FACTORS INFLUENCING RIVER DISCHARGE IN MOIBEN RIVER CATCHMENT, KENYA

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DECLARATION

Declaration by the Candidate

This thesis is my original work and has never been presented for the award of an academic degree in any other university and should not be copied, or reproduced in any format without written authority from the author and/or University of Eldoret.

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This work is attribute to my parents, Philip Maiyo and Lucy Sawe, my uncle Joseph Sawe, my brothers Felix, Kelvin, Collins, Ivan and to my friends for their unwavering support and encouragement throughout my academic journey.

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ABSTRACT

This study examines the factors influencing river discharge in the Moiben River catchment, Kenya by looking at the shifts in the trends of river discharge, the changes that are associated with the changes in land uses and the socio-economic influences from the period 1995 to 2024.Some of the environmental and socio-economic changes over the period are farm land expansion, deforestation, and increasing water needs of the people. These shifts have raised concerns about fluctuating river discharge, water scarcity and the sustainability of available water for both the people and ecological needs. Kenya is among the water-deficient nation with a yearly per capita water supply being less than 1000 m^3; therefore, its water sources needs conservation. Most of the water needs in the Kenyan watersheds are influenced by the human activities around these watersheds. In the case of the Moiben River catchment, discharge fluctuations, declining water levels, and water shortages have been observed but limited research has been conducted to investigate the exact reasons behind the declining and fluctuating river discharge. The primary objective of the study is to assess the key factors influencing river discharge in this area, which is important for local water supply and resource governance. The study utilized GIS-based methods and satellite images to analyze the changing LULC, alongside data from hydrological data such as river discharge and rainfall records. Household surveys and key informant interviews assessed socio-economic factors influencing discharge patterns. Statistical and geospatial techniques were used to establish relationships among these factors, and also hydrological modelling using HEC-HMS was utilized to simulate the peak discharge over the period. The findings revealed fluctuations in river discharge, with a slight but statistically insignificant upward trend at $p < 0.05$ ($Q_t = 0.8534t + 112.96$, $R^2=0.0221$, $p=0.530$). Wet season discharge (1.25 ± 0.12 m^3/s) was higher than the dry season (1.07 ± 0.41 m^3/s). LULC analysis showed cropland expansion (51.48% to 77.67%) and forest cover slightly increased from (30.53% to 31.22%), while rangeland and grassland have declined. Temperature rose significantly ($r= 0.926$, $p= 0.074$), while rainfall was moderate ($r= 0.751$, $p= 0.249$). Cropland ($r= 0.922$, $p= 0.078$) and built area ($r= 0.914$, $p= 0.086$) increased with time. River discharge had positive correlations with forest cover ($r= 0.964$, $p= 0.036$) and rangeland ($r= 0.983$, $p= 0.017$) changes and the peak discharge was 87.9m^3/s in a 30-year return period. The results will inform sustainable water resource management and sustainable land use planning measures, providing valuable insights benefiting policymakers, conservation agencies, and local communities to mitigate the implications of the changing climate and land uses on river discharge through practices such as reforestation, adoption of water-efficient irrigation methods, protection of riparian zones, and promotion of sustainable land management techniques. The findings from this research will contribute to improving water conservation and enhancing resilience for this region.

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LIST OF ABBREVIATIONS

AI- Artificial intelligence

CBO-Community Based Organization

CIDP- County Integrated Development Plans

DEM- Digital Elevation Model

FAO – Food and Agriculture Organization (of the United Nations)

GIS-Geographic Information System

GNSS – Global Navigation Satellite System

GPS-Geographic Position System

IPCC – Intergovernmental Panel on Climate Change

IRIS – Integrated Regional Information Systems

KI- Key Informant

KMD – Kenya Meteorological Department

KVDA-Kerio Valley Development Authority

LULC-Land Use Land Cover

MLC- Maximum Likelihood Classification

NAP – National Adaptation Plan

NDVI-Normalized Difference Vegetation Index

NGO-Non Governmental Organization

SA- Climate Smart Agriculture

SDG -Sustainable Development Goals

SPSS – Statistical Package for the Social Sciences

SRTM-Shuttle Radar Topography Mission

SVM-Support Vector Machines

TLS – Terrestrial Laser Scanning

UN – United Nation

UNFCC -United Nations Framework Convention on Climate Change

UNICECE – United Nations Economic Commission for Europe (UNECE)

UNICEF- United Nations Children Fund

USGS- United States Geological Survey

UTM – Universal Transverse Mercator

WHO- World Health Organization

WMO – World Meteorological Organization

WRA – Water Resources Authority

WRA- Water Resource Authority

KEY OPERATIONAL TERMS

Catchment-is an area of land where all precipitation, such as rainfall, drains into a common outlet.

Hydrologic Engineering Center (HEC) - refers to a division of the U.S. Army Corps of Engineers that develops computer models and analytical tools for hydrologic and hydraulic analysis.

Hydrologic Modeling System (HMS) - is a computer program developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center to simulate the rainfall-runoff processes within a watershed.

Land use is defined as the process in which humans utilize the terrestrial surface in activities.

Remote sensing- entails a process of getting data regarding a structure or an area from a distance.

River discharge- refers to the volume of water flowing through a river channel at a given point and time.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Water is an important natural resource benefiting all life forms, and not evenly distributed across the globe. It also occupies about 71% of the Earth's surface, less than 3% is freshwater, and an even smaller proportion is accessible for human use. It has been projected that roughly 0.5% of the global freshwater is contained in rivers, lakes, and shallow groundwater (Oyekale & Ogunsanya, 2012). Water supports increasing human populations, agriculture, industry, and ecosystems. However, as the world faces rapid globalization and the negative effects of climate change, water scarcity is becoming a significant global challenge, affecting billions of people (Uhlenbrook & Connor, 2019).

The Sustainable Development Goal 6 (SDG 6) of the United Nations has a goal of ensuring all people can get clean water and sanitation by the year 2030, but this progress has been slow as seen in the international trends, which suggest increasing pressure on water resources (Sadoff *et al.*, 2020). Similar projections have shown that water demand will affect more than 6 billion people by 2050 because of its rising rate of 1% per annually. (Boretti & Rosa, 2019). Furthermore, climate change will cause a water crisis, with prolonged droughts, shifts in rainfall patterns, and glacier melting contributing hence reducing water availability (Verschuuren, 2022).

Africa is particularly vulnerable to water scarcity. It is expected that by 2030, over 600 million people will be facing water scarcity, exceeding the current 160 million people and a potential of more than one billion by 2050. (Hasan *et al.*, 2019). This has been recognized by the African Union Agenda 2063, which urges sustainable water resource management to enhance climate resilience (Söderbaum & Stapel, 2022).

Kenya is one of the African nations that has per capita water availability below 1,000 m^3 annually (Mulwa & Fangninou, 2021). Some of the common rivers in Kenya like the Tana and Athi rivers have served in providing water for domestic, agricultural as well as other needs. The growing number of people and other water needs have been associated with stressing the water sources (Langat *et al.,* 2019). In Kenya's Nationally Determined Contributions (NDCs), the changing climate has been given a priority in its plan in an attempt to mitigate the negative impacts it has on the Kenyan rivers (Dal Maso *et al.,*2020).

The river discharge of a river is the amount of flowing water at a specific location in the river at it is usually expressed in cubic meters per second. The discharge of a river can aid in may areas, it can serve to determine the amount of water available in a stream, the type of irrigation that can be practised, the health of an ecosystem and also it can serve in the management of floods and droughts. Both natural and anthropogenic factors can influence river discharge, and these can be the vegetation cover, rainfall, evaporation, LULC and human (Holmes *et al.*, 2021).

The Moiben River catchment is an important agricultural area. However, the area has experienced a lot of changes, ranging from LULC changes, including farming practices, deforestation, to increased settlements over time, which could be attributed to the declining and fluctuating river discharge. The shifting seasonal rainfall patterns, which influence runoff and river flows, are exacerbated by the changes in climatic conditions. This causes increased river discharge in the wet season and reduced river discharge in the dry season, affecting water availability for both domestic and agricultural practices. Other human infrastructural developments, such as roads and dams, have also altered the natural flow of the water paths.

