POTENTIAL IMPACTS OF LAND USE CHANGE ON SUSTAINABLE MANAGEMENT OF WATER BODIES: THE CASE OF MASINGA DAM

AYOO LIZA ATIENO
B63/33418/2019

UNIVERSITY OF NAIROBI
SCHOOL OF BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF MASTER OF ARTS IN PLANNING

DECEMBER 2022

DECLARATION

This research proposal is my original work and has not been presented for a degree in any other university.

Signature   Date

24th November, 2022

Ayoo Liza Atieno
B63/33418/2019
(Student)

This research proposal has been submitted for affirmation with our approval as university supervisor
Signature   Date 30/10/2023.

Dr. Fridah W. Mugo
(Supervisor)

ACKNOWLEDGMENT

I extend my gratitude to the Department of Urban and Regional Planning at the University of Nairobi for granting me the invaluable opportunity to embark on this research endeavour. I am sincerely indebted to my dedicated Supervisor, Dr. Fridah Mugo, whose unwavering guidance, extensive knowledge, and expert insights significantly enriched the quality of this research. My heartfelt appreciation also extends to my esteemed colleagues whose unwavering support and encouragement played an instrumental role in facilitating the successful completion of my master's degree.

Furthermore, I wish to express my sincere thanks to Chief Phyllis Njeri, Planner Maina Karuru, KFS official Silas Kanyor, Ann Njeru of KENGEN, and Alexander Waweru, whose invaluable contributions and insights greatly enriched this study. I also thank all the interviewees who shared meaningful insights towards the study, and my research assistants who played an active role in data collection.

Additionally, I am grateful to my family members for their unwavering support, encouragement and motivation that enabled me to navigate through this study. I would also like to acknowledge my colleagues and fellow classmates for their academic support during the course of my studies.

ABSTRACT

Land degradation poses a real threat to agricultural production and water availability in Sub-Saharan Africa. Land use and land cover change have critical environmental consequences at local, regional, and global levels. These changes have led to loss of biodiversity, disruption of hydrological ecosystems, soil degradation, and sedimentation. All these factors greatly affect communities. The existence of irregular and inconsistent geospatial distribution of global freshwater resources, human beings have been compelled to harness surface waters by constructing dams to retain water, especially during periods of scarcity. However, the efficiency of dams worldwide is undermined by the gradual loss of storage capacity due to sedimentation. Dams have traditionally played a pivotal role in providing water for domestic and commercial use, flood control, hydropower generation, irrigation, and fisheries. This study focused on land use changes within Mbiri Ward, situated in Murang'a County, within the upper Tana River Catchment. It examined the impacts of upstream land use changes on the sustainable management of downstream water bodies, specifically focusing on the Masinga Dam, which lies downstream in the lower Tana River catchment. The study's objectives were to assess the changes of land cover in Mbiri Ward over the past forty years, identify drivers of land use changes in the area, evaluate the implications of land use alterations on Masinga Dam, and recommend land use planning and management interventions to minimize sedimentation impacts on Masinga Dam. To achieve these objectives, a cross- sectional research design was used to collect data from various stakeholders in Mbiri Ward. The target population was stratified and included local farmers, businesspersons, and residents, officials from the Kenya Forest Service, Kenya Electricity Generating Company, the National Environment Management Authority, agricultural officers, catchment management officers, physical planners, and conservation officers. Stratified random sampling was used, with each stratum receiving an equal number of questionnaires through random selection. A total of 96 participants were interviewed. The data collection methods employed included questionnaire administration, interviews, observation, photography, mapping, and a comprehensive literature review. The study found that significant land use change had occurred within Mbiri Ward over the past forty years; water land use increased from 107.54 hectares in 1980 to 117.53 hectares in 2021, urban land use expanded from 2.031 hectares in 1980 to 542.17 hectares in 2021, while ploughed land increased from 3.04 hectares in 2000 to 184.37 hectares in 2021. Forest land use decreased notably from 2732.11 hectares in 1980 to 972.56 hectares in 2021, while cultivated land, increased from 214.20 hectares in 2000 to 4106.58 hectares in 2021. 86% of respondents reported a consistent decline in forest cover within the ward over the past four decades. Furthermore, 66% of respondents identified forests as the predominant land use cover in Mbiri Ward in the past. The major drivers for reduction of forest cover being population pressure and conversion of forest land to residential use being key drivers of land use changes, accounting for 41% of changes. Given the area's agricultural nature, forest land use is being converted to accommodate agricultural needs, with crop farming practices contributing to soil erosion and the introduction of loose soil into rivers. The study also found that 39% of migrants in Mbiri Ward relocated to engage in farming activities, and 48% of the population relied on firewood as their primary energy source, while 43% used charcoal, indicating a heavy dependence on trees to meet energy demands. Land use changes in Mbiri Ward have led to various adverse consequences, including environmental degradation, land and soil deterioration, and pollution, primarily due to inadequate agricultural and conservation practices. Agricultural activities result in a significant sediment load that is subsequently transported from the catchment area into the rivers. The study recommends a series of management practices and policy interventions to address these challenges including forest and agricultural management initiatives, riparian land management, and policy enforcement measures such as afforestation, natural regeneration, protection, regulated agriculture, prohibition of slope cultivation, adoption of food forest designs, comprehensive land management policies, monitoring and evaluation of catchment areas, enforcement of environmental laws, zoning for production and protected areas, village forest management, and multi-stakeholder engagement.

DEDICATION

I dedicate this thesis to the spirited people of Mbiri Ward, whose unwavering support and invaluable contributions were instrumental in the successful execution of my research. Additionally, I extend my heartfelt dedication to my family, whose unwavering support and constant motivation have been the cornerstone of my perseverance and dedication throughout the arduous journey of conducting this research and composing this thesis.

TABLE OF CONTENTS

List of Equations

List of Figures

List of Graphs

List of Maps

List of Plates

List of Tables

ACRONYMS

ASL – Above Sea Level
CFA – Community Forest/Agricultural Associations
E.A.T - East African Time
ECD - Early Childhood Development
EMCA - Environmental Management and Coordination Act
FD – Forest Department
GIS – Geographic Information Systems
GoK – Government of Kenya
HEP – Hydroelectric power
KENGEN - Kenya Electricity Generating Company
KES – Kenya Shillings
KFS - Kenya Forestry Service
KNBS – Kenya National Bureau of Statistics
KWS – Kenya Wildlife Service
M&E – Monitoring and Evaluation
NEMA – National Environmental Management Authority
NWCMP - National Water Catchment Management Programme
SPSS – Statistical Package for Social Sciences
TARDA - Tana and Athi Rivers Development Authority
WARMA – Water Resources Management Authority
WCA – Water Catchment Area

CHAPTER 1 - INTRODUCTION

1.0 Overview

This chapter provides the outline of the study; it includes the development of the problem, the problem statement, research questions and research objectives. It gives the geographical scope within which the study operates, explains the rationale and significance of the study, and creates clear definitions for key terminology used throughout the study.

1.1 Development of the problem

Kenya's forests offer a multitude of commercial, social, environmental, and cultural benefits. These forests yield timber, fuelwood, transmission posts, pulpwood, and various non-wood products. Additionally, they serve as vital water sources for key regions including Mount Kenya, Aberdares, the Mau Complex, Cherangani Hills, and Mt. Elgon. These forests are the origins of the country's main rivers, supporting freshwater needs for hydroelectric power generation, irrigation, domestic and commercial consumption. However, persistent challenges persist, including resource scarcity and heightened reliance on forest resources due to poverty and population growth. These issues hinder the government's efforts in establishing sustainable long-term forest management practices. Ongoing forest cover loss exacerbates habitat destruction, disrupts wildlife habitats, and impairs watersheds, leading to reduced water supply and quality, as well as diminishing timber and non-wood forest product yields.

As Oloo (2010) explains, several factors contribute to deforestation. In some instances, extreme poverty compels communities residing near forests to clear land for subsistence farming. Planned deforestation for developmental purposes also accounts for a substantial portion of forest loss. Regrettably, reforestation efforts have struggled to keep pace with this depletion, resulting in significant planting deficits. Population growth driven by village and community resettlement has further accelerated forest cover loss. Unsustainable logging practices, illegal harvesting, and forest fires have also played their part in exacerbating this loss. Beyond Kenya, several Sub-Saharan African nations confront the severe threat of land degradation, adversely impacting agricultural productivity and water availability. Indicators of land degradation include soil infertility and erosion. Alterations in land use and ground cover have profound ecological consequences on local, regional, and global scales, manifesting in species loss, hydrological disruptions, intensified soil degradation, and increased sedimentation loads. These transformations significantly affect the livelihoods of local communities.

The management of land use, both in rural and urban contexts and at the land-water interface, raises widespread concern. Rapid urbanization, unsustainable agricultural and industrial practices, inadequate environmental management, cultural practices, and ecosystem conservation shortcomings characterize pressing challenges requiring clear policy solutions. The absence of a well-defined national land use policy has resulted in a fragmented approach to regulating diverse land use practices, yielding policy implications that have persisted since the country's independence. Furthermore, the resolution of land use issues remains entangled within fragmented regulatory and legal systems that are ill-equipped to address the multifaceted challenges affecting land use management. The effectiveness of governance mechanisms in promoting productive and sustainable land use directly influences economic, social, and political stability. While Kenya has made notable strides in fostering productive and sustainable land use, there remain critical policy concerns to address. This necessitates informed, participatory planning and equitable, efficient, and sustainable resource utilization (Physical Planning Department, Ministry of Lands and Physical Planning, 2016).

1.2 Problem statement

The global functionality of dams faces a significant threat in the form of declining storage capacity due to sediment accumulation. This phenomenon progressively diminishes the reservoirs' ability to retain the water essential for their operational purposes. Over time, the dependence on dam water storage has escalated in several basins due to factors such as population growth, increased irrigated agriculture, and socio-economic and hydrological transformations. According to Saleh et al. (2005), the distribution of global freshwater resources exhibits irregular temporal and spatial patterns. Consequently, humans have resorted to constructing dams as a means to harness available surface waters, primarily to secure water reserves during periods of scarcity. Saleh et al. (2005) further highlights that annually, approximately 3,400 km^3 of global water supplies are stored within man- made dams. Dams have historically played pivotal roles in providing water for domestic and commercial use, flood control, hydropower generation, irrigation, and fisheries. Nonetheless, as argued by Walling (2008), despite these invaluable benefits, dams are increasingly imperilled by sedimentation, which curtails their water storage capacity. The issue of dam sedimentation is a global concern intricately linked to agricultural practices and deforestation.

As predicted by Ongley (1996), it is anticipated that sediment accumulation resulting from agricultural silt inflow leads to an annual capacity loss of 1% or more in large reservoirs. This loss is influenced by various factors, including watershed activities, river characteristics, watershed land use patterns, and dam management strategies (Walling, 2008). In a river system, sediment yield and loading serve as critical indicators of the hydrology within the drainage area, reflecting the processes of weathering and sediment deposition within each basin. Walling (2008) further confirms that elevated rates of dam sedimentation profoundly impact both the operational efficacy of these structures and the sustainable utilization of water resources.

Masinga Dam, the largest component of the Seven Forks Hydropower Project, boasts a capacity of 1,560 million cubic meters and was completed in 1981. It encompasses a total operating surface area of 125 square kilometres and draws from a catchment area of approximately 6,255 square kilometers. The dam's multifaceted functions encompass hydropower generation, regulation of downstream water flow, and flood management. However, the escalating sedimentation resulting from activities within the drainage area and river tributaries threatens the dam's operational functions and long-term sustainability. Despite these concerns, there is a noticeable lack of accurate and adequate data regarding the phenomenon of the land use changes and how it influences sedimentation in the upper Tana catchment.

This study seeks to address this knowledge gap by conducting research about the phenomenon of land use changes and the sedimentation process in the Upper Tana catchment, with a specific focus on the Mbiri ward as a case study. The study will contribute to an improved understanding of what is happening in the Upper Tana catchment and how it may represent broader trends within the catchment. This research seeks to establish a clear link between the land use activities in the Upper Tna Catchment and their contribution to the sedimentation of the Masinga Dam.

1.3 Research questions

i. How has forest cover in Mbiri Ward changed in the last 40 years?
ii. What are the major drivers of forest land use change in Mbiri Ward?
iii. What are the implications of forest land use change to Masinga dam?
iv. What forest land use planning and management interventions can ensure the minimum sedimentation impacts on the Masinga dam?

1.4 Research objectives

The objectives of this study were to:

i. Determine how forest cover has changed in Mbiri Ward in the last 40 years.
ii. Identify the major drivers of forest land use change in the Mbiri Ward.
iii. Determine the implications of forest land use change on Masinga dam.
iv. Identify forest land use planning and management interventions that can ensure minimum sedimentation impacts on Masinga dam.

1.5 Geographical Scope

This research will be conducted within the Upper Tana watershed, with a specific focus on Mbiri Ward, situated in Kiharu Sub-County, Murang'a County, located in the Central region of the Republic of Kenya. The theoretical framework of this study encompasses the investigation of sedimentation rates attributed to alterations in forest land cover within the upstream catchment areas.

1.6 Justification & Significance

Natural resources derived from Kenya's environment not only drive the country's progress and economic growth but also contribute significantly to the income of its citizens. Kenya's population has continued to experienced rapid growth over the past years, surpassing the available natural resources (land and water). This situation has compelled urgency for effective resource management, particularly in crucial water catchment areas. This is important for Kenya, because a substantial portion (almost 80% of the landmass) is classified as arid or semi-arid, making it ecologically fragile and susceptible to degradation.

Water Catchment Areas (WCAs) in Kenya hold substantial economic significance, as highlighted by research on the Mau Forest Complex and analysis of the Aberdares system. The annual economic value of the Mau Forest Complex, inclusive of its biodiversity, stands at Kes.56.5 billion, with anticipated financial benefits from ecotourism, hydroelectric power generation, and optimized tea production exceeding Kes.20 billion annually (Government of Kenya, 2009). Furthermore, native forests in these catchment areas play a critical role in mitigating sedimentation in hydroelectric plants, thereby reducing surface runoff, enhancing permeation, and positively influencing water availability for hydropower generation, which accounts for approximately 60% of Kenya's electricity production.

Consequently, sustainable management and safeguarding of groundwater catchments hold pivotal significance for the nation. It underscores the necessity of maintaining access to natural resources and services such as clean water, fertile soil, and intact ecosystems, while simultaneously addressing long-term economic imperatives like employment generation.

1.7 Definition of terms

Upstream - This word refers to the direction against a river's flow toward its source.

Downstream – This word refers to the area covering the flow direction of a river from the source to its mouth.

Land Use - Land use relates to the role or purpose to which the land is used by the native human population and is defined as human actions that are closely related to land, utilizing or influencing its resources (FAO 1995). Land cover and land use are not synonymous; land cover refers to the biophysical state of the earth's top and near subsurface (Turner et al. 1995).

Land use change - There are two kinds of land cover change: conversion and modification (Turner et al. 1995, 22; Skole 1994, 438). Land cover conversion involves moving from one type of vegetation to another. Land cover alteration refers to structural or functional changes that do not necessarily imply a full shift from one form to another; it may include changes in yield, biomass, or phenology (Skole 1994, 438). According to Meyer and Turner (1996), land use changes affects land cover in three different ways: converting it or changing it to a substantially different form; modifying it or numerically altering its condition without complete conversion; and sustaining against natural change agents (Meyer and Turner 1996, 238).

Catchment area - Any section of territory drained by a creek, river, or permanent water body and its channels that share a similar source of surface water is referred to as a catchment area (Kenya Forest Act 2005).

Forests - forests are defined as any location with a vegetation pattern comprised of trees of any type, whether usable or not, able to produce wood or other products, theoretically capable of influencing climate, modifying soil and water regimes, and providing animal habitat, and including woodlands (Kenya Forest Act 2005).

CHAPTER 2- LITERATURE REVIEW

2.0 Overview

This chapter provides an extensive review of the literature regarding changes in forest land use within Mbiri Ward over the past forty years. It examines the drivers responsible for changes in forest land use in Mbiri Ward; it also assesses the implications of these land use changes on Masinga Dam, and explores approaches for effective land use planning and management to minimize the impact of sedimentation on Masinga Dam. Additionally, this chapter covers discussions on theoretical, policy, and conceptual frameworks relevant to the study. It draws upon a synthesis of secondary data sources and plays a crucial role in providing insights into the current state of research in the context of this study, as well as identifying areas where knowledge gaps exist.

2.1 Forest Land Cover Change

Land is the foundation for all human activity and the major source of resources for those activities. Human use of land resources results in "land use," a phenomenon that varies based on its intended purpose and includes agriculture, housing, recreation, resource extraction, and other activities, in addition to the inherent physical features of the land itself. As a result, two primary variables impact land use: human needs and the natural characteristics and processes of the land. Neither of these forces remains static, as change is an intrinsic aspect of existence, with both continuously evolving. The alterations in land use, observable across diverse geographical scales and timeframes, serve as tangible manifestations of the interplay between human and environmental processes, mediated through the medium of land. These changes yield both favorable and adverse outcomes, with the latter being of greater concern due to their distinct impacts on the well-being and welfare of individuals.

The changes in land use play a substantial role in driving global changes in ecosystems. The expansion of pastoral and agricultural areas represents the most prevalent form of land change within natural environments. As reported by Lambin and Meyfroidt (2011), the period from 1980 to 2000 witnessed more than half of the expansion of cropland in tropical regions occurring at the expense of pristine forests, while an additional 28% encroached upon already disturbed forest areas. These trends have raised worldwide concerns regarding the preservation of environmental services and biodiversity.

Land management practices or policies in one nation can have ripple effects on global trade patterns, indirectly impacting land use in other countries. In contrast to Sub-Saharan Africa, where tropical deforestation was positively correlated with urban population growth and agricultural production between 2000 and 2005, it is important to note that consumers in urban and affluent regions consume more than their rural counterparts in tropical areas undergoing agricultural expansion, thereby increasing production pressures. The process of globalization also amplifies the influence of large agricultural enterprises and the flow of global capital on local land use decisions, potentially undermining national regulations designed for the public good. Conversely, international trade has the potential to enhance global land use efficiency by enabling the specialization of regions in land use expertise and facilitating increased production in response to a global scarcity of productive land.

2.1.1 Forest land use change in the upper Tana River Basin in the last 40 years

Kenya faces a critical challenge concerning the utilization of forest land, a predicament that mirrors the struggles encountered by many developing nations. This challenge involves a fierce competition for the limited forested areas between livestock farming and agriculture, on one hand, and the imperative need for watershed preservation, forest-derived resources, ecotourism, and conservation efforts, on the other. Kenya's predicament is further intensified by its high population growth and an economy heavily reliant on agriculture. Land stands as Kenya's most valuable and indispensable asset. Kenya is characterized mostly by semi-arid to dry conditions, with the majority of its people coexisting with indigenous forests within the bounds of a limited agricultural land base that accounts for just one-fifth of the total land area.

Indigenous forests are under tremendous strain as a result of agricultural expansion and other uses such as timber extraction and residential construction, resulting in the reduction of forested areas and affecting the dynamics of these ecosystems. Previous research indicates a noteworthy decline of 25% in Kenya's forested areas between 1990 and 2015, equivalent to an annual loss of 33,000 hectares, or, put differently, the daily disappearance of forest cover equivalent to 100 football fields and over 200,000 individual trees (Mwenda Ntarangwi & Ingham, 2019). Despite their relatively small geographical coverage, forests hold immense economic significance. The majority of forested areas consist of scrubland, bamboo, and grasslands, with some portions designated for the cultivation of softwood species primarily utilized by the domestic paper industry. Forests serve an important role in protecting Kenya's land and water resources; yet, they are increasingly under threat from a fast rising population that requires more land for settlement and energy production. The use of wood as a key source of fuel for home cooking aggravates the situation. In response to these challenges, initiatives to cultivate fast-growing indigenous and imported tree species have been initiated in ecologically suitable locations.

Historically, Kenya boasted more extensive forested areas. The conversion of forests into farmland dates back to the 17th century when established agriculture gained prominence. Forest losses have been recorded since the late 19th century, stemming from clearing for European settlement and traditional small-scale agriculture. Subsequent years witnessed additional clearing, primarily for the cultivation of exotic tree species. Despite Kenya's industrialization accomplishments, its service and industrial sectors remain modest and underdeveloped, posing difficulties in absorbing surplus labour and generating the necessary foreign capital. Consequently, agribusiness emerges as a cornerstone of Kenya's 21st-century development. The majority of gazetted forests have been transformed into agricultural land either through illegal encroachments, involving forest incursions leading to clearing, burning, and settlement, or through legal encroachments for agricultural settlement projects on formally designated forest lands. Additionally, other forest ecosystems in Kenya undergo transformation when government-owned forest lands transition into private ownership, often followed by clearance for farming.

Another significant forest land-use issue in Kenya revolves around unsustainable timber harvesting practices, resulting in forest depletion and degradation. Tree extraction has consistently exceeded the forests' capacity for sustainable regeneration due to overcutting permits, excessive licensing, and illegal logging activities. In many accessible forests that have been logged for extended periods, mature trees of valuable timber species are now on the brink of extinction. Historical practices have compounded this issue. While certain areas were closed to harvesting due to their importance for watershed protection or environmental preservation, those open to harvesting were managed primarily to generate wood and revenue, without a long-term commitment to sustainable harvests. Efforts to enhance forest management are hindered by a lack of essential data required for sustainable harvesting.

The Upper Tana basin, located approximately 50 kilometres northeast of Nairobi and covering an area of around 16,000 square kilometres, serves as a critical watershed. This region encompasses 11 districts, including Maragua, Thika, Murang'a, Kirinyaga, Nyeri, Embu, Mbeere, Meru, and Tharaka. Characterized by the Inter-tropical Convergence Zone, the Upper Tana region experiences two distinct rainy seasons each year: heavy rains from March to June and lighter rains from September to December. Rainfall patterns and the duration of the rainy season exhibit significant variability from one year to the next. The Tana River plays a central role in this region, channelling water from elevated areas such as Mt. Kenya and the Aberdares Ranges. Several tributaries, including Rutugi, Thingithu, Ena, Nyandi, Rupingazi, and Thiba, originate from Mount Kenya, while the Aberdares River feeds the Maragua, Mathioya, and Sagana tributaries. Water resources from the Upper Tana basin support agricultural production and irrigated areas, with irrigation water being particularly critical for sustaining horticultural activities on the slopes of Mount Kenya. However, upstream water usage has repercussions on downstream regions with drier climates. Furthermore, water is a vital resource for electricity generation, and Kenya's electricity company, KenGen, operates seven hydroelectric facilities in the Upper Tana region, with Masinga Dam being the largest.

The Mount Kenya National Forest Reserve and National Park, coupled with adjacent agricultural lands, serve as the catchment and headwaters for two major rivers, the Ewaso Nyiro and Tana. Accordingly, as per Kitheka et al. (2005), the majority of river sediments within the Tana watershed result from soil erosion attributed to poor land use practices. The annual suspended sediment load is estimated at 6.8 million metric tonnes, representing a reduction from pre-damming sediment levels in the Upper Tana region. This decline is attributed to sediment retention in dams situated within the Upper Tana basin. Land use within the Upper Tana basin encompasses three primary categories: natural vegetation (including forests, grasslands, and marshes), rain-fed and irrigated crops (such as tea, coffee, maize, and grains), and rangeland. The dominant soil type in the Upper Tana basin is Humic Nitisol, which forms on volcanic deposits and is prevalent in higher altitude zones. Nitisols predominantly support tea and coffee cultivation and are generally resistant to erosion. However, improper land management practices can degrade these soils and contribute to erosion. Other soil types found in the Tana basin include Cambisols, Vertisols, Ferralsols, Andosols, and Leptisols, each with its unique characteristics and susceptibilities.

2.2 Major drivers of forest land use change globally and in Kenya

In the context of academia, politics, and land management, a comprehensive understanding of the root causes and consequences of deforestation is necessary for the formulation of effective strategies and policies. Previous research highlight that the immediate driver of deforestation is the expansion of agricultural activities. It is important to recognize that deforestation is fastened by a variety of factors, including population growth, biophysical conditions, legislative changes, and societal disruptions. Population growth places a significant strain on land resources, resulting in increasing agricultural production, housing demand, and demand for timber as a fuel and building material. When paired with resource demand, population growth is a direct cause that accelerates the depletion of available natural resources.

Soil degradation is often a consequence of human activities, including intensive farming practices and inadequate soil conservation measures. Unfavorable natural conditions such as steep terrains promote soil erosion and reduce soil fertility. Climate variability, characterized by erratic weather patterns, also influences land use changes. Furthermore, biophysical variables such as sedimentation, rainfall changes, and extended droughts impact land use decisions. The primary drivers of land use change are further discussed below.

As highlighted by Opiyo et al. (2022), the transformation of land use and land cover has been a significant focus of attention since the 1970s, with its intense impact on various global environments. The alteration of land use and land cover is primarily driven by the competing human demands for land resource exploitation, management, and conservation. Munthali et al. (2019) explains two main categories of changes in land use and land cover: proximate drivers, which directly alter land cover through human activities, and underlying drivers, which encompass a wide range of biophysical, demographic, social, cultural, technological, economic, political, and institutional factors.

2.2.1 Biophysical Factors

Biophysical such as topography, altitude, and soil composition play a significant role in shaping the original and predominant patterns of land use. In as much as the aforementioned factors are contributors of land use change, human activities can magnify the impact of biophysical processes on regional land use trends.

2.2.2 Human activities

Land use change is, to some degree, the product of conventional human activities shifting in accordance with the human environment pressures. As industry makes the majority of land use choices, land resources are influenced the human economic environment as well. Majority of the environmental issues experienced are normally linked to the development of human activites. Policies are only effective for a limited time, and their change may cause certain inactive effects with time.

Agriculture and its related technology (pesticides, chemical fertilizers, weed killers) contributes to a wide range of environmental issues, including land and river contamination, greenhouse gas emissions, air pollution, and land desertification. The economic benefit that comes with land use change encourages agricultural intensification, urbanization, deforestation and desertification.

2.2.3 Environmental factors

Climate, geology, geomorphology, and soil-related factors are active contributors of land use change. Firstly, climatic changes influences differences in forest or farm land use; temperature, precipitation, and solar radiation all have a substantial influence in shaping land uses in specific regions. In relation to the above, geological variables such as rock types or sediments may influence impacts and change of land use change. Altitude levels and slope are geomorphological factors that also influence how land is utilized and are especially relevant in mountainous areas. Slopes, for example, enhance soil degradation and land degradation, both of which are linked to the predominant land use. Furthermore, soil quality is critical when it comes to land use as this promotes agricultural use of land.

2.2.4 Economic factors

Geist and Lambin (2002) outline those economic factors are the primary drivers of tropical deforestation globally. Land use change is often influenced by market development, rising population, commercialization, and even changes in poverty rates. In this context, market accessibility has a significant economic impact.

2.2.5 Demographic factors

Demographic aspects, such as population density and growth, have been extensively linked to be significant drivers of the changes in land use. Alexander et al. (2015) explains that Population growth is among the top five global drivers that leads to agricultural expansion. Rising affluence leads to dietary changes, animal production output, and the use of cropland for bioenergy, all of which have an influence on agricultural land utilization. The growth of urban residents, especially in the tropical regions, places strain on rural landscapes for agricultural production. Mutoko et al. (2014) affirms that population growth increases food needs, but their research also shows that growth in population does not always result in agricultural intensification; other variables, such as economic and technical developments, play an active role in determining the utilization of land.

2.2.6 Technological factors

Geist and Lambin, 2002 and Mutoko et al., 2014 explain that technological innovation, particularly agro-technological breakthroughs, influences land use change. The changes in soil conservation practices, use of fertilizers, and introduction of different crop breeds, for example, influence agricultural processes and land utilization. In this context, Geist and Lambin (2002) argue that technological advances in the wood sector may be a driving force behind tropical deforestation.

