no significant differences between the three sections of the river ($F(2, 33) = 14.588$, $p = 0.000$). Increasing fecal loading towards the downstream could be attributed to increased population, housing, and livestock densities. Bensig et al. (2014) observes that FC counts are linked to the population density, housing density, livestock density, and imperviousness of the area.

Seasonally, the mean FC observed during the sampling period ranged from 399.32-621.97 cfu $100ml^{-1}$ in the dry season and 471.64- 611.63 cfu $100ml^{-1}$ in the wet season; hence the FC count for the wet season was higher due to the increased inflow of fecal materials by rainfall runoff from point and non-point sources in the watershed. However, this variation between seasons was not significant difference (at $p<0.05$) between the means of the two seasons ($t(34) = 0.783$, $p = 0.561$). This observation is similar to the findings of Seo et al. (2019) in the Nakdong River in South Korea.

4.4.2 Overall River Water Quality Status Based on the CCME-WQI Analysis

The CCME-WQI model, constructed using a set of 16 of the studied water quality parameters listed in Tables 4.14 or 4.15, was used to assess the spatio-seasonal variations in the suitability of the Migori river water for domestic purposes. The model comprises *scope (F1)*, the number of parameters that are not in compliance with water quality standards; *frequency (F2)*, the number of times that the standards are not respected; and *amplitude (F3)*, the difference between non-compliance measurements and the corresponding standards. These are used to generate WQI values from 0 to 100 upon which the water quality condition is characterized (see Table 3.4).

(i) Spatial Variation of Water Quality Status

The overall spatial analysis of the CCME-WQI ranked the river's condition as "poor" to "marginal" (Table 4.16), meaning that its water quality variables usually deviate from recommended water quality standards and the water is polluted and unfit for human consumption (drinking purposes) due to physical impurities and bacterial contaminants. The

upstream waters presented the best condition “marginal” with a value of 46.9, whilst the midstream and downstream waters were classified as “poor” (Table 4.16); this indicates that as the river flows downstream the quality of the water deteriorates due to the influence of human activities, domestic and industrial wastewater pollution, mining activities of gold and copper, and agricultural runoff from the landscape along the stretch of the river.

Table 4.16: Spatial variation of water quality index in Migori River

Section	F1 (Scope)	F2 (Frequency)	F3 (Amplitude)	CCME WQI	WQI Category
Upstream	40	27.8	85.8	46.9	Marginal
Midstream	40	32.8	97.7	36.2	Poor
Downstream	46.7	35	97.9	34.2	Poor

(ii) Seasonal Variation of Water Quality Status

Although the overall seasonal analysis of the CCME-WQI ranked the river’s water quality condition as “poor” during both seasons, it indicated that the wet season (with a value of 36.6) had the better water condition, than the dry season (with a value of 34.9) (Table 4.17). This is an unusual occurrence because, for most rivers the water quality is normally better in the dry season than in the wet season (EPA, 2020). This anomaly could be attributed to the high streamflow from increased runoff which brings a dilution effect on the concentration of most parameters, generally keeping them within recommended standards (Ngatia et al., 2023). Hence, during high flow times (wet season) water quality is better than during low flow times (dry season) due to dilution of the concentration of certain water quality variables by the increased streamflow events (Mena-Rivera et al., 2017).

The low CCME-WQI values, representing poor water quality, observed across the stretch of the river in both seasons were found to be mainly emanating from consistently higher values

of temperature, DO, BOD, pH, turbidity, and FC in the river water which depicts the intensity of waste pollution from anthropogenic activities and inflowing tributaries. These variables play a major role in lowering the WQI of a water body since they influence the levels of other variables, therefore watershed management strategies should be directed at reducing pollutants from industrial effluents, domestic wastewater, and agricultural runoff.

Table 4.17: Seasonal variation of water quality index in the Migori River

Section	F1 (Scope)	F2 (Frequency)	F3 (Amplitude)	CCME-WQI	WQI Category
Dry Season	46.7	33.3	97.2	34.9	Poor
Wet Season	40	30.4	97.6	36.6	Poor

4.4.3 Households River Water Utilization and Associated Health Risks

Summary of household heads' survey responses to questions concerning perceived water pollution status, indicators and causes, as well as health implications are presented in Table 4.18. A total of 114 households out of the sampled 318 (i.e. 35.8% of the total sample size) were found to be solely dependent on the Migori River water for their household needs. The specific respondents chosen from each of these households as participants in this assessment were exclusively women as households in Kenya culturally rely on children or women of child-bearing age (or both) for water collection.

The survey revealed that 78.9% of the 114 participants (n=90) solely utilize raw untreated water from the Migori River for their drinking and household purposes while the rest (13.09%) treat the water in some form before use. This indicates that most households are at risk of exposure to polluted waters of the river. Approximately 76% and 56% of the raw untreated river water users perceived that the water was most suitable for washing and

cooking respectively; while 69.8% perceived the water as unsafe for drinking purposes constituting an acknowledgement of the polluted nature of river water which was ranked as moderate by 49.3% of the same participants (Table 4.18), confirming the CCME-WQI findings which categorized the water quality between “poor” to “marginal”. Approximately 81% acknowledged the need for treatment of water for household usage; and by far the most common forms of household treatment in use by a section of the respondents are cloth filtration, boiling, and chlorination using Water Guard (small bottles of chlorine solution). These results suggest that the household water treatment forms used by the watershed communities are insufficient to remove pathogens in river water which may expose them to health vulnerabilities.

Concerning pollution indicators, the participants perceived that turbidity (color of dirty water), increased debris suspension on the river, unusual taste, and unusual smell are the major indicators (Table 4.18). The main causes of river pollution reported by most of the participants included inflowing tributaries (90.8%), direct washing and bathing in the river (71.6%), discharge of mining wastes (62.5%), municipal/industrial wastewater (58.4%), and farm-eroded wastes (45.3%). The survey established that the pollution of the river has negatively impacted some socio-economic and health aspects of about 68% of the participating households (Table 4.18). Socio-economically, it has increased expenditure on household water treatment (as reported by 25% of participants), whereas health wise it has increased expenditure on treatment of water-borne illnesses (59.2%). About 37% of participants claimed to have experienced illnesses they attributed to the usage of the polluted river water, with typhoid (43.9%) and amoebiasis (38.6%) being the most commonly

reported diseases. This raises serious concerns about the health impacts of river water usage among the communities nearby.

Table 4.18: Survey respondents' perceptions of river pollution condition, indicators, causes, and health implications

Responses on river pollution and impacts		**Freq. (N=90)**	**Percent (%)**
Level of river pollution	High	15	16.2
	Moderate	44	49.3
	Low	23	25.7
	No response	8	8.8
River pollution indicators*	Turbidity (dirty water color)	58	64.5
	Increased debris suspension on the river	33	36.9
	Biochemical contamination	4	4.4
	Unusual taste	36	40
	Unusual odor/smell	11	11.7
	Others	1	0.9
Perceived causes of river pollution*	Direct disposition of household waste	18	19.9
	Direct discharge of farm-eroded waste	41	45.3
	Direct discharge of municipal/industrial wastewater	53	58.4
	Pollution from inflowing streams/runoff	82	90.8
	Direct bathing and washing in the river	64	71.6
	Discharge of mining waste	56	62.5
Impacts of river pollution*	Increased expenditure on livestock health	6	6.6
	Increased expenditure on treatment of water borne illnesses	53	59.2
	Increased expenditure on water treatment before household usage	23	25.0
	Increased river infestation of water hyacinth and other weeds	4	3.9
	Reduction in overall fish catch in the Migori river	5	5.3
Prevalent water-borne diseases caused by polluted river water*	Cholera	20	22.1
	Typhoid	40	43.9
	Diarrhea	26	28.8
	Amoebiasis	34	38.6
	Skin infections	8	9.4

Key: * means the question allowed ticking as many responses as appropriate, and the percentage for each response item is indicative of the no. of responses out of the total sample population.

4.5 The Sustainability of Community Livelihoods in the Migori River Watershed and Associated Vulnerability to Climate Change Impacts

The analyses and discussions presented in this section relate to the last objective, which aimed to answer the research question "how sustainable are the household livelihoods' for the watershed communities and what's the level and sources of these livelihoods' vulnerability to climate change impacts?" The household livelihoods' sustainability level was measured using the Livelihood Sustainability Index (LSI) while the associated vulnerability of household livelihoods to climate change impacts was measured using the Livelihood Vulnerability Index framed on the IPCC framework (LVI-IPCC).

4.5.1 Household Livelihoods' Sustainability Analysis for the Migori River Watershed Communities

(A) Household Livelihood Capitals

(i) Natural Capital

The study evaluated households' natural capitals using indicators that represent households' crop production, livestock production and access to land resources, grazing pastures, water resources, forest resources, and fishery resources (Table 4.19). The average households' landholding size in the watershed zones was 2.91 acres; the highest size (3.02 acres) was at the downstream whereas the lowest one (2.76 acres) was at the upstream (Table 4.19). However, the variation in household landholding size among the three watershed zones was not statistically significant (Table 4.23). Based on farmers' responses (Table 4.19), soil fertility level was moderate in the two watershed zones (upstream and midstream) and high in the downstream. Generally, land fertility in the watershed zones was moderate, and the

ANOVA statistical test confirmed that the difference in land fertility level among the watershed zones was not statistically significant at $p < 0.05$. This is consistent with the analyses of Shiluli et al. (2021) which showed that about 42% of farming households in this watershed experience soil fertility problems.

The average households' annual production of the principal staple food crop (maize) in the watershed zones was 787kgs; the highest average annual maize production was observed at midstream (967kgs) while the lowest one (558kgs) was in the downstream (Table 4.19). However, this variation in households' average annual maize production among the three watershed zones was not statistically significant (Table 4.19). The current maize production estimates seem to be consistent with the 900Kgs (10 bags) average households' annual production reported for Migori County by Nyamohanga (2018). Further, the household survey revealed that three-quarters (75.49%) of respondents are not engaged in commercial agriculture, which should be an extra source of income for households. A comparison of the three watershed zones showed that commercial agriculture uptake in the upstream zone was significantly higher (at $p < 0.05$; Table 4.23). In the other two watershed zones (midstream and downstream), about 21-22% of households are engaged in commercial agriculture. This finding is consistent with the conclusions of Otieno et al. (2013) that indicate that uptake of commercial agriculture is low in this region compared to other regions of Western Kenya.

The average number of livestock owned by the watershed households was 5.73 TLU (Table 4.19). The households in the upstream owned a greater number of livestock than the other two watershed zones (midstream and downstream) which had the almost same number of livestock possession (Table 4.19); however, this difference was not statistically significant at

$p < 0.05$ (Table 4.23). The ownership of large livestock sizes among the watershed households can be attributed to the availability of grazing pastures; as 100% of the upstream households, 95.18% of the downstream households, and 78.21% of the midstream households indicated that they have access to grazing pastures (Table 4.19). These findings are consistent with the previous studies by Makalle et al. (2008) and Yamane et al. (2015) which generally reported high livestock ownership in Western Kenya due to the high availability of pasture lands.

For water access, households have to walk for 15.23 minutes on average to reach their portable water source with significant differences (at $p < 0.05$) between watershed zones (Table 4.23). At the watershed level, the average distance traveled by households to reach a portable water source was 19.52, 13.27, and 12.91 minutes at the upstream, midstream, and downstream zones respectively (Table 4.19). These distances imply that the majority -if not all of the watershed households have no household-level water point. Moreover, the water quality of water sources utilized by watershed households was perceived to be high in the upstream, moderate in the midstream, and low at the downstream (Table 4.19). Perceptions on water quality was based on the respondents' observations and interactions with the resource, with classifications of low, moderate and high based on the three organoleptic properties (Doria, 2010), namely smell, taste and transparency. The variations in perceived water quality among the zones were found to be statistically significant at $p < 0.05$ by the ANOVA test (Table 4.23).

Table 4.19: Survey responses on natural capital indicators

Indicators		Watershed zones			
	Responses	**Upstream**	**Midstream**	**Downstream**	**Total**
Land holding size	In acres	2.76	2.98	2.99	2.91
Land fertility level	Low (%)	0.00	4.76	5.95	3.56
	Moderate (%)	98.82	88.10	35.72	74.31
	High (%)	1.18	7.14	58.33	22.12
Annual production of the principal staple food crop	In Kilograms	846	957	558	787
Commercial agriculture (cash crops)	Yes (%)	29.41	21.43	22.62	24.51
	No (%)	70.59	78.57	77.38	75.49
Livestock possession size (TLU)	TLU	6.34	5.53	5.33	5.73
Access to grazing pasture	Yes (%)	100.00	78.21	95.18	91.10
	No (%)	0.00	21.79	4.82	8.90
Distance to portable water	Minutes	19.52	13.27	12.92	15.24
Water quality of household drinking water point	Low (%)	6.60	43.46	51.90	26.17
	Moderate (%)	17.90	48.10	37.30	64.15
	High (%)	75.50	8.44	10.80	9.68
Access to tangible forest resources	Yes (%)	100.00	58.50	96.20	84.90
	No (%)	0.00	41.50	3.80	15.10
Access to fishery resources	Yes (%)	52.80	32.10	88.70	57.90
	No (%)	47.20	67.90	11.30	42.10

The majority of respondents (84.9%) had access to tangible forest resources with a significant difference between watershed zones (at $p < 0.05$). Results (Table 4.19) indicate that 100%, 96.2% and 58.5% of the upstream, downstream and midstream households respectively had access to tangible forest resources (such as fuel wood, timber, medicinal substances, honey, and fruits). A study by Magige (2018) indicates that the upstream region (Kuria and Trans Mara sub-counties) has more gazetted forest blocks; the downstream region (Nyatike sub-county) has more households with private forest plantations due to non-governmental organization's efforts to curb the drought situation, and the midstream region (Suna sub-county) has more farms compared to the three zones which might be the reason for less forest coverage. Regarding access to fisheries resources, it was observed that a greater proportion of the downstream households (88.7%) were fishing or trading in fish resources compared with the upstream (52.8%) and midstream (32.1%); however, this difference was not statistically significant at $p < 0.05$ (Table 4.23). The downstream region has the greatest proportion of fisher folks majorly because it is dominated by the Luo ethnic group who are historically known to be fisher folks and it is close to Lake Victoria hence greater access to fishery resources and opportunities.

The overall measure of the natural capital showed that households in two watershed zones (upstream and downstream) have better access to natural capital compared to the midstream zone (Table 4.23). The limited access to tangible forest resources and fishery resources by the majority of households in the midstream could probably be some of the major reasons for low natural capital in that zone. ANOVA test indicated that the variation in natural capital index between the three watershed zones was statistically significant at $p < 0.05$ (Table 4.23). It's noteworthy that natural capital is highly vulnerable to changes occasioned by

climate variability and the occurrence of natural disasters like earthquakes, floods, and wildfires (Soulineyadeth, 2014); hence its stability is unpredictable.

(ii) Human Capital

The study explored households' human capital by employing metrics that measure households' knowledge, skill level, and access to information (Table 4.20). The study evaluated the respondent's level of educational attainment as an indicator that represents their knowledge and skillset level and about 23% of the household heads had post-secondary education (college or university), while 25.5% had attained secondary education, another 23% had primary education and 28% had no formal education (Table 4.20). At the watershed level, the mean educational attainment index was higher at the upstream (0.53) compared to the midstream (0.47) and the downstream (0.44); however, ANOVA confirmed that variation was not statistically significant at $p < 0.05$ (Table 4.23). This implies that access to education in the watershed is relatively similar, which contrasts with the Kenya 2019 Census (KNBS, 2019) results which show that the Suna Sub-county (midstream) has higher educational attainment among household heads, followed by Nyatike Sub-county (downstream) and then Kuria Sub-county (upstream). The reason for this disparity could be attributed to the study concentrating around the watershed boundaries, which usually don't follow administrative boundaries that are normally used in census. Generally, access to education in Migori County under which the watershed is located has been previously reported to be at par with the national average (UNICEF, 2017).

Community-based training has been proven to be valuable in transmitting technical knowledge aimed at enhancing livelihoods to protect fragile ecosystems like watersheds

(Palanisami & Kumar, 2009). Over three-quarters of household heads in the upstream and the downstream zones had received various watershed conservation and development trainings compared to about 63% of household heads in the midstream zone (Table 4.20), with significant differences between watershed zones (Table 4.23). An interview with one of the community leaders revealed that these trainings are offered by various conservation groups (water resource users associations and community forest associations) which are sponsored and have been trained by various NGOs and county government departments. The insights obtained from such trainings have the potential to greatly improve household livelihoods while also enhancing watershed conservation (Siraw et al., 2018).

The average households' labor force size (number of adult working family members) in the watershed zones was 3.74 persons (Table 4.20). At the watershed level, the mean family labor force index was higher at the midstream (0.56) compared to the upstream (0.44) and the downstream (0.34); however, ANOVA confirmed that variation was not statistically significant (Table 4.23). The technical skill level of households' labor force was moderate in the two watershed zones (upstream and midstream) and high in the downstream (Table 4.20). However, ANOVA (at $p < 0.05$) found no significant difference in the technical skill level of family laborers among the watershed zones (Table 4.23). The majority of households in the watershed had a normal level of daily nutritional intake; 98.1% of the upstream households, 72.6% of the midstream households, and 66% of the downstream households reportedly take 3 meals a day. Unfortunately, about a quarter of households in both the midstream and the downstream zones reportedly had low daily nutritional intake levels (i.e., less than 3 meals a day). This variation in daily nutritional intake was found to be statistically significant at $p <$

0.05 (Table 4.23). This can be attributed to the erratic precipitation patterns in the lower parts of Migori County coupled with high drought prevalence (Ayugi et al., 2016), all of which contribute to reduced agricultural productivity.

In terms of households' health status (Table 4.20), about 84% of households in the watershed had better health status (51.3% moderate and 33.6% high health status). At the watershed level, over half of the households at the midstream and the downstream had moderate health status (less than half of the household members suffer from chronic illnesses) while two-thirds of households in the upstream had high health status (no household member suffering from chronic illnesses); however, this variation was not statistically significant (Table 4.23). The survey further revealed that the average distance traveled by households to reach the nearest medical facility was 30.44, 21.37, and 11.68 minutes at the midstream, upstream, and downstream watershed zones respectively (Table 4.20), with ANOVA (at $p < 0.05$), indicating significant differences between watershed zones (Table 4.23).

The overall human capital index was higher in the upstream Zone than in the midstream and downstream zones (both of which had nearly similar index values) (Table 4.23). The lower human capital index at the two watersheds was due to lower levels of health status and longer distances to the nearest health facilities as compared to the households in the upstream zone. However, the difference in human capital index between watershed zones was not statistically significant (Table 4.23). Studies show that human capital changes depending on factors such as household size, gender, age, educational levels, leadership capabilities, and health condition of the members, among others (Alhassan, 2010; Hautala, 2013; Kedir, 2015).

Table 4.20: Survey responses on human capital indicators

Indicators		Watershed zones			
	Responses	**Upstream**	**Midstream**	**Downstream**	**Total**
Educational attainment of household head	No formal education (%)	20.80	36.80	26.40	28.00
	Primary (%)	26.40	12.30	30.20	23.00
	Secondary (%)	26.40	23.60	26.40	25.50
	Tertiary (%)	26.40	27.40	17.00	23.60
Watershed conservation or development training	Yes (%)	86.80	63.20	90.60	80.20
	No (%)	13.20	36.80	9.40	19.80
Family labor force size (household healthy adults)	Count	3.76	3.80	3.69	3.75
Technical skill level of laborers	Low (%)	9.40	21.70	14.20	15.10
	Moderate (%)	54.70	67.00	30.20	50.60
	High (%)	35.80	11.30	55.70	34.30
Daily nutritional intake level	Low (%)	0.00	24.50	23.60	16.00
	Normal (%)	98.10	72.60	66.00	78.90
	High (%)	1.90	2.80	10.40	5.00
General health status of the household	Low (%)	1.90	16.00	27.40	15.10
	Moderate (%)	33.00	67.90	52.80	51.30
	High (%)	65.10	16.00	19.80	33.60
Distance to the nearest medical facility	Minutes	21.37	30.44	11.68	21.16

(iii) Financial Capital

The study employed 8 indicators to measure the financial capital in the watershed zones (Table 4.21). The average monthly income of households in the watershed zones was approximated to be 10,856 Kshs. The upstream (Kshs 12,566) had the highest monthly household's income, followed by the midstream (Kshs 11,785), while the downstream (Kshs 8,216) had the lowest. This difference in annual mean households' income among the watershed zones was found to be statistically significant (Table 4.23). Based on the household survey responses (Table 4.21), the average financial value of the current standing crop was highest in the midstream (Kshs 74,074) followed by the upstream (Kshs 56,158) and lowest at the upstream (Kshs 43,621), and ANOVA showed that this variation between watershed zones was statistically significant (Table 4.23). On the other hand, the average financial value of available livestock was greater at the upstream than at the midstream and the downstream (both of which had nearly similar amounts as shown in Table 4.21), and ANOVA showed that this variation between watershed zones was not statistically significant (Table 4.23).

The average annual household savings was greater in the midstream (Kshs 91,583) compared to the downstream (Kshs 87,500) and the upstream (Kshs 47,564), and ANOVA showed this variation between watershed zones was statistically significant (Table 4.23). Access to credit services and savings services was highest at the downstream (59.4% and 63.2% respectively), followed by the midstream (52.8% and 51.9% respectively), and lowest at the upstream (36.8% and 36.8% respectively).

Table 4.21: Survey responses on financial capital indicators

Indicators	Responses	Watershed zones			
		Upstream	Midstream	Downstream	Total
Participation in off-farm activities	Yes (%)	32.10	39.60	64.20	45.30
	No (%)	67.90	60.40	35.80	54.7
Participation in non-farm activities	Yes (%)	55.70	67.90	76.40	66.70
	No (%)	44.30	32.10	23.60	33.30
Household monthly income	Amount (Kshs.)	12566.04	11785.38	8216.98	10856.13
Access to credit/loan services	Yes (%)	36.80	52.80	59.40	49.70
	No (%)	63.20	47.20	40.60	50.30
Ownership of savings accounts in financial institutions	Yes (%)	36.80	51.90	63.20	50.60
	No (%)	63.20	48.10	36.80	49.40
Annual household savings	Amount (Kshs.)	47564.10	91583.64	87500.00	75549.25
The financial value of available livestock	Amount (Kshs.)	206187.00	139917.00	136857.00	160987.00
The financial value of the current standing crop	Amount (Kshs.)	56158.30	74074.23	43621.21	57951.25

The study found that the variation in both access to credit services and access to savings services among watershed zones was not statistically significant at $p < 0.05$ (Table 4.23).

Apart from crop production, the high annual income and annual saving levels observed among the watershed zones were supported by participation in non-farm activities rather than off-farm activities, as results show that 66.7 percent and 45.3 percent of watershed households, respectively, engage in these income-generating activities (Table 4.21). Evidently, participation in non-farm activities was highest in the downstream and lowest in the upstream (Table 4.21) with significant statistical differences between watershed zones (Table 4.23). High participation in non-farm activities in the downstream zone could be due to the thriving gold mining business which its residents participate in. On the other hand, participation in off-farm activities was generally low in both the upstream and the midstream and only higher among households in the downstream zone, and the difference between watershed zones was not statistically significant at $p < 0.05$ (Table 4.23).

The financial capital measurement revealed that the midstream and the downstream had better financial endowment compared to the upstream zone. The overall financial capital index was highest at the midstream (0.57), followed by the downstream (0.52), while lowest at the upstream (0.44) (Table 4.23). The variation in mean household financial capital between the watershed zones was found to be statistically significant (Table 4.23). The financial capital index was generally low across the watershed zones, which is a reflection of the depth of household poverty (Alhassan, 2010).

(iv) Physical Capital

In measuring the household's physical capital in the watershed zones, the study used several indicators (Table 4.23). From the results, about three-quarters of respondents (78.49%) in the watershed owned iron-roofed houses with no statistically significant differences (at $p < 0.05$) between watershed zones (Table 4.23). A large proportion of the houses owned by the respondents, that is, over 70% in each watershed zone, were mud-walled, with no statistically significant differences (at $p < 0.05$) between watershed zones (Table 4.23). Nearly all of the sampled households (95.28%) possessed furniture (chairs, tables, and beds) that was adequate for their household needs, and no statistically significant differences ($p < 0.05$) was found between watershed zones (Table 4.23). All households (100%) owned food storage facilities, with no significant difference across the watershed zones. Over 90% of households in each of the three watershed zones possessed a sanitary latrine, and the variation across the watershed zone was not significantly different at $p < 0.05$.