This catchment allows an opportunity for examining various factors such changes in LULC, climatic changes, and socio-economic factors that interact to influence the river discharge. The study of other Kenyan catchments, such as the Kilungu sub-catchment (Wambua *et al.,* 2021), has demonstrated the same problems. Limited research has been conducted in the catchment, especially around the influence of the changing climate and land uses on water availability.

The results from this study is directed to help key actors which are the farmers in this catchment and the government authorities at both national and county levels, on better ways to protect and conserve water resources even with the changing climate and the increasing human pressure on natural resources by assessing important factors influencing river discharge in the Moiben River catchment from 1995 to 2024.

1.2 Statement of the problem

A healthy watershed or catchment is supposed to be able to meet human and ecological needs such as providing safe and dependable water supply, mitigating flooding, stable soils and supporting biodiversity (Gatgash & Sadeghi, 2024). Such a system can maintain good vegetation cover, minimal soil erosion, and consistent flows of river that sustain both human and ecological needs. The catchment covers about 86741 hectares with a population of about 24,679 people. The Moiben River catchment supplies water to the rural communities in Moiben and the surrounding areas and the urban population in Eldoret city through the Chebara Dam (Chepkurui *et al.,* 2022). Over many years, the catchment has been providing enough river discharge that is able to support and sustain the livelihoods of the people through domestic and agricultural water use.

The Moiben River catchment has increasingly shown signs of water stress, which can be noted through the declining and inconsistent river discharge, especially during dry seasons, suggesting that the catchment may not consistently provide adequate water for the needs of the people with time (Chepkurui *et al.,* 2022). Based on the Uasin Gishu County Integrated Development Plan (CIDP, 2023–2027), the county is facing challenges related to the overuse and degradation of water catchments (Uasin Gishu County Government, 2023). Chebara Dam, which depends on inflows from the Moiben River, currently supplies around 18,000 m^3 per day, which is below its expected design capacity of 26,000 m^3 per day (The Nature Conservancy, 2022). This reduction in water supply has resulted in reduced water availability in Eldoret city and rural communities that depend on this catchment for water. This situation has further led to the risk of water security, food production and the health status of the people who depend on the river.

Although changes in discharge fluctuations, declining water levels, and water shortages have been observed, limited research has been conducted to investigate the exact reasons behind the declining and fluctuating river discharge in the Moiben River catchment. The absence of detailed scientific studies makes it difficult for institutions and local communities to make sound judgment about water resource planning and management. Without this evidence, there is a risk of implementing ineffective measures that may worsen the situation. The gap can then be filled by identifying factors influencing the river discharge in the catchment and the findings from the study will help guide on practices that aimed at enhancing sustainable water management for both rural and urban communities in the region.

1.3 Significance of the study

The findings from the study are important because they show how land use changes, climate variability and human activities have jointly affected river discharge. This understanding help guide water management decisions, supports sustainable land use planning and reduce water scarcity in the catchment.

1.4 Research objectives

1.4.1 Overall objective

The overall objective of the study was to assess the factors influencing river discharge in the Moiben River catchment, Kenya.

1.4.2 Specific objectives

The study has the following three specific objectives that were formulated to achieve the overall objective;

1. To analyze the trends in River discharge of the Moiben River from 1995 to 2024.

2. To determine the extent and patterns of land use and land cover change in the Moiben River catchment from 1995 to 2024.

3. To evaluate the factors that have significant impact on river discharge in Moiben River catchment.

1.5 Research questions

1. What are the trends in river discharge in the Moiben River?
2. How have the land use/land cover in the Moiben River catchment changed from 1995 to 2024?
3. Which factors have significant impacts on river discharge in Moiben River catchment?

1.6 Justification of the study

Water is an important resource which helps by providing different services like production of food, production of electricity, improving human and animal health and economic developments (Strang, 2020; Kılıç, 2020). Globally there is concern for sustainable water management because the climate is changing rapidly, population is rising and land uses are also changing. The Moiben River catchment has supported rural livelihoods over many years by providing them water for their domestic, agricultural, and livestock needs. The river has also been supplying water to Eldoret and other neighboring towns, making it an important source for both rural and urban water needs. Over the past three decades, the locality has seen some changes in LULC, demographic and settlement patterns, and there has been an increasing climate-related pressure, all of which could have contributed to changes in the river discharge, raised concerns over water scarcity and caused degradation of the catchment.

Given that the catchment is an important source of water which sustains humans, agriculture and economic activities in the area, there is limited scientific information on climate variability, the land use shifts in the area and socio-economic factors that could link them to influence the river discharge over time.

The study fills a critical gap in understanding the relationship between land use change, climate variability, and human activities on river discharge. This lack of knowledge could result in poor water management decisions, increased vulnerability to water scarcity, reduced agricultural productivity, and further degradation of the catchment. Policymakers, local authorities, and community stakeholders would have limited evidence to guide sustainable water resource planning, which eventually can lead to over-extraction, inefficient irrigation practices, and inadequate adaptation measures to climate impacts. The communities dependent on the catchment would also be at higher risk of water insecurity and environmental degradation.

Therefore, the findings from this research will provide informed guidance for sustainable water management practices and support suitable local adaptation strategies that will be useful in water conservation, improving agricultural productivity, and strengthening the resilience of the communities that depend on the catchment.

1.7 Thesis structure

The thesis is categorized into six chapters. Chapter One introduces the study background, statement of the problem, significance of the study, objectives, and scope of the study. Chapter Two reviews related literature and identifies research gaps. Chapter Three contains the study area, research design, data collection, and analysis methods. Chapter Four presents the results, while Chapter Five discusses the findings in relation to existing studies. Chapter Six concludes with a summary of findings and provides recommendations for sustainable water and land resource management in the catchment

1.8 Scope of the study

This study focused on assessing factors affecting river discharge in the Moiben River catchment in the period 1995 to 2024. This period was chosen because it provides a long timeframe to capture major changes in LULC, climatic conditions, and social and economic changes in the catchment. The catchment covers about 86741 hectares with a population of about 24,679 people. It targeted 388 households within the catchment using a mixed study approach.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is on literature review focusing on important scholarly works regarding the main factors influencing river discharge in catchments, involving variations in climate, shifts in land cover, and human-induced activities. This chapter reviewed books, journals and relevant publications. Various methodologies used in other studies to solve catchment challenges were also examined, and therefore, clear information on important variables and issues used in other studies were analyzed.

2.2 River discharge

The quantity and quality of river discharge are dependent on numerous interplays of climate, biotic systems, geology, and terrain features that coexist within a region. Discharge monitoring assists in the detection of climatic and environmental change (Depetris, 2021). Stream gauges are used to obtain direct observations of stream flows at a particular point in a stream. These gauges serve to show the levels of processes at the upstream of a catchment (Zimmer *et al.,* 2020). The interaction that occur between underground water and surface water are often influenced by the activities that occur on the surface of the Earth that is why it is important to protect both the environment and the water bodies (Conant *et al.,* 2019). According to Gudmundsson *et al.* (2021), the slope of a catchment and the balance of water such as the precipitation and evapo-transpiration are key components in determining the amount of surface runoffs meaning that a protected catchment will have a nearly proportional runoff over time even during hotter summer as the catchment has enough groundwater storage to sustain it.

The primary contributor of river discharge changes are the effects caused by the changing climate which are associated with the alteration of rainfall patterns and increase in temperature trends hence affecting the hydrological cycles (Gebrechorkos *et al.*, 2019). Since river discharge responds directly to changes in rainfall and temperature, it can therefore be used as a clear indicator of the changing climate thus aiding in enhancing reliability of information for future forecasts and mitigations (Akpoti *et al.*, 2024). Across East African basins, the shifts in seasonal rainfall patterns due to climate variability have altered the flow of rivers which have caused the problems of water availability in the times of drought and during rainfall periods, water sources are contaminated by the occurrence of floods, therefore, these shifts are important in providing information on annual and seasonal changes in river flows (Nsubuga *et al.*, 2019).