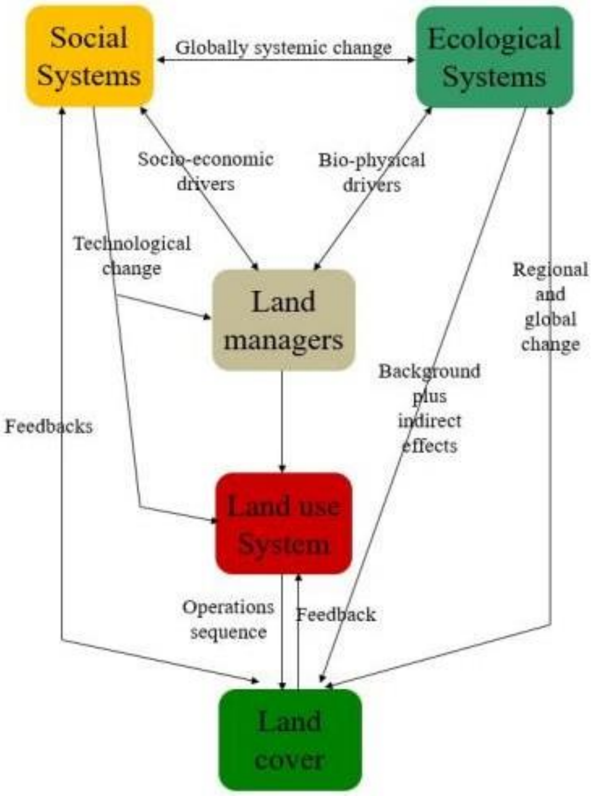
2.2.7 Cultural factors

Cultural factors often form a background and influence institutional and economic drivers of how land is utilized in different regions. People's perceptions, values, and ideas about their immediate environment can have a big impact, for instance, although governments and policies may prioritize economic expansion or modernity, indigenous local people may hold different values for the same , this influences the reception of changes introduced to them. Understanding community values and beliefs is crucial as it influences largely the changes in land usage.

2.2.8 Policy or institutional

As illustrated in figure 1 below, the existing policies and institutional frameworks have a substantial influence on how land is used; complementarily, a change in law can have far-reaching implications for land use. Kissinger et al. (2010) examine how a lack of governance in several countries, including Kenya, encourages land use changes, specifically notable in the forest sector. In this context, Were et al., 2013 associates forest conversion in Kenya to change in legislations and faulty policies.

Figure 1: Drivers of Land use change



Source: Adapted from Briassoulis, 2019

2.2.9 Political factors

In the Kenyan context, after obtaining freedom from British colonial administration in 1963, Kenya had a reputation of having a generally well-managed forestry industry in the mid-1970s. Additionally, according to World Bank 2007, by the late 1970s, Kenya had established itself as one of Africa's forerunners in indigenous woodland and tree plantation administration. Kenya's forestry industry was regarded as reasonably stable, with a big and very well managed Forest Department (FD) benefiting from state foresters' and a high degree of technical knowledge. The timber sector's security started to decline in the early 1990s, and this became severe in the 1990s. The Forest Service was dubbed "one of the nation's most corrupt agencies." It is unclear what caused the reduction in forest governance, but one important factor was Kenya's fast rising population.

In addition to that, land tenure problems, as well as accusations of "land theft" and misconduct in land administration, are among Kenya's most contentious political issues. Corruption in land management promoted land grabbing and the destruction of state forests management systems. The table below shows the direct and indirect drivers of and use change.

Table 1: Direct and indirect drivers of land use change

DRIVER CATEGORY	DIRECT DRIVERS	INDIRECT DRIVERS
Governance drivers	Forest land de-gazetting (this was a significant driver of deforestation historically)	Poor governance, characterized by weak institutions, corruption, wood extraction, and ineffective enforcement of the law. Communal engagement in forest management is low. Insufficient value share from forest resources, also known as revenue sharing. Land-sharing schemes. Uncertainty over ownership and use of forest resources.
Policy drivers	Charcoal burning and Illegal logging are two examples. The prohibition of the Shamba method has hindered reforestation. The shamba system was poorly managed.	Farmers were encouraged by agricultural policy to grow more export crops. The emphasis on gazetted forests has diminished interest in dry land woods and other forms of forests.
Other factors		Inadequate economic and accounting convergence of the forest sector.
Economic factors	Poverty (emphasis on livelihoods). Dependency on unsustainable charcoal fuel by the urban charcoal fuel market. Population growth necessitates the clearance of competing land uses, including agricultural expansion.	Expensive agricultural products.
Technological factors	The people are unaware of the consequences of deforestation. Technology advancements in sawmilling.	Insecurity in the supplying of timber to the sawmilling sector.
Cultural factors		The cultural urge to own land.

Source: Adapted from Ruri Consultants, 2013

2.3 Implications of forest land use change on Masinga Dam

The yearly loss in storage capacity of the world's dams owing to sedimentation is estimated to be between 0.5 and 1.0%. However, yearly depletion rates for many dams are substantially greater and can reach 4% or 5%, causing them to lose the bulk of their capacity within only 25 - 30 years. The Masinga dam, one of Kenya's main dams for hydropower production, municipal water supply, and farmland, is heavily silted. The planned silt load into this dam in 1981 was estimated to be 318 m3 year (roughly 1% yearly dam decline). By 2000, annual sediment inflow had nearly tripled to approximately 11.0 10 6 m3, reducing the intended capacity.

As soil degradation has grown increasingly visible with rising land use change inside the Masinga watershed over the years, the functioning and life span of the Masinga dam are now in jeopardy due to erosion and sedimentation. Sediment delivery is an important component of floods in the Tana Basin. The Masinga dam, one of Kenya's main dams for hydropower production, municipal water supply, and farmland, is heavily silted. The planned silt inflow into this dam in 1981 was estimated to be 318 m3 year (roughly 1% yearly dam decline). By 2000, annual sediment inflow had nearly tripled to approximately 11.0 10 6 m3, reducing the intended capacity. Growing rural populations in the upper catchments have contributed to converting wooded areas into small-scale agricultural plots, as has increased demand for agricultural land. Farmers frequently engage in unsustainable agricultural methods such as continual tillage, which increases run-off volume.

Soil erosion is more serious during the shorter rains (October - November) compared to the lengthy rainfall due to a dearth of plants on the terrain (March-May). According to accounts, there is an obvious relationship among both river flow and silt loads in the upper basin, with stream flow of 0.10 m3 s-1 generating 2-5 mg/l loads and high stream flow of 100 m^3 generating up to 100 mg/l. According to Kitheka et al. 2005, the Tana River's sediment burden varies between 2,796 tonnes daily during the dry season and approximately 24,322 tonnes per day during the wet season. This silt burden ranges from 1- 8 million tonnes per year. This silt weight ranges from 1 to 8 million metric tonnes per year. These recent projections of sediment movement in the Tana Basin are considerably greater than earlier estimates, and these were 0.25 million metric tonnes annually in 1965 and 2.5 million metric tonnes annually as of 1986 (IFADUNEP-GEF, 2004).

Despite the fact that Masinga Dam is the main upper dam in the Tana Basin, it was designed with a silt rate of 3 million metric tonnes of silt per year in mind. By 1988, the silt rate had increased to ten million metric tons per year, resulting in a 6% decrease in water accumulation over an eight-year period. According to study (Mogaka et al. 2006), most silt flows in higher catchments are associated with bad land use practices and land use change. Due to huge inflows compared to current holding capacity, the lakes' ability to control sediment movement is restricted, resulting in poor sediment trap efficacy for the dams. Masinga, the largest dam, has already lost significant capacity due to massive sediment fluxes far above.

The significant sedimentation influx immediately impacts the dam and the lower Tana River watershed. During the long rain season, potential flooding occurs in the lower basin, impacting agricultural and residential lands and temporarily destroying livelihoods. Soil erosion and land use practices in the catchment area directly impact sediment deposits in the dam. A few patches of water hyacinth have been discovered floating on the water in Masinga Dam. This is due to agricultural, and wastewater flows from the catchment region into the dam. The existence of the plant jeopardizes the dam's functionality. High silt loads from upstream catchments can provide a significant mechanical problem in dam structures for hydropower production. This is a concern for the Seven Forks Project, as per Bunyasi et al. (2013), because gathered silt has an abrasive effect on power production devices, raising energy losses and upkeep costs. Controlling sediment distribution through better upstream land management techniques is thus an important objective for dams' downstream life. According to Bunyasi et al. (2013), the annual catchment rainfall range of 1,035mm indicates sporadic rainfall, suggesting that the watershed will be exposed to more regular flood events, which significantly raise run-off wash impacts producing more sediment, jeopardizing the dam's storage space as well as HEP generation capacity.

The Masinga dam's sedimentation rate is assessed to be 5.45 M m3/year, indicating that the dam has lost approximately 10% of its capacity within the first 30 years. However, based on KENGEN statistics (1981-2011), this is lower than the overall quantity of annual sediment flowing into the dam, which is approximately 215.26 M m3. This results in a 13.8% decline in the holding capacity of the Masinga Dam, which is 1,560 M m3. Masinga, according to Bunyasi et al. (2013), will be full in less than 187 years. Because of the region's rapid population development and a rise in dam silt inflow of 0.063 M m3 yearly, the time required for dam sedimentation may be significantly reduced.

Uncontrolled run-off from roads, loose earthworks, and culvert overflow onto unguarded areas account for about 25% of the sediment output in the Masinga Watershed. Furthermore, run-off from cities, organizations, and homes that lacks rainwater gathering structures or soil and water conservation systems accounts for approximately 10% of total sediment production. As a consequence, human activities are contributing more to watershed sediment production. According to this, the Masinga dam capture rates will be 100% for sand, 99% for sediment, and 2% for clay, with a weighted mean of 84%. (WRMA, 2010). The turbid water outflow from the Masinga dam through its spill path at the Masinga dam is accounted for by the unusually low clay trap rate.

The trend of spillage of Masinga dam shows that since 1999, spilling has happened every 2 - 3 years on average. However, since 1988, the number of years with no spills has increased. This indicates years when the dam's storage capacity is exceeded. Sediments may harm power production methods and machinery if not properly controlled. Therefore the complete management of the catchment solution to retain sediments at the source is the only viable choice.

2.4 Forest land use planning and management interventions that can ensure minimum sedimentation impacts on the Masinga dam.

There are three fundamental methods for safeguarding protected areas, according to Galvin and Haller (2008), and they are reliant on these decision-making structures on which they are founded:

i. Populist Approach
ii. Poverty is the main cause of environmental degradation
iii. Principles of cost-benefit analysis

The populist method presupposes a bottom-up strategy in which decisions on acceptable measures are entirely in the hands of the local people, who are also responsible for providing leadership in conservation program execution.

The second strategy, which considers poverty to be the main factor contributing to environmental damage, seeks to provide sustainable livelihood to people who depend on environmental assets that must be protected. Conservation efforts may collide with development goals in this case, necessitating the employment of prohibitive techniques to restrict communities from using preserved resources.
The third method is based on cost-benefit analysis principles; in this setting, conservation becomes a business model that requires action based on declared advantages and costs. However, measuring and valuing nebulous conservation benefits like pure air is a problem that affects the cost-benefit method, which is also founded on rational choice principles.

2.4.1 Governance of Water Catchment Areas

In the Kenyan context, amongst others, the Water Act 2002, Agriculture Act 1986, Water Policy (Sessional Paper No. 1 of 1999) on Water Resource Management and Development), Wetlands Regulations 2009, Forests Act 2005, and EMCA 1999 are all being reviewed and harmonized to control the management of water catchment regions.

2.4.2 Communication strategy

There is a need to establish a communication strategy that will improve information access and utilization in the following ways:

i. Creating, uploading, and maintaining an information data base, a website and information centres on WCA.
ii. Development, integration, and implementation of WCA curricula at all school levels.
iii. Establishment of conservation-reward systems on WCA activities among local communities and groups.
iv. Publicizing information through brochures, newsletters, sports, arts, competitions, media, billboards, and posters, community, and youth forums.
v. Establishing information systems and centres for the management of water catchments in all local governmental entities.

2.4.3 Capacity Building - Management and restoration of Water Catchment Areas

To handle issues such as insufficient water catchment preservation, unsustainable usage and consuming of watershed resources, unplanned communities and developments, and land erosion, water catchment areas require repair, conservation, and long-term management. The following are the key interventions:

i. Monitoring and, if required, prohibiting cattle feeding, deforestation, and charcoal burning in crucial water catchment regions to enable for groundwater recharge.
ii. Surveying, demarcating, and recording crucial water catchment forest regions where non-destructive forest use should be prohibited.
iii. Assisting communities living near indigenous woods in establishing timber lots on private property and engaging in non-destructive bio-enterprises.

2.4.4 Land Use and Management

Solving some problems connected with insufficient water catchment protection and unsustainable water resource usage by implementing soil conservation strategies and including land use management. The following are the main interventions:

i. Building channels and gabions within fields to control run-off.
ii. Enforcing agricultural (land forestry) regulations in 2009.
iii. Considering water catchments as important regions.
iv. Introducing and supporting sustainable land-management technologies such as minimal tillage, organic agriculture, terrace building, contour cultivation, as well as other preservation measures will assist in the rehabilitation of regions that have lost their ability to serve as water catchments.
v. Mapping vulnerable habitats in crucial watershed areas and revising all catchment area soil and geology maps.
vi. Spatial planning for limited land usage and regulated growth within the drainage basin.
vii. Planting conservative forest species, such as bamboo, along riparian waterway areas.

2.4.5 Water catchment Conservation and Management

Water catchment management and conservation interventions should be developed to support catchment conservation across the terrain. The major treatments are as follows:

i. Conducting a thorough water-use study and resource evaluation to determine water balance
ii. Development and implementation of catchment control strategies.

2.4.6 Alternative Livelihoods

Providing citizens with alternative livelihoods will minimize the stress and demand on natural resource use, improve management, and promote livelihood sustenance. Diversification of incomes allows safe use of environmental assets in water catchment regions, which are key resources that many communities depend for survival.

2.4.7 Monitoring and Evaluation Systems in Watershed Areas

i. Creating and implementing M&E models for watershed management.
ii. Installing M&E equipment for water collection in all catchments.

2.4.8 Localizing the existing and creating new Community Forest/agricultural Associations

One of the issues encountered in the development of CFAs is the working relationship with the government, notably the KFS and KWS. Despite the idea of decentralization espoused by the Forests Act of 2005, it is alleged that the government maintains a strong position of control, including stringent surveillance of CFA activities and exercising arbitrary powers. To revive the land and forest cover within watershed regions, participatory forest management must be promoted to give residents a sense of belonging to the natural ecosystem. This entails the empowering of existing associations as well as the formation of new ones.

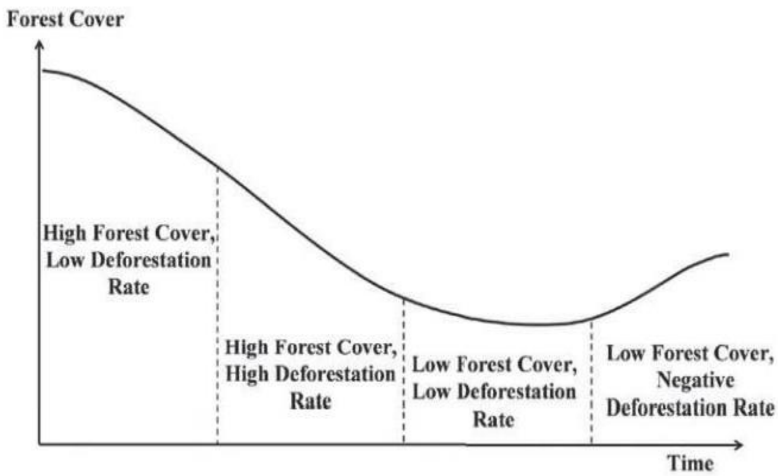
2.5 Theoretical framework

The theoretical review on forest changes in land use contains a broad variety of concepts wherein land use is addressed and is the primary subject of theoretical inquiry.

2.5.1 Forest Transition Theory

This theory was concepted by A. S. Mather (1992). Initially, he based this idea on a complete sequence of environmental resource destruction and conservation, or on Whitaker's and Friedrich's (1940) depletion-melioration model. The Forest Transition Theory contends that, in the early phases, natural resource loss is unavoidable in order to fulfil human requirements.

Figure 2: Forest Transition Theory



Source: Adopted form Mutaqin, 2016

Figure 2 explains the forest transition and how it is widely thought to take place in a solitary transition period, from high to low forest cover, then increasing forest cover. As a result, Grainger, 1995 explains that this U-shaped curve model is made up of two patterns: forest deterioration and forest revival, which are usually depicted by a U-shaped or inverted J-shaped curve. In most nations, forest cover loss is an inevitable result of development processes. Factors such as increasing population and food consumption, as well as farming land expansion, put significant strain on the forested area during the early stages of development. Increased demand for forest products and services will encourage the regeneration process as nations expand.

2.5.2 Land rent theory for deforestation

This concept of forestry is deeply embedded in von Thunen's land value theory, which he developed in 1826. In this context, Chomitz & Gray, 1996; von Amsberg, 1994 explain that this spatial economic theory of land use's central tenet is that a plot of land should be allocated to the user with the greatest possible rent. Distance or transportation cost is significant in terms of spatial competition. In this instance, the land use that generates the highest land rent/value will be anticipated to control the maximizing profit incentive and competitive pressure among land uses.

The differences in land rents of various users are crucial in understanding variations in land cover and use. Forests should be preserved first and foremost when this land use produces the greatest value in comparison to other feasible land uses. According to Walker, 2004, land revenue can be related to rent, wages, or utility. This worth can also be seen constantly in land rentals for farming and woodland land uses may change due to land competition. Agricultural land rent fluctuations can be attributed to changes in farming supply and product price dynamics, agro-ecological factors and innovation, transportation, or labour cost.

Angelsen, 2007 continues to explain that while forest land rent may fluctuate due to shifts in forest product prices, forest technology, or the implementation of economic benefits the land rent theory describes how land uses differ regionally in general. He further explains that this method enables scholars to investigate how position affects the landscape. and This method can also be used to investigate the regional trend of timber exploitation.

2.5.3 Agricultural Land Rent Theory

Thunen's agricultural land rent theory, developed in 1826, influenced the study of land use trends and their variations not only in the micro-economic but also within the macro-economic theorization discipline. Von Thunen's experiment tried to determine the best layout of country land uses around a town centres. The basic concept he used was land rent, which is defined as the "price for the use of a piece of land" or, more accurately as Romanos 1976 describes, "The price of the services produced by land within a certain time frame."

The regionally evaluated land use groups to which von Thunen's term primarily refers to are different types of farmland and, secondly, forest land. The land was assumed to be a uniform, isotropic (equal productivity), level plane with movement possible in all directions around a market village in the middle of the area of interest. Each crop has a rent gradient (or rent curve) that stretches in all directions from the centre, as well as the same delivery price and unit transit cost regardless of location or season. Furthermore, regardless of the relative prices of land (rents), other inputs, or output, the amount of land utilization and production per acre for each commodity are consistent. Prices are expected to be completely competitive. The criterion for determining where a specific activity (land use) should be located in relation to the market centre is that each land use should be located in the zone where the user can pay the greatest rent in comparison to any other user. Furthermore, the worth of the items produced on a parcel of land determines the rent a land user can pay. As a consequence, in land economics terms, the user of a high-value activity (land use) can offer higher land fees and thus outbid other users who cannot.

The occupation (land use) with the highest yield per acre (highest output value) has the highest rent gradient, according to von Thunen's idea. It is thus nearest to the market area. The remaining activities (land uses) are enumerated in decreasing order of fee gradient slope. The outcome is a succession of concentric circles focused on the market, with each ring devoted to cultivating a specific crop. The envelope of the different crop rent slopes is the offer rent curve (created by their highest sections). Finally, Hoover and Giarratani 1984 suggest that the best solution to the preceding approach's land use pattern is self - reliant, whether one person owns and farms all of the land, trying to seek massive returns; one company holds all of the property but leases it out to tenant farmers, charging the highest rents possible; or the property has numerous independent land owners and farmers, each pursuing his or her own gain.

The von Thunen version makes no specific reference to land use change processes since it's a static theory in which the optimum land use pattern is meant to develop immediately. Despite the theory's strict constraints, an underlying process is easily identified. Assume crop relative value changes exogenously. In that situation, the relative ability of farmers (land users) to bid for specific regions will be affected, making a location shift (the land use pattern maintaining its circularity) feasible. Von Thunen and scholars who used the agrarian land rent theory in the future decreased the original formulation's overly restrictive and unrealistic assumptions. Blaikie 1971 and Chisholm 1979, as cited in Johnston et al. 1994, state that these applications covered a wide range of scales ranging from worldwide scale to individual village and farm holding), as well as other land uses such as residential and commercial. Perhaps more importantly, this concept served as the foundation for Alonso's (1964) urban land market theory. In conclusion, von Thunen's theory is unquestionably the parent of both location theory and the study of metropolitan and regional spatial organization.

2.6 Policy Framework

2.6.1 Environmental Management and Coordination Act

The Environmental Management and Coordination Act (EMCA) was enacted by Parliament in 1999 to create an overarching legal and regulatory structure for environmental management. The Act creates a structure for carrying out and enforcing its provisions, which integrate concepts to control environmental management in order to support sustainable growth. It establishes NEMA as the main body in charge of overseeing, coordinating, and executing federal environmental policies.

The Act is important to the administration of water catchment areas because it is the foundation law in environmental matters. Section 42 is focused on wetlands protection, while Section 44 is concerned with the conservation and protection of hilltops, hillsides, hilly regions, and woodlands. The latter Section requires NEMA, in collaboration with main authorities, to develop, issue, and execute laws, procedures, suggestions, and measures for the safe use of hilltops, slopes, mountain regions, and forests.

The Environmental Management and Coordination Act (EMCA) of 1999 is a crucial in Kenya's environmental governance. It establishes a clear structure and assigns responsibilities for coordinating and implementing environmental policies. It is efficiency lies in its Comprehensive Framework, NEMA Oversight, Legal Clarity: however this Act would be more impactful if it included an Enhanced Monitoring and Enforcement system, promoted active Community Involvement, Adaptation to Changing Conditions and global trends, investment in Research and Data Collection: and efficient Public Awareness and Education. The above will provide an enabling environment in the protection and management of environmental resources.

2.6.2 Forest Conservation and Management Act No 34

The purpose of this Act is to preserve, defend, and regulate all public:

- i. Develop and implement management policies for all public forests, and if necessary, help in the development of planning processes for community or owned forests in collaboration with the proper proprietors.
- ii. Accept and evaluate license or permit applications pertaining to natural forests, nature conservation, or any other topic covered by this Act.
- iii. Develop and implement benefit-sharing programs in accordance with the provisions of this Act.
- iv. Assist county administrations in building forests and forest management capacity.
- v. Collaborate with pertinent partners to develop tourist and leisure and ceremonial use of public forests initiatives.
- vi. Support the advancement of forestry education and instruction.
- vii. All woodland management strategies must be registered and kept on file.

viii. Work with pertinent individuals to discover research requirements and implement research results to forestry.
ix. Manage water catchment areas in cooperation with pertinent parties and service functions for conserving water and soil, carbon sequestration, and other ecological benefits.
x. Produce a forest state record for the cabinet secretary every two years, as well as a resource evaluation report for the cabinet secretary every five years.
xi. Consider and suggest to the cabinet secretary the creation of public woods on un-allotted public property or other public land.
xii. Consider and suggest to the cabinet secretary the determination and modification of public forest borders.
xiii. Create forest conservancy regions for protection and administration.
xiv. Approve the supply of credit, professional instruction for community-based forest businesses, and incentives to individuals for the sustainable use of timber and non-wood forest goods.
xv. Implement and implement rules and laws regulating forest product importation, exportation, and trade; and
xvi. Create, manage, and routinely keep updating a geographic information system catalogue of all Kenyan forests.

The objectives of this Act are commendable for the management of public forests and catchment areas in Kenya. However to enhance its impact, it's crucial to focus on strengthening the enforcement mechanisms to discourage illegal logging and deforestation, it should provision to enhance collaboration with local communities in forest management, streamline the evaluation process to ensure thorough and effective environmental assessments. It should also ensure an implementation strategy for equitable distribution of benefits to local communities and to develop and enforce measures for sustainable tourism. And finally adopt a continuous assessment and adaptation of sustainable initiatives addressing the evolving environmental challenges.

2.6.5 Agriculture Act (Cap 318)

This is the main legislation in Kenya that governs agricultural activities in order to promote agricultural development. The Act's long-term aim is to guarantee the expansion of arable land in accordance with sound land use planning and husbandry methods, hence the emphasis on soil preservation and fertility. The Act empowers the Minister of Agriculture to issue orders, among other things, to prevent soil erosion and thus safeguard the land. The Minister for Agriculture gazetted the Agriculture Farm Forestry Rules here, with the aim of "developing and maintaining farm forest cover of at least 10% of each and every agricultural landholding and conserving and sustaining the ecosystem in combating climate change and global warming.

The Act seeks to create and sustainably manage woodlands for the protection of water, soil, and wildlife, and also the protection of banks of rivers, coastlines, and riparian and wetland areas. Such limitations, according to Section 48 of the Act, will ban the removal of certain areas of land for farmland and land draining, protect slopes and catchment regions, and preserve soil on hills, slopes, or valleys. This eventually results to resource sustainability.This Act and its associated rules ensure Preservation of Soil and Fertility, setting a bar for Forest Cover Requirements, Protection of Water Bodies, enhancing sustainable land management practices. To further ensure effective this Act should adopt and effectively incorporate Monitoring and Enforcement to ensure efficiency, Education and Awareness, Adaptability and boost Collaboration for efficient upholding of the Act's objectives.

2.6.3 National Forest Policy, 2014

This Forest Policy creates a structure for improved governance systems, allocation of resources, partnerships, and interaction with both state and non-state stakeholders with the goal for the sector to sustainably add to the country's development and poverty alleviation objectives. The following are the objectives of the National Forest Policy:

i. Increase and sustain vegetation and woodland cover of at least 10% of Kenya's geographical area. 2014 National Forest Strategy.

ii. Create an enabling legal and institutional structure for forest industry growth.
iii. Promote sustainable development through forestry study, education, mentoring, knowledge generation, distribution, and technology transmission.
iv. Encourage public, private, and neighbourhood involvement and collaboration in the growth of the forest industry.
v. Encourage investment in business tree planting, the forest sector, and commerce.vi. Improve woodland resource management for water, soil, environmental and biodiversity safety.

This policy is sufficient especially in terms of promoting sustainable land use, particularly within catchment areas, playing a crucial role in management of downstream water bodies.

2.6.4 Water policy

Water catchment area management is mainly concerned with ensuring the supply and water delivery of water. The legislative and policy structure for the water sector has experienced significant revisions over the preceding decade, starting with Session Paper No. 1 on Water Resource Management and Development in 1999. (Water Policy, 1999). The policy's primary aim is to enhance the water sector's sustainable and integrated growth and administration:

i. The preservation, conservation, and security of water resources, as well as their sustainable, logical, and economical dispersal
ii. Providing adequate quantities of high-quality water for a variety of reasons, including poverty reduction, while keeping waste water disposal secure and contributing to environmental protection.
iii. Establishing an effective and profitable institutional framework
iv. Establishment of a long-term financial framework for effective management of water resources, water delivery, and sanitation development.