In over half of the watershed households (55%), firewood was the main source of cooking energy. Firewood was utilized by 74.5% of the upstream households, 49.1% of the midstream households, and 41.5% of the downstream households; however, the variation across the watershed was not statistically significant (Table 4.23). The dominant source of light in the upstream and the midstream was solar power utilized by 53.8% and 60.4% respectively, whereas in the downstream it was kerosene which was utilized by close to half of the sampled households (46.6%). The variations in the utilization of various sources of light across watershed zones were found to be statistically significant (Table 4.23). Since access to information is an important part of livelihood, the survey revealed that over 80% of

households in each of the three watershed zones had at least one functional communication device (such as radio, TV, and phones). However, the study found no significant variation in ownership of a functional communication device among the watershed zones. Less than one-fifth households in each watershed zone, owned some type of transport means (bicycle, motorcycle, car, or ox-drawn cart), and there was a statistically significant difference among the watershed zones (Table 4.23).

About 61% had full farm equipment (implements used to cultivate crops) with no significant differences among watershed zones. Only a third of the study respondents owned irrigation equipment (especially water pumps) for pumping water from the rivers/streams to the adjacent farms, and the majority of these respondents (84.9%) were located in the upstream, followed by the midstream and finally the downstream. A significant difference across the watershed zones in terms of ownership of irrigation equipment was revealed by the ANOVA at $p < 0.05$ (Table 4.23). Over two-fifths of the respondents (44.96%) utilize fertilizers (such as Urea, DAP) to boost the fertility of their farms. The percentage of households who utilize chemical fertilizers was significantly higher in the midstream (65.29%) in comparison to households in the upstream (58.15%) and the downstream (42.62%). Although these estimates are a bit lower than the estimates provided by Shiluli et al. (2021) which show that 86% of households in the entire Migori County are using fertilizers, they still show high usage which could be attributed to the moderate soil fertility level reported by the respondents.

The majority of the respondents, over three-fifth of the households, had used improved seeds, and there were significant differences between watershed zones at $p < 0.05$ (Table

4.23). Therefore there seems to be less dependence on local seeds among the watershed farmers, which is consistent with the conclusions of Shiluli et al. (2021) that most farmers in the region are increasingly taking up fertilizing. Contrarily, only a few households (about two-fifth of the total sample) reportedly apply herbicides/pesticides to their croplands, and there was no significant difference (at $p < 0.05$) between watershed zones (Table 4.23). The proportion of households using herbicides/pesticides on their farms was relatively similar among the three watershed zones. In the last planting season of 2021, close to a half of the watershed households (43.77%) reportedly prepared and applied compost manure on at least one part of their farm to boost soil fertility, but the level of utilization significantly varied (at $p < 0.05$) among watershed zones (Table 4.23). This implies that manure application is also a key soil management strategy in the watershed.

The overall physical capital index showed that the upstream and the midstream had the same level of households' access to physical capital, which was a little higher than the level of access at the downstream. The ownership of full farm equipment and the usage of herbicides/pesticides or fertilizers by a large number of households in the upstream and midstream compared to the downstream could probably be some of the major reasons for low physical capital in the downstream zone. The variation in physical capital index between the watershed zones was not statistically significant at $p < 0.05$ (Table 4.23).

(v) Social Capital

The study employed 7 indicators to measure the social capital in the watershed zones (Table 4.22). The study findings revealed a high level of households' membership (91% to 95%) in various social organizations in the religious, political, and environmental conservation

realms. These organizations play a critical role in establishing and strengthening bonds of social obligation, reciprocity, solidarity, and mutual assistance, all of which play a key role, particularly during shocks, hardships, and periodicity (Morse & McNamara, 2013). Participation in social organizations seems to be lowest in the downstream (91.5%) and highest in the midstream (95.6%), but there was no statistically significant difference across the three zones. On the other hand, households' membership in conservation groups (WRUAs and CFAs) was lower in all three watershed zones. The highest membership was observed at the midstream (37.2%) and the lowest was observed at the upstream (17%), and the difference in household's membership in conservation groups between the watershed zones was statistically significant at $p < 0.05$ (Table 4.23). Participation in community barazas was generally high in all the watershed zones, with over 80% of households in each zone reportedly participating in these barazas (Table 4.22). Participation in barazas was higher in the midstream (92.5%) as compared to the downstream (87.7%) and the upstream (81.5%), and ANOVA showed no significant difference in barazas participation across the watershed zones.

The level of trust in community social relations was generally high in the upstream and midstream as reported by 97.2% of households respectively while in the downstream it was reported to be moderate (47.2%). However, no significant difference was observed between the three watershed zones. In the upstream and the downstream, the majority of households (81.2% and 90.6% respectively) indicated high mutual trust and reliability of relatives while in the midstream the level of mutual trust and reliability of relatives was equally rated high and low by the households; ANOVA confirmed that significant difference (at $p < 0.05$) exist between the watershed zones. Concerning the relationship with neighbors, both the

downstream (0.81) and the midstream (0.84) recorded high index scores compared to the extremely low score recorded by the upstream (0.59), with no significant difference between the three watershed zones (Table 4.23). This implies that the downstream and the midstream communities enjoy better relationships with other neighboring communities as compared to the upstream which usually faces the challenge of cattle rustling by the neighboring communities.

Relatively few households in the upstream (14.29%) and downstream (9.4%) reported that they got sufficient support from the local government administration (County government) in various activities including the enforcement of laws and implementation of community development programs. This was however different from the midstream where almost half of the households (48.1%) reported that they got support from the local administration. The study observed a significant variation (at $p < 0.05$) in the access to local administration's assistance among the watershed zones (Table 4.23).

The social capital index of the watershed households was generally high, which is commendable since the access and management of other types of capital are directly influenced by social capital (Chirau, 2012). The downstream and the midstream both had the same social capital index, which was higher than the one for the upstream (Table 4.23).

The variation in social capital index between the watershed zones was not statistically significant at $p < 0.05$ (Table 4.23). The low social capital of the upstream is attributable to the low support from local administration and the poor relationship with neighbors as observed in the study.

Table 4.22: Survey responses on social capital indicators

Indicators		Watershed zones			
	Responses	**Upstream**	**Midstream**	**Downstream**	**Total**
Mutual trust and reliability of relatives	High (%)	81.20	49.10	90.60	79.90
	Low (%)	18.80	50.90	9.40	20.10
Support from local administration	Yes (%)	14.29	48.10	9.40	20.11
	No (%)	85.71	51.90	90.60	79.89
Relationship with neighbors	Bad (%)	43.10	9.40	2.80	10.90
	Good (%)	34.70	28	49.10	31.10
	Very good (%)	22.20	62.60	48.10	58.00
Extent of trust on community social relations	Low (%)	0.00	6.60	10.40	5.70
	Moderate (%)	2.80	47.20	2.80	17.60
	High (%)	97.20	46.20	86.80	76.70
Membership of social organizations	Yes (%)	93.84	95.30	91.50	95.60
	No (%)	6.16	4.70	8.50	4.40
Membership of WRUA/CFA	Yes (%)	17.00	37.20	29.60	31.34
	No (%)	83.00	62.80	70.40	68.66
Participation in community barazas	Yes (%)	81.50	92.50	87.70	83.40
	No (%)	18.50	7.50	12.30	16.60

Table 4.23: Mean index of indicators and comparisons of significant differences between watershed zones

Indicators	Mean Index			One-way ANOVA	
	Upstream	Midstream	Downstream	F Value	p
Land holding size	0.19	0.24	0.25	0.113	0.894
Land fertility level	0.66	0.67	0.84	2.112	0.595
Annual production of principal staple food crop	0.57	0.54	0.42	0.142	0.069
Commercial agriculture (cash crops)	0.29	0.21	0.23	3.182	0.018*
Livestock possession size (TLU)	0.87	0.76	0.73	0.547	0.948
Access to grazing pasture	1.00	0.78	0.95	0.294	0.911
Distance to portable water	0.40	0.30	0.29	4.191	0.006*
Water quality of household water point	0.89	0.55	0.53	3.566	0.024*
Access to tangible forest resources	1.00	0.59	0.96	6.418	0.002*
Access to fishery resources	0.53	0.32	0.89	1.263	0.318
Natural Capital	**0.64**	**0.50**	**0.61**	**7.101**	**0.031***
Educational attainment of household head	0.53	0.47	0.44	0.445	0.086
Watershed conservation and development training	0.87	0.63	0.91	13.201	0.019*
Labor force size	0.44	0.56	0.34	0.366	0.071
Technical skill level of laborers	0.75	0.63	0.80	0.092	0.913
Daily nutritional intake level	0.67	0.59	0.62	7.724	0.000*
General health status of the household	0.88	0.66	0.64	3.192	0.087
Distance to nearest medical facility	0.42	0.33	0.30	0.183	0.007*
Human Capital	**0.65**	**0.55**	**0.58**	**0.742**	**0.459**
Participation in off-farm activities	0.37	0.40	0.64	0.571	0.579
Participation in non-farm activities	0.56	0.68	0.76	3.144	0.032*
Household monthly income	0.15	0.14	0.09	5.392	0.002*
Access to credit/loan services	0.47	0.53	0.59	2.084	0.920
Ownership of savings account	0.37	0.52	0.63	0.393	0.684
Annual household savings	0.09	0.25	0.10	8.659	0.013*
Financial value of available livestock	0.82	0.96	0.73	0.114	0.893
Financial value of current standing crop	0.69	1.07	0.60	2.573	0.001*

Financial Capital	**0.44**	**0.57**	**0.52**	**13.097**	**0.008***
Ownership of any transport means	0.14	0.26	0.10	3.141	0.000*
Ownership of any functioning communication devices	0.92	0.88	0.89	0.382	0.537
House roof type	0.81	0.94	0.67	2.160	0.154
Housing quality	0.66	0.66	0.70	0.307	0.633
Possession of sanitary toilet	0.96	0.95	0.81	2.056	0.096
Household cooking fuel	0.56	0.63	0.64	1.526	0.374
Household light source	0.78	0.81	0.72	21.023	0.026*
Ownership of full farm equipment	0.85	0.61	0.41	0.683	0.524
Ownership of irrigation equipment	0.19	0.15	0.26	4.496	0.022*
Fertilizer use	0.58	0.65	0.43	6.256	0.041*
Herbicides/pesticides use	0.31	0.35	0.26	0.123	0.885
Compost manure application	0.68	0.56	0.50	10.152	0.015*
Improved seeds use	0.66	0.58	0.80	9.156	0.001*
Possession of furniture (table, chair, bed)	0.99	1.00	0.87	0.336	0.605
Possession of silo/storage facilities	1.00	1.00	1.00	0.847	0.053
Physical Capital	**0.67**	**0.67**	**0.60**	**2.322**	**0.197**
Mutual trust and reliability of relatives	0.81	0.49	0.91	9.495	0.033*
Support from local administration	0.14	0.48	0.09	3.067	0.034*
Relationship with neighbors	0.59	0.84	0.81	0.194	0.826
Extent of trust on community social relations	0.99	0.80	0.92	0.210	0.931
Membership of social organizations	0.94	0.95	0.92	1.753	0.217
Membership of WRUA/CFA	0.17	0.37	0.30	5.735	0.0425*
Participation in community barazas	0.82	0.93	0.88	0.724	0.076
Social Capital	**0.64**	**0.69**	**0.69**	**2.013**	**0.987**
LSI	**0.61**	**0.62**	**0.60**	**0.396**	**0.714**

Note: * indicates significant difference at $p < 0.05$.

N/B: For the procedure used for the computation of the presented index scores, refer to subsection (I) of section 3.7.3 in the methodology.

(B) Livelihood Sustainability Index (LSI)

The SLI for each watershed zone was determined based on the individual indices for the five livelihood capitals (natural capital, human capital, financial capital, physical capital, and social capital). The distribution of the individual scores for the five livelihood capitals among the three watershed zones is shown in a spider diagram (Figure 4.13) with a scale ranging from 0 (least livelihood asset level) to 1 (most livelihood asset level). Aggregated values of the livelihood assets for the entire watershed, shows that social capital had the highest index values (ranging from 0.64-0.69), and physical capital had moderately high index values (ranging from 0.60-0.67), followed by natural capitals (0.60-0.64). Human capital (0.55-0.65) and financial capital (0.44-0.57) recorded relatively low index values, which imply that they were the least possessed assets by the rural households in the watershed. The low levels of financial and human capitals could potentially hinder the watershed households from respectively developing the necessary infrastructure and increasing farm or non-farm productivity; as a result, achieving livelihood diversification becomes more challenging.

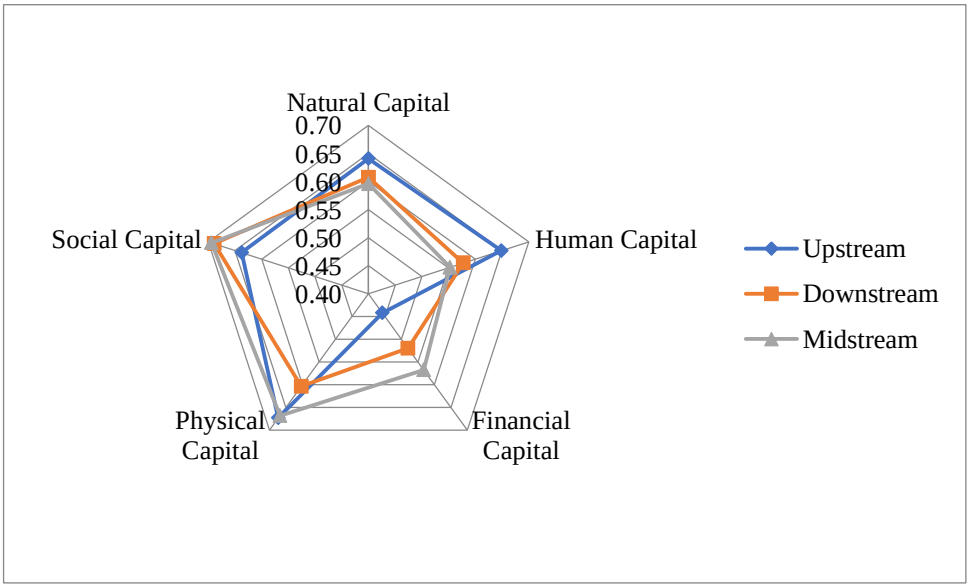


Figure 4.13: Livelihood capital variations across watershed zones

The LSI estimates for the upstream, midstream, and downstream were 0.61, 0.62, and 0.60, respectively, with no significant differences across the watershed zones. On the rating criteria, these values indicate that the livelihoods of all the three watershed zones are moderate sustainability. Even though there were no substantial variations between watershed zones, the total LSI was highest in the midstream zone and lowest in the downstream zone, indicating that the livelihoods of midstream households are the more sustainable followed by those in the midstream and downstream zones (Table 4.23). The livelihoods of upstream and midstream zones are most sustainable (because they possess high physical, social, and natural capitals) while the livelihoods of the downstream are least sustainable probably because they are prone to natural disasters like floods and droughts. Moderate sustainability level suggests that household heads within the watershed have limited access to natural resources (especially quality and adequate land), formal education, income-generating opportunities, credit services, and physical property.

4.5.2 Household Livelihoods' Vulnerability to Climate Change Impacts Analysis for the Migori River Watershed Communities

This section presents the assessments on the household livelihoods' vulnerability to climate change impacts for communities in the three watershed zones (upstream, midstream, and downstream) using the three contributing factors (exposure, sensitivity, and adaptive capacity), their respective major components and composite indicators. Noteworthy, a comparison of the vulnerability level of the three contributing factors, their respective major components and composite indicators across these watershed zones is based on their index scores where higher scores represents higher/more vulnerability and vice versa.

(A) Exposure

Exposure is a major contributing factor to the vulnerability of rural households, and it describes the nature and extent to which agro-based livelihood systems are vulnerable to significant variation in climate (IPCC, 2007). Exposure analysis generally reveals that the downstream (0.486) was the most exposed to climate-change-related shocks followed by the midstream (0.468) and the upstream (0.345) (Table 4.24). Exposure vulnerability dimension at each watershed zone was captured through analysis of its two major components– natural disasters and climate variability – whose results are shown in Table 4.24.

(i) Natural Disasters

Natural disasters component consisted of eight indexed-indicators (Table 4.24). When these eight were aggregated, the downstream (0.309) was found to be the most vulnerable based on natural disaster vulnerability index followed by the midstream (0.285) and the upstream (0.107) (Table 4.24). The average number of floods, drought, and landslides incidences in the past ten years was highest at the downstream (6.25, 3.3, and 2.7 respectively), followed by the midstream (3.7, 2.4, and 1.8 respectively), and lowest in the upstream (2, 0.5, and 1.1 respectively). This implies that the downstream has greater vulnerability to natural disasters than did the midstream and the upstream sections. Over the years, the downstream zone has experienced frequent occurrences of drought, floods, and landslides (Magige, 2018). Regions that experiences frequent floods or droughts incidences are known to be more exposed and thus more vulnerable (Feyissa et al., 2018). About 11% of upstream, 6.25% of midstream and 3.08% of downstream households did not receive a warning about an impending natural disaster - floods, droughts, or landslides - translating to indices of 0.110, 0.063, and 0.31 respectively. As a result, 51.9% of downstream, 45.1% of midstream and 15.8% of upstream

households reported a natural-disaster-related injury or death to a household member(s) in the last 6 years. Households in the watershed zones, midstream downstream and upstream reported a natural-disaster-related injury or death to their livestock in the last 6 years by 82%, 74% and 43% respectively. About 48.1% of downstream households, 27.9% of midstream and 8.55% of upstream have experienced crop failure in the past 6 years. However, there was a minimal loss to physical assets such as homestead structures or farming equipment as a result of natural disasters since 7%, 5.8% and 3.2% of downstream, midstream and upstream households respectively reported experiencing such losses for the past 6 years.

(ii) Climate Variability

Climate variability component consisted of three indexed-indicators (Table 4.24). When the three indicators were aggregated, the upstream (0.979) was found to be the most vulnerable on the climate variability component followed by the downstream (0.959) and midstream (0.953) (Table 4.24). The proportion of households that have experienced daily temperature changes for the last 10 years was 98.1%, 95.3%, and 94.3% for the upstream, midstream and downstream respectively while the proportion of households that have experienced annual temperature changes for the last 10 years was 100% for upstream, 95.3% for midstream and 93.4% for downstream. Temperature fluctuations has significant implications for agricultural livelihoods' vulnerability as rising temperatures have been known to have major impacts on crop growth and hence yields (Hussain et al., 2013). With respect to precipitation, 100% of downstream, 95.7% of upstream and 95.3% of midstream households have experienced annual rainfall changes for the last 10 years. This indicates that there's not much difference in climate variability across the three watershed zones, which could be attributed to their similar agro-ecological settings. It has been previous established that erratic precipitation patterns contributes to low agricultural production leading to food shortages which exposes households in the East African countries to vulnerability (Araya et al., 2015).

Table 4.24: Indexed scores of exposure analysis across the zones of Migori River watershed

Indicators	Index Scores			Major Components	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
Average frequency of floods in the past 10 years	0.000	0.350	0.179	Natural Disasters	0.107	0.285	0.309
Average frequency of droughts in the past 10 years	0.000	0.100	0.217				
Average frequency of landslides in the past 10 years	0.050	0.167	0.237				
% of HHs with an injury or death as a result of natural disasters in the last 6 years	0.157	0.451	0.519				
% of HHs that do not receive a warning about the pending natural hazard	0.110	0.063	0.031				
% of HHs with an injury or death to their livestock as a result of natural disasters in the last 6 years	0.425	0.816	0.740				
% of HHs with losses to physical assets due to natural disasters	0.032	0.058	0.070				
% of HHs with crop failure as a result of natural disasters in the last 6 years	0.085	0.279	0.481				
% of HHs that perceived a rising trend in daily temperature	0.981	0.953	0.943	Climate Variability	0.979	0.953	0.959
% of HHs that perceived annual temperature changes	1.000	0.953	0.934				
% of HHs who have experienced annual rainfall changes	0.957	0.953	1.000				
Exposure LVI					0.345	0.468	0.486

Note: For the procedure used for the computation of the presented index scores, refer to subsection II of section 3.7.3 in the methodology.

Generally, the watershed people's perceptions of climate variability agree with the meteorological records concerning temperature and rainfall variations in the watershed. Over the last 30 years, the Migori region has been recorded to be experiencing irregular precipitation patterns, increasing temperatures and rainfall volumes, frequent and lengthy dry seasons, and spells of water shortages (Ayugi et al., 2016; Relief-Web Kenya, 2021). This situation constrains its ability to produce ecological services, which puts further strain on accessibility to and utilization of livelihood resources (Relief-Web Kenya, 2021).

(B) Sensitivity

Sensitivity, as a major contributing factor to the vulnerability of rural households, describes the extent to which an agro-based livelihood system is impacted, either negatively or positively, by climate-related events/elements (IPCC, 2007). Sensitivity major components are health, food and water, whose results are shown in Table 4.25. Sensitivity analysis shows that the downstream (0.412) has the highest sensitivity in ecological stability followed by the upstream (0.365), then midstream (0.349 (Table 4.25).

(i) Health

This component consisted of four indexed-indicators (Table 4.25). When these four indicators were aggregated, the resulting overall health vulnerability index (Table 4.25) showed that the midstream (0.493) was the most vulnerable on the health component followed by downstream (0.435) and upstream (0.418). The midstream households reportedly travel an average of 30.4 minutes to reach the nearest health facility on foot while the upstream households travel an average of 21.4 minutes and downstream an average of 11.7 minutes. This implies that the midstream households are more vulnerable than the downstream and upstream with regards to the average time a household takes to reach the nearest health facility on foot. Poor access to health care tends to deteriorate the health

condition of rural households, making them more vulnerable to adverse climatic circumstances (World Bank, 2010; Adu et al., 2018). Chronic illnesses were reported by two-thirds (67.9%) of households in the midstream compared to 52.8% in the downstream and 33% in the upstream; an indication that the downstream and the upstream are less vulnerable to chronic illnesses compared to the midstream due to better access to private and government health facilities. Physical wellness is critical since it allows people to efficiently engage in various agricultural and non-agricultural activities and attain their livelihood goals. Poor access to health care services may put a strain on households' adaptive capacity, increasing their sensitivity to climatic variability and other extreme climate events (Asrat & Simane, 2017).

Further, the proportion of households where a family member had to miss work or school in the past 6 months due to illness was highest in midstream (91.5%) than the upstream (88.7%) and downstream (82.1%). This could be attributed to the documented high malaria prevalence in the midstream area (Solis et al., 2018) and the lack of sanitary latrine/toilets. Evidently, about 40% of households in the downstream, 24.7% in the midstream, and 23.8% in the upstream reportedly lack sanitary latrines. Lack of sanitary latrines makes households vulnerable to contracting illnesses including cholera and typhoid.

(ii) Food

This component consisted of five indexed-indicators (Table 4.25). When these five indicators were aggregated, the resulting overall food vulnerability index showed that the downstream (0.365) was the most vulnerable on the food security aspect followed by upstream (0.232) and then midstream (0.205) (Table 4.25). The average number of months that households struggle to find adequate food was zero months per year for the upstream while the downstream and midstream is two months per year. This implies that the upstream has

greater food security compared to other areas of the watershed. Food security enhances a household's resilience to external stressors such as catastrophic weather occurrences (World Bank, 2010). This is because when households and communities get access to larger amounts of high-quality food; real prices decline, leading to a rise in real income, which may encourage them to adjust their climate change plan (World Bank, 2010). Approximately 80% of upstream households are solely dependent on their family farm for food compared to the 67.9% of downstream and 61.3% of midstream households. Studies show that households that obtain their main food source from their family farms are more vulnerable to the effects of climate change (Shah et al., 2013; Minh et al., 2019; Zhang & Fang, 2020). Based on the average crop diversity index, the midstream (0.29) and the upstream (0.31) were less vulnerable compared to the downstream (0.40). On average, the downstream households grow 1.65 types of crops, the upstream households grow 2.32 types of crops, and the midstream households grow 2.64 types of crops. The less vulnerability of the upstream and midstream zones in terms of crop diversity may be due to the fact that households in these zones have access to land through various arrangements, family-inherited land, rented, and leased land, which promotes the cultivation of various crops and hence lessens household sensitivity to climate-change-related stressors. All households in the upstream and midstream reportedly store crops and save seeds while 2.38% of downstream households don't store crops and don't save seeds.