2.3 Hydrology of river catchment

Human practices within a catchment such as the construction of dams, for example, has drastically changed the Mekong River's flow patterns as the recording from 2010 to 2014 at the Chiang Saen gauging station have shown that stream flows are low during rainy seasons and high during dry seasons thus illustrating distinct seasonal variation in the stream flow (Li et *al.*, 2017). Studies of Rwigi *et al.* (2024) and Taye *et al.* (2021) suggest that land uses like cleared lands may reduce the retention capacity of the soil, leading to increased surface runoff and increased flows, while also causing declined flows during dry periods. On the other hand, Sang, (2022) emphasizes that traditional methods of irrigation like flood irrigation and increased farming activities, can increase the rate of water extraction from rivers and it can cause disruption of the original flow patterns of the river thus increasing the occurrence of seasonal variability. The combined effects that arise from these land use changes has the ability to alter the hydrological balance of catchments which greatly contribute to the frequent fluctuations in river discharge (Liu *et al.,* 2020). In the cases where water needs exceed the supply, the normal circulation of water is interfered with thus causing scarcity in fresh water sources because of excessive water consumption (Ingrao *et al.,* 2023). Other similar instances have been reported in the upper Yongding River watershed in North China where over-extraction of water for human use has caused a reduction in the flow of the river, rendering it unsafe for drinking and farming activities (Dai *et al.,* 2020). This suggests that over extraction of groundwater can decrease the underground water levels and reduce the amount of water that flows into rivers especially during dry seasons thus leading to declines in river flows (Lomova *et al.,* 2018).

According to Ghebrehiwot and Kozlov, (2019), Digital Elevation Model (DEM) is particularly important for supporting natural resource management and other environmental analyses which is among the many uses that it can offer. Currently, there are several resolutions available, ranging from low to high precision which can be used to identify and extract watershed boundaries, the elevation of a place, drainage networks within a watershed, the flow directions of a river, and environmental changes that allows the physical characteristics of the river basin to be investigated (Demiray *et al.,* 2021). During the process of determining river discharge, forecasting the occurrence of floods, and managing water resources, it is necessary to have delineated catchments to represent how water flows across a terrain to allow the hydrologists to estimate the runoff from the events of precipitation (Kayembe & Mitchell, 2018).

2.4 Hydrological modeling using HEC-HMS

The Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) has been widely used to simulate the flow caused by rainfall-runoff processes in many watersheds to either show event-based or continuous predictions resulting from the changes in precipitation of a catchment by the U.S. Army Corps of Engineers (Zhao *et al.*,2024). HEC-HMS has been used in many areas, like in flood predictions and land use impact on river flow studies, because it is designed with flexibility and it suits various applications (Sahu *et al*, 2023).

This model can be used in the case of scarce meteorological measurements of rainfall, like in the Dabus Watershed, within the Abbay Basin of Ethiopia, where Belayneh *et al.* (2020) used the HEC-HMS model since the area had limited rainfall data for the runoff simulation; therefore, data from satellite was used instead. The model can also be useful in areas which experience floods, as Natarajan and Radhakrishnan,(2020) demonstrated how suitable HEC-based models is in capturing the impacts of land use changes and rainfall changes on river flows in urban environments through the combined hydrologic and hydraulic flood modelling using HEC-HMS and HEC-RAS in Tiruchirappalli City, India.

Event-based modelling to show the impacts of land use changes using HEC-HMS along with GIS and remote sensing tools showed that year 2014 had the peak flow in Godavari River Basin in 29 years which was linked to the growing urban areas and increased farming practices that led to a decrease in evapotranspiration and infiltration, while surface runoff increased (koneti *et al.,* 2018). In a related study of Kabeja *et al.* (2020) the HEC-HMS simulations that were applied to the years from 1990-2017 using Landsat-generated LULC scenarios illustrated that forest expansion led to a reduction in peak flood discharge by up to 14% in the Yanhe basin, thus it shows the positive effect of land cover restoration on the watershed for flood mitigation. Janicka and Kanclerz (2022) performed HEC-HMS modelling in the Wirynka River catchment in Poland to illustrate the effects of different scenarios of land uses on the river discharge from 1990 and 2018, which demonstrated that urban growth has changed the catchment's flow through the reduction of infiltration capacity and increased surface runoff, thus helping in improving urban planning of the areas.

The frequent lack of long-term runoff data in small catchments, especially those in developing countries has been made possible by HEC-HMS which combines GIS and remote sensing for spatial modeling thus allowing researchers to assess how land use, climate variability, and watershed characteristics which influence the generation of runoff and stream flow behavior (Belayneh *et al.,*2020)). In smaller catchments like the Isserstedt sub-basin in Germany, HEC-HMS enabled the prediction of peak flows and hydrograph responses for extreme rainfall events, which helped identify important source areas and support informed decisions in the water management of the area (Zhao *et al*, 2024).

2.5 Land Use /Land Cover change (LULCC)

The change in LULC is a description of activities that are happening on the earth surface caused by human activities which including the expansion in farm lands, felling of trees, urbanization, and settlements (Tassi & Vizzari, 2020). Therefore, LULC maps are used to show and analyze these changes from a certain period to another or the current state of the environment (Twisa & Buchroithner, 2019). They are useful in detecting the human practices that form the earth surface and also important in determining and detecting the human influences on the planet's topography (Chowdhury *et al.,* 2020). The shifts that are important for planning, monitoring and assessing the environment can be identified and can aid in illustrating changes such as when determining the flow level of a river basin (Patil & Nataraja, 2020).

According to Tena *et al.* (2020), land use refers to the practices on the land that arise from how the human use the land and manage it while land cover refers to land characteristics which include its biophysical condition. Land cover changes is usually a result from land use and the land use is a product of a combination of production and consumption that are directly related to social, political, and economic activities from humans. When the land cover changes, it has an impact on how the land is used and vice versa. Land use is defined as the process in which humans utilize the terrestrial surface in activities like farming, mining as well as pastoralism (Khan *et al.,* 2021). Similar changes have been observed in areas such as Shimla, Himachal Pradesh, India, where the natural vegetation have been observed to decline while the urban settlements, crop lands and bare ground increasing over a period of 20 years (Azad & Singh, 2021). According to Kipkulei *et al.* (2022), farming practices is a common LULCC which is associated with reduction of other natural land covers like forests, grasslands, rangeland, and other natural environments.

Human and natural processes have caused changes of LULCC at local and international levels causing the hydrological variables to change because of continuous human interferences in an attempt to meet their needs (Sodango *et al.,* 2017; Twisa &

Buchroithner, 2019). The felling of trees and increase of farm lands have been seen to, in a great extent, affect land surface runoff, infiltration rates and the presence of water in many rivers (Chepkirui *et al.*, 2022). International changes in environment such as climate change, decrease in biodiversity, increasing greenhouse gas levels and the over utilization of soil, have all been related with LULCC (Maina *et al.*, 2020). Appropriate land conservation and protection requires knowledge of these changes and their effect on the catchment. This implies that to lower the adverse impacts on future land utilization, it is important to be equipped with adequate knowledge about the responses to LULC changes (Kayitesi *et al.*, 2022). It is advised that information on LULC should be regularly updated to serve socio-economic and environmental needs such as planning and also management efforts of environmental resources (Maina *et al.*, 2020).

2.6 Methods and techniques for LULCC assessment

The process of classifying LULCC requires inputs from ground-based surveys, Geographic Information Systems (GIS), and Remote Sensing for successful analysis. This can be achieved with the help of remote sensing satellite images which are useful for analysis while ground-based surveys help in validating the obtained images through the ground truthing processes and GIS on the other hand facilitates the overlaying and interpretation of spatial data.

2.6.1 Geographic Information System (GIS)

GIS is made up of technologies, software, spatial data, and experts of GIS, organizational structures, and institutional setups whose role is to analyze spatial data and disseminate geographical data (Ali, 2020). Geospatial analysis of spatial data has been made possible by the invention of powerful software that can enable someone to process and visualize geographic information of the real world (Zhu *et al.*, 2021. GIS software perform its tasks by combining various data layers which may include land cover classification maps, topographic, and socio-economic layers using advanced technologies that allow multiple computations (Ali, 2020; Wilson *et al.,* 2021). Some of the common examples of GIS software that are commonly used in spatial analysis include ArcGIS, QGIS, and Google Earth Engine which can be open source or they require licenses to operate (Zhu *et al.*, 2021).