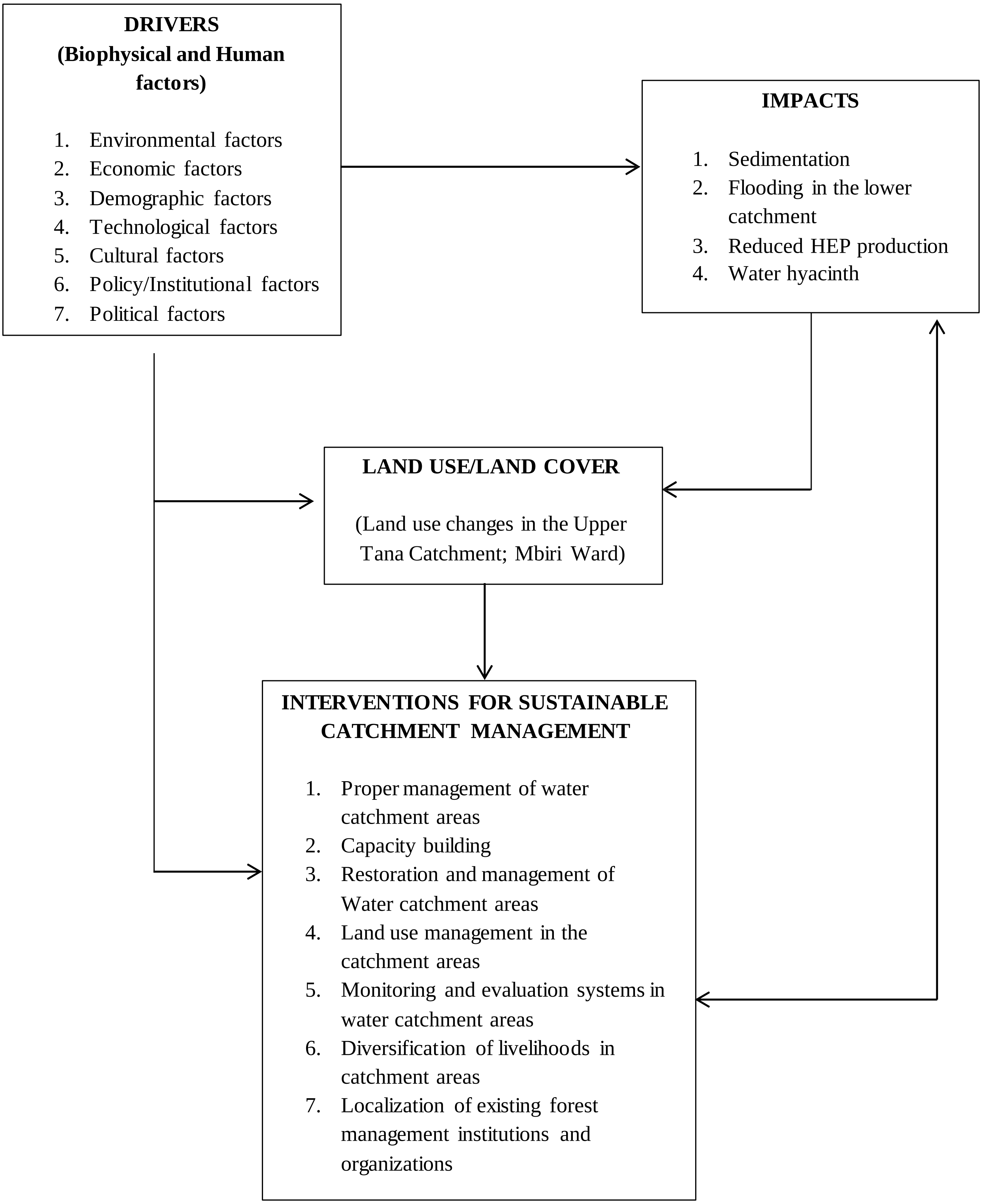
This is relevant in this instance since water management in Kenya is carried out along watershed or basin borders, which supports the preservation of catchment regions. This policy ensures sustainable water resource management. Its efficiency lies largely on how well it is implemented and enforced so as to ensure compliance with water resource management regulations.

2.7 Overall Information Gap

Rarely is the problem of deforestation studied in terms of pricing and responses to resource scarcity. This omission leads to serious policy issues. The scarcity of resources stimulates investments in subsistence and commercial forest uses once prices cover the expenses of forest maintenance, property rights, and revenues from alternative agricultural land uses.

2.8 Conceptual Framework

Figure 3: Conceptual Framework



Source: Author 2021

CHAPTER 3 - RESEARCH METHODOLOGY

3.0 Introduction

This section outlines the process that was followed during the research is described. This also explains the study findings and conclusions. This section includes the research design, target population, sampling plan, sample size of the population, size of the sample and selection strategy, data collection methods and data collection techniques, data analysis, data presentation, ethical issues, and data needs matrices.

3.1 Research design

The design of the research serves as the basis for data gathering and analysis. A cross-sectional research method was used in this study to collect information from a cross-section of farm owners in the subject area.

3.2 Target population

The target demographic was carefully selected and based on the study data requirements. To facilitate data collection and data analysis, the population was stratified. To get the target population, sampling was used to:

i. Achieve more precision
ii. Cover a broader scope; and
iii. Cut on the research expenses
iv. Reduce time of study

The target population consisted of local farmers, business persons, other residents, KFS officials, KENGEN officials, NEMA officials, agricultural officers, catchment management officers, physical planners, and conservation officers.

3.3 Sample size and sampling plan

The research used stratified random sampling, in which the sample was divided into three strata, with each stratum receiving equal questionnaires and being randomly sampled. A total of 96 people were polled, including citizens, farmers, and business owners. Key informants were selected from KENGEN, KFS officials, NEMA officials, an agricultural officer, a catchment management officer, a physical planner, and the conservation officer.

The study aimed to investigate the cause-effect connection by manipulating the causes. The cause- and-effect link in this context was predicated on upstream land use changes and their effects on the ecological sustainability of downstream water bodies, in this example, the Masinga dam.
According to the 2019 Census (KNBS), the Household number for the Mbiri Ward was 2468, therefore

Equation 1: Sample Size Formula

$$\text{Formula is } n = \frac{N}{1+N(e)^2}$$

$$n = \frac{2468}{1+2468(0.1)^2}$$

$$\frac{2468}{1+24.68}$$

$$\frac{2468}{25.68}$$

$$n = 96$$

The sample size is 96

With the above formula, the sample size is 96. The study, therefore, gathered data from 96 farmers from the Ward. The sample was then sampled into three strata 32 questionnaires from each stratum, administered randomly and distributed in the three regions: Gakindu, Kayuyu, and Mirira. The research used trained assistants to administer questionnaires.

3.4 Purposive Sampling

The purposive sampling technique was to select key informants who provided resourceful information. This method identified various groups of interest, i.e., KFS officials, NEMA officials, agricultural officers, catchment management officers, physical planners, and conservation officers. Both online and offline forms were to be used by each key informant.

3.5 Data collection methods

The research used questionnaire administration; employ interviewing, Observation, Photography, mapping, and literature review. The questionnaires were sent to Ward household farmers, and key informant guides were employed to collect information from the key informants, i.e., KFS officials, NEMA officials, the agricultural officer, the catchment management officer, the physical planner, the conservation officer.

3.5.1 List of data collection instruments

i. Household questionnaires
ii. Interview schedules for key informants
iii. Observation schedules/guides
iv. Photography

3.6 Methods of data analysis

Analysis of quantitative data - this kind of data was analysed and presented in charts, percentages, tables, and graphs.

Analysis of qualitative data– this kind of data was analysed through content analysis of the administered questions regarding the study objectives.

Analysis of spatial data – this kind of data was analysed through maps.

3.7 Interpretation of data

To evaluate quantitative data, the study employed applications such as Microsoft Excel and SPSS. Maps reflecting the ground survey were created using ArcGIS software. Pie and bar charts, tables, and pictures were utilized to analyze factors. Cross-tabulation and Excel were used for further analysis. Microsoft Word was used in the research for reporting, word interpretations, suggestions, and analytical results.

3.8 Data presentation plan

Data presentation was descriptive and used to make general interpretations and draw logical conclusions. Ms Excel, SPSS, and GIS software were used to carry out data processing, management, and documentation, and graphs, pie charts, cartographic maps, pictures, and tables were utilized to depict the data and conclusions where relevant.

3.9 Ethical considerations

All responses must were over the age of 18. Because the research was undertaken during the Covid-19 pandemic, online interviews were suggested. Face-to-face collection of data and contact was done with reference to the global and national Covid-19 standards and procedures. The research adhered to all necessary requirements, which are listed below.

i. All correspondents were over the age of 18.
ii. All respondents wore masks and maintained a social distance of a minimum of 1 meter from the research assistants.
iii. Data was collected from 9 a.m. to 5 p.m.

3.9.1 Voluntary participation

Participation in every study should be voluntary, with no compulsion or fraud. For the most part, I should not be able to compel responders to participate, although there are several circumstances in which this may happen. I should keep in mind that participants are helping me, and they should be urged to participate with the knowledge that they'll be under no obligation to participate and that there will be no negative consequences if they decide not to support you in your study (Polonski 2004).

3.9.2 Informed Consent

Another critical worry in human based studies is the comprehension of what they are being requested to do and are made aware of any prospective negative repercussions of their involvement. The most effective method to handle the issue of full consent is to provide everyone who has been asked to partake with an official document. If at all feasible, put this on formal university letterhead to increase response rates and to inform recipients that this is a legitimate academic activity (Polonski 2004).

3.9.3 Confidentiality and Anonymity

The information sheet will state that the poll members' information will remain private and anonymous. Anonymity necessitates that individuals stay anonymous. This could be accomplished through random telephone interviews or by having a group disseminate a survey on behalf of the student. Confidentiality means that you are aware of the names of the individuals but will not disclose them in any way in the final report (Polonski, 2004)

Table 2: Data Needs

0

Objective	Data needs	Data types	Data sources	Collection methods	Analysis methods	Presentation methods	Expected output
To determine how forest land use has changed in Mbiri ward in the last 40 years.	Current land uses Previous and historical land uses	Spatial	Fieldwork	Observation Mapping Administration of questionnaires Key information guides	SPSS GIS	Maps	Change detection land use maps
To identify the major drivers of forest land use change in Mbiri ward.	Drivers of land use change	Qualitative	Literature review Fieldwork	Administration of questionnaires Key informant guides	SPSS	Photographs Tables charts,	Drivers of forest land use change
To determine the implications of forest land use changes in relation to Masinga Dam.	Land use change impacts	Qualitative Quantitative	Literature review Fieldwork	Administration of questionnaires Key informant guides	SPSS	Photographs Report	Implications of forest land use change
To identify forest land use planning & management intervention measures necessary to influence forest land use change in Mbiri ward to ensure the minimum negative impacts on Masinga dam.		Spatial Qualitative		Administration of questionnaire Key informant guide	SPSS GIS	Report	Recommendations Sustainable catchment land use management plan

CHAPTER 4 – STUDY AREA

4.0 Introduction

This chapter provides information about the Mbiri Ward, describing Mbiri's geographical location, size, climatic conditions, natural features, physiography, and demographic characteristics. This chapter also provides the ward's political and administrative units, additionally; it provides information on the region's social and physical infrastructure, as well as its socio-economic and cultural features.

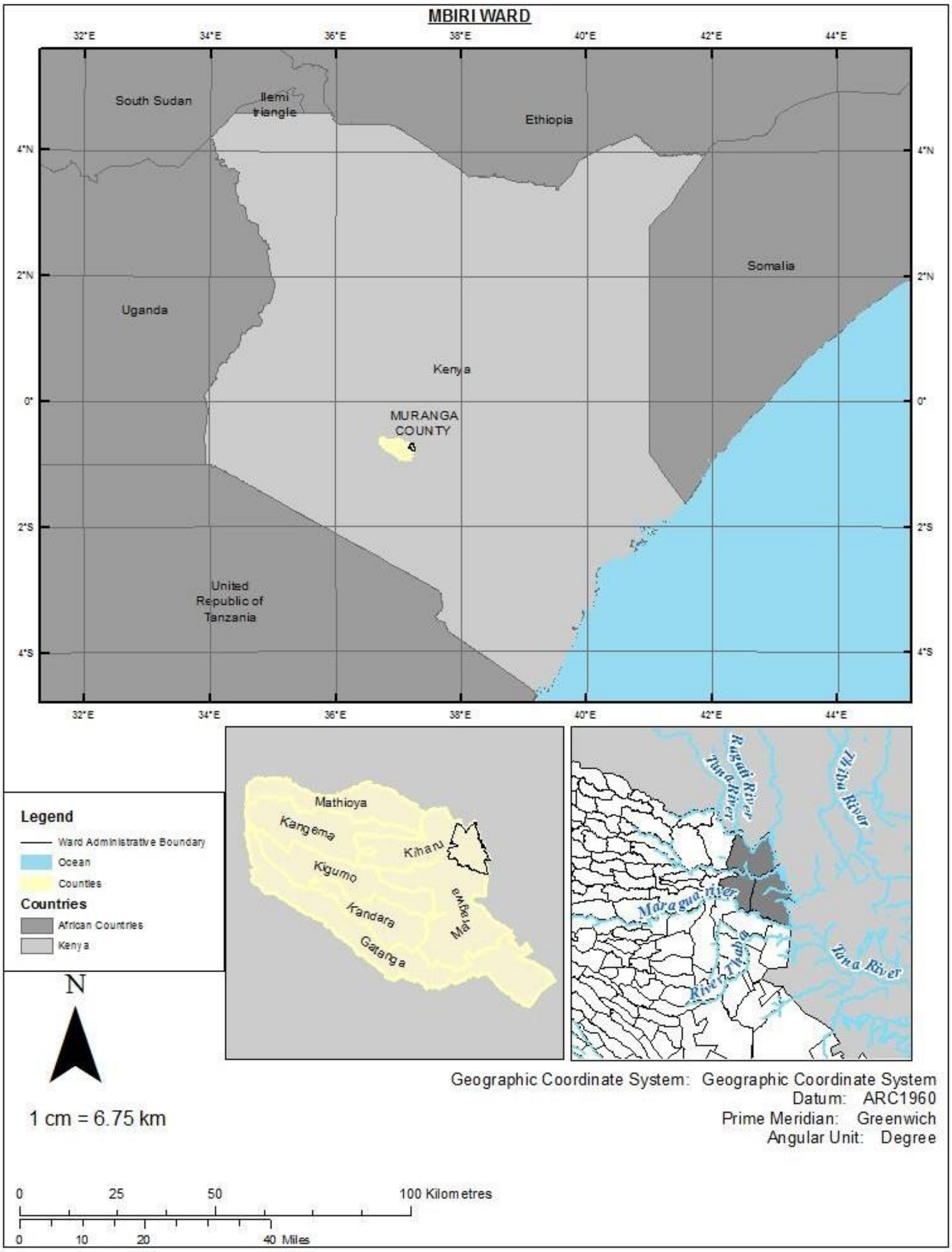
4.1 Geographical location

The Upper Tana River catchment accounts for approximately 21% of Kenya's total national area. It covers an area of roughly 126,927 km^2. River Tana runs approximately 1,200 meters from its headwaters in the central Kenya highlands to its outlet in the Indian Ocean. This river is critical to the survival of the seven forks HEP projects. Masinga dam may be found at latitude 000 89' South and longitude 370 59' East. Masinga Dam is the Seven Forks HEP projects' biggest dam and hence the most significant in regulating the Tana River catchment and the Seven Forks scheme.

The Upper Tana watershed is situated in the northern part of Nairobi and comprises the Aberdares and Mount Kenya highlands. It has an area of around 12,500 km2. The elevation of the watershed ranges from 5199 meters atop Mount Kenya to 400 meters in the east. The major rivers in the watershed are the Thiba and Sagana. Significant tributaries include the Chania, Maragua, Mathioya, Ena, Nyamidi, Rupingazi, Gura and Tunga rivers. The administrative districts included in the catchment area include Meru, Nyeri, Muranga, Kirinyaga, Embu, Maragua, Mbeere, Tharaka and sections of Thika. The watershed contains several conservation areas, including the Aberdares and Mount Kenya National Park. These locations feature a diverse range of rare forest environments.

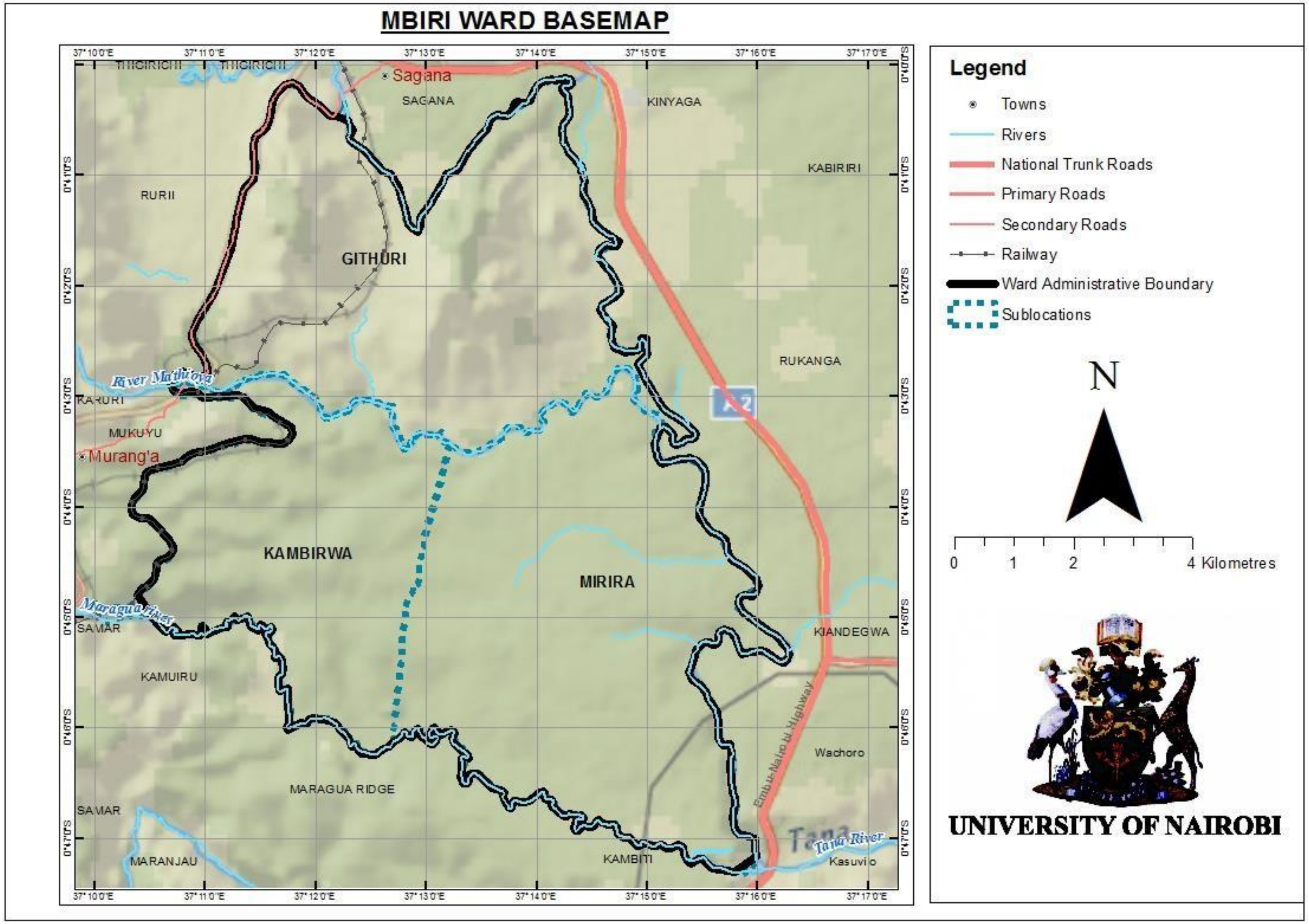
The Upper Tana watershed is experiencing significant water scarcity. Throughout dry periods, most rivers are unable to provide enough freshwater for all users. Possible evapotranspiration in the forest varies from 500 mm per year to 1700 mm in the lowlands, resulting in a rainfall evaporation deficit in almost all places below the forest zone (Notter et al. 2007). Mbiri Ward is in Kiharu Sub County, Murang'a County, in the Central Region of the Republic of Kenya. The county is bordered by Nyeri to the north, Kiambu to the south, Nyandarua to the west, and Embu, Kirinyaga, and Machakos to the east. It is located between the coordinates of 00 34'; 10 7' South and the longitudes of 360; 370 27' East. The county has a total size of 2,558.8 kilometres. The maps below shows both the national and local contexts of Mbiri Ward.

Map 1: Study Area, Mbiri Ward



Source: Author, 2022

Map 2: Administrative boundaries, Mbiri Ward



Source: Author, 2022.

4.2 Demographic dynamics of the study area

Below are the demographic dynamics of the study area:

Table 3: Demographic dynamics of Mbiri Ward

Total population	Female	Male	Conventional households	Persons per sq. km
2468	1252	1216	683	634

Source: (KNBS, 2019)

4.3 Climatic and physiographic features

Muranga County is divided into 6 ecological zones:

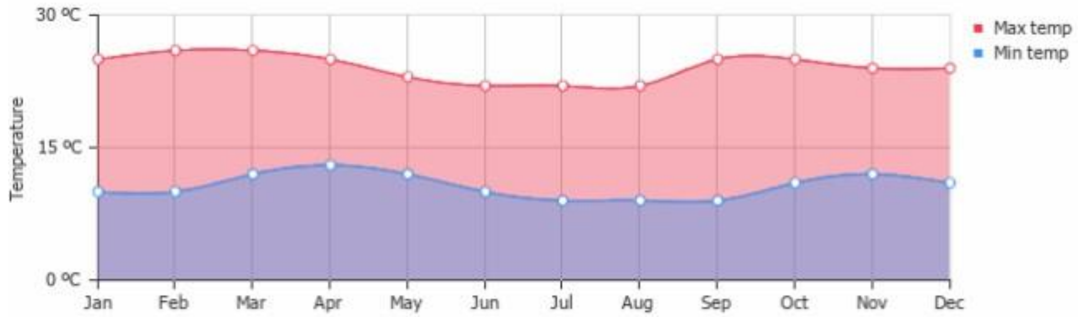
i. Zone 1 comprises of high-potential areas with key economic activity like as forestry, tea, and tourism.
ii. Zones 2 and 3 – on the foothills east of Aberdares, which are often best for dairy and coffee cultivation.
iii. Regions 4, 5, and 6 are distinguished by desert and semi-arid climates. Irrigated coffee and pineapple farms thrive in these zones.

The County has three climatic zones:

i. Equatorial climate – the Western part of the County, covering Gatanga, Kangema, and upper parts of Kandara and Kigumo, are commonly wet and humid owed to its closeness to Mt. Kenya and the Aberdare Ranges.
ii. Sub-tropical climate – mainly the central region.
iii. Semi-arid conditions - in the lower parts of Kiharu (where Mbiri ward lies), Kigumo, and Kandara, Maragua constituencies experience less rainfall, and crop production entails consistent irrigation.

The graphs below illustrate the climate conditions and weather patterns of Mbiri Ward. They provide the average temperatures, precipitation, humidity and wind speed characteristics of the ward.

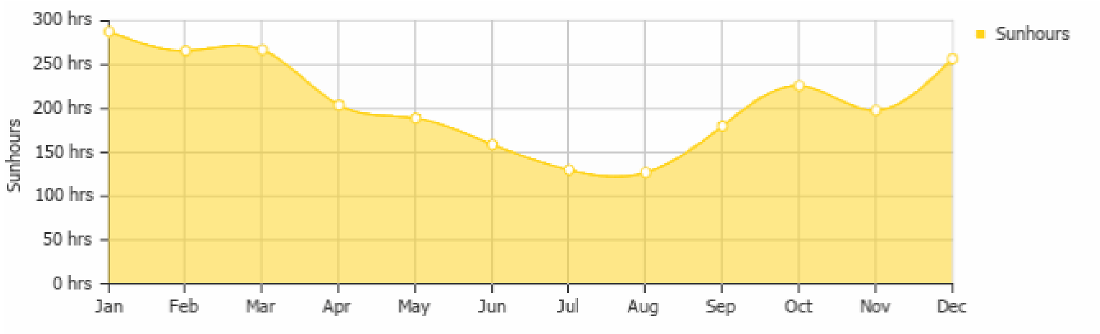
Figure 4: Average Day and Night temperature



Source: (Climate in Muranga, Kenya, 2019)

Figure 4 above shows a graphical representation of the average day and night temperatures in Mbiri Ward. In the months of January, April, May, June, August, September, October, November, and December, the average temperature falls within the range of 20°C to 25°C. March is the warmest month, with a mean high temperature of 26°C and July marks the coolest month, with a maximum temperature reaching 22°C.

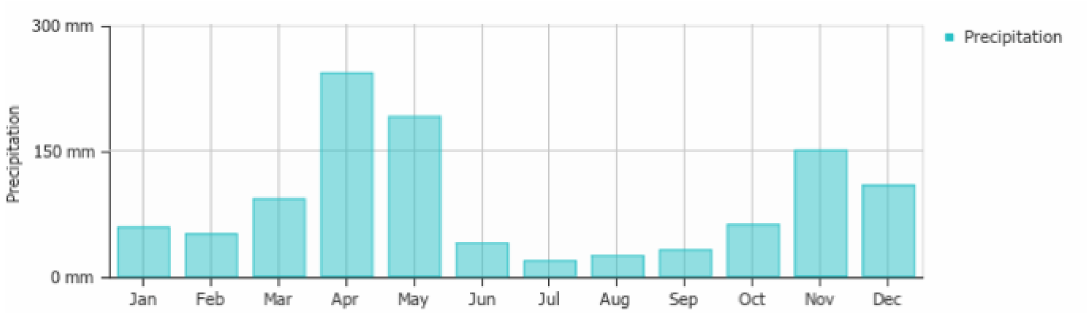
Figure 5: Monthly hours of sunshine



Source: (Climate in Muranga, Kenya, 2019)

Figure 5 illustrates the monthly distribution of sunshine hours in the area. January is considered the sunniest month, with nearly 300 hours of sunshine, while July and August experience the lowest sunshine hours, with both months registering just below 150 hours of sunlight.

Figure 6: Monthly precipitation in inches



Source: (Climate in Muranga, Kenya, 2019)

Figure 6 above shows the monthly precipitation rates of the ward, providing a distinct pattern throughout the year. April experiences the highest precipitation levels, reaching around 250mm, closely followed by May with nearly 200mm. November and December both experience notable precipitation, around 150mm. The months of January, February, July, August, and October record the lowest precipitation, indicating drier conditions during these periods.

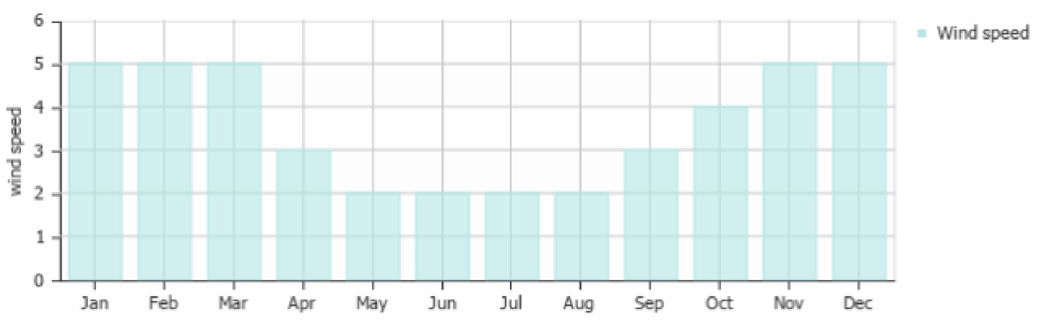
Figure 7: Average relative humidity

Source: (Climate in Muranga, Kenya, 2019)

Figure 7 shows the graphical representation of the average relative humidity rates and patterns in the ward and its surrounding areas.
The months of May, April, November, and December exhibit the highest levels of humidity, indicating a more humid climate during these periods. In contrast, the months of January, February,

March, June, July, and August are characterized by lower humidity levels, representing the drier months throughout the year.

Figure 8: Average speed of wind in meters per second



Source: (Climate in Muranga, Kenya, 2019)

Figure 8 shows the area's average wind speed patterns. The highest wind speeds are consistently recorded during the months of January, February, March, November, and December. In contrast, the lowest wind speeds are consistently observed in the months of May, June, July, and August.