(iii) Water

This component consisted of six indexed-indicators (Table 4.25). When these six indicators were aggregated, the resulting overall water vulnerability index showed that the upstream (0.440) was the most vulnerable on the water security aspect followed by the downstream (0.434) and finally the midstream (0.372) (Table 4). About 94% of households in the downstream, 82% of households in the upstream, and 56% of households in the midstream

reportedly use natural water sources such as rivers and streams for their domestic water needs. Using a natural water source has a greater likelihood of increasing a household's exposure to waterborne infections and water shortages during drought periods (Etwire et al., 2013). On average, the midstream households store 492L of water compared to 127L in upstream households and 87L in downstream households. Consequently, 100% of upstream, 91.5% of downstream and 71.7% of midstream households have a consistent water supply. This is attributable to the existence of the Migori River and its tributaries (streams) which supplies adequate water to the households within the three watershed zones, even during dry seasons. With about a third (28.3%) of midstream households reportedly not having water available at their source every day, the midstream households seem extremely vulnerable in terms of water insecurity compared to other watershed sections. This explains why they reportedly store higher volumes of water compared to the households from other sections that have a consistent water supply.

The findings established that about 68% of upstream, 60% of downstream and 49% of midstream households have to go far to fetch drinking water i.e. beyond the 1km distance recommended by the WHO (Huong et al., 2019). Upstream households reportedly walk 44.0 minutes of a round-trip on average to get water compared to 33.8 minutes in the midstream and 25.2 minutes in the downstream of a round-trip to get water. Since the SDGs recommends that access to basic drinking water should take 30 minutes or less for a round-trip (Water Supply Sanitation and Collaborative Council, 2015), it’s evident that both the upstream and the midstream have greater vulnerability compared to the downstream in terms of the average time for water access. Water conflicts are minimal in the watershed as only 18.9% of midstream, 14.2% of upstream and 5.5% of downstream households experience water conflicts in the previous years.

Table 4.25: Indexed scores of sensitivity analysis across the zones of Migori River watershed

Indicators	Index Scores			Major Components	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
Average time to nearest health facility (on foot)	0.418	0.330	0.299	Health	0.418	0.493	0.435
% of HHs with a family member with chronic illness	0.330	0.679	0.528				
% of HHs where a family member had to miss work or school in the past 6 months due to illness	0.887	0.915	0.821				
% of HHs without sanitary toilet	0.038	0.047	0.094				
% of HHs dependent on family farm for food	0.792	0.613	0.679	Food	0.232	0.205	0.365
Average crop diversity index	0.367	0.113	0.600				
Average number of months, households struggle to find food	0.000	0.300	0.500				
% of HHs that do not save crops	0.000	0.000	0.024				
% of HHs that do not save seeds	0.000	0.000	0.024				
% of HHs use natural untreated water (river, pond)	0.821	0.557	0.943	Water	0.440	0.372	0.434
Time to travel the source of natural water/	0.398	0.303	0.288				
% of HHs that have to go far to fetch water	0.689	0.491	0.585				
% of HHs that do not have a consistent water supply	0.000	0.283	0.085				
% of HHs reporting water conflicts	0.142	0.189	0.057				
The inverse of the average number of liters of water stored per household (range: > 0–1)	0.588	0.412	0.647				
Sensitivity LVI					0.365	0.349	0.412

Note: For the procedure used for the computation of the presented index scores, refer to subsection II of section 3.7.3 in the methodology.

(C) Adaptive Capacity

Adaptive capacity is one of the contributing factors to vulnerability of rural households and it is based on three indicators (Table 4.26). It is the ability of an agro-based livelihood system to adjust to climate change in order to lessen probable losses, capitalize on opportunities, or cope with the repercussions (IPCC, 2007). Findings show that upstream (0.481) has a higher adaptive capacity than the midstream (0.477) and the downstream (0.475) (Table 4.26). High adaptive capacity is critical in reducing the vulnerability of households to multiple climate-induced stressors (Tewari & Bhowmick, 2014).

(i) Socio-Demographic Profile (SDP)

The socio-demographic profile component consisted of eight indexed-indicators (Table 4.26). When these eight indicators were aggregated, the upstream (0.479) was found to be the most vulnerable on the socio-demographic profile followed by the downstream (0.433) and the midstream (0.429) (Table 4.26). The proportion of female-headed households was highest in the downstream (34.9%) of the watershed and lowest in the upstream (26.4%) and midstream (26.4%). This could be due to migration from rural areas of male household members to urban places to earn a living or the death of male household heads. Studies have shown that female-headed households are less adaptive and hence more vulnerable compared to male-headed ones (Daudu et al., 2021).

The upstream showed more vulnerability (1.42) on the dependency ratio index than the downstream (1.09) and midstream (0.95). This is an indication that the proportion of dependent household members (<18 years and > 65 years) is higher in the upstream zone than in the other watershed zones. The average age of household heads was 44.6 years in the

upstream, 47.2 years in the downstream, and 48.7 years in the midstream. With respect to education, over half of the household heads in the downstream (56.6%), and nearly a half of household heads in the midstream (49.1%) and upstream (47.2%) have not gone beyond primary-level education. This level of limited schooling makes households more vulnerable to climate-induced stressors, due to reduced adaptive capacity (Deressa et al., 2008). Such households are unable to undergo meaningful training, have minimal diversification experience, and rely mainly on climate-sensitive activities such as rain-fed cultivation and livestock breeding (Dumenu & Obeng, 2016). Furthermore, in watershed sections where the majority of household heads had not gone beyond primary education, informally or formally acquired vocational skill level was high: downstream (0.123), midstream (0.292), and upstream (0.613).

Formal education enhances a household's adaptive capacity as it improves the household's capacity to better recognize challenges affecting them and, as a result, look for feasible solutions in the proper places (Etwire et al., 2013). The results indicated that 91.4% of downstream households, 83.8% of midstream households, and 78.4% of upstream households have a household size beyond the 4-members national average. Large family sizes that exceed the national average are said to be more vulnerable to environmental stressors since they are more likely to have a large proportion of dependent household members (<18 years and > 65 years) (Nkondze et at., 2013). On the other hand, other studies concur that large family sizes with working-age members possess an increased supply of human capital that would contribute to the strengthening of livelihood resilience through labor-force participation, remittance flows, and risk management (Weldegebriel & Amphune, 2017). Based on the proportion of households with orphans, the downstream (0.877) was found to be more vulnerable than both the midstream (0.642) and the upstream (0.745). The

study revealed that 87.7% of downstream households, more than three-quarters of upstream households (75.4%), and about two-thirds of midstream households (64.2%) have at least one orphan.

(ii) Livelihood Strategies

A livelihood strategy is a survival or wealth accumulation plan for households/communities, intended to mitigate risk and also reduce poverty (Gautam & Andersen, 2016). This component consisted of six indexed-indicators (Table 4.26). When these six indicators were aggregated, the upstream (0.605) was found to be the most vulnerable on the livelihood strategies vulnerability index followed by the downstream (0.596) and then the midstream (0.506) (Table 4.26). This study established that the livelihood strategies of households in the Migori River Watershed are diversified and include crop production, livestock keeping, and access to other natural resources, off-farm activities, and household members working outside the locality of Migori County. In terms of the proportion of households with family members working in a different county, the upstream showed less vulnerability (0.99) than did downstream (0.78) and midstream (0.63). Results showed that 99.1% of upstream households, 78% of downstream households, and 63% of midstream households had at least one working in a different county.

High proportion of households in the upstream (87.8%), downstream (78.3%), and midstream (73.6%) are solely dependent on agriculture as the only source of income; which makes them highly vulnerable since agriculture is a climate-sensitive sector (Tewari & Bhowmick, 2014). In this case, the upstream was found to be more vulnerable (0.87) in terms of dependency on agriculture compared to the other watershed sections, since it is believed that households that depend exclusively on agriculture are more vulnerable to climate change

than those that don't depend exclusively on agriculture (Hahn et al., 2009). Based on these figures, there is a high sole dependency on agriculture as an income source by households in the watershed, and Žurovec (2018) believes that such a situation is driven by the deficiency of alternative sources of income in the region.

Based on the average agricultural livelihood diversification index, the midstream was less vulnerable (0.39) compared to the upstream (0.24) and the downstream (0.21); this means that the households in the midstream engaged in more diverse agricultural practices (crop production, livestock rearing, aquaculture, and agroforestry) than those in the upstream and the downstream. This phenomenon was also reflected in the income diversification index where the midstream (0.35) showed less vulnerability compared to downstream (0.31) and upstream (0.29). This is because diversifying agricultural practices and income sources serve as insurance against the impacts of climate-related shocks and allows the household to shift to a better income level, which facilitates the development of a suitable climate change response hence greater adaptive capacity (Eakin et al., 2008). On the natural resource and livestock index, however, the upstream (0.50) was less vulnerable compared to the midstream (0.380) and the downstream (0.34).

The three livelihood strategies, on-farm, off-farm, and non-farm, as defined by Barrett et al. (2001) were pursued by the households in the Migori River watershed with varying degrees of engagement. Even though on-farm livelihood strategy (crop production, livestock rearing) generally accounts for the vast majority of income sources, with over three-quarters of households in each watershed zone reportedly relying solely on it as their everyday income source, some households in the watershed pursued off-farm (processing, packaging, transport or sale of farm produce) and non-farm livelihood strategies (small-scale trade, remittance,

forestry, rental income, and employment in healthcare, education, mining, tourism or governance sectors) with varying degrees of involvement to augment their earnings from on-farm livelihood activities. Alongside on-farm activities, 32.1% of upstream households, 39.6% of midstream households, and 64.2% of downstream households engaged in off-farm activities while 55.7% of upstream households, 67.9% of midstream households, and 76.4% of downstream households engaged in non-farm activities.

The proportion of households that took a loan in the past 5 years was 59.4%, 52.1%, and 36.8% in the downstream, midstream, and upstream respectively, indicating that there's lower intake/access to loans for households in the upstream compared to the other watershed sections. In conclusion, most households in the three watershed zones had less diverse livelihood strategies, a situation which could be attributed to their understanding and experience of exposure to environmental stressors including disasters.

(iii) Social Networks

Social networks have a significant role in managing risks (Zhao, 2013). This component consisted of seven indexed indexed-indicators (Table 4.26). When these seven indicators were aggregated, the midstream (0.507) was found to be the most vulnerable on the social network vulnerability index followed by the downstream (0.418) and the upstream (0.376) (Table 4.26). The average receive-give ratio was higher among households in the midstream (1.49) compared to households in the upstream (1.37) and downstream (1.18); implying that households in the midstream were reportedly receiving more in-kind help from others than they were offering it to others compared with the upstream and downstream. The study also established that 100% of upstream households, 90.6% of downstream households, and 48.1% of midstream households have not asked their local government for any assistance in the past

12 months. This is an indication that although households in the three watershed sections received assistance, they preferred to request aid from friends and family relations rather than their local government officials.

The results on the average borrow-lend money ratio indicate that households within the entire watershed borrow more money than they lend, and are therefore financially vulnerable. However, midstream households reported that they borrowed money more frequently than the downstream and upstream households; the borrow-lend money ratio was 1.49 for the midstream, 1.47 for the downstream, and 1.01 for the upstream. The study established that the midstream households are borrowing more money than they are lending it, and thus are financially more vulnerable compared to the other zones. Hahn et al. (2009) observe that households are more vulnerable when they often borrow money more than they lend money. Borrowing and lending money represents the monetary and in-kind financial support that households obtain from their social network (Hahn et al., 2009). Therefore, the high financial exchange between the watershed households indicates that the social network is stronger.

Regarding membership in social organizations, 100% of upstream households, 95.3% of midstream households, and 91.5% of downstream households reportedly have some household members with membership in social organizations such as sports, religious, or conservation groups. This high participation in social organizations increases the adaptive capacity of the watershed households to multiple stressors. According to Armah et al. (2010), community-level associations are formed through friendship, monetary exchange, kinship, or similar cultural and religious beliefs. Such networking helps sustain livelihoods and manage environmental stressors and disasters, especially those caused by climate change (Etwire et al., 2013). The proportion of households in the downstream, upstream, and midstream that

received some training from either government or non-governmental organization was 90.6%, 86.8%, and 63.2% respectively.

The majority of households own some type of communication device as reported by the 91.5% of upstream households, 88.7% of downstream households, and 87.7% of midstream households. Access to communication devices like phones, radios, and TVs promotes exposure to climate-related information which enhances the household's adaptation to climate-induced stressors including disasters like floods (Gbetibouo, 2009). Regarding, the average number of amenities, the downstream section was reported to have more amenities (0.22) compared to upstream (0.18) and midstream (0.20). The downstream households are therefore less vulnerable in terms of institutional access compared to the other two watershed zones because households with greater institutional access are better positioned to cope with various climate-induced risks (Agrawal, 2010).

The strong social networks observed among the households in the watershed are indicative of the abundant social capital possessed by rural households in the Migori River watershed, as evidenced by the study findings. Social networks serve as a proxy for social capital, playing a pivotal role in facilitating access to and management of other forms of capital (Chirau, 2012). People can use social capital to obtain loans, childcare, meals, housing, and information about jobs and opportunities through mobilizing relationships of cooperation and reciprocity that exist within and across households, close relatives, and communities (Hautala, 2013). Households in most rural communities are often interconnected by bonds of social obligation, reciprocity, solidarity, and mutual assistance, all of which play a key role in managing vulnerability to climate change, particularly during shocks, hardships, and seasonality (Morse & McNamara, 2013).

Table 4.26: Indexed scores of adaptive capacity analysis across the zones of Migori River watershed

Indicators	Index Scores			Major Components	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
% of female-headed HHs	0.264	0.264	0.349	Socio-demographic Profile	0.479	0.429	0.433
Dependency ratio/level of HHs	0.273	0.158	0.156				
The average age of household heads	0.488	0.471	0.365				
% HH who have not gone beyond primary education	0.472	0.491	0.566				
% of HHs with more than four members	0.784	0.838	0.914				
% of HHs with orphans	0.745	0.642	0.877				
% of HHs where members had any informal skill	0.613	0.292	0.123				
% of HHs with members needing dependent care	0.191	0.274	0.117				
% of HHs with members working in a different county	0.009	0.368	0.217	Livelihood Strategies	0.605	0.506	0.596
% of HHs solely dependent on agriculture	0.878	0.736	0.783				
Average agricultural livelihood diversification	0.788	0.333	0.879				
% of HHs who took a loan in the past 5 years	0.632	0.479	0.406				
Income diversification index	0.700	0.500	0.633				
Natural resource and Livestock index	0.625	0.620	0.660				
Average Receive: Give ratio	0.646	0.717	0.804	Social Networks	0.376	0.507	0.418
Average Borrow: Lend Money ratio	0.892	0.940	0.887				
% of HHs that have not asked their local government for any assistance in the past 12 months	0.000	0.519	0.094				
Availability of amenities	0.875	0.833	0.848				
% of HHs with membership in social groups	0.000	0.047	0.085				
% of HHs that have received or attended training	0.132	0.368	0.094				
% of HHs owning communication device	0.085	0.123	0.113				
Adaptive Capacity LVI					0.481	0.477	0.475

Note: For the procedure used for the computation of the presented index scores, refer to subsection II of section 3.7.3 in the methodology.

In general, the vulnerability scores of all the eight major components of each watershed zone were summarized in a vulnerability spider diagram (Figure 4.14), with a scale ranging between 0 (least/less vulnerable) and 1.0 (most vulnerable). Accordingly, the upstream is more vulnerable in terms of climate variability (0.98), livelihood strategies (0.61), and the socio-demographic profile (0.48) while the midstream is more vulnerable in terms of climate variability (0.95), livelihood strategies (0.51) and social networks (0.51). The downstream was found to be the most highly exposed to climate variability (0.96) and natural disasters (0.31) and less adaptive in terms of livelihood strategies (0.60).

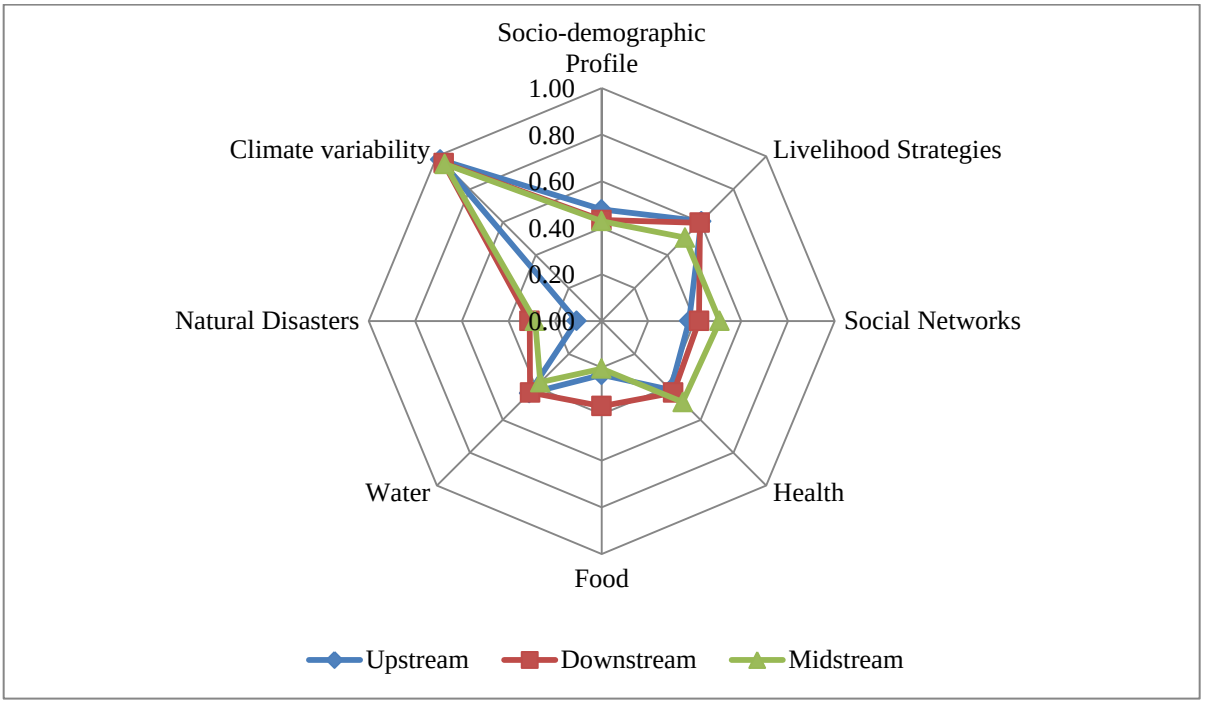


Figure 4.14: Vulnerability spider diagram of the major components of LVI-IPCC

Of the entire set of major components of LVI-IPCC, climate variability seems to be the major factor that contributed considerably to the high levels of vulnerability of the watershed zones whereas socio-demographic profile and food were the two major contributors to less levels of vulnerability.

Livelihood Vulnerability Index Assessment and Policy-program Implications

Based on the IPCC approach, overall vulnerability is assessed based on the individual indices for the contributing factors of exposure, sensitivity, and adaptive capacity. The distribution of the indexed major components for the three vulnerability contributing factors and the overall LVI-IPCC across watershed zones is presented in Table 4.27 and Figure 4.15. The LVI-IPCC estimates for the upstream, midstream, and downstream were -0.047, -0.003, and 0.008, respectively (Table 4.27), with One-way ANOVA (at $p<0.05$) indicating that statistically significant differences exist in the computed LVI-IPCC scores between the three watershed zones ($F = 2.498$, $p = 0.019$). These estimates compared to the rating scale (Table 3.7) indicate that the livelihoods of all the three watershed zones are *moderately vulnerable* to environmental and socio-economic stressors, probably due to the similar agro-ecological settings. Although the three watershed zones are moderately vulnerable to environmental and socio-economic stressors, the total LVI-IPCC score was highest in the downstream zone and lowest in the upstream zone; an indication that the livelihoods of downstream households are the most vulnerable to multiple stressors followed by the midstream households and then the upstream households. The livelihoods of the downstream zone are most vulnerable because they have the least adaptive capacity (0.47), highest exposure (0.49), and highest sensitivity (0.41) whereas the upstream households are relatively least vulnerable than the other zones due to less sensitivity (0.36), less exposure 0.35) and better adaptive capacity (0.48). Previous studies show that communities with high exposure to climate variability and extreme climate-induced events but low adaptive capacity experience high livelihood vulnerability (Deressa et al., 2008; Feyissa et al., 2018).

Table 4.27: Summary of the Livelihood Vulnerability Index results for the three watershed zones

Major Components (No. of indicators)	Index Scores			LVI-IPCC Vulnerability Dimensions	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
Socio-demographic profile (8)	0.48	0.43	0.43	Adaptive Capacity	0.48	0.48	0.47
Livelihood Strategies (6)	0.61	0.51	0.60				
Social Networks (7)	0.38	0.51	0.42				
Health (4)	0.42	0.49	0.44	Sensitivity	0.36	0.35	0.41
Food (5)	0.23	0.21	0.37				
Water (6)	0.44	0.37	0.43				
Natural Disasters (8)	0.11	0.29	0.31	Exposure	0.35	0.47	0.49
Climate variability (3)	0.98	0.95	0.96				
LVI-IPCC Index = (Exposure-Adaptive capacity) × Sensitivity					**-0.047**	**-0.003**	**0.008**

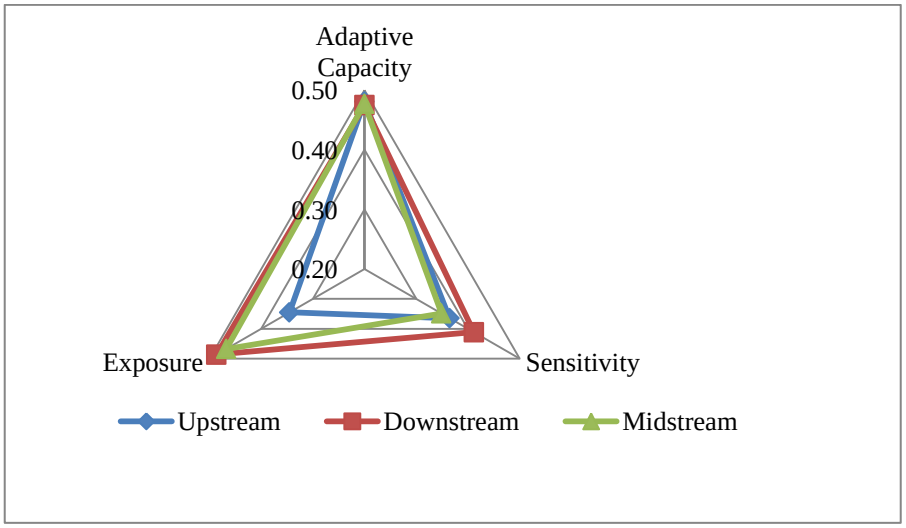


Figure 4.15: Vulnerability triangle diagram of LVI-IPCC vulnerability dimensions for watershed zones

Generally, the livelihoods of all the three watershed zones of the Migori River socio-ecological system are moderately vulnerable under environmental and socio-economic stressors caused by climate change, mostly due to the less adaptive capacity and greater sensitivity. Based on the findings, the low adaptive capacity of the households in the watershed is mainly contributed to by large family sizes, which are beyond the national average; heavy dependence on agriculture and natural resources which are climate-sensitive livelihood sources; comparatively high dependency ratios due to less number of members employed adults; and low literacy levels of household heads. These factors make households less able to cope with diverse stressors.