The GIS software can be combined for better output as in the case of Andhra Pradesh, India where ArcGIS and ERDAS software have been used together to obtaining better outcomes of LULC maps that involved wasteland demarcation (Ramanamurthy & Victorbabu, 2021).This has also been demonstrated in other areas in the work of Seyam et al. (2023) who used Arc GIS 10.8 software to classify LULC change which had five classes using Landsat 7 and 8 images this therefore GIS can also been utilized in modeling and predicting future LULCC and Urban Heat Island (UHI) patterns GIS models such using CA-Markov model, which a GIS-based technique that utilizes both Cellular Automata and Markov Chain modeling in urban sustainability development (Liu *et al.*,2020).In most LULC classification, GIS has been useful in visualizing remote sensing data and since GIS has various application which may include LULC change in a catchment, other functions like determining area of a place, finding spatial patterns and carrying out modelling are also possible (Twisa & Buchroithner, 2019; Jalayer *et al.*,2022).

The spatial interactions between forested areas and farm lands in Moldova using GIS techniques has enabled identification of areas where deforestation and with agricultural expansion are prone thus aiding in identifying vulnerable regions to environmental degradation (Valjarević *et al.*, 2025). It can also be valuable in other areas, such as hazard analysis, by overlaying datasets like different land uses, soil types, rainfall patterns, and historical hazard events (Ali, 2020). Other than GIS being used solely, it can be combined with other technologies to solve environmental challenges for example, it can be valuable in the agriculture sector in enabling the implementation of smart farming and sustainable food production (Ghosh & Kumpatla, 2022).

2.6.2 Remote sensing

Remote sensing entails a process of getting data regarding a structure or an area from a distance (Chuvieco, 2020). It is also a tool that enables the Earth's resources to be observed using satellites and it can also be combined with ground surveys for better accuracy using the electromagnetic spectrum (visible, infrared, and microwaves). According to Abbas and Jaber, (2020), remotely sensed images are widely used because it has up-to-date information of the whole globe and they are also reliable with some sources being open sources. Satellites and drones are the common remote sensing systems that can take multispectral images and use their spectral fingerprints to distinguish between various land cover classes that absorb or reflect light at different wavelengths making it possible to classify them differently (Li *et al.*, 2020). Remote sensing techniques are usually further analyzed for LULCC assessment to monitor large areas therefore it is an important data source for GIS (Maina *et al.*, 2020). In the past, classification utilized low and medium resolution satellites images such as Indian Remote Sensing (IRS) Satellite Resource, but with the replacement with hyper-spectral sensors of the satellites, high resolution images such as Sentinel images can be used (Talukdar *et al.*, 2020).ED Chaves *et al.* (2020) have offered a new approach where medium resolution images which are of 10-30 meters such Sentinel-2 Multispectral Instrument (S2/MSI) and Landsat 8 Operational Land Imager (L8/OLI) and multispectral images have been used together to gathering data on LULC. This combination can offer better detection of change which is important for informing decisions on changes like agricultural practices and felling of trees. Multispectral images have been used in a study conducted in the Akola district of Maharashtra, India, where a land use classification process used medium-resolution satellite imagery to produce five land use classes (Pande *et al.*, 2018).

2.6.3 Ground-based surveys

Ground-based surveys involve obtaining data to verify images obtained from remote sensing and the researchers have to physically visit the site where the classified land cover has been illustrated by the images (Ali *et al.*, 2022). Information gotten from satellite images about land cover types, the human practices, and the features on the land may not be clear, therefore, field surveys can be used in such cases, for instance, ground-based field survey data was used to support the classification of Landsat satellite images in Okara, Pakistan, in the process of analyzing the LULCC in the area (Hussain *et al.,* 2022). According to Zhao and Lu, (2018), ground-based surveys, such as ground-based SAR (GB-SAR), terrestrial LiDAR (TLS) and Global Navigation Satellite Systems (GNSS), provide high-resolution, close-range, and real-time measurements that complement remote sensing data. Although ground-based surveys has been commonly used to compliment remote sensing data, they can solely be used in environmental monitoring especially in cases where remote sensing data has been limited by cloud cover, temporal gaps or spatial resolution

(Stuart *et al.,* 2019). Moreover, it is important for validity, temporal consistency and reliability of LULC maps in environmental monitoring (Tsendbazar *et al.*, 2021).

In the study on quantifying habitat availability using remote sensing, Henrys and Jarvis, (2019) used ground-based surveys to provide accurate measurements of habitat in specific areas, which help correct errors in remote sensing data and improve the national habitat estimates in the model created. Ground- based survey has also been used in Azrou Forest in the Middle Atlas, Morocco for vegetation change analysis, where it supported and improved the accuracy of land cover analysis by helping distinguish between different vegetation density categories identified from Landsat satellite images (Mohajane *et al.,* 2018). In addition, ground- based survey data from the Italian Institute of Geophysics and Volcanology (INGV) and the Department of Civil Protection assisted in validating and assessing the accuracy of building-level earthquake damage classifications using Very High Resolution (VHR) satellite images (Anniballe *et al.,* 2018).

In a study that involved the collection of maize yield data at village level in Burkina Faso, ground-based surveys were used to verify the accuracy of estimation models generated from remote sensing (Leroux *et al.,* 2019). While ground-based surveys can be usefully, it is also limited to smaller areas at a time, thus it cannot be helpful in a large environment and their effectiveness also depends on the accessibility of a place, making them less suitable for remote or hazardous environments (Casagli *et al.,* 2023).

2.6.4 Image classification methods

Classification is important in identifying the changes that occur on the surface of the earth as it has the capability to extract vital data from satellite images in a process that involves combination of pixels (Dahiya *et al.,* 2021; Dhingra & Kumar, 2019).Image classification classifies pixels in satellite imagery into useful land cover types such as forest and agriculture which are important in decision-making (Ozdogan, 2024).The results of classification are maps which guide environmental conservation and protection at all levels of governance (Alshari & Gawali, 2021). There are two methods of image classification which are supervised and unsupervised classification and Maximum Likelihood (ML) is the commonly used supervised classification techniques that uses training samples from the image that has to be classified (Richards & Richards, 2022). The classification process is done by using the class average and variability to predict the allocation of a pixel thus allowing the pixel with the highest chance to be assigned to the appropriate class using training samples. This is made possible in Maximum Likelihood analysis because it has distinct analytical capabilities which makes it the common classification technique in land use classification. (Ibrahim, 2022). Some of other common supervised classification techniques include ensemble methods like Random Forest and instance-based classifiers like k-Nearest Neighbors (k-NN) have been used in analysis of spatial data (Brendel *et al.*, 2019). For example, supervised classification has been used to determine levels of aridity in Akola district of Maharashtra, India using LISS-III and Landsat satellite images (Pande *et al.*, 2018).

In unsupervised classification, labelled data is used for classification. (Schmarje, 2021). The image uses knowledge from labelled data where each input is paired with a known output, allowing the system to classify. Unsupervised classification is employed when the researcher doesn't have access to training images, allowing the discovery of patterns and structures without predefined labels. K-Means and hierarchical clustering are among the commonly applied approaches in unsupervised image classification while others are;

Autoencoders, Apriori algorithm, and Latent Dirichlet Allocation (LDA) (Van Strien & Grêt-Regamey, 2022).

According to Boori *et al.* (2018), supervised and unsupervised classification are both important for LULC classification however, supervised classification slightly has better classification accuracy compared to unsupervised classification. This is reinforced by the study on identification of vegetation in Akinyele Local Government area Ibadan, Oyo state, Nigeria where supervised classification has better visual interpretation compared to unsupervised classification (Kehinde *et al.,* 2020). Although supervised classification is preferred, the use of hybrid classification which combines both classification are still common. For example, in a study in Ethiopian highlands where LULC was used to determine the heterogeneity of the landscape, a hybrid classification was used to differentiate land use classes (Kassawmar *et al.*, 2018).