In terms of physiography, the county's elevation ranges from 3,353m above sea level along the slopes of the Aberdare Mountains to 914m asl in the east. The highlands to the west are characterized by a highly fragmented topography that drains into many rivers. These rivers flow from the Aberdare highlands to the Tana River in the east. The County's basement and geological system are composed up of Achaean rocks and Pleistocene volcanic rocks. The County’s western part that borders Aberdares, is composed of volcanic rocks, whilst the eastern section (which includes Mbiri Ward) is built up of basement system rocks. Significant aquifers are generated by porous layers and disconformities underlying volcanic rock formations that absorb and transfer groundwater, so regulating water supply from the volcano.

In terms of development, it's rugged, fragmented geology and topography are both an asset and a challenge. The highest sections of the County around Aberdares are catchment areas, where the majority of the rivers that pass through the County originate. As a result of the volcanic rocks' rich soils, agricultural activities thrive. The natural conditions in the highlands are ideal for tea and coffee cultivation. However, because of the dissected landscape, gulley erosion and landslides occur, making the building and upkeep of bridges and roadways prohibitively expensive.

4.4 Socio-economic/cultural profiles

Mbiri Ward is in Murang'a County, the homeland of the Gikuyu and Mumbi, the Kikuyu's forefathers. The area is mainly by Kikuyu. The ward is located in the vibrant Muranga County of the former central province. Because of the fertile soils, the top half of the County is mostly agricultural. The lower section (where the study area is located) is dependent on irrigational farming and different informal industries such as bee keeping, boda-boda riding and quarry mining. Small-scale fishing, banking, hotel and tourism, nut processing, and other small-scale enterprises are also economic activities. Marketplaces in neighbouring counties, supplement fresh agricultural goods. There exists an active exchange of products and services in the education, labour, infrastructure, tourism, and business sectors. The region is home to several agricultural tribes, including the Kikuyu, Kamba, and Embu, as well as the Mbeere and Meru. Archaeological evidence demonstrates that they are all related and that major inter-tribal marriages occur leading to the shared traditions (Mwakikagile 2007). Most importantly, Mount Kenya's surroundings, particularly the peak, are historically important to the region's people as "the place of God, Ngai" (Emerton 1999).

Mount Kenya is crucial to the cultural identity and customs of the Kikuyu, Kenya's largest ethnic group. Yet, throughout the colonial era, traditional land tenure patterns disintegrated, giving rise to a more agricultural and commercial system that considerably stretched the terrain (Kenyatta 1961).

This has had long-term negative consequences for Upper Tana and has had substantial influence on a human habitation since independence. Yet, while many aspects of other traditions may be seen in their contemporary way of life, traditional values and customs are strongly adhered to (Mwakikagile 2007). The Embu are related to the Kikuyu and have major historical ties, most notably in their resistance to British colonial dominance (Mwakikagile 2007). The Embu, like the Kikuyu, are historically agriculturalists, but in the Upper Tana woodlands and highlands, they also undertake beekeeping and honey production (Tanui 2006). Other Upper Tana tribes, such as the Tharaka, Kamba and Mbeere, are distributed widely, albeit they are mostly located in lowland areas and hills (Ngari 2013). Kamba people, who are originally mixed agrarians and hunter-gatherers, can be found in urban cities and towns across the basin (Irungu 2000).

However according Ngari (2013), the linguistic related peoples migrated from Mount Kilimanjaro region to the Upper Tana's resource-rich and favourable environment. Under favourable weather conditions, their numbers increased and extended across the basin, suggesting a clear, powerful, and early interaction between people and Upper Tana's ecosystem, as proposed by Ngari (2013).
Residents in the Tana River Basin make a living via a variety of activities like fishing, agriculture, livestock, and nomadism, along with labour in national parks and conservation or protected areas and jobs in metropolitan or industrial regions. Popular industrial livelihoods in the region include food processing, leather manufacturing, beverage production, textiles, steel, printing, and tea and coffee (Ministry of Environment, Water and Natural Resources, 2013).

4.5 Social infrastructure

4.5.1 Health Facilities

In accordance with Kenyan physical planning standards, Muranga County, encompassing Mbiri Ward, consists of healthcare infrastructure comprising a total of 272 health facilities. These facilities comprises of various healthcare provision, including a County referral hospital, sub-county hospitals, mission hospitals, and private hospitals. The region is well-served by a mix of private and public clinics, along with dispensaries that are both governmental and operated by mission or non- governmental organizations (NGOs). This diverse healthcare ecosystem adheres to Planning standards for ensuring access to quality medical services for the local population.

4.5.2 ECD Centres

Murang'a County has a total of 1,000 Early Childhood Development (ECD) centers. Given Mbiri ward's estimated population of over 2,000 residents, the allocation of these 1,000 ECD centers across the wards within Murang'a County aligns with established planning standards. According to the Kenyan Planning Handbook of 2002, it is recommended that one educational facility catering to a population of 2,500 should ideally serve a student body ranging from 150 to 260 children. This guideline is designed to ensure adequate educational coverage for the population. In the case of Mbiri Ward, the provision of ECD centers sufficiently caters to the educational needs of the ward's population.

4.5.3 Primary education facilities

In reference to Kenyan physical planning standards, Murang'a County has approximately 512 primary schools distributed across its various wards. Focusing on Mbiri Ward, with a demographic of approximately 2,500 residents, these standards dictate that a ward with a population of 3,500 should ideally have at least one primary school accommodating 960 pupils. This reveals that Mbiri Ward is satisfactorily equipped with primary educational facilities to serve the educational needs of its resident children.

4.5.4 Secondary education facilities

Murang'a County consists of a total of 306 secondary schools, distributed across its wards, including the Mbiri Ward. In accordance with physical planning standards, the allocation of secondary schools should ideally adhere to a school-to-population ratio of 1:8000. This indicates that the Mbiri Ward is well-served in terms of secondary education facilities, ensuring that educational access is both equitable and sufficient within the ward's boundaries.

4.5.5 Youth Vocational Training Centres

Muranga County has a network of educational institutes, youth polytechnics, accredited universities, and non-accredited colleges aimed at equipping the region's youth with practical skills and knowledge. These institutions sufficiently serve the youths of Muranga county as well as those in Mbiri ward.

4.5.6 Higher Education Institutions

Muranga County is host to both public and private higher education institutions, including Murang'a University of Technology and Pioneer University. These tertiary education facilities play a pivotal role in ensuring accessible educational opportunities for the youth in the region, particularly within Mbiri ward.

4.5.7 Adult and Continuing education Centres

In the context of adult and continuing education, Muranga County features a total of 127 centres, strategically positioned to enhance adult literacy levels within Mbiri ward and the broader counties. These are sufficient in terms of enhancing adult literacy levels in Mbiri ward and in the county at large.

4.5.8 Sports, Culture, and Creative Arts

i. Cultural Preservation Sites

Muranga County preserves its cultural heritage through various sites such as the Tuthu Cultural Site in Kangema, Mukurwe-wa-Nyagathanga in Kiharu, and the Mugo Wa Kibiru Centre in Gatanga. These sites serve as custodians of community traditions, values, and norms, adequately catering to the needs of Mbiri ward and Muranga County.

ii. Sports facilities

Muranga County has a number of sports facilities, including General Kago in Kangema, Rurii in Mathioya, Mumbi and Ihura grounds in Kiharu, Kimorori in Maragua, Matenjagwo in Gachibi, and Kandara grounds, aligning with the physical planning standards of Kenya to support sports and recreation.

iii. Information and Civic Services Hubs

The Kenya National Library Services operates multiple libraries in Murang’a town, supplemented by information centres in Kiharu, Mathioya, Maragua, Kangema, Gatanga, and Kandara. These facilities serve as vital resources for knowledge dissemination and citizen services in the county.

4.6 Physical infrastructure

Although the County has a variety of road types, its mandate is restricted to unclassified roadways. Murang'a town, Kangari in Kigumo, Kiria-ini in Mathioya, Kangema town, and Kirwara in Gatanga are the County's five bus stations. The County has also allocated land in Kiharu constituency for the development of an airstrip. The old rail line of 65 kilometres long traverses the county, with one endpoint at Maragua.

CHAPTER 5 - FINDINGS

5.0 Introduction

This chapter presents the study's findings, including data presentation, analysis, and interpretation. It outlines the demographic characteristics and presents how forest cover has changed in Mbiri Ward in the last 40 years. It also explains the major drivers of forest land use change in the Mbiri Ward and outlines the implications of forest land use change on Masinga dam. This chapter also identifies forest land use planning and management interventions that can ensure minimum sedimentation impacts on Masinga dam.

5.1 Presentation, Analysis, and Interpretation of Data

5.1.1 Demography and socioeconomic findings

In the study conducted in the Mbiri ward in Mirira, Gakindu, and Kayuyu sub-locations, a total of 96 questionnaires were distributed to randomly selected farmers and businesses. Key informants including a KENGEN official, a Muranga town planner, and a KFS officer were interviewed as well. The response rate stood at 88%, highlighting active participation from the target population, which greatly contributes to a more comprehensive understanding of community needs. From the target population, 39% originated from Mirira, 33% from Kayuyu, and 28% from Gakindu, signifying diverse input sources within the study area. This diversity strengthens the relevance of the feedback collected.

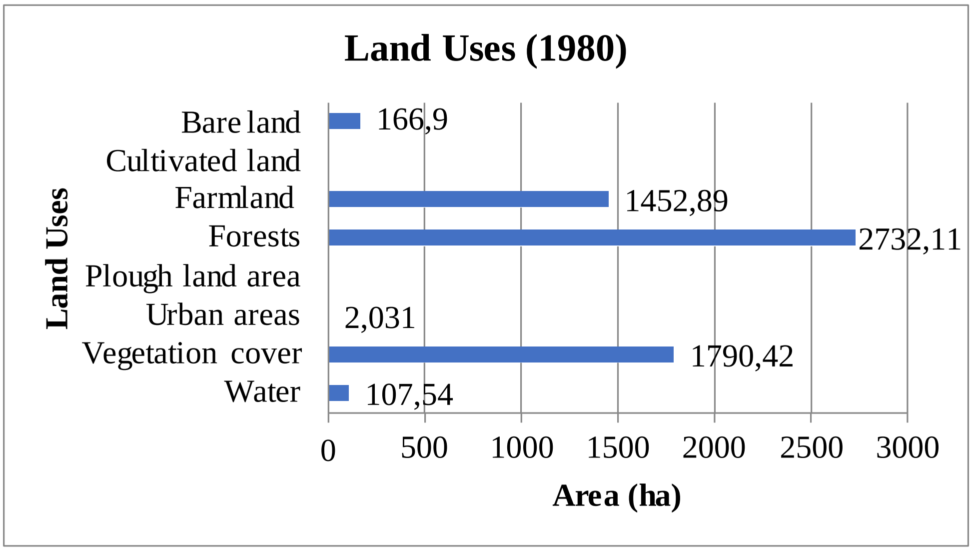
Demographically, a majority, accounting for 55%, were above 50 years old, while 34% fell within the 35 to 50 age bracket. The youngest respondents, between 18 and 35 years old, constituted 11% of the total. Many of these individuals had resided in the area for an extended period, enabling them to provide valuable insights into forest land use changes spanning the last four decades. This also indicates the need for a more inclusive and responsive urban environment to cater to the diverse needs of the population. Gender-wise, the findings showed that 55% of respondents were male, with female respondents comprising the remaining 45%. This distribution highlights a relatively balanced gender composition in the Mbiri ward, emphasizing the importance of inclusive gender perspectives in decision-making processes and equitable access efforts. Furthermore, household heads were predominantly male, representing 66% of responses, while 34% were female, underscoring the prevailing male-dominated breadwinning roles.

In terms of family structure, the 40.9% of the households in Mbiri ward consisted mostly of middle-aged individuals, followed by those below 18 years old representing 25% of the household population, and 27.3% those between 35 and 50 years old. This demographic profile suggests that a significant portion of respondent households consists of young adults and youths indicating the high economic potential of the ward. Family sizes in the ward were generally small, with most households having fewer than five children of both genders. Specifically, 39% had more male children, 37% had more female children, and only a few had more than five children, with a slight skew toward females. This trend indicates the need for development efforts that encompass social inclusivity.

Regarding education levels, 43% of respondents had completed elementary education, 42% had finished secondary education, 8% had not pursued any formal education, 6% had attained a college- level education, and 1% had achieved a university-level education. These educational attainment levels highlight the overall literacy of the population, presenting opportunities for sustainable livelihoods. Occupationally, 37.9% of respondents were engaged in farming, 25.9% were involved in agricultural product trading as businesspersons, 10.6% combined farming with domestic work, 9.4% were both farmers and businesspersons, 5.9% were housewives, and 3.5% worked as domestic workers, professionals, or construction workers. This distribution shows the predominance of farming in the local economy and emphasizes the importance of diversifying economic activities and promoting responsible land management for long-term sustainability.

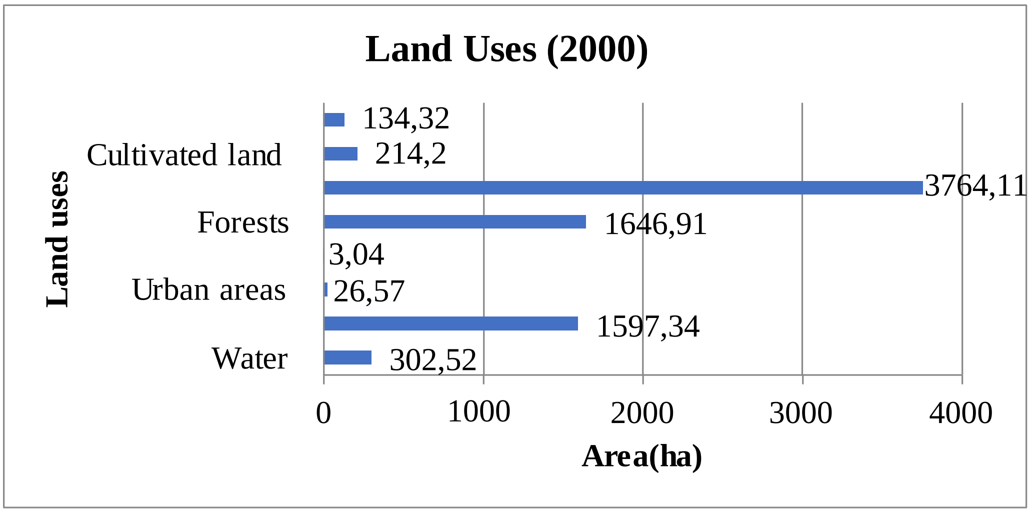
5.2 Forest land cover change in Mbiri ward in the last 40 years.

Graph 1: Dominant Land Uses in 1980



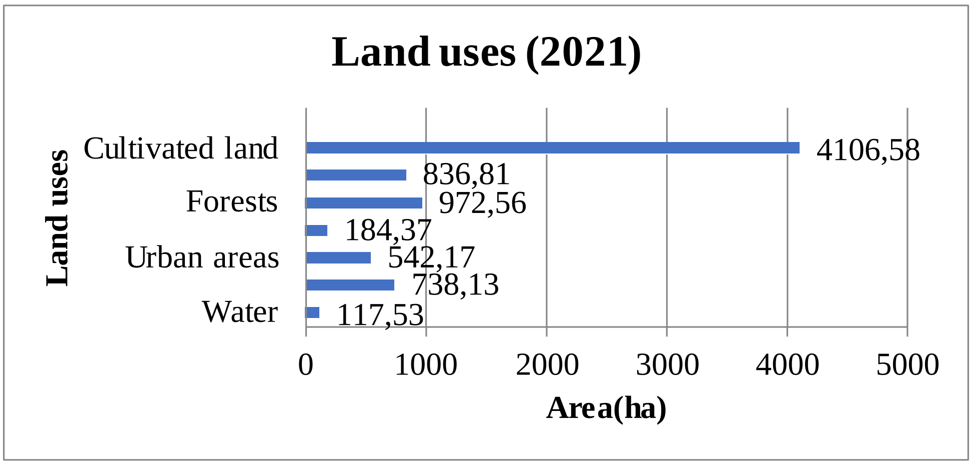
Source: Field Survey, 2022.

Graph 2: Dominant Land Uses in 2000



Source: Field Survey, 2022.

Graph 3: Dominant Land Use in 2021



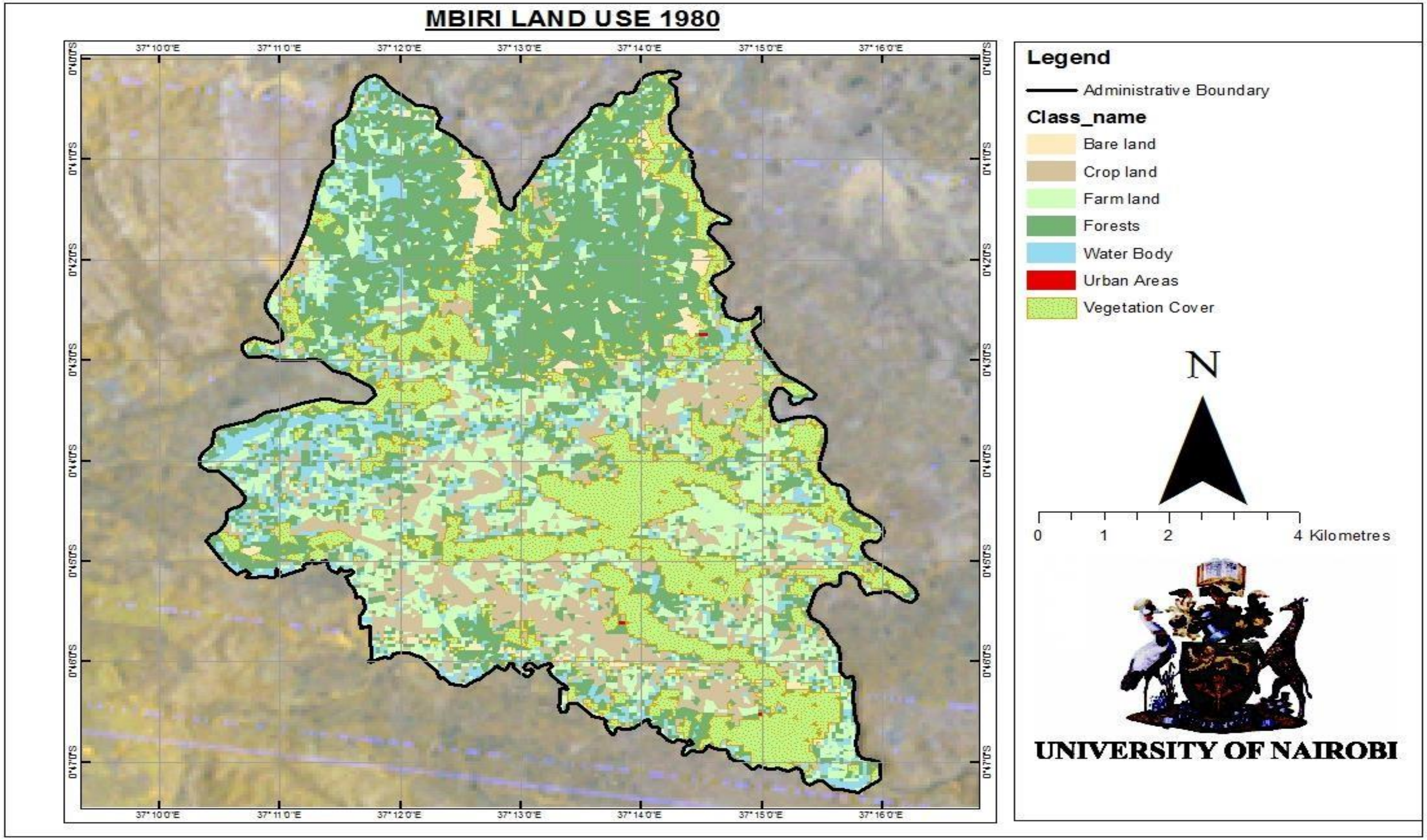
Source: Field Survey, 2022.

Graph 1, 2 and 3 above above show the changes in land use areas over the years 1980, 2000, and 2021. In 1980, the water land use covered 107.54 hectares, which increased to 302.52 hectares in 2000 but then significantly decreased to 117.53 hectares by 2021. Vegetation cover, on the other hand, occupied 1790.42 hectares in 1980, reduced to 1597.34 hectares in 2000, and further decreased to 738.13 hectares in 2021. Urban area land use was recorded at 2.031 hectares in 1980, expanded to 26.57 hectares in 2000, and saw a substantial increase to 542.17 hectares by 2021. Ploughed land area, which was 3.04 hectares in 2000, experienced an increase reaching 184.37 hectares in 2021. Forest land use stood at 2732.11 hectares in 1980, and declined to 1646.91 hectares in 2000, and dropped significantly to 972.56 hectares by 2021. Farmland covered 1452.89 hectares in 1980, expanded to 3764.11 hectares in 2000, but then decreased to 836.81 hectares by 2021. On the other hand, cultivated land increased significantly from 214.20 hectares in 2000 to 4106.58 hectares in 2021. Additionally, bare land also increased from 166.90 hectares in 1980 to 134.32 hectares in 2000, and finally to 756.50 hectares in 2021.

The significant increase in urban area land use from 2.031 hectares in 1980 to 542.17 hectares in 2021 indicates rapid urbanization in the ward presenting challenges associated with urban expansion, such as infrastructure development, housing, transportation, and land allocation for various purposes like residential, commercial, and industrial zones. The increase of cultivated land from 214.20 hectares in 2000 to 4106.58 hectares in 2021 highlights the changes in agricultural practices and land allocation. These potentially impacts highly on food security, irrigation, and sustainable agricultural development in Mbiri Ward. However, the decrease in vegetation cover and forested areas is a concerning trend in the ward. It indicates potential challenges related to deforestation, biodiversity loss, and ecological imbalance presenting the need for Sustainable land management and conservation efforts. The fluctuations in water land use from 107.54 hectares in 1980, to 302.52 hectares in 2000, and 117.53 hectares in 2021 presents the need for monitoring. Changes in water bodies potentially impact water resources management, downstream flood control, and water supply infrastructure. The increase in bare land, 166.90 hectares in 1980, 134.32 hectares in 2000, and 756.50 hectares in 2021 indicates land degradation and potential areas for future development. There is therefore need to should assess these trends and plan for reclamation or suitable land use.

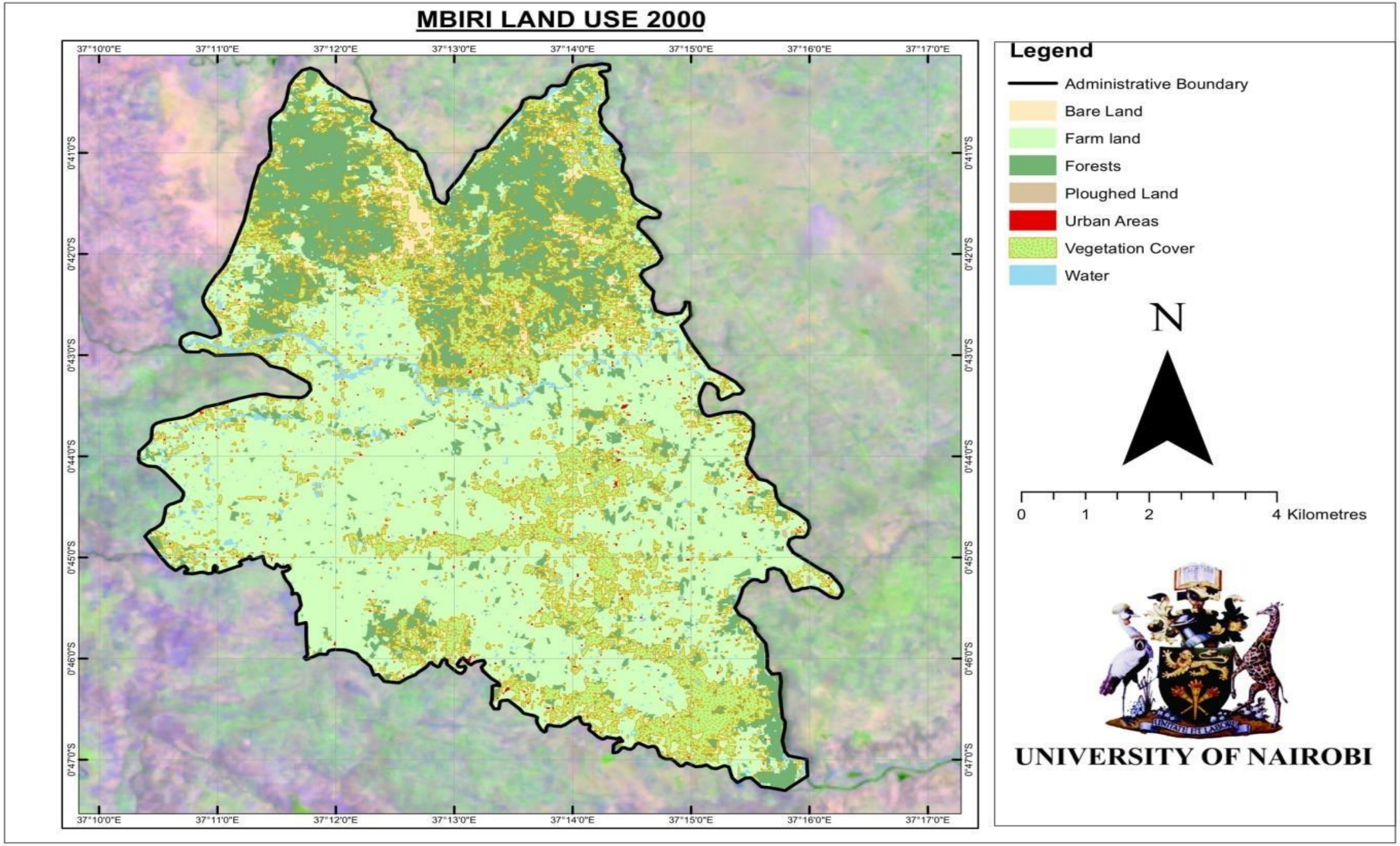
From the findings above, there is a trend of increased urbanization and expansion of cultivated areas, while vegetation cover and forested areas have experienced significant decrease. Maps 2, 3 and 4 below, illustrate a detailed land use analysis in Mbiri ward for the years 1980, 2000, and 2021.