A high level of sensitivity of health of households to climate-induced risks is mainly contributed to by limited access to health care services characterized by widespread lack sanitary latrines, majority of households having at least one member suffering chronic illness, and having a family member who missed work or school in the past 6 months due to illness; these contribute to the exposure of the households to vulnerabilities and so targeted installation of latrines, regular and free household-level health checkups, and construction of more health facilities can help increase the health index of the people living in the watershed.

On the other hand, high level of sensitivity of water to climate variability is majorly contributed to by majority of households using unsafe drinking water from natural water sources which could be contaminated with heavy metals and disease-causing pathogens, households having to travel beyond 1 km distance to fetch water and occasionally experience water conflicts with other communities.

4.6 Reflection on Theories, Methods and Approaches

The governance networks theory used in this study specially emphasizes the interactions of actors in river basin management without paying much attention to the political perspective of the network as an institution. Political institutions tend to design and influence the construction and perception of the reality where action is to be directed, hence shaping the actions of the actors. By incorporating the political institutionalism, the networks can deliver negotiated solutions to certain problems, break policy stalemates, and turn socio-economic challenges into new opportunities. Also, the variables for analyzing network governance theory ought to be at the network level instead of at the actor level since the policy formulation and execution seems to be a collective action process.

The biophysical processes controlling stream flows and sediment yield in the Migori River watershed were sufficiently captured by the SWAT model. The SWAT model was suitably chosen for this study because of its ability to fill in missing datasets using its weather generator engine system, this is critical because incomplete and missing climate datasets are commonplace in developing nations like Kenya. The study observed that while evaluating the effects of LULC on the hydrological cycle, the impacts of LULC and climate on one another are not simulated, i.e., one component is held constant as the other is modeled and this is not a reflection of what occurs in reality.

The CCME-WQI approach employed in spatio-seasonal water quality assessments showed flexibility — in terms of the type and number of variables tested, the period of application, and the type of water body — and robustness in reporting water quality problems in a non-technical fashion that is easily understood by professionals, decision-makers, and general

public alike. The CCME-WQI was able to identify the specific river section, season, or parameters upon which pollution management interventions can be directed and this makes water quality monitoring more cost-effective in the long-term for relevant decision-makers. This is particularly important in developing nations like Kenya where limited financial resources is always a hindrance to regular monitoring.

The LVI-IPCC and SLI used in the study proved useful for analyzing the livelihood aspects of the watershed communities. The LVI-IPCC methodology is quite data intensive and involves a complex procedure for selecting simple, cost-effective and comparable indicators that are within the confines of data availability and local realities. This study used more indicators compared to the previous studies, which not only shows the dynamism of the tool but also demonstrates the global applicability of this tool in understanding the local communities' vulnerability to environmental and climate change regardless of the number of indicators selected. Moreover, The LVI-IPCC approach could be used to forecast future vulnerability, such as under basic future-climate scenarios or even evaluating the effect of a particular policy or program by adjusting the value of the indicator that is anticipated to change and re-computing the overall vulnerability index. The LSI methodology used in the study constitutes its first application in the tropical region and this shows the global replicability or applicability of this tool in various agro-ecological settings. Due to its simplicity in quantifying community livelihood capitals endowment, it could help in prioritizing watershed management programs and the development of interventions aimed at a specific livelihood asset. It may also help policy-makers in project monitoring and evaluation, where it provides feedback critical for continual project improvement.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a summary of the major findings, conclusions, and recommendations of the study that investigated dynamics of ecohydrology, governance, and livelihood systems of Migori River watershed. These sections are structured per each of the four specific study objectives; to examine the institutional arrangements in the Migori River watershed management and their influence on the nature and level of coordination among the actors, to evaluate the impacts of land use and land cover (LULC) changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 – 2020, to assess the spatio-seasonal variations of water quality parameters of Migori River and associated household health risk implications in Migori River watershed, and to assess the level of sustainability of community livelihoods in the Migori River watershed and its associated vulnerability to climate change impacts. Additionally, areas that require further research are highlighted in this chapter.

5.2 Summary of Findings

The first objective of the study was focused on examining the institutional arrangements in the management of Migori River watershed and how they influence the nature and level of coordination among the actors. The results indicate that the management of the Migori River watershed is characterized by a multi-level governance structure with vertical and horizontal dimensions. The structure and roles of institutions at various levels revealed adequate representation of the river basin management actors within the Migori River watershed; but the associations among these actors are weak due to conflicting and overlapping mandates,

and gaps in the coordination processes of administration, organizing, planning, execution, and monitoring of river basin management programs. Coordination across levels exists and it's moderated by both WRA and NEMA, but it is low-level and not all-encompassing; and whereas efforts to collaborate were noted among actors, they were inconsistent and tended to be on a per-need basis hence culminating in coordination neglect. This coordination neglect is arising from inadequate communication caused by a lack of a common forum for stakeholder interactions, a lack of a common management plan for a clear vision and direction of actors' activities, and ineffective information sharing among river basin management actors. It is also arising from the absence of incentives for a combined action among actors, institutional complexity caused by unclear delineation of roles in the institutional structure, and the independent nature of state institutions which has contributed to weak relationships among most actors. Nevertheless, empirical evidence generally showed that coordination is stronger among domestic or international NGOs than among governmental actors, and it is poorest among private entities.

For the second objective, the study modeled the impacts of land use and land cover changes on the trends of stream flow and sediment yields in Migori River watershed from 1980 - 2020 using the SWAT model. The model results indicated that the hydrology of the watershed has been changing over the years with changes in LULC. Between 1980 and 2020, the watershed experienced a considerable decline in shrub lands by 40.63%, grasslands by 84.86%, forests by 52.90%, water by 82.03% and wetlands by 38.44%; whereas cultivated land, bare land and built-up areas expanded over the same period by 34.25%, 132.28% and 461.20%, respectively. These LULC changes, driven majorly by population pressure and high poverty levels, have contributed to the decline of annual actual evapotranspiration by

2.83%, annual potential evapotranspiration by 5.38%, and annual groundwater flow by 19.06%; while they caused an increase in annual surface runoff by 32.57%, water yield by 4.82%, and sediment yields due to soil erosion by 84.58% over the same period. The loss of vegetation cover in the watershed resulting from the expansion of cultivated lands and bare lands by displacing shrub lands, grasslands, and forests is responsible for the increased sedimentation and surface runoff, and the reduction in groundwater recharge to the aquifers. The reduction in evapotranspiration is partially linked to the decline of the areas covered by water and wetlands. The hydrological imbalance characterized by the increase in annual surface runoff generation, sedimentation, and water yields over the years is responsible for flooding events in the downstream area of the watershed.

Findings for the fourth objective, which focused on the spatio-seasonal variations of water quality parameters of the Migori River and associated household health risk implications, generally revealed that the river water is polluted and potentially hazardous for human usage. While most of the physico-chemical variables were within maximum permissible limits, the bacteriological levels exceeded the prescribed standards and thus the CCME-WQI ranked the river's water condition between "poor" to "marginal". The upstream has better water condition that gradually decreases toward the downstream, and water quality is better in the wet season than the dry season. The assessed water quality variables, with exception of DO, BOD, pH, and fecal coliforms, showed significant seasonal variability but no significant spatial differences in the river (at $p<0.05$); an indication of the influence of weather changes on point and non-point pollution in the watershed. The health risk survey revealed that over three-quarters of watershed households solely utilize the river water for their household needs. About 85% of these river water users acknowledged the polluted nature of river water

and often utilized various household drinking water treatment forms, which are insufficient in removing pathogens hence exposing them to health vulnerabilities.

For the fifth objective, community livelihoods' sustainability level in the Migori River watershed and its associated vulnerability to climate change impacts were analyzed using the LSI and LVI-IPCC, respectively. The LSI estimates categorized the sustainability of household livelihoods of the watershed as *moderate* because household heads have limited access to quality and adequate land, formal education, income-generating opportunities, credit services, and physical property. Although there were no significant variations in LSI between watershed zones (at $p < 0.05$), the midstream household livelihoods are the most sustainable because they possess high physical, social, and natural capitals; whereas the livelihoods of the downstream are the least sustainable due to their low livelihood assets endowment. The LSI showed that human and financial capitals are the least possessed assets in the watershed. Regarding vulnerability, the LVI-IPCC estimates indicated that the household livelihoods of the three watershed zones are *moderately vulnerable* to climate-induced environmental and socio-economic stressors. The downstream livelihoods are most vulnerable because they have the least adaptive capacity, highest exposure to climate risks, and highest sensitivity to climate-induced stressors; whereas the upstream households are relatively least vulnerable than the other zones due to less sensitivity, less exposure and better adaptive capacity.

5.3 Conclusions

The institutional arrangement of the Migori River watershed management is comprehensive but has flaws in the delineation of roles and responsibilities, and channels for horizontal engagement between actors. Coordination among watershed management stakeholders is low-level, weak, and appears to be primarily restricted to compliance with legal obligations rather than appreciation of the importance of inter-actor cooperation. There's a lack of clarity in the regulatory framework regarding which agency is the overall coordinator, processes for coordination, and implementation of joint programmes leading to conflicts. This nature of coordination is unsustainable because it has few points of intersection and it is heavily reliant on the individuals participating in the coordination process.

The changes in land use and land cover in the watershed over the past four decades (1980-2020) have negatively impacted the hydrological and sedimentation-related processes within the watershed. The conversion of the natural vegetation-covered landscapes to other land uses in the watershed contributed to the increased generation of annual surface runoff and sedimentation, and reduced evapotranspiration, which consequently led to increased water yield for the watershed. This increasing trend in water yield over the years is responsible for the frequent occurrence of flooding events in the downstream area of the watershed. The streamflow in the watershed is majorly controlled by runoff and groundwater flow processes.

The Migori River is contaminated with high levels of bacterial contaminants and physical impurities, hence potentially hazardous to the over three-quarters of watershed households that solely utilize it for their domestic needs. The deterioration of the river water quality gradually increases as the river flows downstream due to increased intensity and magnitude of waste pollution from anthropogenic activities and inflowing tributaries. Although spatial

variations in the levels of water quality variables were not significant, significant seasonal variability of the variables were observed with the wet season presenting better water condition than the dry season. The poor river water quality indicates inadequate environmental protection in the watershed.

The household livelihoods of the watershed have moderate level of sustainability due to insufficient endowment of human and financial capitals among households. The midstream households have a relatively higher sustainability level than upstream and downstream households due higher endowment of physical, social, and financial capitals. The overdependence of watershed household livelihoods on natural resources especially rain-fed agriculture makes them moderately vulnerable to climate-induced environmental and socio-economic stressors. When the level of exposure to climate risks is higher than adaptive capacity as observed in downstream livelihoods, the household livelihood vulnerability level becomes high, and when the adaptive capacity is higher than exposure, there is low livelihood vulnerability to climate change impacts.

5.4 Recommendations

To improve coordination in the Migori River watershed management, this study recommends the creation of a management council — Migori Watershed Management Council — with representation from all key actors to serve as the single coordinating body for RBM activities in the watershed. This council should have a designated lead agency (either NEMA or WRA) that facilitates meetings, oversees communications, and manages any problems or gaps in collective planning, execution, and monitoring of various RBM projects, but does not make final decisions.

Effective resolution of the institutional complexity and subsequent coordination neglect requires interventions in the institutional design, including the amendment of regulations and laws to cure design gaps and omissions, as well as the establishment of robust planning, implementation and monitoring processes, to create an inclusive institutional framework with clearly defined roles, responsibilities, and channels for horizontal reporting/engagement among actors.

The study recommends the implementation of land use zoning in the watershed to designate specific areas for settlements, conservation and protected areas, and agricultural lands. This zoning approach aims to regulate physical development and protect fragile conservation areas like forests, wetlands, and water sources. Additionally, efforts should be directed towards promoting the adoption of alternative cooking energy sources among watershed households to reduce the overall demand for fuel wood and alleviate the pressure on forests.

The sedimentation and the flooding problems in the watershed resulting from increased erosion and stream flows should be reversed and sustainably mitigated through implementation of comprehensive soil and water conservation interventions including the promotion and monitoring of conservation agriculture practices among watershed communities by the county agricultural extension officials, the intensification of activities of WRUAs and CFAs, and the installation of dams along the river to collect excess runoff.

For river pollution management, appropriate multifaceted management measures need to be taken by relevant government agencies, including regular water quality monitoring especially in the mid-to-downstream sections and during the dry season, enforcement of the

existing river basin protection laws and policies, development of efficient water treatment infrastructure to safeguard public health, and improving catchment protection measures.

To improve the sustainability of household livelihoods, the study recommends increasing the natural capital through sustained conservation of natural resources to ensure a continuous supply of ecological goods and services; increasing human capital by providing skills training to households on alternative livelihood options; and increasing access to financial capital by strengthening rural entrepreneurships. Further, the exposure to climate risks in the downstream should be reduced by enhancing the judicious provision of climate information to improve household's preparedness for extreme events, and strengthening households' adaptive capacity by increasing the accessibility to amenities, climate-smart agriculture technologies, and livelihood diversification incentives.

5.5 Areas for Further Research

Given the alarming rates of conversion of natural landscapes and sedimentation in the watershed, future studies should utilize advanced machine learning approaches and tools to predict the future deforestation and erosion patterns over the next decade or two, enabling identification of erosion-susceptible regions significantly contributes to sediment generation.

This study only focused on the distribution of fecal coliforms in the Migori River and didn't establish the specific bacteriological strains present therefore further research is needed on the genetic identification of the bacterial communities in the water. Further, since the study concentrated only on the presence of bacteria in the river, future studies should focus on the presence of other microbiological contaminants like protozoa, viruses, and helminthes.

REFERENCES

Abbaspour, K. C. (2015). SWAT-CUP: SWAT Calibration and Uncertainty Programs-A User Manual. Eawag: Swiss Federal Institute of Aquatic Science and Technology.

Abbassi, F. A., Ullah, A., Hashmi, M. S., Hussain, K., & Akhter, N. (2020). The role of livelihood assets' endowment in the adoption of rural livelihood strategies: an intra-regional comparison of district Bhimber, AJ&K. *Sarhad Journal of Agriculture*, *36*(1), 258-271.

Abera, T. A., Vuorinne, I., Munyao, M., Pellikka, P. K., & Heiskanen, J. (2022). Land cover map for multifunctional landscapes of taita taveta county, kenya, based on sentinel-1 radar, sentinel-2 optical, and topoclimatic data. *Data*, *7*(3), 36.

Adelagun, R. O. A., Etim, E. E., & Godwin, O. E. (2021). Application of Water Quality Index for the Assessment of Water from Different Sources in Nigeria. *Promising Techniques for Wastewater Treatment and Water Quality Assessment*, 267.

Adu, D. T., Kuwornu, J. K., Anim-Somuah, H., & Sasaki, N. (2018). Application of livelihood vulnerability index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana. *Kasetsart journal of social sciences*, 39(1), 22-32.

Agrawal, A. (2010). Local institutions and adaptation to climate change. In: R. Mearns & N. Andrew (Eds.), Social dimensions of climate change: Equity and vulnerability in a warming world. New frontiers of social policy. Washington, DC: World Bank, pp. 173–197.

Agustina, S. R. (2008). *Land Use-farming System and Livelihood Changes in the Upper Catchment of Lake Naivasha, Kenya* (Master's thesis, Institute for Geo-information Science and Earth Observation).

Ahmed, M., Saha, S. M., Hossain, M. E., Khan, M. A., & Prodhan, M. H. (2021). Assessment of livelihood and food poverty status of the floating fishermen in riverine system of Bangladesh. *Social Sciences & Humanities Open*, *4*(1), 100219.

Alam, G. M., Alam, K., Mushtaq, S., & Clarke, M. L. (2017). Vulnerability to climatic change in riparian char and river-bank households in Bangladesh: Implication for policy, livelihoods and social development. *Ecological Indicators*, *72*, 23-32.

Alawamy, J. S., Balasundram, S. K., Mohd. Hanif, A. H., & Boon Sung, C. T. (2020). Detecting and analyzing land use and land cover changes in the region of Al-Jabal Al-Akhdar, Libya using time-series landsat data from 1985 to 2017. *Sustainability*, *12*(11), 4490.

Al-Faraj, F. A. M. (2015). *Sustainable management of transboundary river basins in a changing climate and human-induced interventions upstream* (Doctoral dissertation,

The University of Salford).

Alhassan, A. A. (2010). *An assessment of rural livelihood systems in selected communities in the northern region of Ghana* (Master's thesis, Kwame Nkrumah University).

Al-Mashagbah, A. F. (2015). Assessment of surface water quality of king abdullah canal, using physico-chemical characteristics and water quality index, Jordan. *Journal of Water Resource and Protection*, *7*(04), 339.

Al-Ridah, Z. A., Al-Zubaidi, H. A. M., Naje, A. S., & Ali, I. M. (2020). Drinking water quality assessment by using water quality index (WQI) for Hillah River, Iraq. *Ecology, Environmental & Conservation*, *26*, 390-399.

Altasseb, H.G. (2021). *Livelihoods and Survival Strategies among the Migrant Shoe-Shinning Children: A Case Study at Arada Sub-City, Addis Ababa* (Master's thesis, Addis Ababa University).

Aly-Abdelrehim, A. M. (2012). *Development of a decision support system for resolving conflicts in environmentally sensitive areas* (PhD Thesis, Newcastle University).

American Public Health Association, APHA. (2017). Standard Methods for the Examination of Water and Wastewater. 23rd Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Denver.

Anaba, L. A., Banadda, N., Kiggundu, N., Wanyama, J., Engel, B., & Moriasi, D. (2016). Application of SWAT to assess the effects of land use change in the Murchison Bay catchment in Uganda.

Ansell, C., & Gash, A. (2007). Collaborative governance in theory and practice. *Journal of public administration research and theory*, *18*(4), 543-571.

Ansoms, A., & McKay, A. (2010). A quantitative analysis of poverty and livelihood profiles: The case of rural Rwanda. *Food Policy*, *35*(6), 584-598.

Araya, T., Nyssen, J., Govaerts, B., Deckers, J., & Cornelis, W. M. (2015). Impacts of conservation agriculture-based farming systems on optimizing seasonal rainfall partitioning and productivity on vertisols in the Ethiopian drylands. *Soil and Tillage Research*, *148*, 1-13.

Ariti, A. T., van Vliet, J., & Verburg, P. H. (2015). Land-use and land-cover changes in the Central Rift Valley of Ethiopia: Assessment of perception and adaptation of stakeholders. *Applied Geography*, *65*, 28-37.

Armah, F. A., Yawson, D. O., Yengoh, G. T., Odoi, J. O., & Afrifa, E. K. A. (2010). Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water*, 2(2), 120–139

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Jha, M. K. (2012). SWAT: model use, calibration, and validation. *Transactions of American Society Agricultural and Biological Engineers*, *55*(4), 1491–1508.

Asif, R., & Dawood, M. (2017). Does new public management practices lead to effective public welfare responses in Pakistan. *Turkish Economic Review*, *5*, 150–173.

Asrat, P., & Simane, B. (2017). Characterizing vulnerability of crop-based rural systems to climate change and variability: agro-ecology specific empirical evidence from the Dabus watershed, North-West Ethiopia. *American Journal of Climate Change*, *6*(4), 643-667.

Ayugi, B. O., Wen, W., & Chepkemoi, D. (2016). Analysis of spatial and temporal patterns of rainfall variations over Kenya. *Studies*, *6*(11).

Azene, Y. B., Zeleke, M. T., & Chekole, A. B. (2018). Vulnerability of mountain communities to climate change and natural resources scarcity in Northwest Ethiopia: the case of Debark Woreda. *Journal of Degraded and Mining Lands Management*, *6*(1), 1467.

Aziz, N., Zain, Z., Mafuzi, R. M. Z. R., Mustapa, A. M., Najib, N. H. M., & Lah, N. F. N. (2016, August). Relative importance index (RII) in ranking of procrastination factors among university students. In *AIP Conference Proceedings* (Vol. 1761, No. 1, p. 020022). AIP Publishing LLC.

Baffoe, G., & Matsuda, H. (2018). An empirical assessment of rural livelihood assets from gender perspective: Evidence from Ghana. *Sustainability Science*, *13*(3), 815 828.

Bai J, Ouyang H, Xiao R, Gao J, Gao H, Cui B, Huang L. 2010. Spatial variability of soil carbon, nitrogen, and phosphorus content and storage in an alpine wetland in the Qinghai–Tibet Plateau, China. *Soil Research*, 48(8), 730-736.

Bensig, E., Joyceflores, M., & Maglangit, F. (2014). Assessment of the Water Quality in Buhisan, Bulacao and Lahug Rivers, Cebu, Philippines Using Fecal and Total Coliform as Indicators. *Current World Environment*, *9*(3), 570.

Berchoux, T., & Hutton, C. W. (2019). Spatial associations between household and community livelihood capitals in rural territories: An example from the Mahanadi Delta, India. *Applied Geography*, *103*, 98-111.

Bilgin, A. (2018). Evaluation of surface water quality by using Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) method and discriminant analysis method: a case study Coruh River Basin. *Environmental monitoring and assessment*, *190*(9), 1-11.

Blackstock, K. L., & Richards, C. (2007). Evaluating stakeholder involvement in river basin planning: a Scottish case study. *Water policy*, 9(5), 493-512.

Bowden, C., Konovalske, M., Allen, J., Curran, K., & Touslee, S. (2015). Water quality assessment: the effects of land use and land cover in urban and agricultural land. *Kansas State University, Manhattan*.

Brandes, O., and O'Riordan, J. (2014). A *blueprint for watershed governance in British Columbia. Victoria, Canada:* POLIS Project on Ecological Governance, University of Victoria.

Brown, V. (2008). Collective Decision-Making, Bridging Public Health, Sustainability Governance, and Environmental Management. In *Sustaining Life on Earth: Environmental and Human Health through Global Governance*. Lexington Books.

Camara, M., Jamil, N. R., & Abdullah, A. F. B. (2019). Impact of land uses on water quality in Malaysia: a review. *Ecological Processes*, *8*(1), 10.

Campbell, D. (2013). *Climate change and livelihood vulnerability in Jamaica's agriculture: A mixed-method sequential explanatory design*. Manuscript submitted for publication to Transactions of the Institute of British Geographers.

Campbell, J.B., Wynne, R.H. (2011). Introduction to remote sensing. Guilford Press.

Cao, Z., Wang, S., Luo, P., Xie, D., & Zhu, W. (2022). Watershed Ecohydrological Processes in a Changing Environment: Opportunities and Challenges. *Water*, 14(9), 1502.

Carr, E.R., Wingard, P.M., Yorty, S.C., Thompson, M.C., Jensen, N.K., & Roberson, J. (2007): Applying DPSIR to sustainable development. *International Journal of Sustainable Development and World Ecology*. 14(6), 543-555

CCME, Canadian Council of Ministers of the Environment (2017). Canadian Water Quality Guidelines for the protection of aquatic life: CCME water quality index, user's manual – 2017 update. In: Canadian Environmental Quality Guidelines, 1999. Canadian Council of Ministers of the Environment, Winnipeg. Available from: https://www.ccme.ca/files/Resources/water/water_quality/WQI 20Manual 20EN.pdf

Chapin, F. S., Kofinas, P.W, and Folke, C [EDS.]. (2009). Principles of ecosystem stewardship. Resilience-based natural resource management in a changing world, 402: Springer. New York, NY, USA.

Chaves, J., Neill, C., Germer, S., Neto, S. G., Krusche, A., and Elsenbeer, H. (2008). Land management impacts on runoff sources in small Amazon watersheds. *Hydrological Processes: An International Journal, 22(12), 1766-1775.*

Chen, H., Zhu, T., Krott, M., Calvo, J. F., Ganesh, S. P., & Makoto, I. (2013). Measurement and evaluation of livelihood assets in sustainable forest commons governance. *Land use policy*, *30*(1), 908-914.

Chen, S. (2008). From community-based management to transboundary watershed governance. *Development*, *51*(1), 83-88.

Chergui, F. H., Errahmani, M. B., Benouaklil, F., & Hamaidi, M. S. (2013). Preliminary study on physicochemical parameters and phytoplankton of Chiffa River (Blida, Algeria). *Journal of Ecosystems*, 2013.

Chilagane, N.A (2017). *Impacts of land use and land cover changes on the ecosystem services of the little Ruaha River catchment, Tanzania* (Master's Thesis Sokoine University of Agriculture, Morogoro, Tanzania).