2.7 Global and local case studies of LULC classifications

In the governance of natural resources, environmental interrelationships and environmental modelling and evaluation, LULC classifications play an important role (Acuña-Alonso *et al.,* 2024). Humans have changed the natural environment over time more than before but they are at different levels based on the rates of political, social and economic influences on that environment (Ochuka *et al.,* 2019). The LULCC have raised a lot of concerns since they have influenced the creation of plans and regulations on the environment in different areas, therefore, accurate information about land cover is always needed as it affects the accuracy of its applications ((Macarringue *et al.*, 2022; Phan *et al.*, 2020).

Most studies have performed LULC classification to detect change, for example, in the Chalus watershed in Iran, spatial changes were performed using a combined method between the segment-based and pixel-based classification of LANDSAT images (Jalayer *et al.*, 2022). This resulted in to increase in farm lands and barren lands with a decrease in forest cover and grassland in the watershed. Birhanu *et al.* (2019) also studied the Gumara sub-catchment in Ethiopia which showed that LULC change is a continuous phenomenon, mainly driven by human activities. The study demonstrated the conversion of forest and grassland into cultivated and urban lands within the sub-catchment. This influenced the river flows, sedimentation, erosion, and socio-economic situation within the Gumara sub-catchment. The Holota watershed in Ethiopia has similar studies that focus on the future impact of LULCC on soil erosion (Guder & Kabeta, 2025). Landsat satellite imagery and GIS techniques used exhibited changes in urban built area, which increased while grassland and rangeland reduced. These changes were mainly attributed to deforestation and agricultural practices.

In the most catchments of central Kenya, unmanaged deforestation to make way for human settlements and subsistence agriculture is a common cause of degradation of the land and soils. This has impacted Lake Ol'Bolossat watershed (Karuku & Mugo, 2019). Similar studies in Njoro and Kamweti River sub-catchment have also experienced shifts in land use leading to shifts in the tree and shrub covers within this sub-catchment (Koskey *et al.*, 2021). Thematic Mapper (TM), sentinel images, and Enhanced Thematic Mapper Plus (ETM+) images were used to show the decline in tree and shrub covers over the years in the region.

Sitati *et al.* (2024), focused on agricultural expansion as a main factor impacting LULC in the Mara and Mau river basins. Multi-temporal satellite images and socio-economic information were utilized to predict the 2040 scenario of the impacts it will have on biodiversity. The expansion of croplands impacted other land covers such as grassland and shrub land. In Khwisero Sub County, Kenya, LULCC is mostly caused by increased settlements in the area, increased poverty levels and changing climatic conditions, which has an impact on the natural vegetation, farmlands and the fertility of the soil (Shumila *et al.*, 2024).In Kieni sub-county in Central Kenya, LULC classification of more than 20 years using Landsat images showed that farmlands, bare ground and surface water increased while the natural vegetation reduced (Maina *et al.*, 2020). This is similar to the case of Marsabit Forest Reserve where Multi-temporal Landsat images helped to identify the pattern of LULCC and it revealed the loss of forest cover, which was associated with increased human settlement (Muhati *et al.*, 2018).

2.8 Water sources

Water systems are important for supplying consumers with water from diverse sources for domestic consumption, farming practices, industrial processes, and other uses (Belur Raju *et al.*, 2025). These systems include surface water, groundwater, rainwater harvesting and wastewater reuse and are important for protecting stability of the ecosystem and the health of human health and production (Mulwa & Fangninou, (2021). Conant *et al.* (2019) assessed groundwater sources to evaluate the suitability of groundwater for human domestic use and farming practices. This study recommends that it is important to monitor the groundwater sources so as to protect the water quality.

Therefore, to protect these systems, sources of water such as wells, rainwater harvesting and boreholes should be utilized as options, as this leads to appropriate utilization of water sources, which leads to sustainability (Belur Raju *et al.,* 2025). According to Opiyo *et al.* (2022), communities that use rainwater are more secure to the changing natural water sources, while Kimani and Wekesa (2020), also emphasized that communities that have alternative water sources are more resilient to prolonged droughts that are caused by the changing climate. Studies done by Nabwire (2020), highlight the use of rooftop water harvesting. This study found that 68% of the people are already practicing it as their water source, hence requiring policy support and awareness.

In the National Water Policy of 2021, sustainable water practice recognizes water reuse, through the treatment of wastewater, as an alternative water source. This is suitable especially in towns and cities where there is a lot of wastewater. Studies done by Zhang *et al.* (2010) revealed that surface water is the common water source whose quality is mostly impacted by both human activities and environmental changes. Therefore, it is recommended that surface water sources be monitored, making it easier to design sustainable practices.

2.9 Socio-economic factors affecting river discharge

Some of the socio-economic factors affecting river discharge are discussed in the following sections;

2.9.1 Population growth and urbanization

The need for water increases with the increase in population and urbanization. More water is needed in growing towns for infrastructural support, sanitation, and residential consumption (Mulwa & Fangninou, 2021). Water demands in a growing population range from water for drinking, sanitation, agriculture, and industry. Existing water resources and supply systems are under pressure from this rising demand, which frequently results in shortages and the need for more infrastructure (Liu *et al.*, 2024). Population growth leads to an increase in water demand, which causes a decline in water quality due to human activities, flooding due to urbanization, heavy metal accumulation, coliforms, and pollution (Ahmad *et al.*, 2024).

Although the Kenyan government has increased water distribution across the country for economic development, the rate of water supply improvement is unlikely to support the country's long-term development goals (Chepyegon & Kamiya, 2018). A study done by Kumar et al. (2020) examined how population growth has affected the quantity of water in the Yamuna River Basin. The results revealed that the basin has experienced urban growth, which has resulted from demand for water and reduced the water retention capacity of the river. Water scarcity has been experienced during the dry seasons, making it hard for the people to meet their needs (Deresse, 2023). Furthermore, the untreated urban wastewater that are being released directly to the river has caused deterioration of the water quality (Chan *et al.*, 2022).

Similar findings from Hassan et al. (2018) demonstrates how urbanization converts land into built areas and roads. This affects the percolation rates and causes increased surface flows especially during rainy seasons thus altering the river discharge patterns. Population growth also stresses the existing water infrastructure hence the people are then forced to over extract the natural water sources such as rivers hence affecting its natural flow.

2.9.2 Migration patterns

Migration of people affects water dynamics both nationally and regionally. Migration is a process that involves movement of people from their original residence to another within their country or across the boarders whether temporarily or permanently (Łukaniszyn-Domaszewska *et al.,* 2025) Rural-urban migration raises the need for water in towns, which could cause shortages if the infrastructure cannot keep up. On the other hand, migration from cities to rural areas can also put strain on rural systems and resources. According to Teweldebrihan *et al.* (2020), increased number of humans and the changing climate have caused people to migrate near water sources because of water demand. This interaction has impacted water infrastructure and led to environmental degradation.

China is among the nations which have experienced water scarcity due to increased population and urbanization (Zhao *et al.*, 2025). In Kenya, people in dry regions are prone to water challenges, forcing them to migrate in search for water, which they also end up migrating further because of the depletion of those water sources (Lundberg, 2025). Xu and Famiglietti, (2023) demonstrated how water availability is linked to the migration patterns of people. This survey discovered that scarcity of water, weather conditions such as floods and activities such as the construction of dams causes people to move from one place to another.

These variables have an effect in river flow, which is able to affect agricultural production as well as the availability of water for domestic use. A Study done by Sun *et al.* (2022) on Minjiang River Basin in China demonstrates how migration which is caused by urbanization modifies the land use patterns and amounts of pollutants along river basins. The urbanization exerts pressure on urban infrastructure and water sources. This leads to changes of flow patterns in the river and increased pollution, which will ultimately result in water stress and problems in water management.