Map 3: Land uses in Mbiri ward in 1980



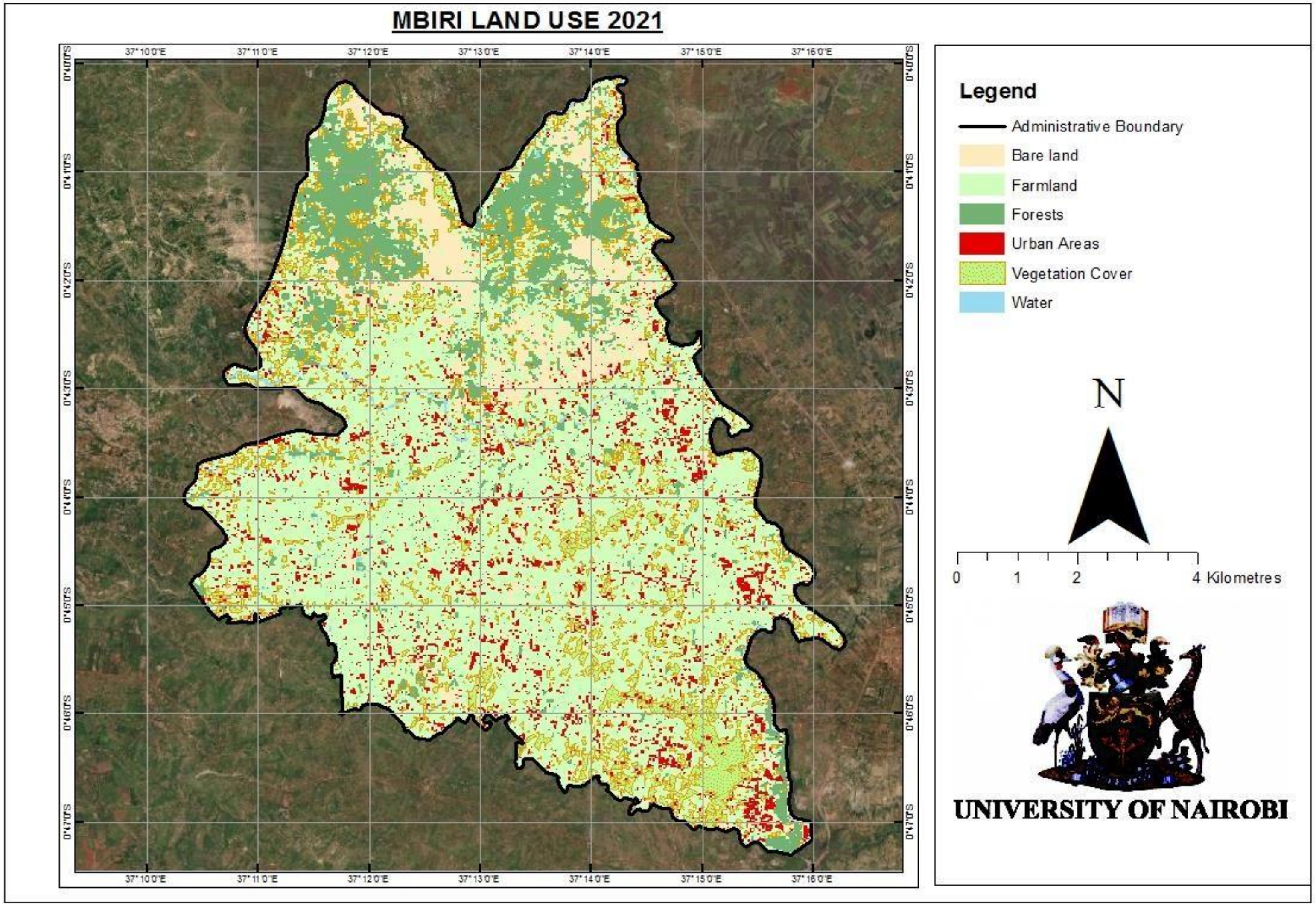
Source: Field Survey, 2022.

Map 4: Land uses in Mbiri ward in 2000



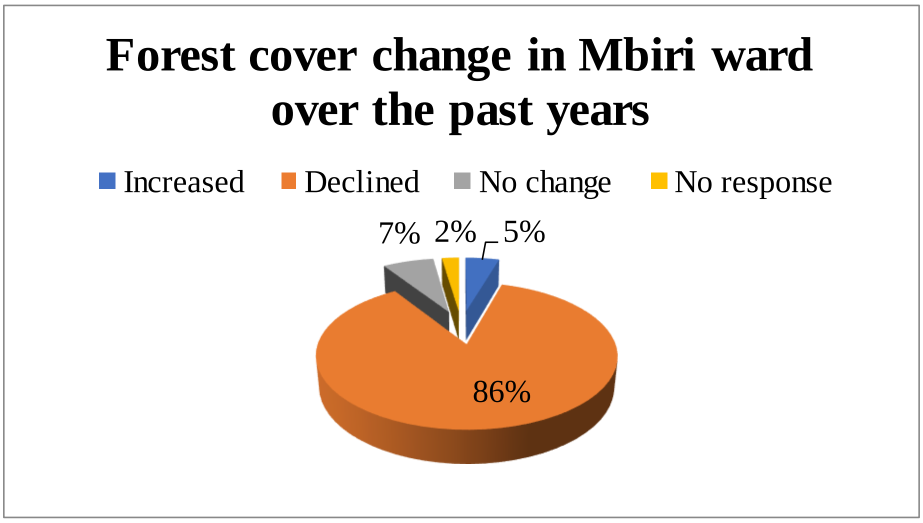
Source: Field Survey, 2022.

Map 5: Land uses in Mbiri ward in 2021



Source: Field Survey, 2022

Figure 9: Opinions on Forest cover change in Mbiri Ward



Source: Field Survey, 2022.

In Figure 9, as shown by the household questionnaire, 86% of respondents agree that there has been a notable decline in forest cover within the Mbiri ward over the past forty years. This trend indicates the need for sustainable land management and conservation strategies in Mbiri. Contrastingly, a smaller proportion of respondents, constituting 7%, have reported an increase in forest cover. While this seems positive, it also indicates afforestation efforts or natural regeneration, both of which should be carefully considered in Mbiri's development plans. Additionally, 5% of respondents indicated that there have been no noteworthy changes in forest cover in recent forty years.

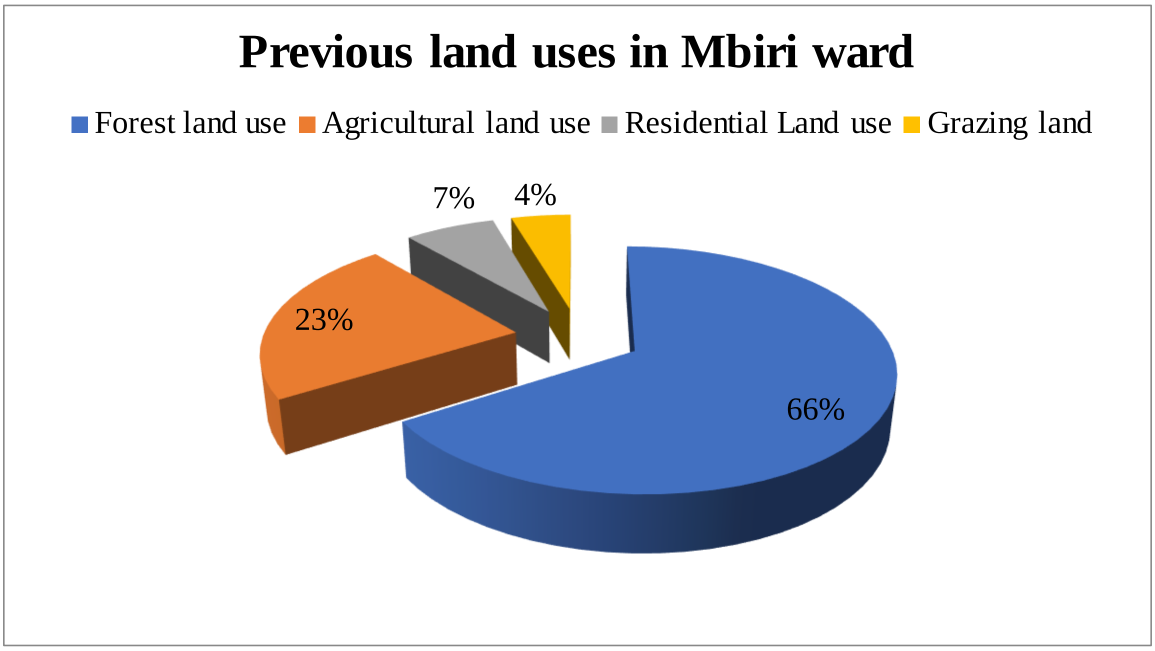
2% of the respondents expressed uncertainty regarding whether the forest cover in the Mbiri ward had experienced growth, decline, or remained the same. This uncertainty indicates the need for awareness-building efforts. To further illustrate this, plate 1 (A) and (B) below depict tree stamps showing chopped trees, indicating the environmental challenges experienced in Mbiri ward.

Plate 1: Tree Stumps

A B

Source: Field Survey, 2022

Figure 10: Previous land uses in Mbiri ward

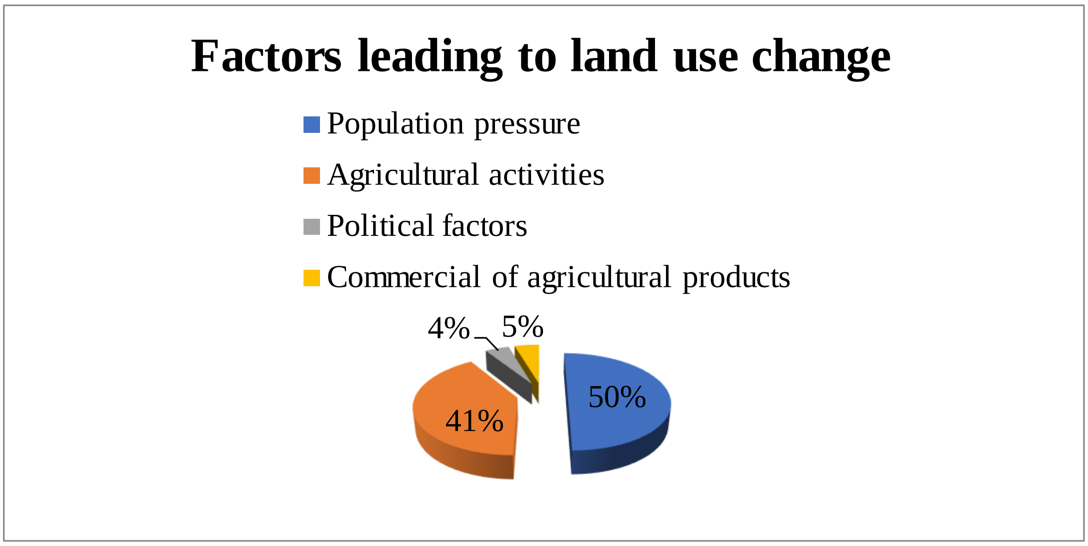


Source: Field Survey, 2022

Figure 10 above shows that 66% of the respondents confirmed that the primary land use in Mbiri ward was forested terrain. 23% of the land was dedicated to agricultural use, which plays a crucial role in shaping the spatial layout and zoning of the ward. Residential land use accounted for 7%, which earlier indicated the need for residential planning and infrastructure development. 4% of the land was designated as grazing land. Seeing that forest land use dominated the previous land use pattern if the ward, it is of importance to guide future land-use decisions and sustainable development strategies in the ward.

5.3 Drivers of forest land use change Mbiri ward.

Figure 11: Drivers of land use change



Source: Field Survey, 2022

Figure 11 above shows the key drivers of land use change in Mbiri ward. Population pressure accounts for 50% as a key factor leading to the conversion of forest land into residential use, as the growing ward population necessitates the expansion of residential areas. Population change outlines the need for effective planning to accommodate the increasing population. Agricultural activities play a substantial role, accounting for 41% of the observed land use changes in Mbiri. Given that Mbiri ward is predominantly an agricultural zone, this changes indicates the need for efficient planning to allocate land for agricultural purposes while preserving forested areas. This balance is an important consideration for sustainability.

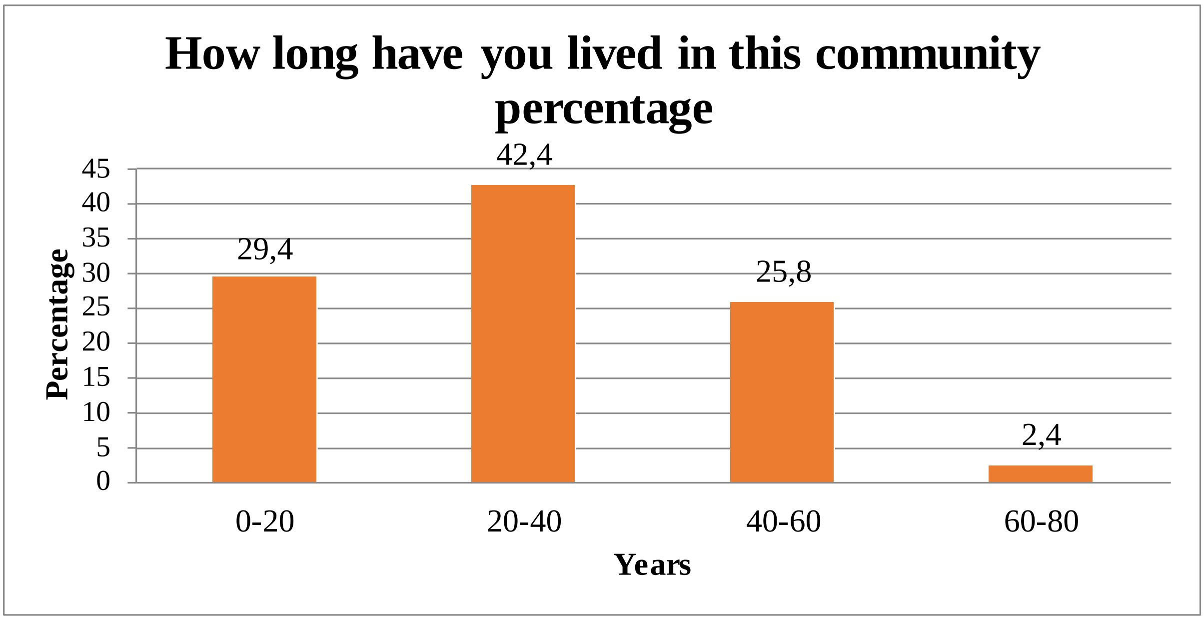
Additionally, 5% of the forested land is transformed to support agricultural product commercialization, indicating the need for strategies that support agribusiness development and related infrastructure. Only 4% of land use changes are attributed to political reasons, suggesting a relatively lower impact on planning decisions compared to other drivers. In relation to the above, agriculture emerges as the predominant driver of land use change in Mbiri ward, suggesting the important role of balancing agricultural expansion with forest conservation and addressing the challenges posed by population growth and commercialization. This information highlights the importance of proactive and strategic land use planning in the context of the observed land use changes.

Plate 2: Previously cleared trees on a farm in Mbiri Ward

Source: Field Survey, 2022.

Plate 2 above illustrates a land within Mirira sub-location, showcasing a significant deforestation. In this image, trees have been deliberately removed to make way for agricultural activities. This land transformation not only affects the natural environment but also necessitates considerations in terms of land use management, conservation efforts, and sustainable development strategies.

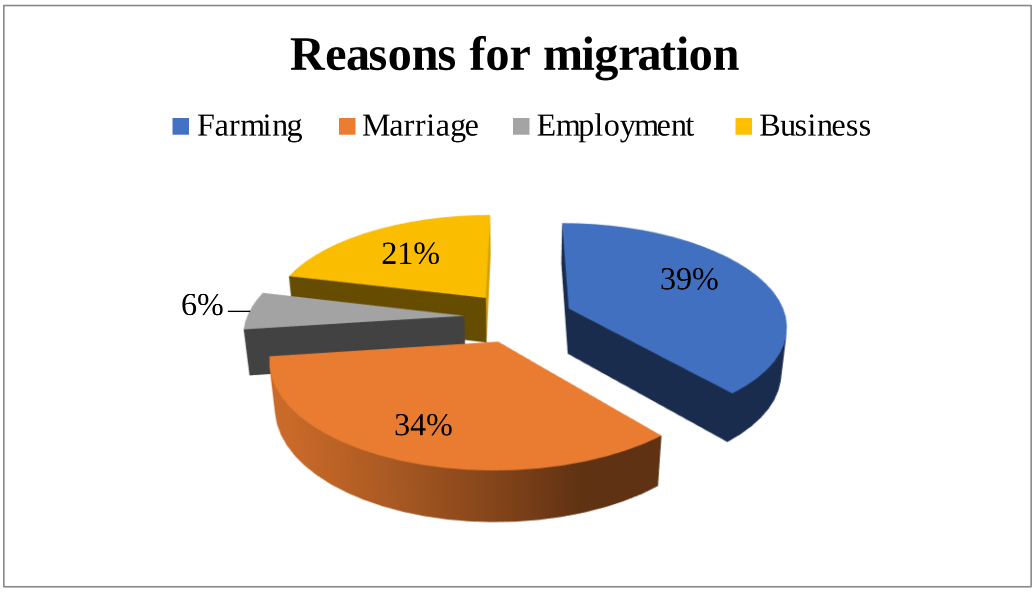
Graph 4: Average life span of respondents in Mbiri ward



Source: Field survey, 2022.

In terms of residential longevity within the Mbiri ward, 42.4% of the interviewed population have lived in the ward for 20 to 40 years. 25.8% have an even longer history, having lived in the ward for 40 to 60 years. Another 2.4% have lived for 60 to 80 years indicating that they witnessed the gradual change of major land use changes that have shaped the physical landscape and spatial dynamics of the ward over the past forty years. In contrast, 29.4% of the ward's residents have migrated from other regions, having resided there for less than 20 years. Understanding the diverse timelines of residency can be essential for tailoring physical planning strategies that balance the needs and perspectives of long-term stakeholders with those of newer arrivals, fostering a comprehensive approach to sustainable development.

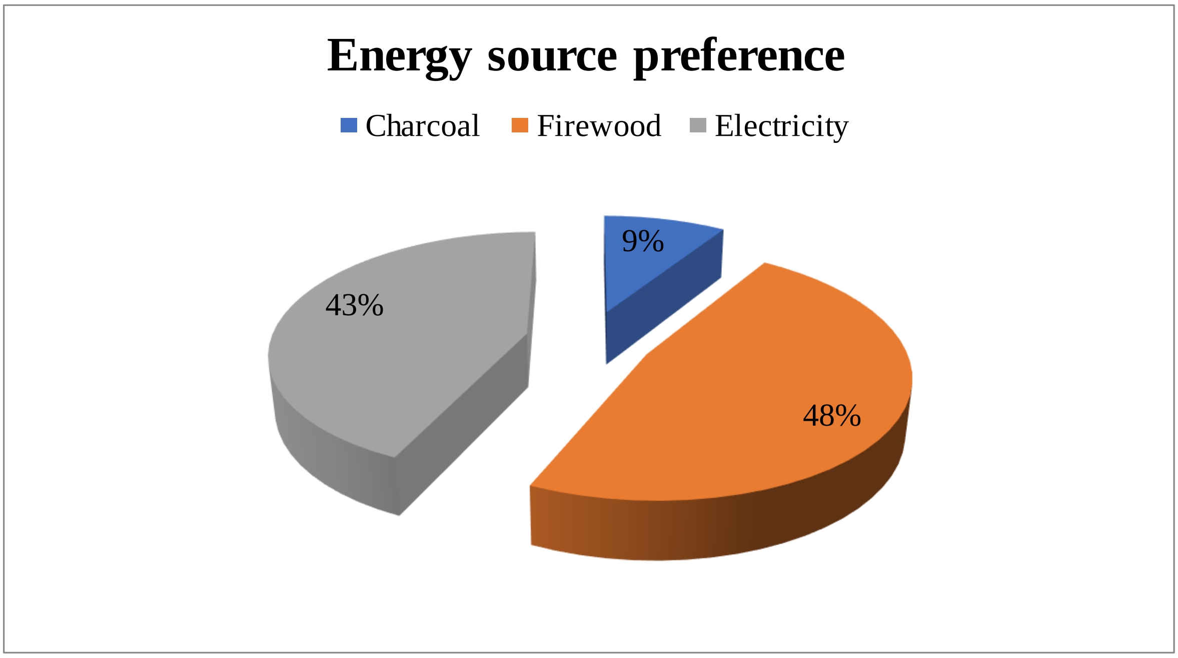
Figure 12: Migration reasons



Source: Field survey, 2022

According to Figure 12, 39% of migrants relocated to Mbiri ward with the intention of engaging in agricultural activities. This influx of individuals seeking agricultural opportunities indicates the need for efficient land allocation, irrigation systems, and support for sustainable farming practices in the ward. 36% of the migration is due to marriage indicating an increase in the residential population. This necessitates the need for housing and related amenities to accommodate the growing households. 21% of the migrants came to Mbiri ward for business purposes indicating a positive contribution to the local economy. This aspect of migration outlines the importance of zoning efforts and infrastructure development to support commercial activities in the ward. Only 6% of the migrants came to seek employment, it still signifies the need for assessing job opportunities, transportation networks, and housing options for these individuals is essential.

Figure 13: Energy preferences



Source: Field Survey, 2022

Figure 13 illustrates the energy dependency patterns of the population in Mbiri ward. It highlights that 48% of the residents rely on firewood, 43% on charcoal, and 9% on electricity as their primary sources of energy. This indicates the critical role of natural resources in fulfilling the energy needs of the community, which has implications for sustainable land use and resource management.

Plate 3: Charcoal burning kiln

A

B

Source: Field Survey, 2022

Plate 3 above, shows an open retort that was utilized in the process of burning charcoal. In contrast, Image 5 shows two Mirira residents in the midst of completing a charcoal-burning kiln. This kiln will be used to burn the wood beneath it. The burning process is executed with restricted oxygen supply to yield charcoal. This particular method typically requires around 14 days or less to produce charcoal, in this context it is necessary to employ resource management and sustainable energy production.

Plate 4: Dry firewood

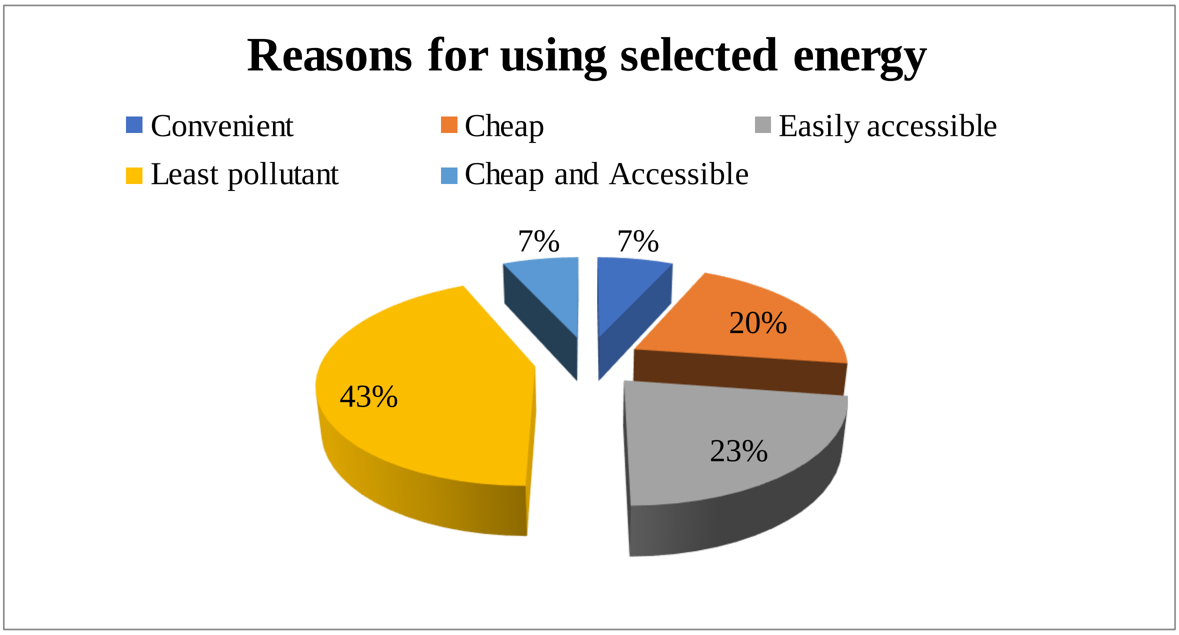
A

B

Source: Field Survey, 2022

Plate 4 (A) and (B) above illustrate the different types of wood harvested from trees to supply energy used for home use in Mbiri ward.

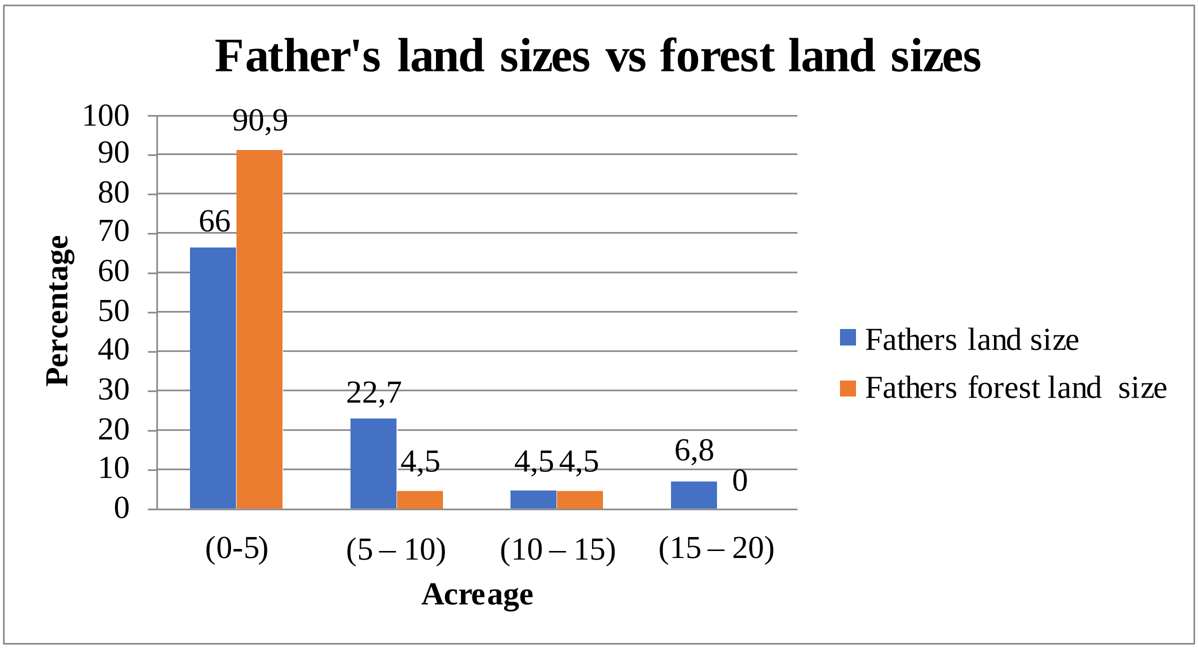
Figure 14: Energy preferences



Source: Field Survey, 2022

As 48% of the respondents rely on firewood, and 43% on charcoal, and 9% on electricity for their energy needs, understanding the reasons for these preferences is essential for effective environmental considerations. Figure 14 illustrates the reasons behind the widespread use of preferred energy sources. Notably, 43% of electricity users choose it due to its minimal environmental impact, 23% and 20% of firewood and charcoal users, respectively, prefer these sources because of their affordability and accessibility. These preferences have implications and they indicate the need for affordable and accessible energy alternatives in the ward.

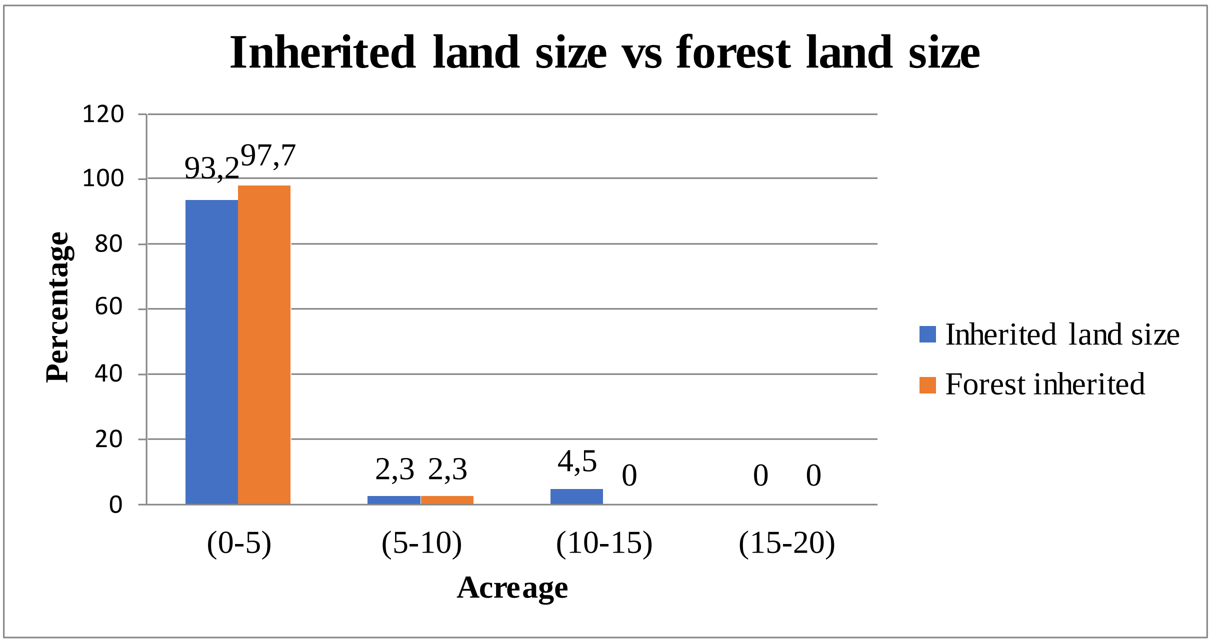
Graph 5: Comparison between land sizes and forest land use sizes



Source: Field Survey, 2022

Graph 5 above illustrates the relationship between the size of fathers' land sizes and the allocation of land for forest use. Among the interviewed respondents, 66% owned land parcels ranging from 0 to 5 acres in size. Within this category, a significant portion of the land, constituting the majority, was designated as forest cover which ensures sustainable land use practices and ecological balance. 22.7% of respondents own land parcels between 5 and 10 acres. In these cases, approximately 4.5% of the land was designated for forest land use, indicating a shift in land allocation practices. Another 4.5% of respondents owned land parcels between 10 and 15 acres. In this category, the same percentage of land was devoted to forest cover and only 6.8% of respondents owned larger parcels of land, between 15 and 20 acres and no portion of these larger land sizes was set aside for forest land use. The above analysis indicates the varying patterns of land ownership and forest land allocation, suggesting the importance of efficient planning to ensure sustainable land use practices and ecological balance.