Congalton, R.G., Green, K. (2009). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC Press, Boca Raton.

Corbett, J., 1988, 'Famine and household coping strategies', *World Development* 16(9), 1099–1112.

Corsame, M. E. S., & van Ast, J. (2016). An Analysis on Governance in Watersheds The Case of Ipo Watershed, Philippines (Master's thesis, Erasmus University of Rotterdam).

County Government of Migori. (2020). Increasing Productivity and Profitability of Smallholder Farmers in Value Chains. Migori County. July 2020.

Cristable, R. M., Nurdin, E., & Wardhana, W. (2020, March). Water quality analysis of Saluran Tarum Barat, West Java, based on National Sanitation Foundation-Water Quality Index (NSF-WQI). In *IOP Conference Series: Earth and Environmental Science* (Vol. 481, No. 1, p. 012068). IOP Publishing.

Cutter, S.L., Barnes, L., Berry, M., Burton, C.G., Evans, E., Tate, E.C. (2008). A place-based model for understanding community resilience to natural disasters', *Global Environmental Change* 18, 598–606.

Darwin, N. T. (2014). *Livelihood strategies of people surrounding the Sundarbans mangrove forest* (PhD Thesis, Charles Darwin University).

Daudu, A. K., Salami, O. S., & Kareem, O. W. (2021). Gender analysis of vulnerability of smallholder farming households to climate variability and change in North-central Nigeria. *Agricultura Tropica et Subtropica*, *5(4*).

De Silva, T.A (2011). Mixed methods: a reflection of its adoption in environmental reporting. *Qualitative Research in Accounting & Management*, 8(1), 91-104.

Demographic and Health Surveys (DHS) (2006). *Measure DHS: Model questionnaire with commentary*, Basic Documentation 2, DHS, Calverton.

Department for International Development (DFID) (2001). *Sustainable livelihoods*

guidance sheets, Section 2. Department for International Development, London. Retrieved on August 9, 2021, from http://www.livelihoods.org/info/guidance_sheets_pdfs/section2.pdf

Deressa, T., Hassan, R. M., & Ringler, C. (2008). *Measuring Ethiopian farmers' vulnerability to climate change across regional states*. Intl Food Policy Res Inst.

Devereux, S., Sabates-Wheeler, R., Taye, M. T., Sabates, R., & Sima, F. (2014). Graduation from the food security programme in Ethiopia: FAC Ethiopia Final Report. *Future Agricultures Consortium working paper. Institute of Development Studies: Brighton*. Retrieved on August 9, 2021, from http://www.future-agricultures.org/publications/research-and-analysis/1864-from-report/file

DFID. (2000). Sustainable Livelihoods – current thinking and practice. London: Department for International Development.

Ding, J., Jiang, Y., Fu, L., Liu, Q., Peng, Q., & Kang, M. (2015). Impacts of land use on surface water quality in a subtropical River Basin: a case study of the Dongjiang River Basin, Southeastern China. *Water*, *7*(8), 4427-4445.

Ding, W., Jimoh, S. O., Hou, Y., Hou, X., & Zhang, W. (2018). Influence of livelihood capitals on livelihood strategies of herdsmen in inner Mongolia, China. *Sustainability*, *10*(9), 3325.

Donohue, C., & Biggs, E. (2015). Monitoring socio-environmental change for sustainable development: Developing a Multidimensional Livelihoods Index (MLI). *Applied geography*, *62*, 391-403.

Doria, M. F. (2010). Factors influencing public perception of drinking water quality. *Water policy*, *12*(1), 1-19.

Dumenu, W. K., & Obeng, E. A. (2016). Climate change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications. *Environmental Science and Policy*, 55, 208–217.

Ekness, P. A. (2013). *Ecohydrologic impacts of climate and land use changes on watershed systems: A multi-scale assessment for policy*. University of Massachusetts Amherst.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford university press.

EPA (2020). Water: Monitoring & Assessment. Retrieved on August 9, 2021, from https://archive.epa.gov/water/archive/web/html/vms511.html

Erute, E.B (2017). *Spatial land use management strategy on sustainable livelihood in Vihiga County, Kenya* (PhD Thesis, Moi University, Kenya).

Essayas, N. A. (2010). *Applying the DPSIR approach for the assessment of alternative management strategies of Simien Mountains National Park Ethiopia* (PhD Thesis, University of Natural Resources and Life Sciences (BOKU), Vienna).

Etana, D., Snelder, D. J., van Wesenbeeck, C. F., & de Cock Buning, T. (2021). The Impact of Adaptation to Climate Change and Variability on the Livelihood of Smallholder Farmers in Central Ethiopia. *Sustainability*, *13*(12), 6790.

Etwire, P. M., Al-Hassan, R. M., Kuwornu, J. K., & Osei-Owusu, Y. (2013). Application of livelihood vulnerability index in assessing vulnerability to climate change and variability in Northern Ghana. *Journal of Environment & Earth Science*, 3(2), 157–170

Fang, X., Ren, L., Li, Q., Zhu, Q., Shi, P., & Zhu, Y. (2013). Hydrologic response to land use and land cover changes within the context of catchment-scale spatial information. *Journal of Hydrologic Engineering*, *18*(11), 1539-1548.

Farrington, J., Ramasut, T., & Walker, J. (2002). Sustainable livelihoods approaches in urban areas: general lessons, with illustrations. *Overseas Development Insitute, London*.

Feyissa, G., Zeleke, G., Gebremariam, E., & Bewket, W. (2018). GIS based quantification and mapping of climate change vulnerability hotspots in Addis Ababa. *Geoenvironmental disasters*, *5*(1), 1-17.

Gain, A. K., Giupponi, C., Renaud, F. G., & Vafeidis, A. T. (2020). Sustainability of complex social-ecological systems: Methods, tools, and approaches. *Regional Environmental Change*, *20*(3), 1-4.

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A. W. (2018). Science of the Total Environment Modeling the hydrological impacts of land use / land cover changes in the Andassa watershed , Blue Nile Basin , Ethiopia. *Science of the Total Environment*, *619–620*, 1394–1408.

Gautam, Y., & Andersen, P. (2016). Rural livelihood diversification and household well-being: Insights from Humla, Nepal. *Journal of Rural Studies*, 44, 239–249

Gbetibouo, G. A. (2009). *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa* (Vol. 849). Intl Food Policy Res Inst.

Geist, H.J. & Lambin, E.F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *Bioscience*, 52:143–150

Geremew, A.A (2013). Assessing the impacts of land use and land cover change on hydrology of watershed: a case study on Gilgel–Abbay watershed, Lake Tana basin, Ethiopia (Master's Thesis). Universidade Nova.

Gessesew, W. S. (2017). Application of DPSIR framework for assessment of land

degradation: A review. *Forest*, *3*(1), 4-000.

Ghaffari, G., Keesstra, S., Ghodousi, J., & Ahmadi, H. (2010). SWAT-simulated hydrological impact of land-use change in the Zanjanrood basin, Northwest Iran. *Hydrological Processes: An International Journal*, *24*(7), 892-903.

Ghorbani, A., Ligtvoet, A., Nikolic, I., & Dijkema, G. (2010). Using institutional frameworks to conceptualize agent-based models of socio-technical systems. In *Proceeding of the 2010 workshop on complex system modeling and simulation* (Vol. 3, pp. 33-41).

Gibson, R. (2018). Searching for multi-level collaborative governance. In K. Vodden, D. Douglas, S. Markey, S. Minnes, & W. Reimer (Eds). (2018), *The Theory, Practice and Potential of Regional Development: The Case of Canada* (pp. 84-103).

Giri, S., & Qiu, Z. (2016). Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of environmental management*, *173*, 41-48.

GoK. (2019). County First Quarter Report 2019. County Department of Livestock Production Migori County. Ministry of Livestock Development.

Goulden, M. C., Adger, W. N., Allison, E. H., and and Conway, D. (2013). Limits to Resilience from Livelihood Diversification and Social Capital in Lake Social-Ecological Systems. *Annals of the Association of American Geographers*, 103(4), 906–924.

Greifeneder, F., Khamala, E., Sendabo, D., Wagner, W., Zebisch, M., Farah, H., & Notarnicola, C. (2019). Detection of soil moisture anomalies based on Sentinel-1. *Physics and Chemistry of the Earth, Parts A/B/C*, *112*, 75-82.

Guo, S., Lin, L., Liu, S., Wei, Y., Xu, D., Li, Q., & Su, S. (2019). Interactions between sustainable livelihood of rural household and agricultural land transfer in the mountainous and hilly regions of Sichuan, China. *Sustainable Development*, *27*(4), 725-742.

Gupta, A.K., & Sharma, M.L. (2017). Sustainable Livelihood System of the Tribes in Chhattisgarh State of India: A Tribe's Perspective Analysis. *Asian Journal of Agricultural Extension, Economics & Sociology*, 16(4), 1-13

GWP - GLOBAL WATER PARTNERSHIP. (2012). What is IWRM? Retrieved on September 3, 2021, from http://www.gwp.org/The-Challenge/What-is-IWRM/

Gyamfi, C., Boakye, R., Awuah, E., & Anyemedu, F. (2013). Application of the CCME-WQI Model in assessing the water quality of the Aboabo River, Kumasi-Ghana. *Journal of sustainable Development*, *6*(10), 1.

Hahn, M.B., Riederer, A.M. and Foster, S.O. (2009). The Livelihood Vulnerability Index: A

pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change*, 19(1),74-88.

Hanlon, J. W. (2017). Complementary safeguards for robust regional watershed governance in a federation: New York City and its municipal water supply. *Environmental Science & Policy*, *75*, 47-55.

Hassen, E. E., & Assen, M. (2018). Land use/cover dynamics and its drivers in Gelda catchment, Lake Tana watershed, Ethiopia. *Environmental Systems Research*, *6*(1),1-13.

Hautala, K. R. (2013). *A Sustainable Livelihoods Analysis of Small-Scale Farmers in M'muock, Cameroon: Local Realities and Structural Constraints* (Master's thesis, University of Oslo).

Heath, C., & Staudenmayer, N. (2000). Coordination neglect: How lay theories of organizing complicate coordination in organizations. *Research in organizational behavior*, *22*, 153-191.

Hennink, M., Hutter, I., & Bailey, A. (2020). Qualitative research methods. Sage.

Hirokawa, K. H. (2012). Driving local governments to watershed governance. *Environmental Law*, 157-200.

Hoffmann, P., Schiele, H., Song, M., & Krabbendam, K. (2012). Supply risk management from a transaction cost and social exchange theory perspective. In *The paper was published at the 27th IMP-conference, Glasgow, Scotland*.

Huang, L., Yang, L., Tuyến, N. T., Colmekcioglu, N., & Liu, J. (2021). Factors influencing the livelihood strategy choices of rural households in tourist destinations. *Journal of Sustainable Tourism*, 1-23.

Hunink, J. E., Niadas, I. A., Antonaropoulos, P., Droogers, P., & De Vente, J. (2013). Targeting of intervention areas to reduce reservoir sedimentation in the Tana catchment (Kenya) using SWAT. *Hydrological Sciences Journal*, *58*(3), 600-614.

Huong, N. T. L., Yao, S., & Fahad, S. (2018). Assessing household livelihood vulnerability to climate change: The case of Northwest Vietnam. *Human and Ecological Risk Assessment: An International Journal*, *25*(5), 1157-1175.

Hussain, S. S., & Hanif, M. (2013). Climate change scenarios and possible adaptation measures. *Districts Chitral and DI Khan. Islamabad, Pakistan: Intercooperation Pakistan*.

Ikiel, C., Ustaoglu, B., Dutucu, A. A., & Kilic, D. E. (2013). Remote sensing and GIS-based integrated analysis of land cover change in Duzce plain and its surroundings (north western Turkey). *Environmental monitoring and assessment*, *185*(2), 1699-1709.

International Institute for Population Sciences (IIPS). (2007). *National family health survey (NFHS-3), 2005-06: India* (Vol. 1). International Institute for Population Sciences.

IPCC. (2007). Climate change: Impacts, adaptation, and vulnerability. In Contribution of Working Group II to the Fourth Assessment Report (Ch. 9). Cambridge, UK: Cambridge University Press.

Isett, K. R., Mergel, I. A., Leroux, K., Mischen, P. A., & Rethemeyer, R. K. (2011). Networks in public administration scholarship: Understanding where we are and where we need to go. *Journal of Public Administration Research and theory*, 21(1), 57–73.

Jacobson, C. R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. *Journal of Environmental Management* 92(6), 1438-1448.

Jaganathan, D., Immanuel, S., More, S. J., & Sivakumar, P. S. (2019). Assessment of livelihood capitals of sweet potato and paddy growers in Karnataka. *Indian Research Journal of Extension Education*, *19*(4), 43-48.

Jansen, H. G., Pender, J., Damon, A., Wielemaker, W., & Schipper, R. (2006). Policies for sustainable development in the hillside areas of Honduras: A quantitative livelihoods approach. *Agricultural economics*, *34*(2), 141-153.

Japan International Cooperation Agency (JICA). (2013). The Project on the Development of the National Water Master Plan 2030, Volume - II Main Report (1/2).

Jerop, D. (2018). *Rethinking our Watersheds: A Community Based Approach for Mitigating the Effects of Climate Change in the Regional District of Nanaimo, British Columbia* (Master's Thesis, Vancouver Island University).

John-Mark, D. (2006). Application and Tests of the Canadian Water Quality Index for Assessing Changes in Water Quality in Lakes and Rivers of Central North America. *Lake and Reservoir Management*, 22:4, 308-320

Kaburi, A.N. & Odera, P.A. (2014). *GIS and Remote Sensing Support in Watershed Conservation and Management: Case Study of the Upper Gucha Watershed-Kenya* (PhD Thesis, Kenyatta University).

Karki, R., Srivastava, P., Bosch, D. D., Kalin, L., Lamba, J., & Strickland, T. C. (2020). Multi-Variable Sensitivity Analysis, Calibration, and Validation of a Field-Scale SWAT Model: Building Stakeholder Trust in Hydrologic and Water Quality Modeling. *Transactions of the ASABE*, *63*(2), 523-539.

Kashaigili, J. J. (2008). Impacts of land-use and land-cover changes on flow regimes of the Usangu wetland and the Great Ruaha River, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, *33*(8-13), 640-647

Kathumo, V.B. (2012). *Application of Remote Sensing and GIS in Assessing Land Use and Land Cover Changes and their Impacts on Hydrological Regime in River Gucha Catchment* (PhD Thesis, University of Nairobi).

Katusiime, J., & Schütt, B. (2020). Integrated water resources management approaches to improve water resources governance. *Water*, 12(12), 3424.

Kedir, K. B. (2015). *Livelihoods and coping strategies of rural households in Abela Lida Peasant Association of Shebedino District, Southern Ethiopia* (Master's thesis, University of South Africa).

Khanna, S. A., Shrestha, K. L., Maskey, R. K., Lamsal, A., Pyakurel, K., Poudyal, M., ... & Shrestha, A. (2016). Integrated water resource management (IWRM): a case study of Durlung Watershed, Bagmati Zone, Nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, *18*, 47-54.

Khuzwayo, H.A. (2016). *A Sustainable Livelihood Approach to poverty reduction: participatory experiences of women involved in art and craft cooperative in Bhambayi, Kwa Zulu Natal* (Master's thesis, University of KwaZulu-Natal).

Kibet, R., Olatubara, C. O., Ikporukpo, C. O., & Jebiwott, A. (2021). Land use land cover changes and encroachment issues in Kapkatet wetland, Kenya. *Open Journal of Ecology*, *11*(7), 493-506.

Kituyi, E. (2004). Towards sustainable production and use of charcoal in Kenya: exploring the potential in life cycle management approach. *Journal of Cleaner Production*, *12*(8-10), 1047-1057.

Klijn, E. H., & Koppenjan, J. (2012). Governance network theory: past, present and future. *Policy & Politics*, *40*(4), 587-606.

Klijn, E. H., & Koppenjan, J. (2014). Complexity in governance network theory. *Complexity, Governance & Networks*, *1*(1), 61-70.

Klijn, E. H., & Koppenjan, J. F. M. (2007). Governing Policy Networks; a Network Perspective on Decision Making in Network Society. In *Handbook of decision making* (pp. 169-187). CRC Press/Balkema-Taylor & Francis Group.

KNBS (2019). 2019 Kenya Population and Housing Census: Volume IV. Retrieved on September 3, 2021, from https://s3-eu-west1.amazonaws.com/s3.net/documents/119795/VOLUME-IV-KPHC-2019.pdf

Koneti, S., Sunkara, S. L. & Roy, P. S., 2018. Hydrological modeling with respect to impact of land-use and land-cover change on the runoff dynamics in Godavari River Basin using the HEC-HMS model. *ISPRS International Journal of GeoInformation*, 7(6), 1–17.

Kundzewicz, Z. (2016). *Extreme Weather Events and Their Consequences. Papers on Global Change IGBP, Vol. 23, Issue 1*. Warsaw: Polish Academy of Sciences, 59–69.

Lal, R., Safriel, U., & Boer, B. (2012). Zero net land degradation, a new sustainable development goal for RIO+ 20; a report prepared for the Secretariat of the UNCCD.

Lambin, E. F., Turner, B. L., Geist, H. J. (2001). "The causes of landuse and land-cover change: moving beyond the myths," *Global Environmental Change*, 11 (4), 261–269.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *biometrics*, 159-174.

Langat, B. C. (2009). *Effects of Run-off from Agricultural Farms onto Kipsonoi River and Arroket Stream in Bureti District, Kenya* (Masters' Thesis, Kenyatta University).

Langat, P. K., Kumar, L., Koech, R., & Ghosh, M. K. (2021). Monitoring of land use/land-cover dynamics using remote sensing: A case of Tana River Basin, Kenya. *Geocarto International*, *36*(13), 1470-1488.

Legese, S. A., Olutayo, O. A., Sulaiman, H., & Rao, P. (2016). Assessing climate change impacts in the Lake Tana Sub-Basin, Ethiopia using livelihood vulnerability approach. *Journal of Earth Science and Climatic Change*, *7*(368), 1-10.

Lejju, J. B. (2012). The Influence of Climate Change and Human-Induced Environmental Degradation on Lake Victoria, 104 pp., Afr. Books Collect. Organisation for Social Science Research in Eastern and Southern Africa (OSSREA), Addis Ababa, Ethiopia.

Leslie, H. M**,** Basurto, X**,** Nenadovic, M**,** Sievanen, L**,** Cavanaug, K**,** Cota-Nieto, J. J**,** Erisman, B**,** Finkbeiner, E**,** Hinojosa-Arango, G**,** Moreno-Baez, M**,** Nagavarup, S**,** Reddy, S. M**,** Sanchez-Rodriguez, A**,** Siegel, K**,** Ulibarria-Valenzuela, J. J**,** Weaver, A & Aburto-Oropeza, O (2015). Operationalizing the Social-Ecological Systems Framework to Assess Sustainability. *Proceedings of the National Academy of Sciences of the United States of America* 112(19): 5979–5984.

Levin, S., Xepapadeas, T., Crépin, A. S., Norberg, J., De Zeeuw, A., Folke, C., & Walker, B. (2013). Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics*, *18*(2), 111-132.

Lewis, S. (2015). Qualitative inquiry and research design: Choosing among five approaches. *Health promotion practice*, *16*(4), 473-475.

Li, G., Zhang, F., Jing, Y., Liu, Y., & Sun, G. (2017). Response of evapotranspiration to changes in land use and land cover and climate in China during 2001–2013. *Science of the Total Environment*, *596*, 256-265.

Li, H., Nijkamp, P., Xie, X., & Liu, J. (2020). A new livelihood sustainability index for rural revitalization assessment—a modelling study on smart tourism specialization in

China. *Sustainability*, *12*(8), 3148.

Li, L., Gou, M., Wang, N., Ma, W., Xiao, W., Liu, C., & La, L. (2021). Landscape configuration mediates hydrology and nonpoint source pollution under climate change and agricultural expansion. *Ecological Indicators*, *129*, 107959.

Lillesand, T., Kiefer, R.W., Chipman, J. (2015). Remote Sensing and Image Interpretation. John Wiley & Sons.

Lumb, A., Sharma, T.C., Bibeault, JF. *et al.* A Comparative Study of USA and Canadian Water Quality Index Models. *Water Qual Expo Health* **3,** 203–216 (2011).

Madhav, G. (2010). Intensive meditation for refractory pain and symptoms. *Journal of Alternative and Complementary Medicine* 16(6), 627–631.

Magige, J. M. (2018). *Impacts of Tobacco Farming on forest cover in Bukira West/Bukira East location, Migori country, Kenya* (MSc Thesis, Kenyatta University).

Mahama, T. A.-K., & Maharjan, K. L. (2017). Determinants of livelihood diversification in Ghana from the national livelihood strategies and spatial perspective. *Journal of International Development and Cooperation*, *23*(1), 75-90.

Makalle, A. M., Obando, J., & Bamutaze, Y. (2008). Effects of land use practices on livelihoods in the transboundary sub-catchments of the Lake Victoria Basin. *African Journal of Environmental Science and Technology*, *2*(10), 309-317.

Marquis, G. (2015). Reducing disaster risk in Pakistan through watershed management. *Unasylva*, *66*(243/244), 19.

Mathetsa, S. M. (2015). *Assessing water quality status by means of the Driver-Pressure-State-Impact-Response (DPSIR) model around Mapungubwe National Park, Limpopo Province, South Africa* (Doctoral dissertation, University of Capetown).

Mathew, S., Mathur, D., Chang, B. A., McDonald, E., Signh, R. G., Nur, D., & Gerritsen, R. (2017). Examining the effects of ambient temperature. *International Journal of Environmental Sciences, Public Health*, 14: 147

Mazibuko, S. (2013). Understanding underdevelopment through the sustainable livelihood approach. *Journal of the community development society*, 44(2),173-187.

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. *Ecology and society*, *19*(2).

McPherson, C. M., & Sauder, M. (2013). Logics in action: Managing institutional complexity in a drug court. *Administrative science quarterly*, *58*(2), 165-196.

Mekonnen, M., Keesstra, S. D., Baartman, J. E., Ritsema, C. J., & Melesse, A. M. (2015). Evaluating sediment storage dams: structural off-site sediment trapping measures in

northwest Ethiopia. *Cuadernos de investigación geográfica*, *41*(1), 7-22.

Mekuyie, M., Jordaan, A., & Melka, Y. (2018). Land-use and land-cover changes and their drivers in rangeland-dependent pastoral communities in the southern Afar Region of Ethiopia. *African Journal of Range & Forage Science*, *35*(1), 33-43.

Mena-Rivera, L., Salgado-Silva, V., Benavides-Benavides, C., Coto-Campos, J. M., & Swinscoe, T. H. (2017). Spatial and seasonal surface water quality assessment in a tropical urban catchment: Burío River, Costa Rica. *Water*, *9*(8), 558.

Mercado, V. (2018). *Analysis of urban wetland governance: A case study on the Las Piñas–Parañaque Critical Habitat and Ecotourism Area (LPPCHEA) in Metro Manila, Philippines* (Master's thesis, Erasmus University of Rotterdam).

Meshesha, T.W., Tripathi, S.K. & Khare, D. (2016) Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. Model. *Earth Syst. Environ*. 2, 1–12.

Michalika, A. (2008). The Use of Chemical and Cluster Analysis for Studying Spring Water Quality in Świętokrzyski National Park. *Polish Journal of Environmental Studies*, 17(3), 357-362.

Milewski, A., Sultan, M., Al-Dousari, A., and Yan, E., 2014, Geologic and Hydrologic Settings for Development of Freshwater Lenses in Arid Lands, *Hydrologic Processes*, v. 7(1), 3185-3194.

Milward, H. B., & Provan, K. G. (2000). Governing the hollow state. Journal of Public Administration Research and theory, 10(2), 359–380.

Milward, H. B., & Provan, K. G. (2006). A manager's guide to choosing and using collaborative networks (Vol. 8). Washington, DC: IBM Center for the Business of Government.

Minh, D. D., Lebailly, P., Nguyen Dang, H., Burny, P., & HO, T. M. H. (2019). The dynamics of livelihood vulnerability index at farm household level: An empirical analysis of the coastal sandy zone in Thua Thien Hue province, Vietnam. *International Journal of Economics and Financial Issues*, *9*(4), 77-89.