2.9.3 Agricultural practices and water use

The sections below contains reviewed literature on agricultural practices and water use;

a) Irrigation techniques

Irrigation practices globally account for up to 70% of the total fresh water withdrawals (McDermid et al., 2023). Flood irrigation is one of the traditional irrigation techniques that frequently results in major water shortages (Zia *et al.,* 2021). Studies on Aksu River catchment in Asia have illustrates that agricultural practices relies on traditional irrigation systems, lower the availability of water, resulting in a decrease in downstream water flows (Hu *et al.,* 2019). Therefore, use of smart agricultural methods by countries will require them to also embrace efficient practices of irrigation (Obaideen *et al.*, 2022). A case in point is the use of smart agricultural techniques like sprinklers and drip farming can increase water preservation although they are pricy to establish (Kipkorir & Mugo, 2018; Liet *et al.*, 2021). An appropriate mode for water usage in any watershed is to assess the common irrigation techniques utilized there.

Some efficient farming methods, like sprinklers and drip farming, are known to be efficient. Implementing efficient irrigation methods serves as a contributor to Sustainable Development Goals (SDGs) under the United Nations, Goal 6, on water conservation (Obaideen *et al.,* 2022). The drip irrigation that utilizes solar power in greenhouse farming has been explained in detail by Ashour *et al.* (2020). When assessed against the traditional methods, the system's automated irrigation timing, which incorporates plant requirements and environmental variables, significantly improves water utilization efficiency. Therefore, use of solar powered smart irrigation system not only protect water but also encourage sustainable agricultural practices (Chaudhry & Garg, 2019). This is useful for dry areas, where irrigation farming is used for both production of food and resource conservation.

Dadhich *et al.* (2012) had similar studies on efficient irrigation techniques. A cyclic sprinkler irrigation system was used where water is consumed efficiently. The method operates through switching between intervals of water delivery and pauses as an alternative to running sprinklers constantly. The circular operation not only conserves water but also promotes better soil moisture distribution, which leads to higher crop growth and less water waste. According to Yan *et al.* (2020), the method increases the rate of water infiltrating the soil and declines the rates of runoff and evaporation losses, especially in soils with poor infiltration rate.

b) Crop choices and water requirements

According to McDermid *et al.* (2023), irrigation practices on the Earth surface account for up to 70% of the fresh water sources and 90% of consumable water, and it covers 3.6 million km^2 of land. Water needs differ from crop to crop; hence, crop selection has a big influence on water consumption, especially in dry seasons, and crops that require a lot of water might worsen water scarcity (Adusumilli & Wang, 2018). When determining the irrigation system to be used in agricultural practice, the key determinant is the crop choice, although farmers' decisions are also influenced by their specific agro-ecological conditions, socioeconomic status, and institutional support structures (Mkuna & Wale, 2023).

Kylstra *et al.* (2021) utilized the Agricultural Water Demand model to find out how crop choice impacted water conservation in agricultural practices and this survey concluded that crops such as raspberries which are for commercial purposes consumed less water compared to forage and pasture crops when irrigated. According to Adusumilli and Wang, (2018), the kind of plants a farmer plant determines whether the farer is going to conserve water as it has been seen in the humid South of United States, where farmers who grew crops with high demand for water used modern irrigation methods and soil moisture management practices while pasture farmers who did not show concern for efficient irrigation practices were those that planted pasture which does not require much water.

Ncisana *et al.* (2024) researched on the water consumption rates of several fodder radish plants in a farm and concluded that several plants used water efficiently, which allowed them to use less water while producing more yield. This is very important especially for farmers in dry area to help them select the crops which require less water to avoid over extraction of the water source thus water catchments can be conserved. Opiyo *et al.* (2022), have added that the rising temperatures and erratic rainfall trends have been affecting agriculture and availability of water in dry areas therefore the farmers should also consider the water consumption rate of the crops they grow.

c) Impact of agricultural policies

Agricultural policies are put in place by any nation whose aim is to ensure maximum agricultural production by guiding the country through a set of regulation for economic growth of the nation (Ajwang *et al.*, 2023). The use of water for farming practices require agricultural policies that support sustainability and use of water efficient. According to Ajwang *et al.* (2023), sustainability in agriculture can only be met if policies for water conservation are formulated, the farmers' groups are supported to recognize that their choices influence actions and outcomes. Faling, (2020) mentioned that the Kenyan strategy on Climate-Smart Agriculture of 2017 has been made in a way that aims to transform Kenya's agricultural system by combining issues of the changing climate, food security and agricultural production. This strategy has implemented some climate-smart farming policies to see whether they can be relied on in water management.

Adom and Simatele, (2024) assessed the challenges that are in the water sector of South Africa and found that some issues like increasing floods, prolonged droughts due to changing weather patterns, growth in population sizes, and unregulated water use combined to increase water scarcity. These problems can get even worse when there is inadequate legislation, proper infrastructure and good governance, which are often associated with high levels of misconducts (Kimani *et al.,* 2022).

In many regions, many policies and regulations have been formulated but the challenge of implementation which are caused by weak institutional and structural protocols hinder success in addressing water problems (Ochieng *et al.,* 2020). Agricultural policies in Kenya that protect riparian land have been formulated but the challenge with it is the poor enforcement rates that results from poor coordination and low adoption rate in sustainable water management practices (Makindi & Mugatsia, 2024). In Slovenia, the New Common Agricultural Policy (CAP) 2023–2027, highlight how agricultural policy enforces the creation of protective riparian strips to conserve river ecosystems, though this has leads to reduced cultivable land and income loss for the farmers (LEŠNIK *et al.*, 2024). Portugal's agricultural policies under the Common Agricultural Policy (CAP) have the challenge of funding and incentives for restoration practices, therefore stronger and proactive policies to support river restoration and sustainable farming should be adopted (Santos *et al.,* 2025).

2.9.4 Industrial activities and water resources

The sections below contains literature on industrial water use;

a) Industrial water demand

Industries often require large volumes of water, clashing with needs for household and agricultural use (Mulwa & Fangninou, 2021). Unlike domestic and agricultural water use, industrial water use change with increased development, improved production levels, environmental conservation requirements, and the changes arising from climate change (Wang *et al.*, 2019). Sustainable water supply while also balancing conflicting water needs can only be achieved if industries use water sparingly because the growth rate of different industries with time will cause an expected increase in industrial water needs (Willet *et al.*, 2019).

Panda and Kim, (2023) developed an industrial water demand map of the world using artificial intelligence to helps improved planning and resource allocation in different sectors using precise estimations of water use. The method used provided opportunities for improvement by offering perspectives on how various industries contribute to water use which helps guide on better and affordable methods for understanding and controlling industrial water demand globally.

According to Gulfam-E-Jannat *et al.* (2023), Bangladesh is one of the countries that is facing a problem of waste water that arise from industries because of increased industrial growth in textile sector. The increasing demand for water from industries, combined with creation of large amounts of wastewater causes a strain on the existing water supply networks (Mulwa & Fangninou, 2021). Mishra (2023), believes that industrialization is among the causes of depletion of water sources and when combined with demand from other sectors, it can cause serious environmental risks such as pollution and degradation. These problems requires urgent mitigation through implementation of sustainable water resource management practices and the enforcement of the available regulations to ensure both industrial expansion and environmental conservation (Oruko *et al.*, 2021).

b) Pollution and water quality

Contaminants that originate from industrial processes has greater potential of worsening the quality of water in many water sources as it has been confirmed by Joseph *et al.* (2019), who claimed that industrial activities have increased the amount of contaminants in the rivers of most developing countries with heavy metals. Apart from heavy metals, micro-plastics in the rivers have increased thus requiring industries to strictly follow environmental standards and implement sustainable practices (Mintenig *et al.,* 2019). The pollution of aquatic habitats have significantly increased over the past years because of activities that cause pollution and also there have been concerns about the safety of using the rivers for drinking water and other uses (Sharma *et al.,* 2020; Katsanou & Karapanagioti, 2019).

Various pollutants are the causes of pollution in many rivers especially in growing towns where various activities take place (Al-Taai, 2021). Rivers greatly influence any nation's natural, cultural, and economic features. According to a study done in Lumbardhi River in Prizren, Kosovo by Gashi *et al.* (2023), untreated waste and industrial waste have resulted in significant amounts of harmful contaminants, including organic compounds, and heavy metals in the water, thus upsetting the sensitive ecosystem balance. A study by Hoang *et al.(*2020) on Houjing River have shown that the river is one of the most polluted river in Asia that flows through a highly industrialized area in Kaohsiung city (the second-largest city in Taiwan) and also it receives effluents from various industries in the area. Industrial wastes reach water sources through surface or underground water flows (Tripathi *et al.*, 2021).