Graph 6: Comparison between inherited land sizes and forest land use

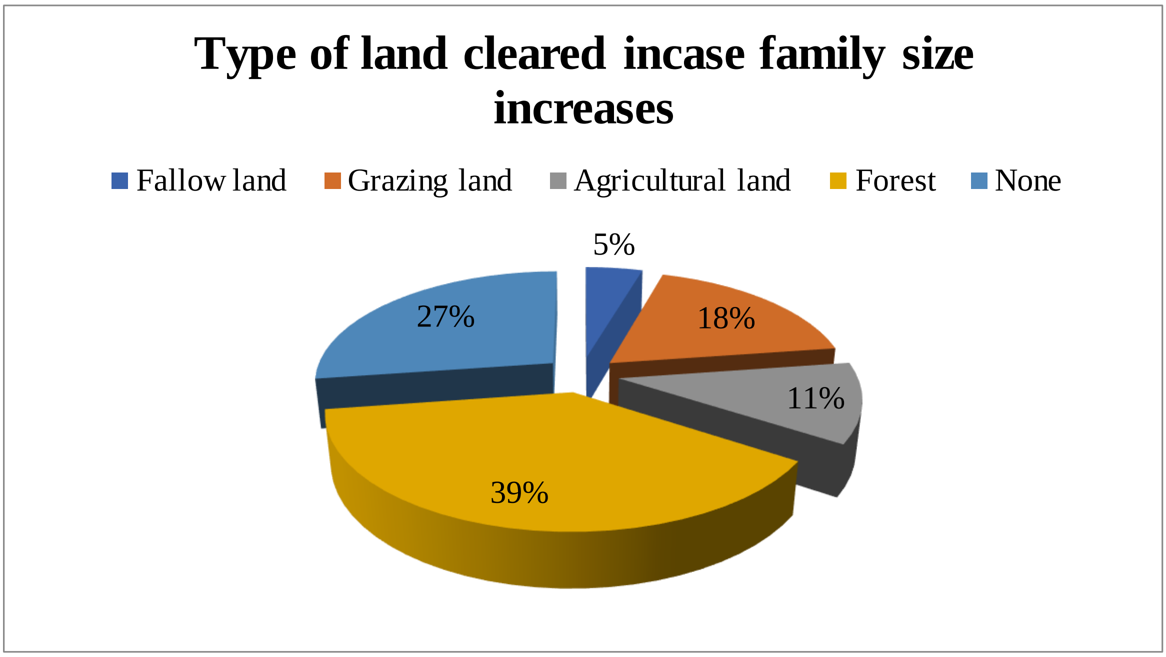


Source: Field Survey, 2022

Graph 6 above shows the relationship between inherited land sizes and forest land sizes. It reveals that 93.2% of individuals inherit land parcels ranging from 0 to 5 acres and 97.7% of this inherited land falls under forest cover. In contrast, a minority, 2.3%, inherit land parcels ranging from 5 to 10 acres, of which only 2.3% is designated for forest land use. Furthermore, 4.5% inherit parcels between 10 to 15 acres, but these do not include any forest cover. In the context of this analysis, there is minimal inheritance of land parcels spanning 15 to 20 acres, a scenario attributed to the current land and inheritance customs in the ward, as well as household family size and composition.

Graph 5 and 6 collectively demonstrate a pattern of diminishing land sizes following inheritance, which in turn leads to reduced allocations for forest land use within inherited properties. The correlation is clear: smaller inherited land sizes correspond to smaller areas designated for forest land, and conversely, larger land inheritances tend to have more substantial forest land allocations. This observation indicates the gradual reduction in forest land sizes over time within the context of due to inheritance practices.

Figure 15: Cleared land for population needs



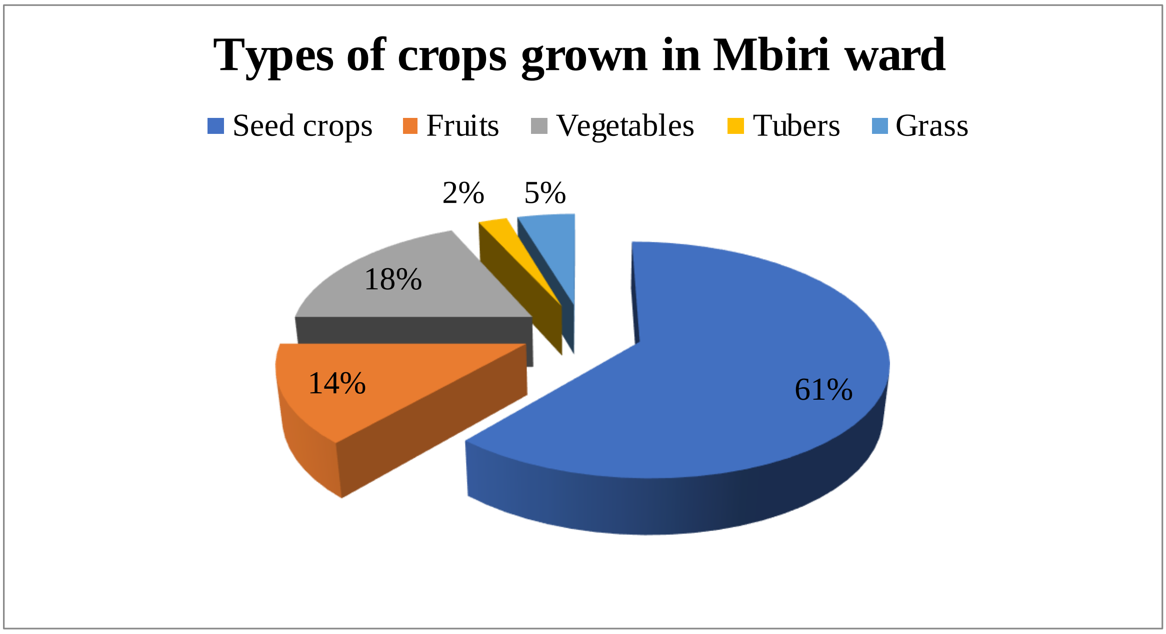
Source: Field Survey, 2022.

Figure 15 illustrates the insights into the land-use preferences of respondents in the occasion of an increase in family members, which has direct implications for family land management. According to the analysis, 39% of respondents expressed their intention to clear forest land to facilitate settlement, highlighting a potential concern for deforestation and its impact on the local environment. 27% of respondents indicated their willingness to utilize fallow land for settlement purposes. This suggests the need of assessing the availability of alternative land for residential use potentially repurposing such land for housing developments.

The analysis also revealed that 18% of respondents would opt to use grazing land for settlement, which may potentially raise issues related to land conflicts and agricultural sustainability. This suggests the significance of land-use zoning and conflict resolution strategies. Moreover, 11% of respondents considered converting agricultural land for settlement, potentially affecting food production and agricultural sustainability. This indicates the need for careful consideration of land conversion policies and agricultural planning within the ward. Only 5% of respondents expressed a preference not to convert any land use for settlement, which indicates a commitment to preserving existing land uses and environmental conservation. This perspective aligns with sustainable land management principles and can inform decisions related to land preservation within Mbiri ward.

The above indicates the relevance of planning in addressing issues related to deforestation, land availability, land conflicts, agricultural sustainability, and environmental conservation within Mbiri. It highlights the importance of informed and sustainable land-use policies and zoning strategies to guide future development in the region.

Figure 16: Crop types in Mbiri ward



Source: Field Survey, 2022

Mbiri ward is located within a predominantly agricultural region. As seen in Figure 16 above, the types of crops cultivated in the region play a crucial role in shaping the ward's land use.

Approximately 61% of the farmers in Mbiri ward are engaged in the cultivation of seed crops. These seed crops, which include maize, beans, French beans, peanuts, rice, and pyrethrum, have a direct impact on land allocation, irrigation systems, and storage facilities within the ward. 18% of the farmers in the ward focus on vegetable cultivation, including kale, okra, spinach, and cabbages. 14% of the farmers in Mbiri ward are involved in fruit cultivation, producing mangoes, avocadoes, tomatoes, oranges, and watermelons. 5% of farmers in the ward specialize in growing grass crops like sugarcane. The cultivation of grass crops often involves large-scale farming practices, which can impact land use, water resource management, and transportation infrastructure. Lastly, only 2% of the farmers in Mbiri ward cultivate tuber plants such as cassava, arrowroots, and sweet potatoes.

Plate 5 below shows various crop types grown in Mbiri ward, these crops include Kales, bananas rice and maize.

Plate 5: Some types of plantations in Mbiri Ward

Kales

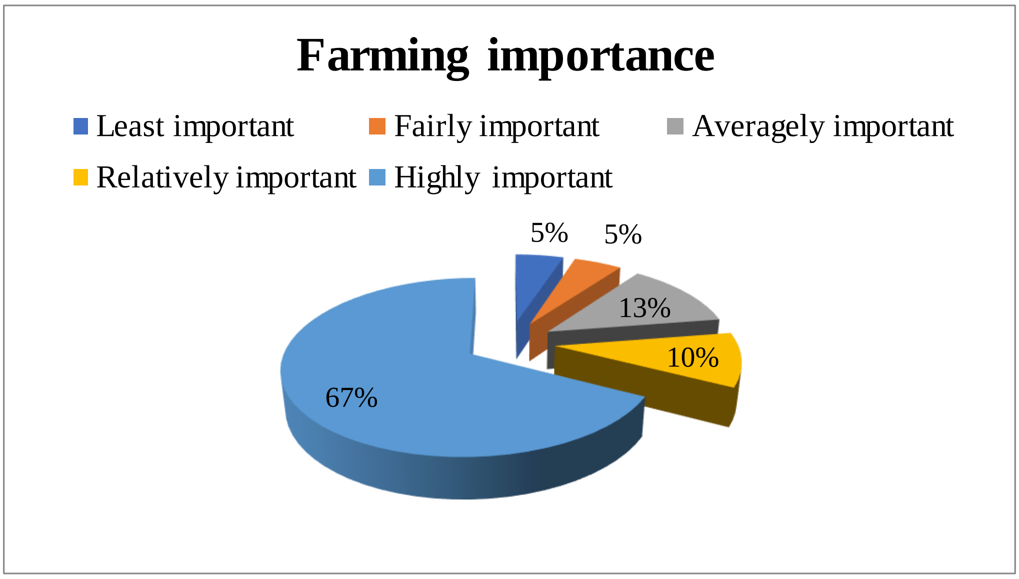
Banana

Rice

Maize and Kales

Source: Field Survey, 2022

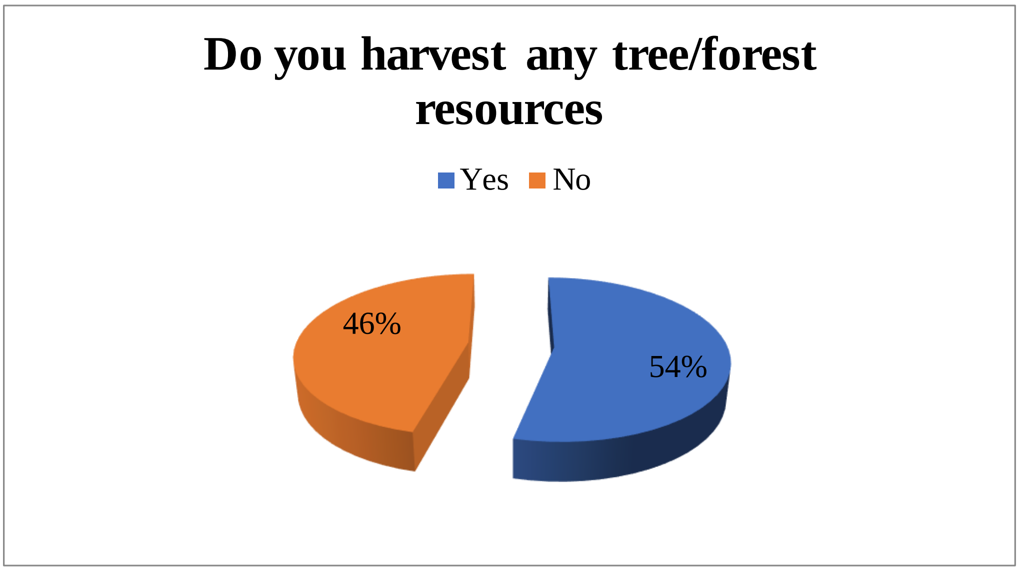
Figure 17: Importance of farming



Source: Field survey, 2022

As shown in figure 17 above, a majority, comprising 67%, consider farming to be of high importance, while 13% of respondents view farming as having average importance, suggesting that while it plays a role in their livelihoods, and 10% perceive farming as relatively important. 5% of respondents regard farming as both fairly and least important to them, highlighting a diversity of economic perspectives within the Mbiri Ward.

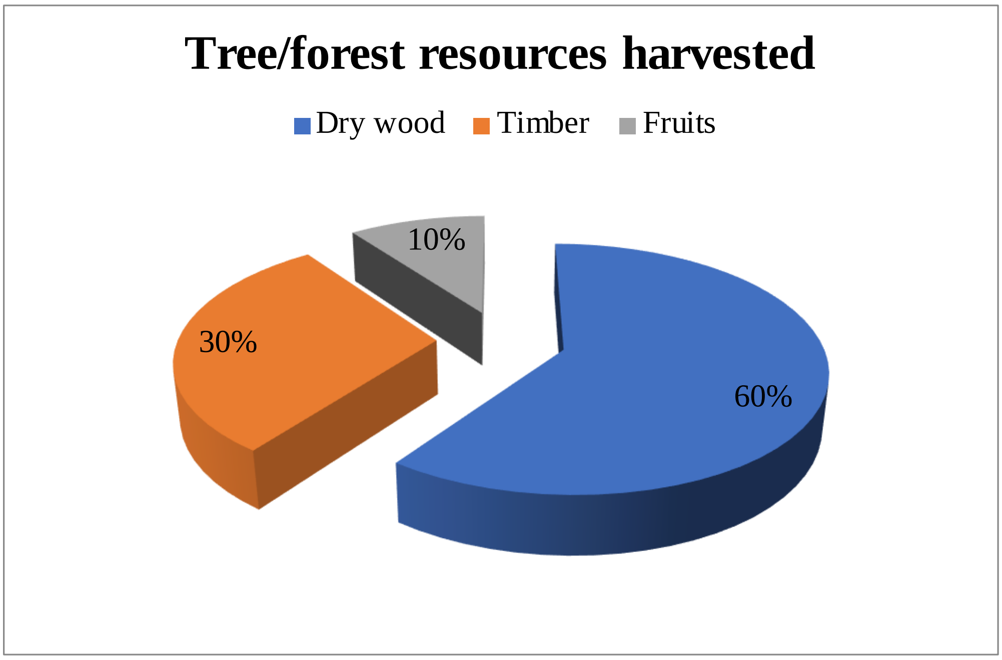
Figure 18: Tree resources harvesting



Source: Field Survey, 2022

Figure 18 shows the percentage of households engaged in harvesting of various forest resources within Mbiri. Among the respondents, 54% actively participate in forest resource harvesting activities, whereas the remaining 46% do not indicating the need for sustainable resource management strategies within Mbiri ward.

Figure 19: Types of forest resources harvested



Source: Field Survey, 2022

Figure 19 shows resource utilization patterns among respondents. 54% engage in the harvesting of forest resources, 60% are involved in the extraction of dry wood, 30% harvest timber, and a smaller proportion of 10% are engaged in fruit harvesting from their trees. These resource utilization trends indicate that forest resources play a significant role in Mbiri's local economy and ecosystem. The images below show some of these resources.

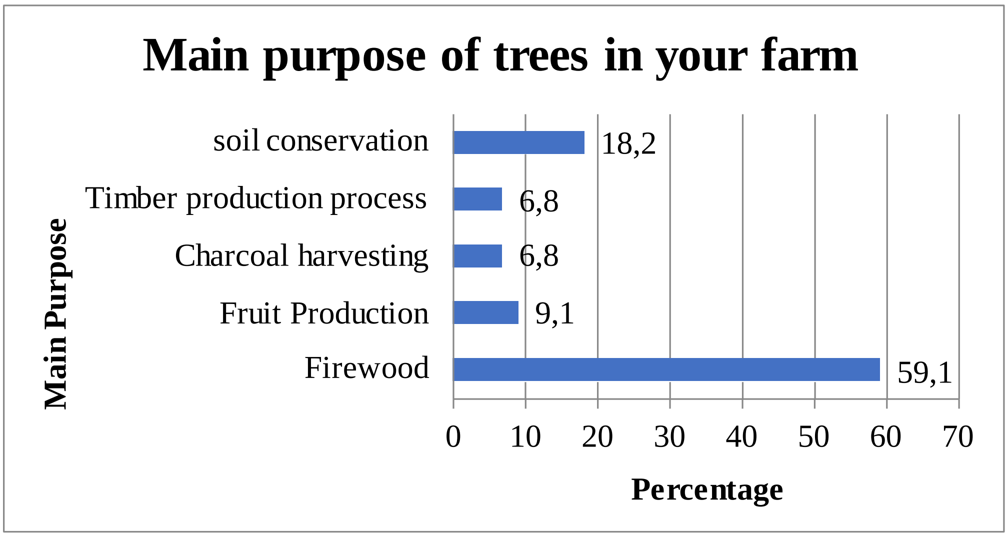
Plate 6: Wood resource utilization in Mbiri Ward

Dry wood (firewood)

Timber poles

Source: Field Survey, 2022

Graph 7: Purposes of trees



Source: Field Survey, 2022

Graph 7 illustrates the primary functions of trees within respondents' land parcels. 59.1% utilize trees for firewood, suggesting their role in meeting their energy needs, 18.2% use trees to conserve soil and mitigate erosion, 9.1% of respondents use trees for fruit production, indicating the potential for agroforestry practices and 6.8% of respondents use trees for both charcoal and timber production, suggesting the need to address management of forest resources within the ward. Plate 7 below show the various tree uses on farms, further indicating the practical relevance of trees in the ward. Some of the ways trees are used in Mbiri ward include use as windbreakers and for fruit provision.

Plate 7: Use of trees in Mbiri Ward

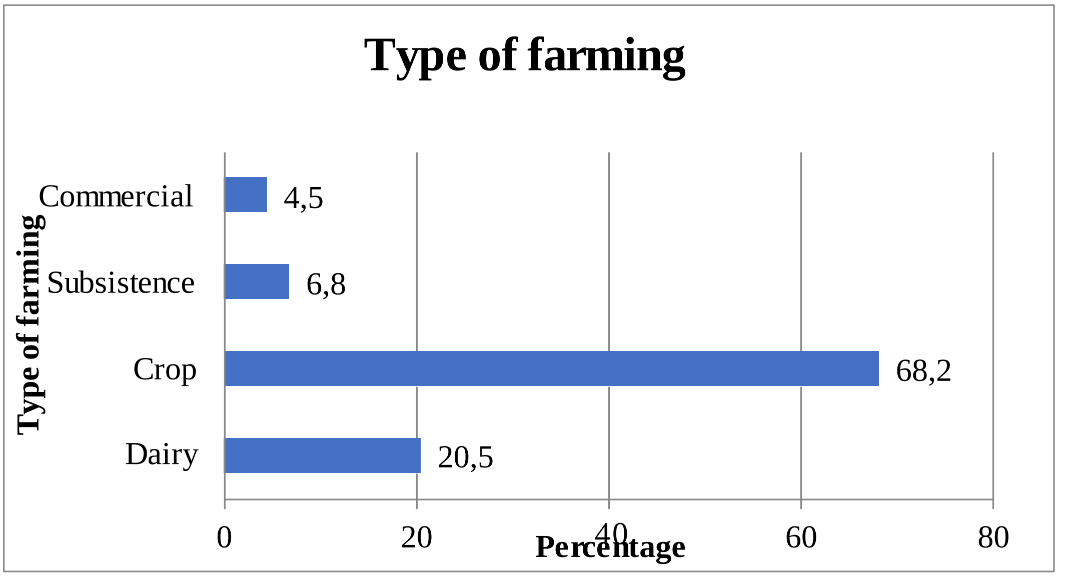
Use of trees as wind breakers

Use of trees for fruit provision

Source: Field Survey, 2022

5.4 Implications of forest land use changes.

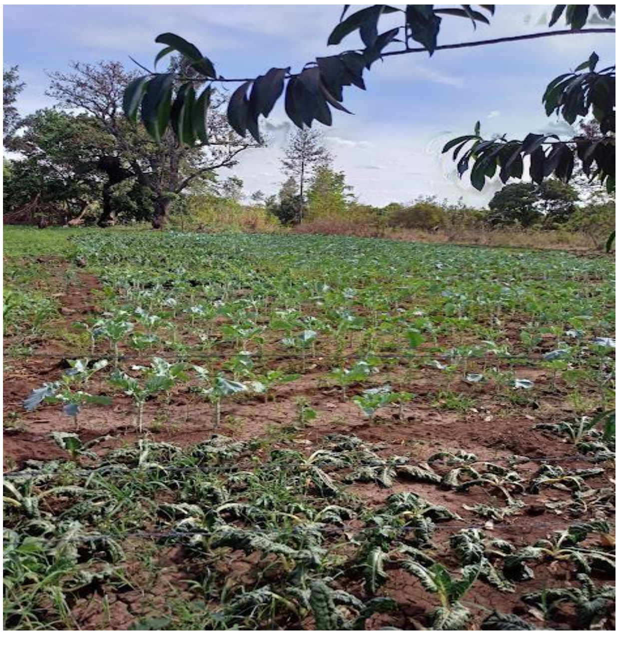
Graph 8: Farming types



Source: Field Survey, 2022

Graph 8 above provides insight into the farming practices engaged in Mbiri ward. The analysis shows that 68.2% of the population in Mbiri engages in crop farming, 20.5% are involved in dairy farming, and 6.8% practice subsistence farming, only 4.5% are engaged in commercial farming. Crop farming is the predominant agricultural activity and it entails the ploughing and tilling of land. Subsistence farming, practiced by 6.8% of the population tends to promote soil erosion and the creation of loose soil, which is susceptible to transport by wind and running water. This soil erosion process has potentially affected not only agricultural productivity but the rivers and water bodies.

Plate 8: Small scale Vegetable farm



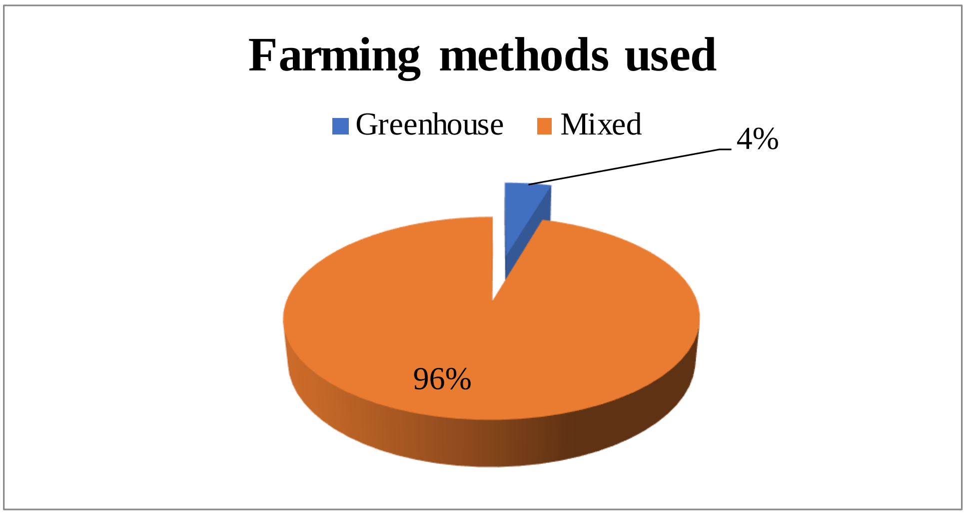
Source: Field Survey, 2022

In plate 8, we observe a vegetable farm that is in close proximity to a river body. The farm appears to have no visible soil conservation methods put in place. This open farmland raises concerns about soil erosion, as the lack of conservation measures makes it more likely for topsoil to be swept away.

This highlights the importance of incorporating soil erosion control techniques for agricultural areas present in Mbiri ward. This would encourage sustainable farming practices and soil conservation efforts to protect the land and the nearby water resources.

There is need for the farmers in the ward to employ soil conservation methods and sustainable water and irrigation techniques that will conserve the top soil.

Figure 20: Farming methods employed



Source: Field Survey, 2022

Figure 20 shows that 96% of the farmers are engaged in mixed farming practices, while 4% are involved in greenhouse farming. The predominance of mixed farming, which comprises of various crop cultivation and livestock rearing, which suggests the need for efficient use of resources and minimizing soil erosion and siltation risks, which is associated with mixed farming.

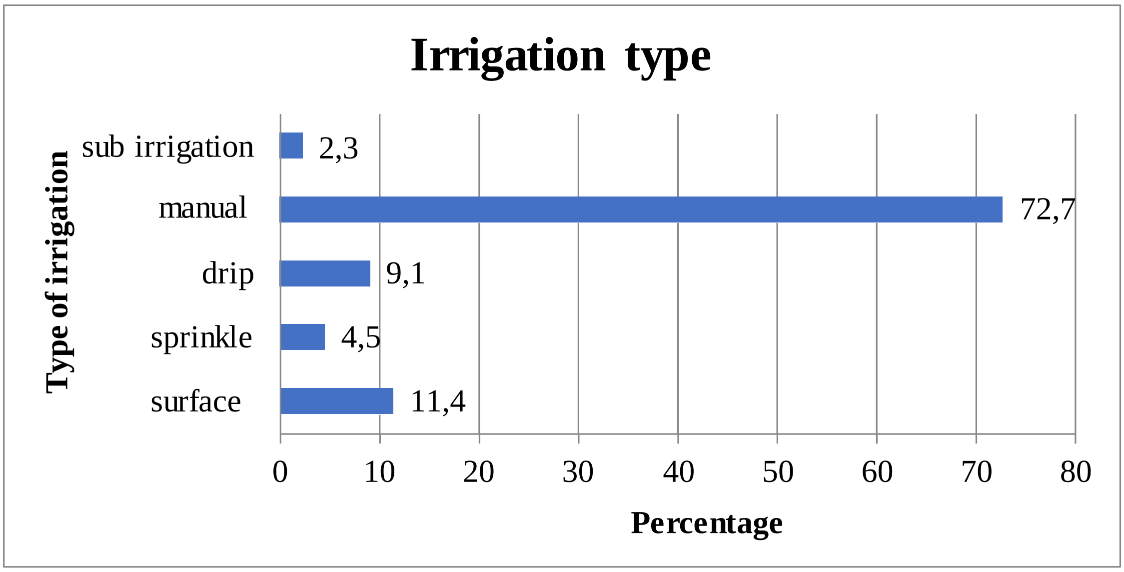
Greenhouse farming, on the other hand, is a more controlled form of agricultural practice. With only 4%of the farmers engaging in greenhouse farming, this indicates the need for infrastructure needs for greenhouse facilities and utility provisions in Mbiri. Additionally, greenhouse farming can be less susceptible to siltation-related challenges as it involves a controlled environment that minimizes soil erosion risks.