Ministry of Environment and Mineral Resources (MEMR) Kenya (2013). National Wetlands Conservation and Management Policy 2013. Final Report. Retrieved August 21, 2021, from http://www.environment.go.ke/wp-content/uploads/2014/01/National-Wetlands-Conservation-and-Management-Policy-Nov-2013.pdf

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith,T. L. (2015). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *Transactions of the ASABE*, 50(3), 885–900.

Morse, S., & McNamara, N. (2013). The theory behind the sustainable livelihood approach. In *Sustainable livelihood approach* (pp. 15-60). Springer, Dordrecht.

Muangkaew, T., & Shivakoti, P. G. (2005). Effect of livelihood assets on rice productivity: A case study of rice based farming in Southern Thailand. *ISSAAS Journal*, *11*(2), 63-83.

Mugo, R., Waswa, R., Nyaga, J. W., Ndubi, A., Adams, E. C., & Flores-Anderson, A. I. (2020). Quantifying land use land cover changes in the Lake Victoria basin using satellite remote sensing: The trends and drivers between 1985 and 2014. *Remote Sensing*, *12*(17), 2829.

Mumuni, E., & Oladele, I. (2016). Access to livelihood capitals and propensity for entrepreneurship amongst rice farmers in Ghana. *Agriculture & Food Security*, *5*(1), 1-11.

Munthali, M. G., Davis, N., Adeola, A. M., Botai, J. O., Kamwi, J. M., Chisale, H. L., & Orimoogunje, O. O. (2019). Local perception of drivers of land-use and land-cover change dynamics across Dedza District, Central Malawi Region. *Sustainability*, *11*(3), 832.

Musa, L. M. A., Peters, K. J., & Ahmed, M. K. A. (2006). On farm characterization of Butana and Kenana cattle breed production systems in Sudan. *Livestock research for rural development*, *18*(12), 2006.

Musyimi, D. M., Wekulo, J. K., & Jiveri, B. (2017). Bacteriological and physicochemical characterisation of aora loko stream water, Maseno, Kenya. *Journal of Asian Scientific Research*, 7(3), 119–128.

Muthee, S. W., Kuria, B. T. O., Mundia, C. N., Sichangi, A. W., Kuria, D. N., Goebel, M., & Rienow, A. (2022). Using SWAT to model the response of evapotranspiration and runoff to varying land uses and climatic conditions in the Muringato basin, Kenya. *Modeling Earth Systems and Environment*, 1-13.

Mwanga, S. S. (2019). *Water dynamics in the Umba river sub-catchment of Tanzania: water resource allocation for livelihoods* (PhD Thesis, University of the Witwatersrand).

Mwangi, H. M. (2013). *Evaluation of the impacts of soil and water conservation practices on ecosystem services in Sasumua watershed, Kenya, using SWAT model* (Doctoral dissertation, Kenyatta University).

Nasong'o, S.W. "Ecological Roots of Social Conflict in Kenya: Pastoralism, Land, and the Development Paradox". In Perspectives on African Environment, Science and Technology, Toyin Falola and Maurice Amutabi, eds. Trenton, NJ: Africa World Press, 2012.

Nasrnia, F., & Ashktorab, N. (2021). Sustainable livelihood framework-based assessment of drought resilience patterns of rural households of Bakhtegan basin, Iran. *Ecological*

Indicators, *128*, 107817.

National Environmental Management Authority, Nema. (2017). Environmental Management and Co-ordination (Water Quality) Regulations. *Kenya Gazette supplement No 68*, pp 9.

Ndetei, C. J. (2006). *A Comparative analysis of the performance of flood frequency distributions in the Lake Victoria Basin in Kenya* (PhD Thesis, University of Nairobi).

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2011. *Soil and water assessment tool theoretical documentation version 2009*. Texas Water Resources Institute.

Ngatia, M., Kithiia, S. M., & Voda, M. (2023). Effects of Anthropogenic Activities on Water Quality within Ngong River Sub-Catchment, Nairobi, Kenya. *Water*, *15*(4), 660.

Nie, W., Yuan, Y., Kepner, W., Nash, M. S., Jackson, M., & Erickson, C. (2011). Assessing impacts of Landuse and Landcover changes on hydrology for the upper San Pedro watershed. *Journal of Hydrology*, *407*(1-4), 105-114.

Njenga, M., Mahmoud, Y., Mendum, R., Iiyama, M., Jamnadass, R., De Nowina, K. R., & Sundberg, C. (2017). Quality of charcoal produced using micro gasification and how the new cook stove works in rural Kenya. *Environmental Research Letters*, *12*(9), 095001.

Nkondze, M. S., Masuku, M. B., & Manyatsi, A. (2013). Factors Affecting households vulnerability to climate change in Swaziland: A case of Mpolonjeni Area Development Programme (ADP). *Journal of Agricultural Science*, 5(10), 108–122

Nyamohanga, P.W (2018). *Factors Influencing Maize Crop Production among Small-scale Farmers in Kuria East Sub-County, Migori County, Kenya* (Msc. Thesis, Egerton University).

Nyika, J. M. (2022). Climate Change Situation in Kenya and Measures Towards Adaptive Management in the Water Sector. In *Research Anthology on Environmental and Societal Impacts of Climate Change* (pp. 1857-1872). IGI Global.

O'Driscoll, M., Clinton, S., Jefferson, A., Manda, A., & McMillan, S. (2010). Urbanization effects on watershed hydrology and in-stream processes in the southern United States. *Water*, 2(3), 605-648.

Odada, E. O., Ochola, W. O., & Olago, D. O. (2009). Drivers of ecosystem change and their impacts on human well-being in Lake Victoria basin. *African Journal of Ecology*, *47*, 46-54.

Odontsetseg, D., Janchivdorj, L., Udvaltsetseg, G., & Frieden, J. (2009). Some Results of Applying DPSIR Analysis for Ulaanbaatar as Part of Selenge River Basin Integrated Water Management System. *Proceedings of Mongolian Academy of Sciences*, 22-31.

Odumo, O., Mustapha, O. A., Patel, J. P., & Angeyo, H. K. (2011). Multielemental analysis of Migori (Southwest, Kenya) artisanal gold mine ores and sediments by EDX-ray fluorescence technique: Implications of occupational exposure and environmental impact. Bull *Environ Contam Toxicol*., 86(5),484–489.

Ogembo, V. (2018). *Hydrological Modeling and Climate Change Impacts on River Kuja Watershed Using HEC-HMS and HEC-GeoHMS Models* (Msc. thesis, Pan-African University).

Ogola, P. (2018). *Human population growth and its implications on the use and trends of land resources in Migori County, Kenya* (Master's thesis, Kenyatta University).

Okab, A. A. (2015). *Evaluation Study for the Characteristics of Drinking Water Resulting from Two Water Treatment Plants and their Networks in Baghdad City* (M.Sc. Thesis, University of Technology).

Okok, M. O. (2015). *The influence of multi-actor coordination on urban household water access: the case of kawangware informal settlement in nairobi city* [Master's thesis, Erasmus University of Rotterdam].

Olaka, L. A., Ogutu, J. O., Said, M. Y., & Oludhe, C. (2019). Projected climatic and hydrologic changes to Lake Victoria Basin Rivers under three RCP emission scenarios for 2015–2100 and impacts on the water sector. *Water*, *11*(7), 1449.

Olal, F. O. (2015). Assessment of the Impact of Urban Runoff from Migori Town on the Concentration Levels of Selected Heavy Metals in Migori River, Kenya. *Journal of Environment and Earth Science*, 5(20), 50 – 59.

Olang, L. O., & Fürst, J. (2011). Effects of land cover change on flood peak discharges and runoff volumes: Model estimates for the Nyando River Basin, Kenya. Hydrological Processes, 25(1), 80–89.

Olsen, R. K. (2006). A Change from Leadership (Vertical Power Structure) to Leadingship (Horizontal Power Structure) at Work. *The New Workplace Reality Series. http://www. humiliationstudies. org/documents/OlsenLeadershipLeadingship.pdf*.

Olusola, A., Onafeso, O., & Durowoju, O. S. (2018). Analysis of organic matter and carbonate mineral distribution in shallow water surface sediments. *Osun Geogr Rev*, *1*(1), 106-110.

Ongwenyi, S.G., Kitheka, J.U., & Nyagaga, J.M. (1993). Impact of hydrological and land use processes on the quality of water in the Gucha catchment, southwestern Kenya. *Hydrology of Warm Humid Regions* (Proceedings of the Yokohama Symposium, Jury 1993). IAHS MM. no. 216, 1993.

Onyango, D. O., Ikporukpo, C. O., Taiwo, J. O., & Opiyo, S. B. (2021). Monitoring the extent and impacts of watershed urban development in the Lake Victoria Basin, Kenya,

using a combination of population dynamics, remote sensing and GIS techniques. *Environmental & Socio-economic Studies*, *9*(2), 11-25.

Opiyo, S. B. (2019). *Integrated Ecological Integrity Assessment Based on Water Quality, Phytoplankton Diversity, Trophic State Indices and Habitat Quality in Lake Simbi, a Deep Alkaline Saline Lake In Western Kenya* (Masters' Thesis, Kisii University).

Otieno, A. C., Mugalavai, V., & Kamau, E. H. (2013). A study on impact of climate change on the food and nutrition security in children of small scale farmer households of Migori area. *Glob. J. Biol. Agric. Heal. Sci*, *2*, 67-71.

Owuonda, H. A. (2016). *Assesing The Socio-Economic Effects of Floods in The Households of Nyatike Division in Migori County-Kenya* (PhD Thesis, ST. Paul's University).

Özerol, G. (2013). Institutions of farmer participation and environmental sustainability: a multi-level analysis from irrigation management in Harran Plain, Turkey. *International Journal of the Commons*, 7(1),73-91.

Pache, A. C., & Santos, F. (2010). When worlds collide: The internal dynamics of organizational responses to conflicting institutional demands. *Academy of management review*, *35*(3), 455-476.

Pai, N., & Saraswat, D. (2011). SWAT2009_LUC: A tool to activate the land use change module in SWAT 2009. *Transactions of the ASABE*, *54*(5), 1649-1658.

Palanisami, K., & Kumar, D. S. (2009). Impacts of watershed development programmes: experiences and evidences from Tamil Nadu. *Agricultural Economics Research Review*, *22*(conf), 387-396.

Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., & Pandey, V. P. (2016). Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal. *Regional environmental change*, *16*(4), 1121-1132.

Parkes, M. W., Morrison, K. E., Bunch, M. J., Hallström, L. K., Neudoerffer, R. C., Venema, H. D., & Waltner-Toews, D. (2010). Towards integrated governance for water, health and social–ecological systems: The watershed governance prism. *Global Environmental Change*, *20*(4), 693-704.

Paudel Khatiwada, S., Deng, W., Paudel, B., Khatiwada, J. R., Zhang, J., & Su, Y. (2017). Household livelihood strategies and implication for poverty reduction in rural areas of central Nepal. *Sustainability*, *9*(4), 612.

Paul, M. (2016). Impacts of Land Use and Climate Changes on Hydrological Processes in South Dakota Watersheds" (2016). *Theses and Dissertations*. Paper 1018. South Dakota State University.

Pederson, N., Hessl, A.E., Baatarbileg, N., Anchukaitis, K.J., Di Cosmo, N. (2014). Pluvials, droughts, the Mongol Empire, and modern Mongolia. *Proc. Natl. Acad. Sci. USA, 111,* 4375–4379.

Phanxay, I., Isao, H., and Satoshi, Y. (2015). Access to livelihood assets under the influence of a climate event in Upland Northern Laos. *Geographical Review of Japan Series B*, 87 (2), 131–145

Piya, L., Joshi, N. P., & Maharjan, K. L. (2012). Vulnerability of Chepang households to climate change and extremes in the Mid-hills of Nepal. *Climatic Change*, 135(3–4), 521–537.

Pollard, S., Biggs, H., & Du Toit, D. (2008). Towards a Socio-Ecological Systems View of the Sand River Catchment, South Africa. *Water Research Commission Project: K8, 591*.

Provan, K. G., & Kenis, P. (2008). Modes of network governance: Structure, management, and effectiveness. Journal of Public Administration Research and theory, 18(2), 229–252.

Puyravaud, J. P. (2003). Standardizing the calculation of the annual rate of deforestation. *Forest ecology and management*, *177*(1-3), 593-596.

Qiu, Y., Chen, H., Sheng, Z., & Cheng, S. (2019). Governance of institutional complexity in megaproject organizations. *International journal of project management*, *37*(3), 425-443.

Raaijmakers, A. G., Vermeulen, P. A., Meeus, M. T., & Zietsma, C. (2015). I need time! Exploring pathways to compliance under institutional complexity. *Academy of Management Journal*, *58*(1), 85-110.

Rai, R., Zhang, Y., Paudel, B., Acharya, B.K., Basnet, L. (2018). Land use and land cover dynamics and assessing the ecosystem service values in the trans-boundary Gandaki River Basin, Central Himalayas. *Sustainability*, 10(9), 30-52.

Rawat, J. S., & Kumar, M. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, *18*(1), 77-84.

Relief-Web Kenya, 2021. Kenya County Climate Risk Profile: Migori County. Retrieved March 19, 2022, from https://cgspace.cgiar.org/bitstream/handle/10568/115067/MIGORI%20COUNTY%20F

Reza R., Singh G. (2010). Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India. *World Applied Sciences Journal* 9, (12), 1392.

Ruttoh, R. C., Obiero, J. P., Omuto, C. T., & Tanui, L. (2022). Assessment of Land Cover

and Land Use Change Dynamics in Kibwezi Watershed, Kenya. *The Scientific World Journal*, *2022*.

Saini, M., Mala N. R., Joshi, P. K. (2014). Measurement of the Impacts of Watershed Management Programme on Livelihoods of a Watershed Community. *International Journal of Development Research,* 4 (3), 511-514.

Sanchez, J. M. P., Picardal, M. T., Libres, M. T., Pineda, H. A., Paloma, M. L. B., Librinca, J. M., ... & Picardal, J. P. (2020). Characterization of a river at risk: the case of Sapangdaku River in Toledo City, Cebu, Philippines. *AIMS Environmental Science*, *7*(6), 559-575

Schlüter, M., Hinkel, J., Bots, P. W., & Arlinghaus, R. (2014). Application of the SES framework for model-based analysis of the dynamics of social-ecological systems. *Ecology and Society*, *19*(1).

Scoones, I. (2009). Livelihoods perspectives and rural development. *The Journal of Peasant Studies*, 36(1), 171-196.

Sehested, K., & Groth, N. B. (2012). Pluricentric coordination in regional planning: The enhancement of planning possibilities in complex governance situations. In *the RSA European Conference 2012: Networked regions and cities in times of fragmentation: Developing smart, sustainable and inclusive places*. Delft University of Technology.

Serrat, O., & Serrat, O. (2017). The sustainable livelihoods approach. *Knowledge solutions: Tools, methods, and approaches to drive organizational performance*, 21-26.

Shah, K. U., Dulal, H. B., Johnson, C., & Baptiste, A. (2013). Understanding livelihood vulnerability to climate change: Applying the livelihood vulnerability index in Trinidad and Tobago. *Geoforum*, *47*, 125-137.

Sharma D., Kansal A. (2011). Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000-2009). *Applied Water Science*, 1, 147.

Shiluli, M., Mogaka, J., Nyaga, J., Kinuthia, R., Njoroge, J., Kidula, N., Öborn, I., Duncan, A. and Hammond, J. 2021. LegumeSELECT: A baseline characterisation of four selected sites in Kisii and Migori counties of western Kenya. ILRI Project Report. Nairobi, Kenya: ILRI.

Shukla, S., & Gedam, S. (2019). Evaluating hydrological responses to urbanization in a tropical River Basin: a water resources management perspective, *Natural Resources Research*, 28(2), 327–347.

Sienkiewicz-Małyjurek, K. (2017). Antecedents of inter-organizational collaboration in public safety management system. *International Journal of Contemporary Management*, *16*(3), 259-273.

Simane, B., Zaitchik, B. F., & Foltz, J. D. (2016). Agroecosystem specific climate vulnerability analysis: application of the livelihood vulnerability index to a tropical highland region. *Mitigation and Adaptation Strategies for Global Change*, *21*(1), 39-65.

Siraw, Z., Adnew Degefu, M., & Bewket, W. (2018). The role of community-based watershed development in reducing farmers' vulnerability to climate change and variability in the northwestern highlands of Ethiopia. *Local Environment*, *23*(12), 1190-1206.

Sirengo, R. K., Mundia, C. N., Sichangi, A. W. (2018). Modelling Land Degradation in Migori County. *SSRG International Journal of Agriculture & Environmental Science (SSRG-IJAES)*, 5(2) 34 – 43.

Song, X. P., Hansen, M. C., Stehman, S. V., Potapov, P. V., Tyukavina, A., Vermote, E. F., & Townshend, J. R. (2018). Global land change from 1982 to 2016. *Nature*, *560*(7720), 639-643.

Soulineyadeth, S. (2014). Impact of Unexploded Ordnance (UXO) on Rural Communities' Livelihoods in Xiengkhouang Province, Lao PDR. Retrieved on August 9, 2021, from http://researcharchive.vuw.ac.nz//bitstream/handle/10063/3670/thesis.pdf?sequence=2.

Stevenson, M., Wilks, T., and Hayward, S. (2010). An overview of the state and trends in water quality of Canterbury's rivers and streams. (Report No. R10/117). Environment Canterbury Regional Council.

Stosch, K. C., Quilliam, R. S., Bunnefeld, N., & Oliver, D. M. (2017). Managing multiple catchment demands for sustainable water use and ecosystem service provision. *Water*, *9*(9), 677.

Su, M. M., Wall, G., & Wang, Y. (2019). Integrating tea and tourism: a sustainable livelihoods approach. *Journal of Sustainable Tourism*, *27*(10), 1591-1608.

Sun, W., Xia, C., Xu, M., Guo, J., & Sun, G. (2016). Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. *Ecological Indicators*, 66, 306-312.

Suthar, S., Sharma, J., Chabukdhara, M., & Nema, A. K. (2010). Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater. *Environmental monitoring and assessment*, *165*(1), 103-112.

Swallow, B. M., Sang, J. K., Nyabenge, M., Bundotich, D. K., Duraiappah, A. K., & Yatich, T. B. (2009). Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa. *Environmental science & policy*, 12(4), 504- 519.

Tackie-Yarboi, D. (2020). *Livelihood strategies and land cover in the Ga central municipality* (Master's thesis, University of Education).

Taloor, A. K., Kumar, V., Singh, V. K., Singh, A. K., Kale, R. V., Sharma, R., ... & Chowdhary, N. H. (2020). Land use land cover dynamics using remote sensing and GIS Techniques in Western Doon Valley, Uttarakhand, India. *Geoecology of landscape dynamics*, 37-51.

Tantoh, H. B., & Simatele, D. (2018). Complexity and uncertainty in water resource governance in northwest Cameroon: Reconnoitring the challenges and potential of community-based water resource management. *Land use Policy*, 75, 237–251.

Tarko, V. (2015). *Polycentric Governance: A Theoretical and Empirical Exploration* (Doctoral dissertation, George Mason University).

Tewari, H. R., & Bhowmick, P. K. (2014). *Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar* (PhD thesis, North Western University).

Torfing, J. (2010). Local forms of governance in Denmark: the revenge of the supplement. *Journal of Power*, 3(3), 405-425.

Toufique, K. A., & Yunus, M. (2013). Vulnerability of livelihoods in the coastal districts of Bangladesh. *The Bangladesh development studies*, 95-120.

Tropp, H. (2007). Water governance: trends and needs for new capacity development. *Water Policy*, 9(S2), 19-30.

Trucano, T. G., Swiler, L. P., Igusa, T., Oberkampf, W. L. and Pilch, M. (2006). Calibration validation and sensitivity analysis. *Reliability Engineering & System Safety* 91(10): 1331 – 1357.

Tsai, H.T., Tzeng, S.Y., Fu, H.H., & Chun-The, W.J. (2009): Managing multinational sustainable development in the European Union based on the DPSIR framework. *African Journal of Business Management*. 3(11), 727-735.

Tu, J. (2011). Spatial and temporal relationships between water quality and land use in northern Georgia, USA. *Journal of Integrative Environmental Sciences*, *8*(3), 151-170.

Turan, S. Ö., & Günlü, A. (2010). Spatial and temporal dynamics of land use pattern response to urbanization in Kastamonu. *African journal of Biotechnology*, *9*(5).

UNESCO (2018). Th United Nations world water development report 2018. Retrieved on August 9, 2021, from https://unesdoc.unesco.org/ark:/48223/pf0000261424

UNICEF (2017). MIGORI SOCIAL SECTOR BUDGET BRIEF (2013-14 to 2015-16). Retrieved on August 9, 2021, from https://www.unicef.org/esa/media/876/file/UNICEF-Kenya-2017-Migori-Budget.pdf

United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2019 Revision. Retrieved April 21, 2022, from https://www.worldometers.info/world-population/kenya-population/

USAID (2020). Kenya at a Glance: Climate Projections and Impacts. Retrieved March 19, 2022, from https://www.climatelinks.org/countries/kenya

USGS, United States Geological Society. (2018). Water Science School. Retrieved on August 9, 2021, from https://www.usgs.gov/special-topics/water-science-school

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., ... & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *nature*, *467*(7315), 555-561.

Wang, F., Yang, D., Wang, C., & Zhang, X. (2015). The effect of payments for ecosystem services programs on the relationship of livelihood capital and livelihood strategy among rural communities in Northwestern China. *Sustainability*, *7*(7), 9628-9648.

Water Supply and Sanitation and Collaborative Council (2015). WASH-Post-2015: Proposed Targets and Indicators for Drinking-Water, Sanitation and Hygiene. 2015. Pp. 1-12. Retrieved March 19, 2022, from http://www.unicef.org/wash/files/2_WSSCC_JMP_Fact_Sheets_2_UK_LoRes.pdf

Waters, E. R., Morse, J. L., Bettez, N. D., & Groffman, P. M. (2014). Differential carbon and nitrogen controls of denitrification in riparian zones and streams along an urban to exurban gradient. *Journal of environmental quality*, *43*(3), 955-963.

Watson, N., Shrubsole, D., & Mitchell, B. (2019). Governance arrangements for integrated water resources management in Ontario, Canada, and Oregon, USA: Evolution and Lessons. *Water*, *11*(4), 663.

Weldegebriel, Z. B., & Amphune, B. E. (2017). Livelihood resilience in the face of recurring floods: An empirical evidence from Northwest Ethiopia. *Geoenvironmental Disasters*, 4(1), 10.

Wickham, J. D., Stehman, S. V., Gass, L., Dewitz, J., Fry, J. A., & Wade, T. G. (2013). Accuracy assessment of NLCD 2006 land cover and impervious surface. *Remote Sensing of Environment*, *130*, 294-304.

Williamsburg Emergency Management (2004). Household natural hazards preparedness questionnaire. Peninsula Hazard Mitigation Planning Committee, Williamsburg, VA.

Woldeab, B., Beyene, A., Ambelu, A., Buffam, I., & Mereta, S. T. (2018). Seasonal and spatial variation of reservoir water quality in the southwest of Ethiopia. *Environmental monitoring and assessment*, *190*(3), 1-13.

World Bank (1998). *Survey of living conditions: Uttar Pradesh and Bihar – Household questionnaire, December 1997–March 1998*, World Bank, Washington, D.C.

World Bank **(**2008). *Watershed management approaches, policies, and operations: lessons for scaling up.* Water Sector Board Discussion Paper Series No. 11.

World Bank (2010) Economics of Adaptation to Climate Change: Ethiopia. Washington, DC. Retrieved January, 4, 2022, from https://openknowledge.worldbank.org/handle/10986/12504.

World Bank. (2016). *Integrated land scape management in Kenya: the state of the policy environment, Land and Poverty Conference*. Washington DC.