Chemicals that are present in the water can cause waterborne diseases, which can negatively impact the public health and strain healthcare systems (Pourfallah Koushali *et al.*, 2021). The study of Singh *et al.* (2022) highlights how urgently improved wastewater treatment facilities are needed to stop more contamination, since the river is becoming more vulnerable to pollution as the amount of industrial and urban litter accumulates.

2.9.5 Policy and governance in water management

The sections below contains literature on policy and governance in water management;

a) Water management policies

Water governance has emerged as an area of interest, especially in the international arena because it acknowledges progress towards achieving Sustainable Development Goal (SDG) 6 (Jiménez et al., 2020). Enforcing fair distribution and controlling water use requires effective water management policies. Policies should address a range of subjects, such as pricing, conservation, pollution control, and the distribution of water. For example, in Shenzhen city in China, the current regulation in water management makes it difficult for decision makers to understand how to relate water supply and demand resources to geographical distribution hence causing delays in decision making (Chen *et al.*, 2020).

European policies like the Water Framework Directive which support the UN's global sustainable development agenda aims for sustainable water management although it requires better policy strategies and stronger integration of environmental, social, and economic aspects (Tsani *et al.,* 2020). Kenya has progressed in its regulations regarding the reuse of water, especially on the benefits that comes with it such as mitigating the effects of climate change, reducing water scarcity, reducing pollution, and also helping industries promote cleaner industrial and food production (Wakhungu, 2019).

The research by Kaluli *et al.* (2011) has shown the efforts that Kenya has done in creating a national policy framework that encourage reusing of wastewater which has led to gradually acceptable of wastewater reuse in the country. Water policies are important in ensuring the protection of water catchment areas, reduce pollution, and provides easy access to sanitary facilities (Odha & Mbataru, 2024).

According to Koehler *et al.* (2022) Kitui County is one of the counties that have adopted water management policies in Kenya, giving them an opportunity to experiment with various measures to improve water availability in rural regions because many of them lack proper water infrastructure. Kenya has implemented many policies because they recognizes the need to protect its water resources in water catchment areas by reducing pollution and improving access to clean water (Ondigo *et al.,* 2018). Some of the initiatives demonstrated by the Water Resources Users Associations (WRUA) in Kenya have shown that constructing infrastructure alone is not enough to implementing effective water policies, other important parts include educating the local people and sharing responsibilities with them, and understanding the nature of the local environment (Richards & Syallow, 2018).

b) Institutional capacity and governance

Strong institutional structures help conserve water while the governance of water involves procedures and regulations that determine access and distribution of water (Bertule *et al.*, 2018). Institutions have a role of conserving water resources, involve the necessary stakeholders, and enforce policies because it has a role of making decisions on water use, policies and water distribution ((Li *et al.*, 2021; Hassenforder & Barone, 2019). The institutional structure that govern water resources and services must involve techniques that allow all the important members to participate in water conservation (Jiménez *et al.*, 2019).

In Chepkaitit and Moiben watershed, the problems of water accessibility are caused by weak water institutional governance where policies are there but the challenge is on enforcing these policies (Chepkurui *et al.*, 2022). In the lower Thiba sub-catchment, Wangechi *et al.* (2023) assessed how institutional structures affect community water governance and found that while the community recognize the need to conserve water resources, only few of them believe that the regulations in place are for the goal of sustainability and they also recognize that the low responses arise from lack of support and awareness on their responsibilities and regulation related to water use.

Kumunga *et al.* (2020) conducted a research in Rwamuthambi catchment in Kirinyaga County, Kenya and found that low enforcement rates and the absence of institutional governance has created problems in the governance of water resources. Community organizations like Water Resource Users Associations (WRUAs) are useful in educating and raising awareness in communities but this have not always been successful because of lack of funds and technical support (Richards & Syallow, 2018).

2.10 Climate change and hydrology

The worldwide water condition will likely change because of the changing climate hence making biodiversity and human communities more vulnerable and as the hydrological cycle changes, it causes the natural river flow patterns to shift (Ostad-Ali-Askar *et al.*, 2018; Ficklin *et al.*, 2018). The water balance processes are greatly modified by the changing climate which causes the moisture levels in the atmosphere to reduce because of increased evapotranspiration rates resulting from global warming and greenhouse gas emissions (Zhang *et al.*, 2019). This affect can change the rainfall patterns causing either frequent floods or prolonged droughts, which would affect the available water for different purposes like human consumption and agriculture (Dunning *et al.*, 2018).

The changes in precipitation patterns can be seen through the occurrence of events like flooding, prolonged droughts, increased glacial melting, and the rising sea levels (Bărbulescu *et al.*, 2025). As per Douville *et al.* (2021), the global water cycle is severely worsening which results to the atmosphere absorbing more moisture when the temperatures are high as a result of greenhouse gas emissions, which causes some areas to experience more rainfall and others to face prolonged droughts. The consequence of this is the occurrence of floods and droughts which have major implications for water management and availability (Clarke *et al.*, 2022). Projections that have been done to show the future scenarios, have shown that wet regions may get wetter while dry areas will possibly become drier because of the additional human activities on the environment (Douville *et al.*, 2021).

Ojeda *et al.* (2021) looked into how the Iberian Peninsula's hydrological cycles are likely to be impacted by the changing climate and found that the flow of the river will be reduced probably because of the high temperatures and reduced rainfall, which creates a danger to water availability. The introduction of adaptive water management structures that can act as a cushion against reduced flows and increasing demands is important, as these changes will likely worsen seasonal water shortages, particularly during the dry seasons (Derepasko *et al.,* 2021).These adaptive systems will be important to many catchments as prediction such as those in Himayat Sagar catchment in India have shown that the ongoing increasing effects of the shifting climate and human practices are likely to reduce the river's discharge by 50%(Swain *et al.*,2022).

2.10.1 Historical climate data

Temperature and rainfall have changed over time in different regions. According to Tang (2019), these records have noted rising temperatures, which are linked to increased rates of evapo-transpiration and possible shifts in rainfall trends. There is evidence of changes in rainfall distribution in various regions, ranging from prolonged droughts to flooding. (Gulev *et al.,* 2021). NOAA (2024) reports have also shown that since 1850, temperatures have been rising at a rate of about 0.06°C per decade, and this rate has increased three times more since 1982, reaching about 0.20°C per decade. This has helped create baseline climate conditions which is important when evaluating historical data trends for creating future projections and models (Lindsey & Dahlman, 2020).

According to Haustein *et al.* (2025), a first time record of an increase of about 1.43 °C in 2023 climate record a raised from a combination of natural climatic variability, especially the influence of El Niño Southern Oscillation and the increasing human-caused greenhouse gas emissions. This rapid warming further intensifies concerns raised by the UNEP Environmental Effects Assessment Panel, (2016), especially for vulnerable regions like East Africa, where erratic rainfall and rising temperatures threaten livelihoods hence adaptation efforts are urgent in such regions. According to this study, assessing the trends in temperature requires considering both natural and human-caused factors since their combined effects may increase impacts of changes in climate. The Earth is currently at the peak warming after crossing the unexpected mark of 1.5°C while Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, (2023), also reporting that globally, human activities have caused the average temperature to be about 1.31°C hotter than it was in the late 1800s. Over the period 2014 to 2023, the average temperature was about 1.19°C higher than before.

2.10.2 Climate trends

At COP28, the Annual Conference held under the United Nations Framework Convention on Climate Change (UNFCCC), (2023), it was noted that Africa is warming faster than other regions globally while East Africa is experiencing increasing climatic changes which is expected to threaten agriculture and water sources. The Intergovernmental Panel on Climate Change (IPCC), (2022), warned about a 2°C rise in temperature which could reduce Africa's GDP by around 5% while the Horn of Africa is projected to face the worst drought in 40 years which comes along with destructive floods. Projections indicate that the average temperatures in East Africa could increase from 2°C to 5°C by the end of the century if global warming is not mitigated.

Artificial intelligence (AI) is important in climate modelling because it can analyze the past and future climate patterns under different conditions scenarios (Ukoba *et al.,* 2025).