Plate 9: Greenhouse farming

Source: Field Survey, 2022

Plate 9 shows a farmer who is engaged in a both traditional farming practices alongside greenhouse farming.

Graph 9: Type of irrigation employed



Source: Field Survey, 2022

Graph 9 above shows 72.7% of farmers in Mbiri rely on manual irrigation methods. Only a smaller percentage of farmers employ the use of different irrigation methods. 11.4% utilize surface irrigation, 9.1% use drip irrigation, 4.5% of farmers use sprinkle irrigation and 2.3% opt for sub-irrigation.

In relation to siltation, it's important to recognize that the irrigation methods influence transportation of sediments and silt into water sources indicating the importance of siltation control measures, such as sedimentation basins or filtration systems, especially when river water is used for irrigation, as depicted in Image 17. These measures help maintain the efficiency and longevity of irrigation infrastructure.

Plate 10 below shows irrigation pipes that are directly sourcing water from river sources, connected to the main pump setup. In this context, the layout and design of such irrigation systems are critical for efficient water distribution and soil management in that it would ensure irrigation pipes are strategically positioned to reach the intended agricultural areas while minimizing water and subsequent soil loss.

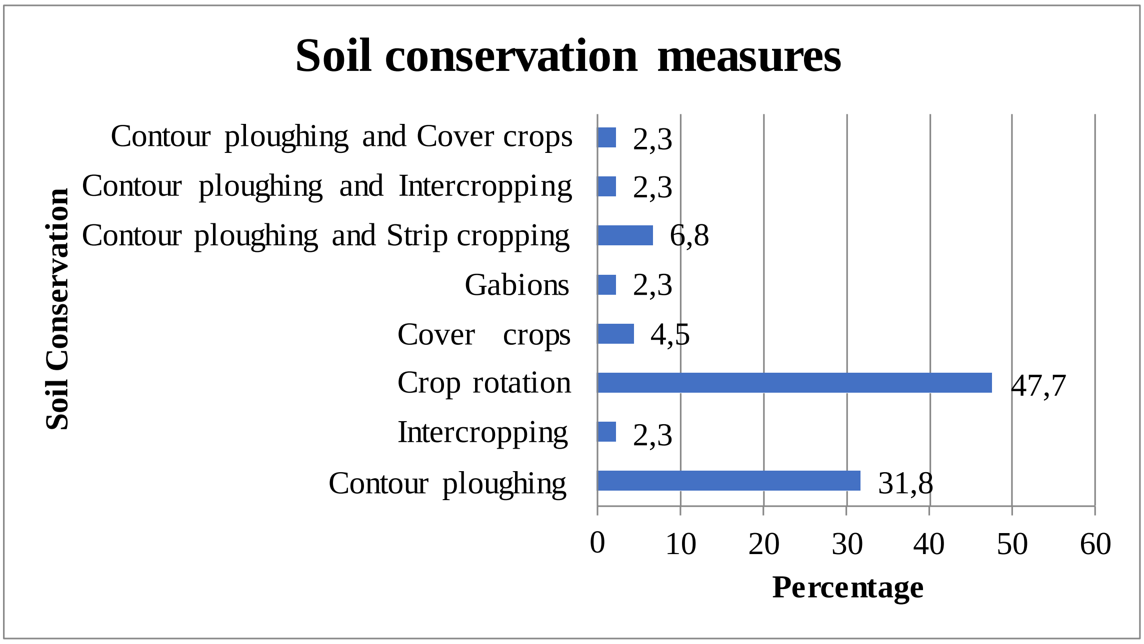
Plate 10: Irrigation methods in Mbiri Ward, along River Tana

Irrigation water pump at River Tana

Irrigation pipes towards River Mathioya

Source: Field Survey, 2022

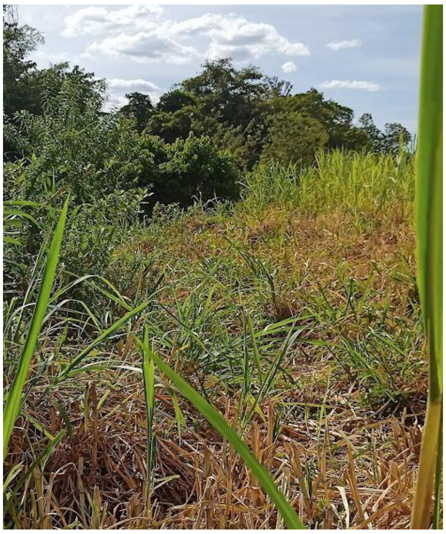
Graph 10: Soil conservation measures



Source: Field Survey, 2022

Graph 10 above highlights the soil conservation measures used by survey respondents. Approximately 47.7% of the interviewed farmers use crop rotation. This practice is crucial for sustainable agriculture and can indirectly influence Mbiri's land use patterns and crop diversification, thereby mitigating soil erosion and reducing siltation risks in the nearby rivers and downstream water bodies. 31.8% of respondents use contour ploughing. 4.5% of the farmers use cover crops, as depicted in image 20, to conserve the soil. Using cover crops directly contributes to siltation prevention by stabilizing top soil and preventing erosion. Some respondents use combined conservation approaches.

Plate 11: Cover crops

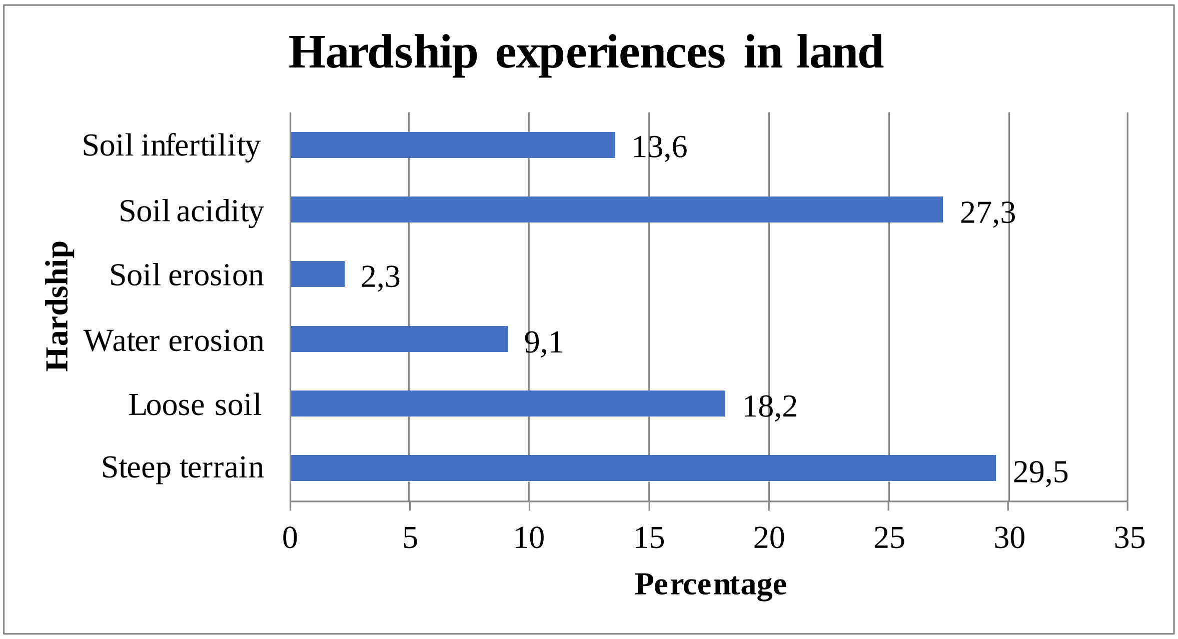


For instance, 6.8% utilize both contour ploughing and strip cropping This combination enhances erosion control and sediment retention in vulnerable areas, reducing the siltation impact on water bodies. 2.3% of respondents use other conservation techniques such as contour ploughing, using cover crops as shown on plate 11, intercropping, building of gabions, and intercropping. These techniques protect the top soils in farms from being swept away during rainy seasons.

The above mentioned methods contribute directly to soil conservation by reducing the rate of erosion in subsequent farms. These methods also indirectly enhance the prevention of siltation into the existing water bodies within Mbiri Ward.

Source: Field Survey, 2022

Graph 11: Hardship experiences related to land usage in the Mbiri ward



Source: Field Survey, 2022

In Graph 11, approximately 29.5% of farmers contend with steep terrain, which not only poses challenges for farming activities and highly contributes to soil erosion. 27.3% faces soil acidity issues attributed to the excessive use of fertilizers. 18.2% of farmers struggle with loose soil, primarily caused by terrain and grazing activities. Loose soil highly contributes to erosion. 13.6% of farmers experience soil infertility due to over cropping and mono-cropping agricultural practices. This has implications on agricultural productivity indicating the need for crop rotation and soil conservation measures. 9.1% of farmers experience water erosion, which is closely related to siltation concerns.

Water erosion can lead to the transport of soil particles into nearby water bodies, causing sedimentation issues that must be addressed in physical planning, especially when considering land use near rivers or streams. 2.3% of the farmers confirm that they encounter soil erosion. Plate 12 provides an image of land near the banks of River Tana, where severe gully erosion has occurred not only affecting land usability but also contributes to siltation in the river as the loose soil is washed into the river.

Plate 12: Soil erosion

Gulley erosion at the bank of River Tana

Farming activities close to River Tana

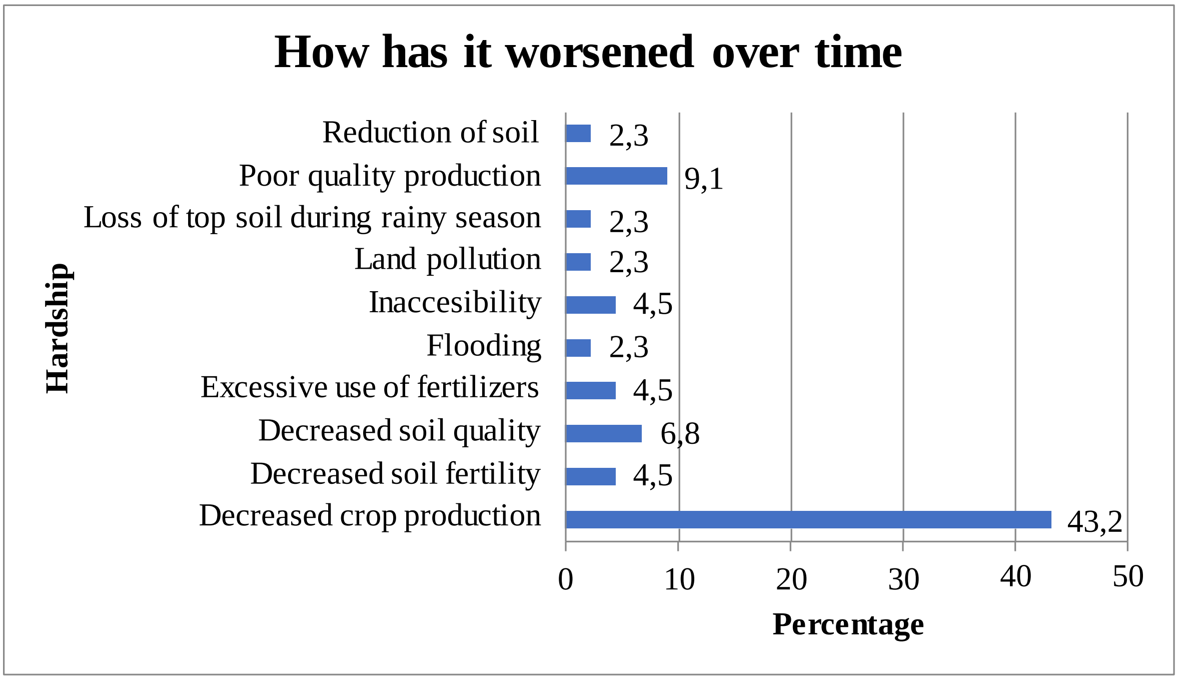
Source: Field Survey, 2022

As shown in plate 12, the farm is situated very close to the river's edge. Geographically, this positioning raises concerns related to erosion. The land exhibits a gentle slope towards the river, which increases the susceptibility to erosion processes. When ploughing activities are carried out, the loose soil becomes vulnerable to displacement, especially during the rainy season when surface runoff is prevalent. This runoff, laden with eroded soil particles contributes to siltation in river Tana.

Plate 13: Sloppy Terrain

Source: Field Survey, 2022

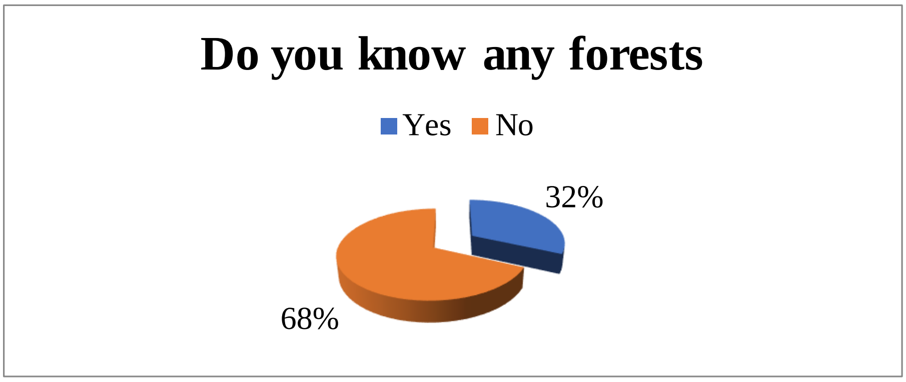
Graph 12: How land-related hardships have worsened over time



Source: Field Survey, 2022

As shown in Graph 12, 43.2% of the farmers interviewed have encountered a decline in crop production indicating issues of food security and as a consequence of decreased crop production, 9.1% of farmers have reported poor-quality harvests indicating the need for soil improvement strategies. 6.8% of respondents have noted a decline in soil quality indicating the consequences for ineffective agricultural practices, making it imperative to consider soil conservation and rehabilitation measures. The rugged terrain, has led to inaccessibility for 4.5% of farmers, in terms of addressing issues of accessibility it is essential to prevent soil erosion that results from poorly planned access routes. 4.5% of farmers have resorted to excessive fertilizer use in response to declining soil fertility suggesting the need for sustainable agricultural practices. In this context, 2.3% of farmers have reported soil reduction, loss of topsoil, land pollution, and flooding challenges. These issues are interconnected and underline the need for planning approaches that incorporate soil conservation, erosion control, and flood management strategies.

Figure 21: Forests in Mbiri ward

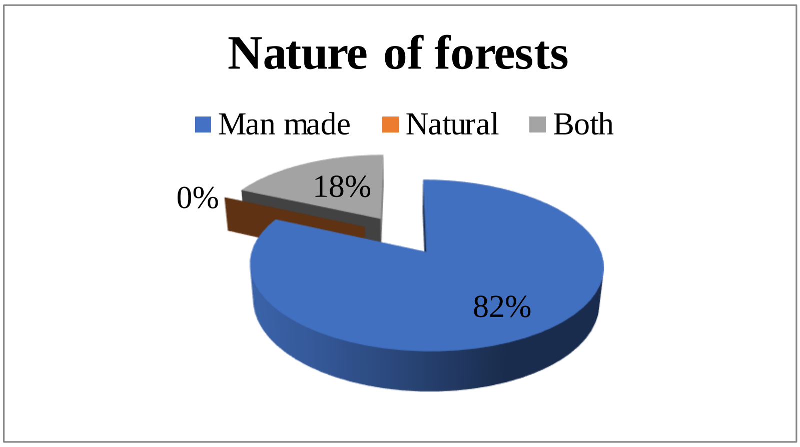


Source: Field Survey, 2022

Figure 21 shows respondents' awareness of forests within the ward. 68% of the respondents demonstrated awareness of the presence of forests in the ward, indicating their recognition of the environmental significance of these forested areas.

Forests serve as natural buffer against soil erosion thereby prevent siltation of rivers and downstream water bodies. 32% of the respondents had limited knowledge of the forests within the ward. This knowledge gap indicates the importance of disseminating information and engaging in educational initiatives in relation to the significance of forests this in turns would aid in mitigating siltation can promote sustainable land use practices.

Figure 22: Nature of forests in Mbiri ward



Source: Field Survey, 2022

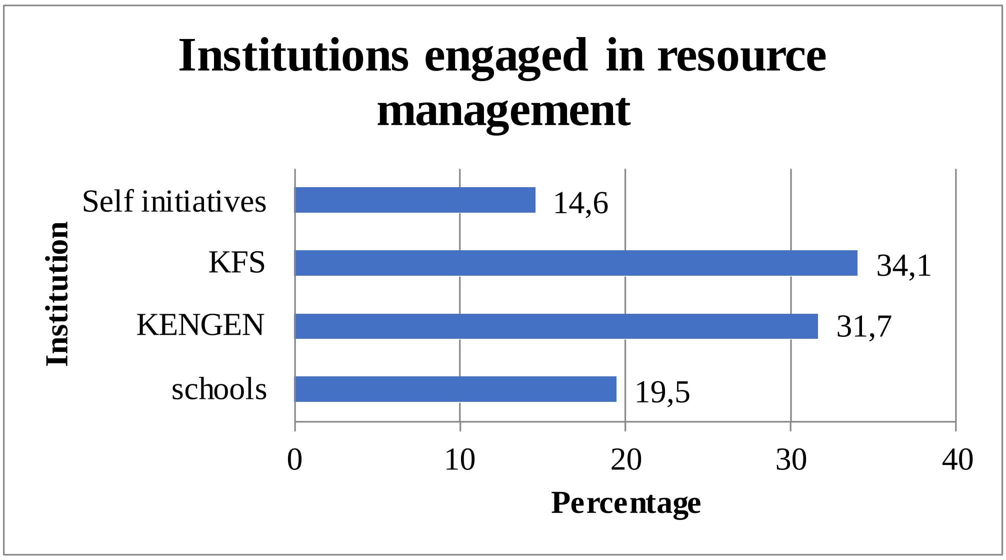
Plate 14: Planted forest

Source: Field Survey, 2022

According to the figure 22, 82% of forests in the Mbiri Ward are planted forests and 18% can be characterized as both natural and artificial. The ward has no significant purely natural forests. In terms of soil conservation efforts, natural forests often have well-established ecosystems that contribute to sediment retention, while artificial forests may require additional management practices to achieve similar siltation control benefits.

Furthermore, the analysis indicates that majority of these forests are locally managed by the families that own them highlighting the significance of community involvement in soil conservation efforts. There is need for the ward to adopt forest management measures to enhance the power of the existing forest cover towards soil conservation.

Graph 13: Forest management institutions in Mbiri ward



Source: Field Survey, 2022

Graph 13 shows the institutions involved in the management of forest resources within Mbiri ward, among these institutions, the Kenya Forest Service (KFS) takes a significant share; overseeing 34.1% of forest resources management in the region, Kenya Electricity Generating Company (KENGEN) plays a crucial role by managing 31.7% of these resources. And, educational institutions actively participate in forest resource management, accounting for 19.5% of the responsibility.

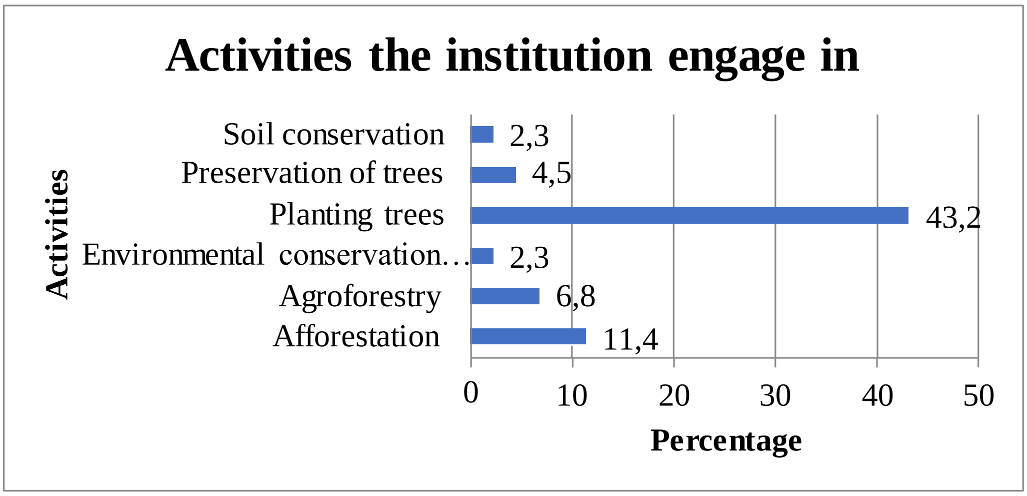
Plate 15: Tree seedlings

Source: Field Survey, 2022

Moreover, 14.6% of forest resource management falls under self-initiated efforts as indicated in plate 15. Each of these institutions plays an important role in addressing conservation-related issues; their activities encompass soil conservation, tree preservation, and tree planting initiatives, environmental awareness campaigns, agroforestry, and afforestation efforts. In the above context, Figure 29 highlights the specific activities undertaken by these institutions, showing their relevance to soil conservation. 43.2% of the institutions engage in tree planting, 11.4% engage in afforestation efforts aimed at increasing forest cover, 6.8% engage in agroforestry practices, and 4.5% of the institutions engage in tree preservation efforts indicating commitment to conserving existing forest resources.

Soil conservation and awareness initiatives each constitute 2.3% of their activities, indicating the recognition of the importance of soil conservation and environmental consciousness.

Graph 14: Management activities



Source: Field Survey, 2022

Plate 16: Agroforestry

Figure 30 shows a range of activities undertaken by various institutions, highlighting their significance. These activities include practices like soil conservation measures, tree preservation, tree planting, environmental conservation, agroforestry, and afforestation. Plate 16, shows agroforestry practices employed in Mbiri.

This aligns with sustainable planning by encouraging soil stability, reducing erosion, and promoting biodiversity.

Source: Field Survey, 2022

5.5 Forest land use planning and management interventions.

The most significant land use change pattern observed in Mbiri ward relates to the conversion of forested land into other land uses, primarily agricultural. Mbiri ward, being located within the upper Tana Catchment, is of importance due to its sensitivity, as it serves as a vital source for both Tana River and Masinga Dam. Within the Ward itself, there is a noticeable decline in tree cover, accompanied by an increase in agricultural activities. This conversion creates pressure on the soil and land resource in the catchment area, resulting in increased siltation of river bodies. This phenomenon mirrors the broader challenges faced in the entire upper Tana Catchment and other water catchment area, where similar trends of soil erosion and declining forest cover threaten the overall quality of water resources. Siltation, a direct consequence of soil erosion, poses a significant concern as it leads to the accumulation of sediments in water bodies impairing water quality, reducing storage capacity of dams, and hindering the reliable supply of clean water.

To address these issues, a multifaceted approach is required in that the interventions must encompass forest management practices to preserve and restore tree cover, sustainable agricultural management to mitigate soil erosion, and riparian land management to protect water systems from siltation. Additionally, the enforcement of relevant policies and regulations is essential to ensure responsible land use practices and the preservation of water resources.

5.5.1 Forest land use management

i. Zoning of production and protection Areas - Zoning plays a crucial role particularly in addressing issues of siltation. Production zones encompass lands designated for commercial timber production, agroforestry commodities, grazing pastures, and other forest land uses. Effective zoning helps to prevent soil erosion and sediment runoff into water bodies, reducing siltation in water systems. Protected areas, such as forest parks and reservations, also contribute to siltation control by preserving critical ecosystems that filter sediments from runoff.

ii. Enhancing security, land tenure, and accessibility to village forests - Secure land tenure reduces land degradation risks associated with land disputes and unregulated land use. Improved accessibility to resident forests allows for better management and conservation practices that mitigate siltation impacts on local water systems.

iii. Encouraging participatory land use planning - this approach helps identify and address siltation issues caused by unsustainable land practices. By involving various stakeholders, including local communities, in decision-making, planners can implement measures to prevent sedimentation.

iv. Forest management in villages - Granting communal land use rights to residents for forest use and individual use rights for private tree plantations can help in controlling siltation. Properly managed forests can act as buffers against soil erosion and sedimentation, preserving water quality in nearby water bodies.

v. Agricultural land use consolidation – it is important to assess agro-ecological potential and available land for cultivation to help in identification of agricultural consolidation zones. This will help in identifying areas more susceptible to siltation. Encouraging farmers to adopt consolidated farming practices so as to minimize soil erosion and sediment runoff, thereby reducing siltation in nearby water sources.

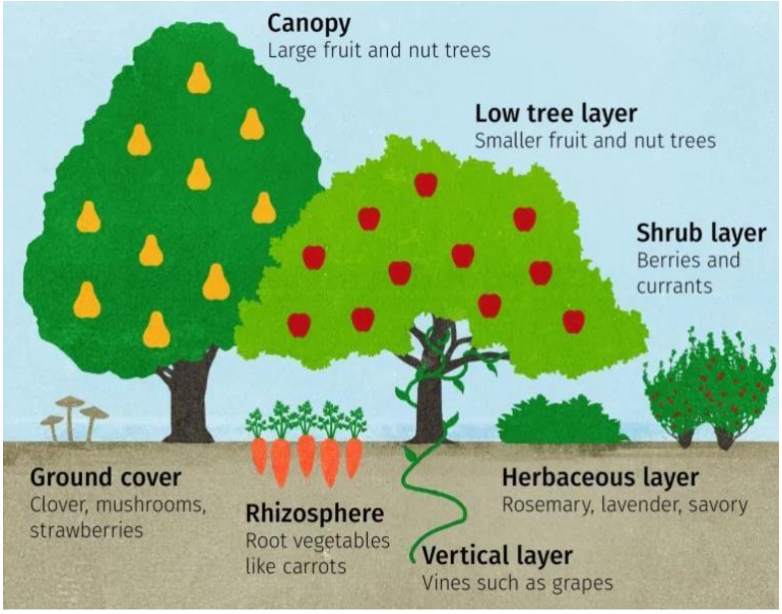
5.5.2 Agricultural Land Management

i. Given the pressing issue of soil erosion, land use recommendations include strategies like afforestation, natural regeneration, and conservation measures. Specifically, afforestation is advised for hilly terrain prone to soil erosion. Implementing tree planting strategies to restore vegetation is essential for the control of soil erosion, which in turn plays a vital role in mitigating siltation in water bodies and preserving valuable soil resources in this area.

ii. In relation to siltation concerns, areas with low or very low levels of existing soil erosion and potential erosion should be allocated for intensive agriculture or moderately intense agriculture, depending on their land capabilities. In areas characterized by moderate soil erosion, agricultural activities should be managed, coupled with soil conservation measures to either maintain or enhance soil productivity. These strategies aim to minimize soil erosion and reduce the downstream siltation.

iii. To combat soil erosion, intense agricultural activities should be prohibited on slopes exceeding 40 degrees and beyond the 1500-meter contour. The implementation of soil conservation measures is important in high-altitude farming areas, as it directly impacts soil erosion. Additionally, it is important to integrate training and extension programs for upland farmers, encompassing measures for soil conservation, proper water management, and controlled use of fertilizers and pesticides.