World Health Organization (WHO) & Roll Back Malaria (RBM), 2003, *Economic impact of malaria, household survey*. Retrieved November 4, 2021, from http:// rollbackmalaria.org/ProgressImpactSeries/docs/report6-en.pdf

World Health Organization, WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

WRMA & JICA. (2014). Gucha Migori river basin integrated flood management plan. Retrieved on September 3, 2021, from https://www.google.com/url?Fopenjicareport.jica.go.jp%2Fpdf%2F1000018470_03.pdf

Wu, Y., Liu, S., Sohl, T. L., & Young, C. J. (2013). Projecting the land cover change and its environmental impacts in the Cedar River Basin in the Midwestern United States. *Environmental Research Letters*, *8*(2), 024025.

Xia, J., Zhang, Y., Mu, X., Zuo, Q., Zhou, Y., & Zhao, G. (2021). A review of the ecohydrology discipline: Progress, challenges, and future directions in China. *Journal of Geographical Sciences*, *31*(8), 1085-1101. Xu, M., Wang, Z., Duan, X., & Pan, B. (2014). Effects of pollution on macroinvertebrates and water quality bio-assessment. *Hydrobiologia*, *729*(1), 247-259.

Xu, X., Shrestha, S., Gilani, H., Gumma, M. K., Siddiqui, B. N., & Jain, A. K. (2020). Dynamics and drivers of land use and land cover changes in Bangladesh. *Regional Environmental Change*, *20*(2), 1-11.

Yamane, Y., Asanuma, S., & Umenura, K. (2015). Influence of livestock farming on vegetation in a degraded soil area on the East Coast of Lake Victoria in Western Kenya: A case study of Jimo East Sub-Location in Nyando Sub-County. *Journal of Environmental Protection*, 6(8), 85-101.

Yang, Y.S., Wang, L. (2010). Catchment-scale vulnerability assessment of groundwater pollution from diffuse sources using the DRASTIC method: a case study, Hydrological Sciences Journal, 55(7), 1206 1216.

Yin, S., Yang, X., & Chen, J. (2020). Adaptive behavior of farmers' livelihoods in the context of human-environment system changes. *Habitat International*, *100*, 102185.

Yu, X. J., Pitt A., Wang J., Baldwin R., Chow, A. (2015). Water quality of small seasonal wetlands in the Piedmont ecoregion, South Carolina, USA: Effects of land use and hydrological connectivity. *Water research*, (73), 98-108.

Zadbagher, E., Becek, K., & Berberoglu, S. (2018). Modeling land use/land cover change using remote sensing and geographic information systems: case study of the Seyhan Basin, Turkey. *Environmental monitoring and assessment*, *190*, 1-15.

Zeray, L. (2007). Calibration and Validation of SWAT Hydrologic Model for Meki Watershed. In *Ethiopia, Conference of Inter national Agricultural Research for Development.* 9 - 11 Oct, 2007 University of Kassel Wizenhausen and University of Göttingen, Germany.

Zhang, C., & Fang, Y. (2020). Application of capital-based approach in the measurement of livelihood sustainability: A case study from the Koshi River basin community in Nepal. *Ecological Indicators*, *116*, 106474.

Zhang, C., Fang, Y., Chen, X., & Congshan, T. (2019). Bibliometric analysis of trends in global sustainable livelihood research. *Sustainability*, *11*(4), 1150.

Zhang, T., Zhang, X., Xia, D., Liu, Y. (2014). An analysis of land use change dynamics and its impacts on hydrological processes in the Jialing River Basin. *Water*, 6(12), 3758-3782.

Zhang, Y. K., & Schilling, K. E. (2006). Increasing streamflow and baseflow in Mississippi River since the 1940: Effect of land use change. *Journal of Hydrology*, *324*(1-4), 412-422.

Zhao, J., Lin, L., Yang, K., Liu, Q., & Qian, G. (2015). Influences of land use on water quality in a reticular river network area: A case study in Shanghai, China. *Landscape and Urban Planning*, 137, 20-29.

Zhao, Y. (2013). Social networks and reduction of risk in disasters: an example of the Wenchuan Earthquake. In *Economic stress, human capital, and families in Asia* (pp. 171-182). Springer, Dordrecht.

Zope, P. E., Eldho, T. I., & Jothiprakash, V. (2016). Impacts of land use–land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. *Catena*, *145*, 142-154.

Žurovec, O. (2018). *Agriculture, livelihoods and climate change in Bosnia and Herzegovina – Impacts, vulnerability and adaptation* (PhD thesis, Norwegian University of Life Sciences).

APPENDICES

Appendix 1: Semi-Structured Interview Guide for Governance Stakeholders

Introduction

Hello, I am Opiyo Stephen; I'm a PhD candidate in the Department of Environmental Planning and Management at the Kenyatta University, under the supervision of Prof. Letema and Dr. Opinde. ***My research project focuses on examining the institutional arrangement and the coordination of the stakeholders of Migori River Watershed.*** This research will be useful in supporting decision-makers in the formulation of informed policies and management measures for conservation and protection of land and water resources within this watershed. Due to the connection of your agency/organization to the management of natural resources of the Migori River Watershed, you have been kindly requested to participate in this interview as a key informant. Please note that your anonymity is guaranteed, and the information acquired from this research will be handled confidentially and will only be utilized for purposes of this academic study.

Interview Questions for National and County Government Actors

1. What is your current designation? How long have you occupied the position?
2. When was this agency established and what's its mandate? What's the legal basis for its creation?
3. What roles does your agency play with respect to the management of natural resources Migori River Watershed)? In your opinion, why is Migori River Watershed important?
4. In carrying out your mandate as it relates to the Migori River Watershed, do you coordinate with other government agencies, NGOs, CBOs or communities? Kindly mention the agencies and the areas in which you collaborate/partner.
5. Which of those collaborations with stakeholders were formalized through signing of MoUs? Were the MoUs for short term engagement or long term partnership? Does a partner who does not honor their obligations based on the MoU get any form of penalization?
6. How are decisions arrived at in project planning, execution or monitoring? Does your agency consult other stakeholders? Which type of decisions that consultation with other stakeholder is not essential?
7. Does your organization carry out regular meetings internally for updates of projects and monitoring of conservation activities in the Migori River catchment? How often in a month/year?
8. Generally speaking, how would you describe the working relationship/communication between your organization and other stakeholder's in the watershed?
9. Is there a single lead agency or coordinating body dedicated to Migori River Watershed? If not, do you think it is essential to institute a single coordinating body for Migori? What's the reason for your answer?
10. As co-managers in Migori River Watershed, is there a clear delineation of roles and responsibilities between your agency and the lead agency/other agencies?
11. Is there a joint master plan of projects and activities for the management Migori River Watershed? Which agencies were involved in the joint planning and why were they included? Any more agency(ies) that you think should have been included during planning?
12. During joint implementation of projects, are the activities executed by respective agencies synchronized? Who performs monitoring and evaluation of the projects and activities being executed by the respective agencies? Does a partner who does not honor their assigned obligations based on the MoU get any form of penalization?
13. Does your organization carry out regular meetings internally for updates of projects and monitoring of conservation activities in the Migori River catchment? How often in a month/year?
14. During execution of some activities or projects, permits from certain agencies such as NEMA, WRA and the Migori County Government may be needed. Do you encounter any problem on this aspect? Why or why not? If any, what are your best practices on this regard?

15. How would you characterize the sustainability (low, moderate, high) of the current integrated watershed governance system of Migori River watershed? Does it help in addressing pressing issues such as gender considerations and poverty? Do you observe any key gaps or areas where more policies and institutional framework is required?
16. In your opinion, what are the challenges facing your agency in effectively carrying out conservation/management operations in the watershed? What measures are being undertaken to overcome these challenges?

Interview Questions for Non-Governmental Organizations (NGOs), Intergovernmental Agencies and Private Enterprises

1. What is your current designation? How long have you occupied the position?
2. When was this institution established, and what is its overall mission?
3. What is its involvement (in terms of goals, responsibilities or priorities) in the conservation/management of Migori River Watershed? What legislation, policies, or local by-laws guide your operations in this watershed?
4. What projects and activities is your organization currently implementing inside the watershed? Which broad category are they; environmental conservation program, livelihood improvement program or cultural and heritage conservation program?
5. How does this institution empowers and builds capacity for the team involved in Migori River catchment conservation to perform their tasks?
6. Does your institution have a work plan for your conservation/management operations in the Migori River sub-catchment? If yes, what's its validity period?
7. Which government agencies, NGOs, private companies, CBOs or local communities do you work with and what procedure do you use in defining the stakeholders who should be involved in your operations? Kindly specify the areas of collaboration for every entity mentioned.
8. Which of those collaborations with stakeholders were formalized through signing of MoUs? Were the MoUs for short term engagement or long term partnership? Does a partner who does not honor their obligations based on the MoU get any form of penalization?
9. Have you been involved by any of the government agencies during planning, project implementation or during watershed monitoring? What type of decisions was your organization involved in?
10. Are your conservation projects for Migori River or its watershed synchronized with other stakeholders? Why or why not?
11. Generally speaking, how would you describe the working relationship and/or communication between your organization and other stakeholder's in the watershed?
12. Is there a single lead agency or coordinating body dedicated to Migori River Watershed? If not, do you think it is essential to institute a single coordinating body for Migori? What's the reason for your answer?
13. During execution of some activities or projects, permits from certain agencies such as NEMA, WRA and the Migori County Government may be needed. Do you encounter any problem on this aspect? Why or why not? If any, what are your best practices on this regard?
14. Since your organization began operating within this watershed up to now, what would be considered your successes and failures in the effort of addressing conservation/livelihoods improvement?
15. How would you characterize the sustainability (low, moderate, high) of the current integrated watershed governance system of Migori River watershed? Does it help in addressing pressing issues such as gender considerations and poverty? Do you see any critical gaps or areas where more policies and institutional framework is required?
16. In your opinion, what are the challenges facing your agency in effectively carrying out conservation/management operations in the watershed? What measures are being undertaken to overcome these challenges?

Interview Questions for Community-based Conservation groups

1. What is your current designation? How long have you occupied the position? What general guidelines are used in selecting the group leaders?
1. When was the group formed and why? What legislation or policies guided the creation and/or operations of the group?
2. What role does your group perform with regards to the management of natural resources in the Migori River Watershed? In your opinion, why is Migori River Watershed important?
3. Does your team have a work plan for your conservation/management of the Migori River sub-catchment? If yes, what's its validity period?
4. What projects and activities is your group currently implementing inside the watershed? Which broad category are they; environmental conservation program, livelihood improvement program or cultural and heritage conservation program?
5. How do your projects and activities benefit the residents and/or the ecosystem of the Migori River Watershed?
6. Does the group have any training on proper land use and watershed conservation? Who offers or sponsor the trainings?
7. Is your group or organization involved in giving any advisory and extension services to farmers to cope with new improved methods of farming and curb things like soil erosion? What mechanisms do you use to reach the local communities?
8. In relation to your conservation activities, do you coordinate with any government agencies, NGOs or CBOs? Kindly mention the agencies and the areas in which you collaborate/partner.
9. Which of those collaborations with stakeholders were formalized through signing of MoUs? Were the MoUs for short term engagement or long term partnership? Does a partner who does not honor their obligations based on the MoU get any form of penalization?
10. Are your conservation projects for Migori River watershed synchronized with other stakeholders? Why or why not?
11. Do you have regular meetings with the agencies you are collaborating with in Migori County (such as NEMA and WRA)? If, yes, how often in a month/year?
12. Does your organization carry out regular meetings internally for updates of projects and monitoring of conservation activities in the Migori River catchment? How often in a month/year?
13. Generally speaking, how would you describe the working relationship/communication between your group and other stakeholder's in the Migori County?
14. Have you ever had any institutional interference during the implementation of your conservation activities?
15. Since your group/organization began operating within this catchment up to now, what would be considered your successes and failures in the effort of addressing conservation?
16. In your opinion, what are the challenges facing your group/organization in their conservation activities? What measures are being undertaken to overcome these challenges?

Appendix 2: A Section of the Expert Validation Tool for Governance Coordination

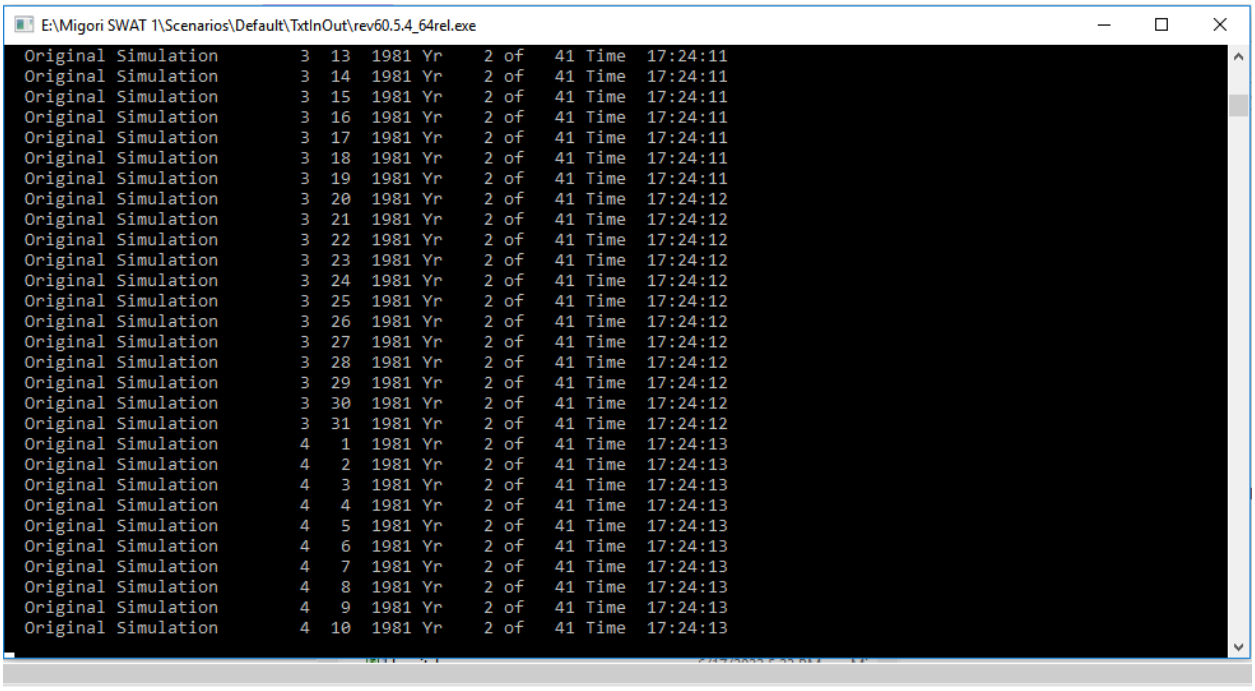
Please rate the level of effectiveness of the outlined coordination attributes by ticking **(√)** based on how effective you feel the attribute is towards watershed governance.

Attributes	**Variables**	**Facts for Migori River Watershed Governance System**	**Attribute's Effectiveness Level (√)**			**Comments regarding your chosen effectiveness level)**
			Low	**medium**	**High**	
Coordination	Existence of single coordinating body for river basin management and how coordination is done	• No single coordinating body available; WRA, NEMA or County Environment Technical Committee should be given that role • No lead agency in joint river basin management programs/projects • Coordination/collaboration between stakeholders is on a per-need basis				
	Stakeholder networks (Existence of partnership agreements between and/or among actors)	• MoUs for long term cooperation are available between government agencies • MoUs for short term cooperation are available between government agencies and NGOs • Only MoUs involving NGOs are well-documented and these involve penalties for non-compliance				
Communicating	Presence of communication channels among actors	• National-government-level agencies (WRA, NEMA, KFS, KFERI) hold internal meetings on river basin management projects monthly while county government departments hold internal meetings on projects weekly • National-government-level agencies (WRA, NEMA, KFS, KFERI) hold meetings on river basin management with stakeholders quarterly • County-government departments hold meetings with stakeholders on a per-need basis on river basin management projects				
	Presence and frequency of information sharing among actors	• Data sharing between national government agencies exists, though it's on a per-need basis & takes long due to bureaucratic procedures • Data sharing between national and county government agencies is highly inefficient due to lack of established legal mechanisms				
Organizing	Presence of a mechanism to distribute authority, roles and responsibilities among actors	• There exists County Environment Technical Committee which coordinates interactions between national government actors and county departments in Migori • Intergovernmental agencies, cross-county agencies, NGOs and CBOs focus on their own jurisdictions				

Appendix 3: Areal coverage of major soil types of Migori River watershed

Soil Type	Area Coverage (km^2)
Nitisols	261.0
Phaeozems	454.5
Gleysols	135.2
Planosols	654.3
Cambisols	262.9
Acrisols	140.9
Arenosols	16.7
Calcisols	24.6
Regosols	0.2
Total Area(Km^2)	**1955.9**

Appendix 4: Sample SWAT scenario simulation in Python



Appendix 5: Household Questionnaire

Introduction

Hello, am Opiyo Stephen; I'm a PhD student in the Department of Environmental Planning and Management at the Kenyatta University, under the supervision of Prof. Letema and Dr. Opinde. ***My research focuses on assessing the sustainability and vulnerability of community livelihoods in the Migori River watershed.*** This research will be useful in supporting decision-makers in the formulation of policies that support conservation of land and water resources as well as improving community livelihoods. You've been chosen to participate in this survey because as a resident of this region, you are conversant with environmental and livelihood conditions of this area. Please note that your anonymity is guaranteed, and the information acquired from this research will be handled confidentially and will only be utilized for purposes of this academic study.

SECTION A: HOUSEHOLD CHARACTERISTICS

Answer the following questions by ticking (√) the correct answer in the provided box.

1. Household Head Details

1.1 Household location along the river: (a) Upstream [ ] (b) Midstream [ ] (c) Downstream [ ]
1.2 Gender of Household Head (HH): (a) Male [ ] (b) Female [ ]
1.3 Ethnic group of Household Head: (a) Luo [ ] (b) Luhya [ ] (c) Kuria [ ] (d) Kisii [ ] (e) Somali [ ] (f) Basuba [ ] (g) Others (Specify).....
1.4 Age of HH: …….....
1.5 Marital Status of HH: (a) Single [ ] (b) Married [ ] (c) Widowed/Divorced/Separated [ ]
1.6 Employment status of the HH: (a) Employed [ ] (b) Self-employed [ ] (c) Unemployed [ ]
1.7 Residential Status of HH: (a) Native [ ] (b) Immigrant [ ]
1.8 Duration of residency (in years) around Migori River watershed of HH
(a) 1 – 10 [ ] (b) 11-20 [ ] (c) 21-30 [ ] (d) 31-40 (e) 41-50 [ ] (f) Above 50 [ ]

SECTION B: LIVELIHOOD ASSETS

Answer the following questions by ticking (√) the correct answer in the box provided.

B1: ACCESS TO NATURAL ASSETS

1. Land Resources

1.1 What is the size of your household-owned land? Acres……..
1.2 How long have you been in possession of this land?
(a) 1-2 years [ ] (b) 3-5 years [ ] (c) 6-10 years [ ] (d) Above 10 years [ ]
1.3 Type of land tenure for your household-owned land
(a) Inherited [ ] (b) Leased [ ] (c) Purchased [ ]
1.4 In what way are the sizes of land parcels changing among various households in your locality over the past ten years? (a) Shrinking [ ] (b) Expanding [ ] (c) No change [ ]
1.5 What is the reason for the change? (a) Sale [ ] (b) Investment acquisition [ ] (c) Redistribution to family members [ ] (d) Other (Specify).....
1.6 According to your observation, are there changes in land use and land cover patterns in the Migori River watershed since the 1980s? (a) Yes [ ] (b) No [ ]

1.7 In what way has the distance to the following infrastructure and services changed?

S/N	Household distance to nearest	Increased	Decreased	No change
1	Schools and colleges			
2	Commercial centers/markets			
3	Health centers			
5	Potable drinking water			
6	Natural water sources (rivers/streams)			
7	Major roads			

1.8 In your opinion, what are the major drivers of land use and land cover changes in your locality? (Rank on a scale of 1 to 5 with 1 = most important and 5 = least important).

Direct causes (proximate drivers)	Rank				
	1	2	3	4	5
Firewood collection					
Charcoal production					
Shifting cultivation					
Settlements					
Timber or poles production					
Agriculture expansion					
Rural infrastructure expansion					
Brick production					
Artisanal gold mining					
Unplanned urban expansion					
Bush fires					
Indirect causes (Underlying drivers)	**Rank**				
	1	2	3	4	5
Poverty					
Population growth					
Insufficient law enforcement					
Weak government policies					
Poor access to alternative-energy supply					
Natural conditions					
Demand for timber					
Urbanization					
Political interferences					

2. Crop Production

2.1 Are you involved in crop farming (a) Yes [ ] (b) No [ ]

2.2 If you engage in crop farming, what is the type of agriculture do you practice?

(a) Subsistence [ ] (b) Commercial [ ]

2.3 What crops does your household cultivate and how much of each crop did you produce, consume and sell during the last year (2020)?

S/N	Type of crop grown	Quantity produced (in 2kg tins)	Quantity consumed (in 2kg tins)	Quantity Sold (in 2kg tins)
1	Maize			
2	Beans			
3	Sorghum			
6	Sweet potatoes			
8	Cassava			
9	Others (Specify)			

2.4 Does your household save/store crops from each harvest? (a) Yes [ ] (b) No [ ]

2.5 Does your household save some crop produce as seeds for planting next season?

(a) Yes [ ] (b) No [ ]

2.6 What is the MAIN source of water for your farms? (a) Rain-fed [ ] (b) Irrigation [ ]

2.7 What is the soil fertility status of your farm? (a) Low [ ] (b) Moderate [ ] (c) High [ ]
2.8 Which of the following farm inputs do you apply for farming?
(a) Improved seeds [ ] (b) Compost manure [ ] (c) Fertilizers [ ] (d) Herbicides/pesticides [ ]
2.9 What is the general trend of crop productivity per hectare of cropland over the past 10 years? (a) Increasing [ ] (b) Decreasing [ ]
2.10 What, in your opinion, are the **MAJOR** causes of crop yield reduction over the years?

1	Erratic rainfall patterns		**2**	Soil degradation (erosion, low fertility)	
3	Unaffordable price of farm inputs e.g. fertilizer		**4**	Pest prevalence (parasite, diseases, weeds)	
5	Lack of access to financial lenders		**6**	Seed scarcity	
7	Poor farming practices		**8**	Availability of Food aid	
9	Shrinking farmland sizes		**10**	Natural disaster (floods, droughts)	

2.11 What coping options do you have during the times of mass crop failure? (May choose more than one)

(a) Remittances [ ] (b) Savings [ ] (c) Work in other's farms [ ] (d) Off-farm activities (e.g processing, packaging, transport or sale of farm produce) in the rural area [ ] (e) Others (Specify).....

2.12 How do you rate the future expectation of availability of farming livelihoods within Migori River watershed? (Tick one) (a) Much better [ ] (b) Better [ ] (c) Moderate [ ] (d) Poor [ ] (e) Much poor [ ]

3. Livestock Production and Pastures

3.1 Are you involved in livestock rearing? (a) Yes [ ] (b) No [ ]

3.1.1 If you don't own livestock, what's your reason (*May tick more than one*)?

1	Shortage of fodder		**2**	Lack of grazing lands	
3	Disease prevalence		**4**	Lack of sufficient veterinary services	
5	Shortage of water		**6**	Lack of breeding animals	
7	I sold to purchase other items		**8**	Others (Specify)	

3.1.2 If you engage in livestock keeping, how many heads of the following livestock does your household keep and what's their total financial value (*May tick more than one*)?

S/N	Livestock type	Number	Total financial value (in Kshs)
1	Poultry		
2	Sheep		
3	Donkeys		
5	Goats		
6	Cattle		
7	Others (Specify).....		

3.2 Do you have access to grazing pastures for your livestock? (a) Yes [ ] (b) No [ ]
3.2.1 If no, what is your major source of fodder for your animals?

(a) The forest reserves [ ] (b) Crop residues [ ] (c) Market (purchase of hay) [ ]

3.2.2 If yes, do you observe the reduction or disappearance of palatable herbs and trees in the grazing areas over the last 10 years? (a) Yes [ ] (b) No [ ]
3.3 Which months of the year do you often face shortage of livestock feed? ……
3.4 What is your major source of water for your animals?

(a) Migori River [ ] (b) Stream [ ] (c) Borehole/wells [ ] (d) Rainwater [ ] (e) Springs [ ]

3.5 Which months of the year do you often face water shortages for the livestock? ……

3.6 Do you sell milk and milk products? (a) Yes [ ] (b) No [ ]

3.7 How is the production trend of these products over the last ten years?
(a) Decreasing [ ] (b) Increasing [ ] (c) Not affected [ ]

3.8 What is the trend of the livestock quantity/number over the past 10 years?
(a) Decreasing [ ] (b) Increasing [ ]

3.8.1 If decreasing, what is the reason for that trend? (*May tick more than one*)?

1	Shortage of fodder		**2**	Lack of grazing lands	
3	Disease prevalence		**4**	Lack of sufficient veterinary services	
5	Shortage of water		**6**	Lack of breeding animals	
7	People selling to purchase other items		**7**	Others (Specify)	

3.9 How do you rate the future expectation of availability of livestock and livestock products within Migori River watershed? (*Tick one*) (a) Much better [ ] (b) Better [ ] (c) Moderate [ ] (d) Poor [ ] (e) Much poor [ ]

4. Water Resources

4.1 What's the primary source of portable water for your household usage?
(a) Migori River/streams [ ] (b) Borehole/wells [ ] (c) Springs [ ] (d) Piped water [ ] (e) Other (Specify).....

4.1.2 If using water from Migori River, for what purpose(s) is the water suitable for? (*May tick more than one*)?

1	Drinking		**2**	Cooking		**3**	Washing	
4	Bathing		**5**	Livestock watering				

4.1.3 Do you think there is need to improve the water quality before household usage due to river pollution? (a) Yes [ ] (b) No [ ]

4.1.4 If treating water before use, what household water treatment form(s) do you usually use (*May tick more than one*)?

1	Cloth filtration		**2**	Boiling		**3**	Chlorination	
4	Solar disinfection		**5**	Traditional treatment		6	Others (specify)	

4.2 How would you rank the water quality of your household portable water point
(a) Low (suspended solids, cloudy, unusual odor or taste) [ ]
(b) Moderate (no suspended solids, clear, unusual odor or taste) [ ]
(c) High (no suspended solids, very clear, normal taste and odor) [ ]

4.3 Compared to few years ago, do you think the water quality of this water resource has changed over time?
(a) Yes [ ] (b) No [ ]

4.4 If yes, what is the nature of the changes? (a) Improved [ ] (b) Decreased [ ]

4.4.1 If the water quality has decreased, what's the major indicator of that? (*May tick more than one*)?

1	Water became dirty (colour/turbidity)	
2	Water became contaminated (bio-chemical)	
3	Water has become saline (salty)	
4	Water has developed an unusual taste	
5	Water has developed an unusual smell/odour	
6	Increase in suspended solids/debris	
7	Others (specify)	

4.4.2 If the water quality has decreased, what's the major cause of the water pollution? (*May tick more than one*)

1	Direct disposition of household waste	
2	Direct discharge of farm-eroded waste	
3	Direct discharge of municipal/industrial wastewater	
4	Pollution from inflowing streams/runoff	
5	Direct bathing and washing	
6	Discharge of mining waste	

7	Others (specify)	

4.4.3 Has the decrease in water quality affected you negatively in any way? (a) Yes [ ] (b) No [ ]

4.4.4 If yes, what is the MAIN way in which it has affected you? (*Tick one*)

1	Increased expenditure on livestock health	
2	Increased expenditure on treatment of water borne illnesses	
3	Increased expenditure on water treatment before household usage	
4	Increased river infestation of water hyacinth and other weeds	
5	Reduction in overall fish catch in the Migori river	

4.4.5 If you have experienced diseases/infections that you can attribute to use of water, which diseases did you experience? (*May tick more than one*)

1	Cholera		**2**	Typhoid		**3**	Diarrhea	
4	Amoebiasis		**5**	Skin infections			Others (specify)	

4.5 Is the water at your selected primary source available every day? (a) Yes [ ] (b) No [ ]

4.6 What's the average time you walk to reach the portable water source for your household.....?

4.7 What's the distance from your place of residence to our source of portable water?
(a) Less than 5km [ ] (b) More than 5 km [ ]

4.8 What's the no. of litres of water stored by your household daily for domestic use? ……

4.9 Does your area sometimes experience conflicts over water? (a) Yes [ ] (b) No [ ]

4.10 How do you rate the future expectation of availability of water resources within Migori River watershed? (*Tick one*)
(a) Much better [ ] (b) Better [ ] (c) Moderate [ ] (d) Poor [ ] (e) Much poor [ ]

5. Forest Resources

5.1 Does your household have access to forest reserves? (a) Yes [ ] (b) No [ ]

5.2 What are the socio-economic benefits obtained from forest reserves in your locality? (May choose more than one)

1	Firewood collection		2	Honey production	
3	Fodder production		4	Herbal medicine	
5	Timber and pole production		6	Employment opportunities	
7	Cultural values		8	Recreational and aesthetic values	
9	Fresh water		10	Knowledge/educational values	

5.3 What do you think is the major cause of damage to forest reserves in the area?

1	Increased demand for crop lands		2	Excessive deforestation for fuel wood	
3	Over grazing		4	Drought	
5	Government weak forest law enforcement		6	Industrial development	
7	Expansion for settlement		8	Poverty	

5.4 How would you characterize the rate of deforestation in your locality?
(a) Fast [ ] (b) Moderate [ ] (c) Slow [ ]

5.5 How do you rate the future expectation of availability of forest resources within Migori River watershed? (Tick one)
(a) Much better [ ] (b) Better [ ] (c) Moderate [ ] (d) Poor [ ] (e) Much poor [ ]

6. Fishing Resources

6.1 Are you involved in fishing/fish trading? (a) Yes [ ] (b) No [ ]

6.2 If you are involved in fishing, what is the trend in quantity (fish catches) and quality (fish sizes) of fish from River Migori over the last ten years? (a) Increasing [ ] (b) Decreasing [ ]

6.3 What is the trend in number of fish species in River Migori from time to time?
(a) Increasing [ ] (b) Decreasing [ ]

6.4 What is the cause of the trend of declining quality and quantity of fish catches in the Migori River? (a) Declining water quality [ ] (b) Declining water levels [ ] (c) Overfishing [ ] (d) Unregulated fishing methods [ ] (e) Others (Specify).....

6.7 What coping options do you have during the times of declining fish catches?

(a) Remittances [ ] (b) Savings [ ] (c) Work in farms [ ] (d) Off-farm activities in the rural area [ ] (e) Others (Specify).....

6.8 How do you rate the future expectation of availability of fish resources within Migori River watershed? (Tick one) (a) Much better [ ] (b) Better [ ] (c) Moderate [ ] (d) Poor [ ] (e) Much poor [ ]

B2: ACCESS TO HUMAN ASSETS

7. Knowledge and training

7.1 Household size (no. of people who reside and eat permanently in the household)
No. of Male: ……. No. of female: ……..

7.2 Does your household takes care of orphaned child/children? (a) Yes [ ] (b) No [ ]

7.3 Education level of HH: (a) No formal education [ ] (b) Primary [ ] (c) Secondary [ ] (d) College/university [ ]

7.4 Do you or any member of your household possess handiwork skills like carpentry, welding etc.?
(a) Yes [ ] (b) No [ ]

7.5 Which of the following institutions are available within your locality (ward)? (Tick more than one)

1	Primary school		**2**	Secondary school	
3	College/university		**4**	Health facility	
5	Town/market centre		**6**	Local government offices	

7.6 Have you or any member of your household been exposed to some trainings on watershed conservation and development by experts? (a) Yes [ ] (b) No [ ]

7.6.1 If yes, what was the training about?

1	Agricultural production		**2**	Natural resources conservation	
3	Health-related issues		**4**	Empowerment of the vulnerable members of the community	
5	Governance policies		**6**	Other (specify)……	

8. Health status and medical availability

8.1 Where does your family gets their primary food
(a) Own farm [ ] (b) Family and friends [ ] (c) Market [ ] (d) Government/NGO donations [ ]

8.2 What is the typical daily nutritional intake for the household?
(a) Low (Less than 3 meals per day) [ ] (b) Normal (3 meals per day) [ ] (c) High (More than 3 meals per day) [ ]

8.3 During the past 12 months, were there month(s) in which your household didn't have adequate food stock for your family needs? (a) Yes [ ] (b) No [ ]

8.3.1 If yes, how many months.....

8.4 Does your household have a member who suffers from physical or mental disability?
(a) Yes [ ] (b) No [ ]

8.5 How do you characterize the general health status of the household?
(a) Low (half the people in the household suffer from chronic illnesses) [ ]
(b) Moderate (only few of the people in the household suffer from chronic illnesses) [ ]
(c) High (none of the people in the household suffer from chronic illnesses) [ ]

8.6 During the last 6 months, did any member of your family miss work or school due to sickness? (a) Yes [ ] (b) No [ ]

8.7 What's the average time you walk to reach the nearest medical facility? ……..

8.8 What's the level of satisfaction with the services offered at your nearest medical facility?
(a) Not satisfied [ ] (b) Partly satisfied [ ] (c) Satisfied [ ] (d) Very satisfied [ ]

9. Labor availability

9.1 What's the **MAIN** type of labour that your household use for their livelihood activities
(a) Family labor only [ ] (b) Hired labor only [ ]
9.1.1 If using family labour, what's the number of working healthy adults (18-64 years) in your household? ……
9.1.2 If using hired labour, how many workers does your household have for their livelihood activities? (a) Less than 2 [ ] (b) 3-5 [ ] (c) 5-10 [ ] (d) More than 10 [ ]
9.2 How do you characterize the level of labor availability for the labor type stated?
(a) Low (workforce is inadequate for the available work) [ ]
(b) Moderate (workforce sometimes adequate for the available work) [ ]
(c) High (workforce is always adequate for the available work) [ ]
9.3 How do you characterize the technical skill level of the available labor force for the household? (a) Low [ ] (b) Moderate [ ] (c) High [ ]
9.4 Does any member of your household work in a different county? (a) Yes [ ] (b) No [ ]

B3: ACCESS TO PHYSICAL ASSETS

10. Ownership and properties of housing

10.1 Type of housing unit (based on wall materials) occupied by your household?
(a) Traditional hut [ ] (b) Mud-walled house [ ] (c) Brick or block walled house [ ] (d) Wood-walled house (e) Tin (Mabati-walled) house
10.2 What is the roofing material of the housing occupied by your household?
(a) Iron sheets [ ] (b) Tiles/asbestos sheets [ ] (c) Grass/Makuti/mud/dung
10.3 What is the flooring material of the housing occupied by your household?
(a) Earth [ ] (b) Wood [ ] (c) Cement [ ] (d) Tiles [ ]

11. Sources of energy

11.1 What's the source of fuel for cooking?
(a) Crop straws/cow dung [ ] (b) Fuel wood/charcoal [ ] (c) LPG gas [ ] (d) Electrical power [ ]
11.2 What type of cooking stove does your household use?
(a) Three-stone open fire [ ] (b) Charcoal stove [ ] (c) Gas cooker [ ] (d) Electric stove [ ]
11.3 What's the source of artificial light for the household?
(b) Candle [ ] (b) Kerosene lamp [ ] (c) Solar power [ ] (d) Electricity (KPLC) [ ]

12. Sanitation and waste management facilities

12.1 How do you dispose of your domestic and farm waste stream (May tick more than one)?
(a) Incineration/Burning in a designated chamber [ ] (b) Open Air burning [ ] (c) Dumping in open fields [ ] (d) Giving to animals [ ] (e) Composting [ ] (f) Other(s) (Specify).....
12.2 Does your household have a sanitary toilet (flash toilets or pit latrines)?
(a) Yes [ ] (b) No (we use open-bush) [ ]

13. Transport and Communication facilities

13.1 Does your household own any transport facility (bicycle, motorcycle or car)?
(a) Yes [ ] (b) No [ ]
13.1.1 If no, what's the most affordable transport means often used by your household members (a) PSVs [ ] (b) Motorcycles/tuktuk [ ] (c) Bicycle [ ] (d) Taxi [ ] (e) None (walking) [ ]
13.2 Does your household own any functioning communication devices (Cell phone, radio or TV? (a) Yes [ ] (b) No [ ]
13.2.1 If no, what's the source of information for your household about the market prices and news valuable for your livelihood (Tick one)?
(a) Friends [ ] (b) Local Govt officials [ ] (c) Newspapers [ ] (d) Local CBOs [ ]

14. Household assets/Production equipment

14.1 Which of the following agricultural production equipment/facilities your household own?

S/N	Production equipment/facility	Yes	No
1	Farm house (Green house or Poultry house)		
5	Stores (for grains or farm equipment)		
8	Irrigation equipment (like pipes, water tanks and pumps)		
9	Full farm equipment (like ox-drawn plough, jembes, machetes)		
10	Furniture (tables, chair, etc.)		
11	Farm machinery (like Tractor/truck/lorry etc.)		

B4: ACCESS TO FINANCIAL ASSETS

15 Which of the following are sources of livelihood/income for your household?
(a) Agriculture [ ]
(b) Off-farm activities (e.g. processing, packaging, transport or sale of farm produce) [ ]
(c) Non-farm activities (employment in non-farm sectors like healthcare education, mining, tourism) [ ]
(d) Remittance [ ]

15.1 If practicing agriculture, please list incoming-generating farming activities for your household.

1	Crop production		**5**	Forestry	
2	Livestock rearing		**6**	Fish farming	
3	Agroforestry		**7**	Apiculture	

15.2 If involved in crop production, what's the total financial value of your household's current standing crop (Kshs.) ……..

16 What's your household's total monthly income? Kshs ……

17 Does any member of your household have access to credit/loan services from lending institutions in the last 5 years? (a) Yes [ ] (b) No [ ]

17.1 If yes, which lending institutions do you get your loan from?
(a) Banks [ ] (b) Sacco's [ ] (c) Friends and relatives [ ] (d) NGOs

18 What's the total loan (Kshs.) borrowed by your HH in the last 12 months? ……

18.1 If you don't have access to loan services, what's the reason?
(a) Have no access to lending institutions [ ] (b) Absence of collateral [ ] (c) High interest rates [ ] (d) I don't need loans [ ]

19 Does your member of your household own a savings account in any of the financial institutions? (a) Yes [ ] (b) No [ ]

19.1 If yes, what's the total amount (Kshs.) your household saved in the last 12 months? …….....

19.2 If no, what's the main reason why you don't have a savings account in financial institutions? (a) Too much debt [ ] (b) Not necessary [ ] (c) Absence of financial institutions [ ] (d) Lack of financial information [ ]

19.3 If no, what type of saving mechanism does your household practice?
(a) Purchase livestock/grain stock [ ] (b) Keep cash at home [ ] (c) Purchase Land/property [ ]
(d) Others (specify).....

B5: ACCESS TO SOCIAL ASSETS

20 Do your relatives and friends live within the locality/ward? (a) Yes [ ] (b) No [ ]

21 What's your level of trust in your family and friends' willingness to support you in times of need (a) High [ ] (b) Low [ ]

22. Do you attend community meetings (*barazas*) and participate in decision-making?
(a) Yes [ ] (b) No [ ]

23. What's your level of trust in the community members' willingness to support one another in times of need?
(a) Low [ ] (b) Moderate [ ] (c) High [ ]

24. How would you generally characterize the relationship between your community and its neighbors? (Tick one) (a) Worst [ ] (b) Bad [ ] (c) Good [ ] (d) Very good [ ]

25. Do you or your household member belong to any group of social nature (political, sports or religious) in your locality? (a) Yes [ ] (b) No [ ]
26. Do you or your household member belong to any conservation groups (WRUA, CFA) in your locality?
(a) Yes [ ] (b) No [ ]
27. What's your or household member's level of participation in the group?
(a) Small extent [ ] (b) Moderate extent [ ] (c) Great extent [ ]
28. What's your level of trust in the group's willingness to support you in times of need?
(a) Small extent [ ] (b) Moderate extent [ ] (c) Great extent [ ]
29. Have you or your household member received any assistance from the local administration during past emergencies or crop failures? (a) Yes [ ] (b) No [ ]
30. During emergencies or crop failures, are you able to get financial aid from family or friends? (a) Yes [ ] (b) No [ ]
31. During emergencies or crop failures, are you able to give financial aid from family or friends? (a) Yes [ ] (b) No [ ]

SECTION C: LIVELIHOOD VULNERABILITY CONTEXT AND ADAPTIVE CAPACITY

Answer the following questions by ticking (√) the correct answer in the box provided.

C1. Flood risks and its impacts

32. Is flooding a common phenomenon in your locality? (a) Yes [ ] (b) No [ ]
34.1 If yes, what is the frequency of flooding in your locality in the past 10 years? .....
34. What is the **MAJOR** effect of flooding on livelihoods in your locality in the last ten years?

1	Crops damage		**2**	Infrastructural damage	
3	Disruption of access to learning, health and social amenities		**4**	Displacement of the vulnerable	
5	Injury or death of household member		**6**	Destruction of other physical household assets	
7	Increase in disease incidents		**8**	Loss of household incomes	
9	Injury or death to the livestock				

35. What is the severity of the flooding impact on the choice above?
(a) Low [ ] (b) Moderate [ ] (c) High [ ]
36. During the last flooding incidence, did you receive an early warning from the government? (a) Yes [ ] (b) No [ ]
37. What are the main coping strategies that you employ during floods in your locality? (May choose more than one)

1	Temporary migration		**2**	Government support/evacuation	
3	Insurance support		**4**	NGO support	
5	Consumption reduction			Borrowing money from financial institutions	
7	Sale of household/productive assets		**8**	Relying on stored food and previous savings	

C2. Drought risks and its impact

38. Is drought a common phenomenon in your locality? (a) Yes [ ] (b) No [ ]
38.1 If yes, what is the frequency (in years) of drought in your locality in the past ten years? .....
40. What is the major effect of drought on livelihoods in your locality in the last ten years?

1	Mass crop failure		**2**	Reduction in agricultural employment	
3	Reduced access to water supply from rivers		**4**	Loss of agri-business incomes	
5	Increased risk of wildfire		**6**	Increased incidences of human and livestock diseases	
6	Transformation to off-farm or non-farm activities				

41. What is the severity of the drought impact on choice above?
(a) Low [ ] (b) Moderate [ ] (c) High [ ]

42. What are the main coping strategies that you employ during droughts? (May tick more than one)

1	Drought-tolerant crop cultivation		**2**	Adoption of irrigation	
3	Relying on relief food and aid from NGO/government		**4**	Charcoal burning	
5	Casual labour			Relying on stored food and previous savings	
7	Sale of household/productive assets		**8**		

C4. Climate Variability

48. Have you experienced changes in daily temperature over the last 10 years?

(a) Yes [ ] (b) No [ ]

49. Over the last 10 years, have you observed changes in temperature from one year to another? (a) Yes [ ] (b) No [ ]

50. Over the last 10 years, have you observed changes in rainfall from one year to another?

(a) Yes [ ] (b) No [ ]

THANKS YOUR COOPERATION.

Appendix 6: Accuracy assessment results for the LULC classification maps

Accuracy-assessment results for the 1980, 1990 and 2000 LULC change maps

LULC Type	1980			1990			2000		
	PA (%)	UA (%)	k	PA (%)	UA (%)	k	PA (%)	UA (%)	k
Cultivated Land	0.9351	0.878	0.75	0.9604	0.8435	0.76	99.49%	82.63%	0.50
Forest	0.7273	0.9412	0.94	0.871	0.9	0.89	75.00%	93.75%	0.93
Wetland	---	---	0.00	0.5	0.6667	0.66	---	---	0.00
Grassland	0.56	1	1.00	0.8824	0.8108	0.79	40.00%	100.00%	1.00
Shrub Land	0.9205	0.8265	0.75	0.8911	0.9375	0.91	71.05%	96.43%	0.96
Bare Land	0.7143	0.8333	0.83	0.7391	1	1.00	43.75%	100.00%	1.00
Water	0.3333	1	1.00	0.4	1	1.00	71.43%	100.00%	1.00
Built-up Area	---	---	0.00	---	---	0.00	---	---	0.00
Overall Accuracy	87.00%			88.33%			85.67%		
Overall Kappa	0.787			0.841			0.693		

Note: PA=producer's accuracy; UA=User's accuracy; k=kappa statistic

Accuracy-assessment results for the 2010 and 2020 LULC maps

LULC Type	2010			2020		
	PA (%)	UA (%)	k	PA (%)	UA (%)	k
Cultivated Land	98.15%	88.33%	0.75	97.33%	91.92%	0.79
Forest	76.00%	95.00%	0.95	84.62%		0.84
Wetland	---	---	0.00	---	---	0.00
Grassland	66.67%	100.00%	1.00	86.36%	100.00%	1.00
Shrub Land	85.86%	92.39%	0.89	92.98%	94.64%	0.93
Bare Land	57.14%	100.00%	1.00	72.73%	80.00%	0.79
Water	100.00%	100.00%	1.00	100.00%		1.00
Built-up Area	50.00%	100.00%	1.00	66.67%	100.00%	1.00
Overall Accuracy	90.33%			92.33%		
Overall Kappa	0.830			0.859		

Appendix 7: Kenyatta University Graduate School Research Approval

KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: kubps@yahoo.com
dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 810901 Ext. 57530

Internal Memo

FROM: Dean, Graduate School

DATE: 31st August, 2021

TO: Mr. Stephen B. Opiyo
C/o Department of Env. Planning & Mngt.
KENYATTA UNIVERSITY

REF: N85/28443/19

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that the Graduate School Board at its meeting 25th August, 2021 approved your Ph.D. Research Proposal entitled **"Linkages Between Land use Cover Changes and Community Livelihood in Migori River Watershed, Kenya".**

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed supervision Tracking and Progress Report Forms. The Forms are available at the University's Website under Graduate School webpage downloads.

By copy of this letter, the Registrar (Academic) is hereby requested to grant you substantive registration for your Ph.D. studies.

Thank you.

KENYATTA UNIVERSITY OFFICE OF DEAN GRADUATE SCHOOL P.O. Box 43844-00100 NAIROBI
31 AUG 2021

REUBEN MURIUKI
FOR: DEAN, GRADUATE SCHOOL

c.c. Chairman, Department of Environmental Planning & Management
Registrar (Academic) Att; Mr. Richard Chweya

Supervisors:

1. Dr. Sammy Latema
C/o Department of Env. Planning & Mngt.
KENYATTA UNIVERSITY

2. Dr. Godwin Opinde
C/o Department of Env. Planning & Mngt.
KENYATTA UNIVERSITY

Appendix 8: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **920571**

Date of Issue: **13/September/2021**

RESEARCH LICENSE

This is to Certify that Mr.. Stephen Balaka Opiyo of Kenyatta University, has been licensed to conduct research in Migori on the topic: LINKAGES BETWEEN LAND USE/LAND COVER CHANGES, WATER RESOURCES, AND COMMUNITY LIVELIHOODS IN MIGORI RIVER WATERSHED, KENYA for the period ending : 13/September/2022.

License No: **NACOSTI/P/21/12817**

920571

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix 9: Research Authorizations from Migori County Commissioner's Office

OFFICE OF THE PRESIDENT

MINISTRY OF INTERIOR AND COORDINATION OF NATIONAL GOVERNMENT

Telephone: (059) 20511
FAX (059)20361
Email:
countycommissionermigori@yahoo.com

When replying please quote

OFFICE OF THE COUNTY COMMISSIONER
MIGORI COUNTY
P.O. BOX 2 - 40400
SUNA- MIGORI.

Ref. No: CC ED.12/19VOLIII/229 **Date:** 21ST September, 2021

TO WHOM IT MAY CONCERN

This is to confirm that **Mr. STEPHEN BALAKA OPIYO NACOSTI**/P/21/12817 of Kenyatta University, has been authorized to conduct a research on "***Linkages between land use/ Land cover changes, water resources, and community livelihoods, Migori County, Kenya.***" For the period ending 13th September, 2022.

Accord him the necessary assistance.

THE COUNTY COMMISSIONER
21 SEP 2021
P. O. Box 2 - 40400, SUNA MIGORI
MIGORI COUNTY

KELVIN M. LEWA
FOR: COUNTY COMMISSIONER
MIGORI COUNTY

CC:

County Director of Education
MIGORI COUNTY