Plate 17: Food forest design



Source: Cowichan Green Community

iv. Adoption of the food forest design – as shown in plate 17, a food forest, as defined by Kamran, represents a biodiverse multifunctional agroforestry system characterized by distinct plant layers based on their height, including shrubs, trees, and ground cover. This approach mimics the stability of natural forest ecosystems. A food forest not only ensures sustainable food production and supports farmer livelihoods but also plays a pivotal role in maintaining adequate forest cover. This, in turn, contributes significantly to soil conservation.

5.5.3 Riparian land management

i. Riparian Buffer Zones - the preservation of riparian buffer zones is vital as these zones, aid in preventing soil loss and maintaining water quality, and should be therefore treated as no-harvest zones. Any destruction of vegetation within these zones, whether due to development or other reasons, should be addressed by implementing strict recovery measures, using only native species. The preservation of these buffer zones is directly related to siltation control and the overall health of river ecosystems.

ii. Bamboo Planting for Soil Erosion Control - the enforcement of the 2019 national bamboo policy holds significant importance as it promotes the strategic planting of bamboo trees along river banks. Bamboo, known for its robust root system, plays an important role in reducing soil erosion. Additionally, bamboo planting contributes to the replenishment of water resources, making it an environmentally sustainable approach for natural resource management. Moreover, bamboo's ability to adapt to changing climate conditions is important in the planning of resilient and climate-responsive landscapes.

5.5.4. Policy enforcement

The formulation and enforcement of comprehensive and consistent policies that prohibit activities leading to the degradation of catchment land and forests are crucial in areas prone to siltation. These policies serve as a foundation for sustainable land use management, reducing the risk of soil erosion and sediment deposition in water bodies.

Monitoring and Evaluation - the identification of degraded catchment areas is significant. Through careful monitoring and the enforcement of relevant laws against offenders, it becomes possible to mitigate the adverse effects of siltation. Moreover, implementing reforestation initiatives within these catchments not only aids in ecological restoration but also plays a pivotal role in controlling soil erosion and sedimentation, thereby safeguarding water bodies and optimizing land use planning strategies.

5.5.5 Institutional measures

The following institutions, including NEMA, KFS, KENGEN, WARMA, and TARDA, should collectively adopt and enforce the following measures for siltation control:

i. Vegetated Buffer Zones - these institutions should mandate the establishment of vegetated buffer zones around dams and along riverbanks, encompassing suitable indigenous tree species. These zones play a critical role in preventing siltation by stabilizing soil and reducing erosion. Additionally, they should ensure approved direct access points to rivers upstream and downstream of dams, aligning with physical planning guidelines.
ii. Silt Harvesting - Silt harvesting should only be permitted in specific areas, such as sand interception dams. This restricts silt extraction activities to designated zones, thereby minimizing the disruptive impact on the landscape.
iii. Check Bunds - Institutions should identify streams contributing the most silt to dams and incorporate check bunds. These bunds, constructed upstream of tributaries, effectively manage silt load sedimentation, ensuring cleaner water reaches the main dam.
iv. Sediment Routing - Sediment routing techniques, including the use of by-pass channels/tunnels and sluicing, should be integrated into dam design and operation. By incorporating such methods, planners can mitigate sediment deposition issues, ensuring the long-term functionality of dams while aligning with siltation control strategies.
v. Sediment Redistribution and Removal - Hydraulic and mechanical methods, like high- pressure water flows and empty flushing, can be employed to maintain dam capacity. These techniques directly relate to managing the physical infrastructure's performance. Empty flushing, involves the drawing down or full emptying of dams, should be considered a periodic maintenance activity in physical planning. This process helps dislodge accumulated detritus from the dam's bottom, facilitating the efficient management of siltation issues.
vi. Mechanical Excavation - Mechanical dredging, a method for removing silt from dam bottoms without lowering water levels, should be incorporated. This approach allows for the targeted removal of sediments, preserving the dam's operational capacity.
vii. Capture Structures - Capture structures like check dams and retention basins should be integrated to serve as proactive measures to capture silt upstream of dams, enhancing siltation control efforts.

Incorporating these measures into the planning and management of dam-related infrastructure not only ensures the sustainability of these structures but also promotes environmental conservation and siltation control as integral components of the development process.

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter provides an overview of the research findings pertaining to changes in forest land cover within Mbiri ward spanning the last four decades. It also covers the drivers of these changes and their implication to Masinga dam. The chapter also recommends forest land use planning and management strategies, and conclusions of the research.

6.2 Research Conclusions

6.2.1 Changes in Forest Land Covers in Mbiri Ward over the Last 40 Years

The field survey conducted reveals notable shifts in forest land use between 1980 and 2021, marked by an increase in urban development, fallow lands, and agricultural activities, while forest land use and vegetation cover have experienced a decline. Forest cover has gradually dwindled to accommodate expanding agricultural practices, a trend acknowledged by more than 60% of the respondents who expressed concern about the diminishing forest cover and the necessity for effective management solutions.

6.2.2 Drivers of Forest Land Use Change in Mbiri Ward

Respondents identified several key drivers behind the changes in forest land use within the Mbiri ward, including population pressure, agricultural activities, political considerations, and the pursuit of livelihoods. To fulfil these needs, forests have been extensively cleared, leading to the extraction of forest resources for sustenance and energy, ultimately resulting in a decline in forest land utilization.

6.2.3 Implications of Forest Land Use Changes on Masinga dam

The consequences of these land use changes extend to environmental deterioration, land and soil degradation, and pollution, largely stemming from inadequate agricultural and conservation practices. The agricultural activities, in particular, contribute to a higher sediment load, which subsequently finds its way from the catchment area into the rivers, exacerbating issues related to siltation.

6.2.4 Forest Land Use Planning and Management Interventions

Efforts to address these challenges encompass a range of planning and management interventions, such as forest management, agricultural management, riparian land management, and policy enforcement. These strategies include afforestation, natural regeneration, protection measures, regulated agriculture, prohibitions on slope cultivation, adoption of food forest designs, comprehensive land management policies, ongoing monitoring and evaluation of catchment areas, legal enforcement against offenders, zoning for production and protected areas, village forest management, and engagement with multiple stakeholders.

6.3 Recommendations

The following recommendations emerge from the research findings and are essential for mitigating the impact of forest land use changes, addressing siltation concerns, and ensuring sustainable development.

6.3.1 Changes in Forest Land Covers in Mbiri Ward over the Last 40 Years

i. Zoning of production and protection areas.
ii. Enhancement of land security, tenure, and access to village forests and land resources
iii. Promotion of afforestation, natural regeneration, and protection of steeply sloped lands.
iv. Encouragement of intensive agriculture in fairly flat areas while restricting agriculture in sloppy areas with existing and potential soil erosion.

6.3.2 Drivers of Forest Land Use Change in Mbiri Ward

i. Prohibition of cultivation on slopes exceeding 40 degrees and elevations above 1500 meters.
ii. Adoption of a food forest design.
iii. Promotion of agricultural land use consolidation to enhance agricultural productivity.

6.3.3 Implications of Forest Land Use Changes on Masinga dam

i. Establishment of riparian buffer zones and other ecological buffers.
ii. Identification and rehabilitation of degraded catchment regions, coupled with activity monitoring and legal actions against offenders, and extensive reforestation efforts.

6.3.4 Forest Land Use Planning and Management Interventions

i. Implementation of participatory land use planning.
ii. Strengthening forest management practices in villages.
iii. Strict enforcement of the 2019 national bamboo policy.
iv. Formulation of comprehensive and consistent policies prohibiting activities that degrade catchment land and forests.
v. Implementation of institutional measures to control sedimentation, including dredging, sediment redistribution, upstream sediment capture, and the use of vegetated buffer zones around the dam.

References

Allaway, J., & Cox, P. M. J. (1989). Forests and competing land uses in Kenya. *Environmental Management*, *13*(2), 171–187. https://doi.org/10.1007/bf01868364

Briassoulis, H. (2019). *Analysis of Land Use Change: Theoretical and Modeling Analysis of Land Use Change: Theoretical and Modeling Approaches Approaches*. https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1000&context=rri-web-book

Bufebo, B., & Elias, E. (2021). Land Use/Land Cover Change and Its Driving Forces in Shenkolla Watershed, South Central Ethiopia. *The Scientific World Journal*, *2021*, 1–13. https://doi.org/10.1155/2021/9470918

Buhr, W. (2003). *(PDF) What is infrastructure?* ResearchGate. https://www.researchgate.net/publication/24130529_What_is_infrastructure#fullTextFileContent

Bunyasi, M., Onywere, S., & Kigomo, M. (2013). Sustainable Catchment Management: Assessment of Sedimentation of Masinga Reservoir And its Implication on the Dam's Hydropower Generation Capacity. *International Journal of Humanities and Social Science*, *3*(9). http://www.ijhssnet.com/journals/Vol_3_No_9_May_2013/16.pdf

FAO. (2012). *FRA 2015 Terms and Definitions Forest resources Assessment Working Paper 180*. http://www.fao.org/3/ap862e/ap862e00.pdf

Geertsma, R., Wilschut, L., & Kauffman, J. (2011a). *Baseline Review of the Upper Tana, Kenya* (W. Critchley & E. Mollee , Eds.). https://core.ac.uk/download/pdf/29246329.pdf

Geertsma, R., Wilschut, L., & Kauffman, J. (2011b). *Green Water Credits Report 8*. https://core.ac.uk/download/pdf/29246329.pdf

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. https://doi.org/10.1080/02626667.2013.774090

Hydrocoop. (2013, August 16). *Dams With Significant Siltation Problems - Dam Engineering*. Dams, Piano Keys Weirs, Tidal Energy & Energy Storage. http://www.hydrocoop.org/dams-with-significant-siltation-problems/

Jacobs, J., Srinivasan, R., Kaitho, R., & Stuth, J. (n.d.). *Exploring the Potential Impact of Reforestation on the Hydrology of the Upper Tana River Catchment and the Masinga Dam, Kenya* . https://medcraveonline.com/IJH/IJH-03-00163.pdf

Kamran, S. (2022). *Designing Food Forest*. https://www.researchgate.net/publication/357974909_Designing_Food_Forest

Kasper, E. (2015). *A Definition for Infrastructure -Characteristics and Their Impact on Firms Active in Infrastructure*. https://mediatum.ub.tum.de/doc/1239467/1239467.pdf

Keely, C. (2014). *Land Use and Energy: Connecting the Dots to Enhance Communities Why Do Land Use and Energy Matter?* https://extension.unh.edu/resources/files/Resource004822_Rep6855.pdf

Kihagi, J. (2000). *LAND USE CHANGES IN THE LAKE NAKURU CATCHMENT ^Implications on Environmental Plan and Management. *RQBI*. http://erepository.uonbi.ac.ke/bitstream/handle/11295/96158/Kihagi_Land%20use%20changes%20in%20the%20lake%20Nakuru%20catchment:%20implications%20on%20environmental%20planning%20and%20management.pdf?isAllowed=y&sequence=1

Kitheka, J. U. (2019). The effect of rainfall variability and landuse/land cover change in a small tropical river basin in Kenya. *International Journal of Hydrology*, *3*(1). https://doi.org/10.15406/ijh.2019.03.00163

KNBS. (2019). *Kenya Population and Housing Census: Volume II i*. http://housingfinanceafrica.org/app/uploads/VOLUME-II-KPHC-2019.pdf

Knudsen, A. (1995). *Living with the Commons: Local Institutions for Natural Resource Management*. https://core.ac.uk/download/pdf/59168453.pdf

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, *108*(9), 3465–3472. https://doi.org/10.1073/pnas.1100480108

LAND COVER CLASSIFICATION SYSTEM. (n.d.). Www.fao.org. Retrieved February 24, 2021, from http://www.fao.org/3/x0596e/x0596e01e.htm

Langat, P. K., Kumar, L., Koech, R., & Ghosh, M. K. (2019). Monitoring of land use/land-cover dynamics using remote sensing: a case of Tana River Basin, Kenya. *Geocarto International*, *36*(13), 1–19. https://doi.org/10.1080/10106049.2019.1655798

Maingi, J. (1998). *Land use and vegetation change in response to river basin development in the lower Tana Basin of Eastern Kenya Item Type Dissertation-Reproduction (electronic); text* [Dissertation]. https://repository.arizona.edu/bitstream/handle/10150/191228/azu_td_hy_e9791_1998_377_sip1_w.pdf?sequence=1&isAllowed=y

Mama, C., & Okafor, F. (2011). SILTATION IN RESERVOIRS. *Nigerian Journal of Technology*, *30*(1).

Martin, M., & Bunyasi, M. (2012). Vulnerability of Hydro-Electric Energy Resources in Kenya Due to Climate Change Effects: The Case of the Seven Forks Project. *Journal of Agriculture and Environmental Sciences*, *1*(1). http://jaesnet.com/journals/jaes/Vol_1_No_1_December_2012/4.pdf

Mitchell, D., Buxton, M., & Budge, T. (2004). *TS14.2 Assessing the Role of Land Use Planning in Natural Resource Management FIG Working Week*. https://fig.net/resources/proceedings/fig_proceedings/athens/papers/ts14/TS14_1_Mitchell_et_al.pdf

Mogosi, D. (2015). *Assessment of Land Use Changes and Its Effect on Stream Discharge in Nanyuki River Watershed* [Thesis]. https://www.grin.com/document/378665

Muhel, K., Skov, I., & Mathiesen, B. (2017). *MSc in Engineering Sustainable Cities MASTER'S THESIS Synergies towards a renewable energy system in Cape Verde - the case of informal settlements of the capital city, Praia*. https://projekter.aau.dk/projekter/files/260119885/Kata_Muhel_MasterThesis_SusCi2017.pdf

Muranga County Assembly. (2018). *MURANGA COUNTY INTEGRATED DEVELOPMENT PLAN 2018-2022*. Https://Assembly.muranga.go.ke/Lib.php?Com=5&Com2=40&Res_id=1016. https://assembly.muranga.go.ke/lib.php?com=5&com2=40&res_id=1016

Mutaqin, D. (2016). *Munich Personal RePEc Archive An overview of theoretical and empirical studies on deforestation*. https://mpra.ub.uni-muenchen.de/70178/1/JIDC_22-2_107.pdf

Mwenda Ntarangwi, & Ingham, K. (2019). Kenya - Transportation and telecommunications. In *Encyclopædia Britannica*. https://www.britannica.com/place/Kenya/Transportation-and-telecommunications

National Forest Policy. (2014). *National Forest Policy*. http://www.kenyaforestservice.org/documents/Forest%20Policy,%202014%20(Revised%2020-2-2014).pdf

National Research Council. (2002). Read "Riparian Areas: Functions and Strategies for Management" at NAP.edu. In *www.nap.edu*. https://www.nap.edu/read/10327/chapter/7#307

Oloo, W. (2010). *SECOND NATIONAL COMUNICATION TO UNFCCC CLIMATE CHANGE MITIGATION MEASURES AND OPTIONS Land Use, Land Use Change and Forestry*. https://fornis.net/sites/default/files/documents/land%20use%20change%20and%20climate.pdf

Physical Planning Department Ministry of Lands and Physical Planning. (2016). http://www.kpda.or.ke/documents/Policies/Draft%20National%20Land%20Use%20Policy%20May%202016.pdf

Postle-Floyd, H., & Erfani, T. (2017). Reliability and Robustness Analysis of the Masinga Dam under Uncertainty. *Climate*, *5*(1), 12. https://doi.org/10.3390/cli5010012

Republic of Kenya. (2007). *Physical Planning Handbook*.

REPUBLIC OF KENYA KENYA GAZETTE SUPPLEMENT. (2016). http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/ForestConservationandManagementActNo34of2016.pdf

RURI CONSULTANTS. (2013). *Ministry of Forestry and Wildlife Analysis of drivers and underlying causes of forest cover change in the various forest types of Kenya*. http://www.kenyaforestservice.org/documents/redd/Analysis%20%20of%20Drivers%20of%20Deforestation%20&forest%20Degradation%20in%20Kenya.pdf

Saenyi, W., & Chemelil, M. (2003). Modelling of Suspended Sediment Discharge for Masinga Catchment Reservoir in Kenya. *Journal of Civil Engineering, JKUAT*, *8*(1). https://doi.org/10.4314/jce.v8i1.18997

Sánchez, J., Añó, C., Pascual, J., & Recatalá, L. (2004). *LAND USE RECOMMENDATIONS. A TOOL FOR LAND USE PLANNING IN THE VALENCIAN REGION, SPAIN*. https://www.tucson.ars.ag.gov/isco/isco13/PAPERS%20R-Z/SANCHEZ%201.pdf

Shao, J., Wei, C., & Xie, D. (2006). An insight on drivers of land use change at regional scale. *Chinese Geographical Science*, *16*(2), 176–182. https://doi.org/10.1007/s11769-006-0014-5

Standing, A., & Gachanga, M. (2014). *The political economy of REDD+ in Kenya Identifying and responding to corruption challenges*.

The catchment planning system. (n.d.). Retrieved November 12, 2020, from https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE02_ENV_UK_000144_LAYMAN.pdf

Uzoma, I. (2018). *CONCEPT OF RESOURCES* [PhD]. https://www.academia.edu/38018268/CONCEPT_OF_RESOURCES

Walker, G. (1995). Energy, land use and renewables. *Land Use Policy*, *12*(1), 3–6. https://doi.org/10.1016/0264-8377(95)90069-e

Weather and Climate. (2019). *Climate in Murang'a, Kenya*. https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,muranga-ke,Kenya

Wilschut, L. (2010). *Land use Map of the Upper Tana, Kenya Based on remote sensing* . https://www.researchgate.net/publication/254904692_Land_use_Map_of_the_Upper_Tana_Kenya_Based_on_remote_sensing/citation/download

World Bank. (2018). *Smart Forest Land Use Planning*. https://documents1.worldbank.org/curated/ar/983821561614605446/pdf/Technical-Bulletin-No-2A-Smart-Forest-Land-Use-Planning.pdf

Appendices

Appendix I: Research work plan

Activity	Dates	Outputs
Data Collection		Filled Questionnaire Observation Notes Photographs
Cleaning and Data Entry		SPPS output Observation Reports
Report writing and Compilation		Draft study report
Corrections		Final Study Report
PowerPoint Presentation		PowerPoint slides
Project Present		Comments
Final Submission		Three hard copies and soft copy

Appendix II: Research work budget

Activity	Requirements	Costs
Data Collection	Questionnaires	Ksh 4,000
	Stationary	Ksh 2,000
	Research Permits	Ksh 5,000
	Travel Costs	Ksh 3,000
Cleaning and Data Entry	Research Assistants	Ksh 10,000
	Printing outputs	Ksh 5,000
Research Compilation	Printing	Ksh 5,000
	Binding	Ksh 3.000
Total		**Ksh 37, 000**

Appendix III: Farmers' questionnaire

UNIVERSITY OF NAIROBI
SCHOOL OF THE BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING
M.A (PLANNING) YEAR II – BUR 604 RESEARCH PROJECT II

DISCLOSURE*: I am a second year Masters Planning student from the University of Nairobi conducting a study in your area and would like your assistance filling out this questionnaire.*
PURPOSE*: Practical appreciation of the planning and development challenges facing urban and rural areas.*
DECLARATION*: Information generated through this questionnaire will be used for academic purposes only and will be handled professionally and treated confidentially.*

FARMERS QUESTIONNAIRE

Date of interview	
Ward	
Sub location/Area	

1. Age of respondent ………………………………………………………………………………
2. Gender of respondent
   - Male
   - Female
3. Head of the household
   - Male
   - Female
4. Family members by age and gender

Age (years)	Male	Female	Total

5. What is your occupation?
   - Farmer
   - Construction
   - Business
   - Craftwork
   - Housewife
   - Student
   - Professional
   - Domestic work
   - Other (Specify) …………………………………………………………………
6. What is the highest level of your education?
   - No formal education
   - Primary
   - Secondary
   - College
   - University
7. How long have you lived in this community? ....years
8. If less than 40 years in (7), what was the reason for migration?
   - Farming
   - Marriage
   - Employment
   - Business
   - Others (Specify) ……………………………………………………………….

9. Which energy source would you prefer for cooking?
   - Charcoal
   - Firewood
   - Paraffin
   - Solar
   - Electricity
   - Other (specify) ……………………………………………………………….
10. Why do you prefer this source of energy?
    - Convenient
    - Cheap
    - Easily accessible
    - Least pollutant
11. What was the size of your father's land?.......................................acres
12. How much of it was forest? .... acres

13. What size is your land?... acres
14. How much of it is forest?... acres
15. What type of land would be cleared if your family size increases?
    Forest
    Fallow land
    Grazing land
    Agricultural land
    Other (specify) ……………………………………………………………….
16. List the major crops grown in your community.

…………………………………………………………………………………………….……………………
……………………………………………………………………………..……………………………………
……………………………………………………….……………………………………………………………
…………………………………………………………………………

17. Which of the listed farming practices are undertaken on your farm?

No.	Type of farming	Farming methods used	Irrigation type	Soil conservation measures
1	Dairy	Greenhouse	Surface	Contour ploughing
2	Crop	Mixed	Sprinkle	Intercropping
3	Fish	Agroforestry	Drip	Strip cropping
4	Subsistence		Manual	Crop rotation
5	Poultry		Sub-irrigation	Buffer strips
6	Commercial			Wind breaking
7				Cover crops
8				Gabions

18. How has technology affected your farming activities?
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    …………………………………………………………………

19. What hardships do you experience in the use of your land
    Steep terrain
    Loose soil
    Water erosion
    Soil erosion
    Soil acidity
    Soil alkalinity
    Soil infertility
20. How has it worsened over time?
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ………………………………………………………….
21. Do you know of any forests in this area?
    Yes
    No
22. If yes, name them
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………

23. If yes, how do you think these forests came into existence?
    Natural
    Artificial
    Both
24. What has happened to the forest cover in your community over the past 40 years?
    Increased
    Declined
    No change
25. What was the previous land use?
    Forest land use
    Agricultural land use
    Residential land use
    Any other (specify) …………………………………………………………..
25. If any in (13) above, what led to the land use change?
    Population pressure
    Agricultural activities
    Political factors
    Commercialization of agricultural products
26. How has culture affected land use in this area?
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………

27. What is the main purpose of the trees on your farm?
    Firewood
    Beautification purposes
    Fruit production
    Charcoal harvesting
    Timber production purposes
    Soil conservation
    Any other, specify …………………………………………………………...
28. Which institution do you engage with for tree planting?
    1. KWS
    2. KFS
    3. Any other (specify) ……………………………………………………….
29. What activities does the institution engage in?
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………………………………………
    ……………………………………………………………………

Appendix IV: Business questionnaire

UNIVERSITY OF NAIROBI
SCHOOL OF THE BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING
M.A (PLANNING) YEAR II – BUR 604 RESEARCH PROJECT II

DISCLOSURE*: I am a second year Masters Planning student from the University of Nairobi conducting a study in your area and would like your assistance filling out this questionnaire.*
PURPOSE*: Practical appreciation of the planning and development challenges facing urban and rural areas.*
DECLARATION*: Information generated through this questionnaire will be used for academic purposes only and will be handled professionally and treated confidentially.*

BUSINESS QUESTIONNAIRE

Date of interview	
Ward	
Sub location/Area	

1. Name of the respondent …………………………….. Tel …………………………….
2. Age of respondent (years) ……………………………………………………………..
3. Gender of respondent
   Male
   Female

3. What is your occupation?
   Farmer
   In construction sector
   Business
   Craftwork
   Housewife
   Student
   Professional
   Domestic work
   Other (Specify) …………………………………………………………………

4. What is the highest level of your education?
   No formal education
   Primary
   Secondary
   College
   University

5. How long have you lived in this community?..years

6. If less than 40 years in (5), what was the reason for migration?
   Farming
   Marriage
   Employment
   Business
   Others (Specify) ………………………………………………………………..

7. What is your household's main source of income? (Tick all that apply)

Source of income	**Tick**	**Degree of Importance** a scale of 1 to 5, where 1= least important and 5 = most important)
Farming activities		
Full-time private/government employment		
Selling of forest produce (e.g., charcoal, firewood, timber, poles)		
Self-employed (business, trade, handicraft)		
Renting out land		
Other (specify)		

8. Do you harvest any tree/forest resources?
   Yes
   No
9. If yes, which forest resources do you harvest?
   Forest pasture
   Dry wood
   Timber
   Any other (specify) ………………………………………………………….

10. How many other business persons from your village trade in tree /forest resources?

1. <100 persons
2. 100–200 persons
3. 200–400 persons
4. >400 persons

11. Which institution governs forest resource management?

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

Appendix V: Key informant questionnaire

UNIVERSITY OF NAIROBI
SCHOOL OF THE BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING
M.A (PLANNING) YEAR II – BUR 604 RESEARCH PROJECT II

DISCLOSURE*: I am a second year Masters Planning student from the University of Nairobi conducting a study in your area and would like your assistance filling out this questionnaire.*
PURPOSE*: Practical appreciation of the planning and development challenges facing urban and rural areas.*
DECLARATION*: Information generated through this questionnaire will be used for academic purposes only and will be handled professionally and treated confidentially.*

KEY INFORMANT QUESTIONNAIRE

Name of interviewer	
Date of interview	

(KENGEN)

1. How has land use change in the Upper Tana Catchment affected the dam?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………..

2. What is the sediment load status of the dam (between 1981 -2021)?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………..

3. What are the implications of sedimentation of the dam?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………..

4. What institutional measures have you engaged in to manage the dam sedimentation sustainably?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………..

5. Is the water hyacinth weed present in the dam?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………

6. What are the implications of the weed in the dam?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………………………….....

Appendix VI: Key informant Questionnaire

UNIVERSITY OF NAIROBI
SCHOOL OF THE BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING
M.A (PLANNING) YEAR II – BUR 604 RESEARCH PROJECT II

DISCLOSURE*: I am a second year Masters Planning student from the University of Nairobi conducting a study in your area and would like your assistance filling out this questionnaire.*
PURPOSE*: Practical appreciation of the planning and development challenges facing urban and rural areas.*
DECLARATION*: Information generated through this questionnaire will be used for academic purposes only and will be handled professionally and treated confidentially.*
.

KEY INFORMANT QUESTIONNAIRE

Name of interviewer	
Date of interview	

(KFS OFFICER)

1. What has been the level of forest cover in the region between 1981 – 2021?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………….
2. What are the major causes of land use change in the upper Tana catchment?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   …………………………………………………………………..
3. What is the state of Soil loss in the upper Tana catchment?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   …………………………………………………………………..
4. What soil conservation measures are being applied?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………….
5. What is the state of riparian land use management?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ……………………………………………………………….
6. What institutional measures have you taken to manage land use change within the catchment?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………
7. What are the dominant tree species in the region between 1980-2021?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ……………………………………………………………...................
8. Are there any illegal logging and charcoal-burning activities in the area?
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………………………………………………
   ………………………………………………………………

Appendix VII: Key informant Questionnaire

UNIVERSITY OF NAIROBI
SCHOOL OF THE BUILT ENVIRONMENT
DEPARTMENT OF URBAN AND REGIONAL PLANNING
M.A (PLANNING) YEAR II – BUR 604 RESEARCH PROJECT II

DISCLOSURE: *I am a second year Masters Planning student from the University of Nairobi conducting a study in your area and would like your assistance filling out this questionnaire.*
PURPOSE: *Practical appreciation of the planning and development challenges facing urban and rural areas.*
DECLARATION: *Information generated through this questionnaire will be used for academic purposes only and will be handled professionally and treated confidentially.*

KEY INFORMANT QUESTIONNAIRE

Name of interviewer	
Date of interview	

(PHYSICAL PLANNER)

1. What was the land use condition in this area before 1981?
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ………………………………………………………………………

   a. Plot sizes
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      ……………………………………………………………………..

   b. Dominant land use types
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      …………………………………………………………………….

   c. What other land use changes have occurred?
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      ……………………………………………………………………………………………
      ……………………………………………………………………

2. What planning interventions are being employed for sustainable catchment land management?
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ……………………………………………………………………….

3. What are interventions for riparian land farming being implemented?
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
   ………………………………………………………………………