National Aeronautics and Space Administration (NASA) has been trying to reduce the effects of climate change through their efforts of using satellites to observe various environmental parameters through advanced space-based technologies (Mertz, 2024). The WMO (2023), strategic plan of 2024-2027, has prioritized improving early warning systems to help provide informed decisions on climate, which is aimed to strengthen global resilience on human and environmental hazards. Artificial intelligence can be helpful to scientists if combined with data from several sources including modern records of observation and past climate to predict future events.

Africa has been warming over time and it is believed to continue warming from 1.2°C to 4.4°C by the end of the century while the Sahara region will be affected the most (Almazroui *et al.*, 2020). While rainfall patterns vary across the continent, with decreases in northern and southern Africa and increases in central Africa, overall rainfall is expected to rise modestly but with considerably unpredictable. According to Gebrechorkos *et al.* (2019) East Africa has experienced rising temperatures, with highs increasing up to 1.9°C and lows by 1.2°C. Rainfall experienced in the long wet season shows a decreasing pattern in parts of Ethiopia, Kenya, and Tanzania, while the short rains have slightly increased in some areas. Projections indicate further rise between 2–5°C by the end of the century and more erratic rainfall, increasing the risk of droughts and floods. Focusing on Kenya, temperature is rising, with more frequent warm days, nights, and prolonged heat spells, while cold days and nights are decreasing. Rainfall trends vary across regions, highlighting the need for location-specific adaptation strategies (Gebrechorkos *et al.*, 2019).

2.10.3 Impact of climate change on water resources

The shift in climate has altered the world's hydrological cycles mainly because of the changes that are seen in temperature and rainfall (Du *et al.,* 2021). Most fresh water sources in many parts of the world are expected to experience negative influences because of this shift (Stoler *et al.,* 2021). The intensity, frequency and timing of the occurrence of weather changes like surface runoff and droughts are strongly linked with the shift in climate (Mengistu *et al.,* 2021).

The presence of underground and surface water is impacted by the extent of changes in climate impacts (Abdelhalim *et al.,* 2020). Shifts in rainfall trends can impact river discharge dynamics, potentially resulting in decreased river flow during dry seasons and increasing the danger of floods during the intense rainy season (Jain & Singh, 2023). Some regions in the world are likely to have an increased number of people at risk of water scarcity because of water shortages that have increased the demand for water for various uses (Stoler *et al.,* 2021).

Percolation rates and recharge of groundwater are more likely to be affected by the changing climate and as temperatures continue to rise and rainfall patterns becoming more erratic the quality of water is worsening through the increasing quantities of pollutants and nutrients in water sources (Lindsey & Dahlman, 2020). Berghuijs *et al.* (2024) also investigated how groundwater recharge rates are influenced by the changes in climate and found out that groundwater recharge is extremely sensitive to weather patterns and any changes in temperature and rainfall causes irregular and exaggerated responses in recharge rates. The groundwater recharge may be significantly reduced in places with increased dry conditions because of climate changes, and significantly increased in areas with higher rainfall because of the changing weather patterns (Douville *et al.*, 2021).

Huang *et al.* (2023) also investigated how shallow water bodies like lakes, rivers, and wetlands, are impacted by these shifts as the study demonstrated that more unpredictable water cycles are a result of climate-related changes which include changed rainfall patterns and rising temperatures. The shift in the occurrence of water will affect, farming practices, human needs and environmental sustainability (Dunning *et al.*, 2018) and the influences related to it will even be more pronounced in developing nations where farming is a major economy (Worqlul *et al.*, 2018). Therefore, global mitigation measures are important as climate change cuts across all nations with different levels of impacts for global sustainability (Abbass *et al.*, 2022).

2.11 Policy, legal and institutional framework of water

The sections below contains policies, legal and institutional frameworks of water;

2.11.1 Policy Framework

The Constitution of Kenya (2010) Article 69 requires that the government ensures sustainable use, utilization, governance, and protection of natural resources. Public participation in environmental governance, including management of water resources, is emphasized in Article 69(1)(d). Communities that rely on rivers, lakes, or groundwater have a right to inclusion in decisions of usage and protection of water resources (Constitution of Kenya, 2010). As highlighted in the Fourth Schedule, the county government has been given the role of providing water services while the national government oversees water policy and resource protection. It also promotes the fair distribution of the benefits that arise. The Sustainable Development Goals (SDGs) and Kenya's water management policies align in their goals which aim for a more sustainable and inclusive system for the protection and conservation of water resources (United Nations, 2015). Sustainable water management processes are important in achieving SDG 6's goal of worldwide access to water and sanitation which directs Kenya's efforts to enhance sanitation services and supply clean water for its citizens. SDG 13 urges urgent action to reduce the impacts of the changing climate that is why Kenya's initiatives to respond to the changing climate have been outlined in its National Adaptation Plans (NAPs) and they are in line with this objective because water resources are greatly impacted by climate change. The process of achieving this goal requires the government and other stakeholders to create resilience in water infrastructure and in climate-smart water management practices. Water storage and quality depend on the ecosystems on land that is why SDG 15 has a purpose on ensuring conservation, restoration, and sustainable use of water resources. Kenya has adopted this SDG by promoting biodiversity conservation and water management through the efforts of preserving forests, wetlands, and other areas that are important for water conservation. Additionally, by encouraging the sustainable use of natural resources, reducing the creation of waste, and promoting sustainable farming practices and manufacturing processes, SDG 12, which focuses on ethical production and consumption of natural resources, supports the efficient use of water. By embracing SDG 12, Kenya's efforts to conserve its water resources for the present and next generations are promised and also can lead to more adoption of practices which are both economically and socially sustainable for water management. The Paris Agreement binds all nations that are involved in it legally with a goal of reducing the warming effects of the earth and plan for ways to mitigate the effects before the situation worsens. This agreement is associated with water resource management in that the decisions and campaigns made for the implementation of a climate-resilient environment relate to water systems and sustainable water practices as Kenya is among the countries that have faced the impacts of the changing climate which includes the changed patterns of rainfall and an increase in droughts and famines (UNFCCC, 2015).

2.11.2 Legal Framework

The Water Act (2016), No. 41, redefines the roles and responsibilities related to the governance, development, and protection of water resources and sewerage services (Water Act, 2016). Furthermore, the Environmental Management and Coordination Act (2015) aids in protecting biological differences and ensures access to resources from genetics, marine and freshwater resources, and wetlands (EMCA, 2015). According to The Physical and Land Use Act (2019), the communities that have access to land are required to live and meet their needs from the land around them sustainably (Physical and Land Act, 2019). This act guides the use of natural resources responsibly for environmental resilience. This is in line with the Forest Conservation and Management Act (2016) which establishes regulations for forests, provides guidelines for the use of forest land, and provides provisions for the conservation and management of public, community, and private forests as well as regions of forest land that need particular protection (Forest Conservation and Management Act, 2016). Additionally, it provides for the commercial activities in forest products, the preservation of Indigenous forests, the community forest association's involvement in forest areas, and the conservation of water resources. The government of Kenya also recognizes the requirement to provide stable agricultural practices while conserving the soil under acceptable land use management (Agricultural Act, 2013). It also aims to reduce the amount of carbon emitted because it can affect water which can be seen through the changing weather events such as droughts and floods (Climate Change Act, 2016). Wetlands are important for preserving the quality of water, controlling the discharge flows, and supporting biodiversity which has led to the creation of the Ramsar Convention agreement among many nations whose goals are to conserve and sustainably use wetlands in their countries (Ramsar Convention Secretariat, 1971). Several wetlands in Kenya have been named Ramsar Sites, thus helping them secure their preservation and sustainable management that have been mentioned in the agreement. The International Guidelines on Water and Health have given out guidelines regarding the need to protect human health which can be done by ensuring that the water sources are safe from any waterborne diseases and other related health issues (UNECE & WHO, 1999). This Protocol is among the first agreements globally that serves to ensure everyone has enough supply of clean water, proper sanitation and it also makes sure that the water sources are protected to ensure a continuous source of safe water for drinking.

2.11.3 Institutional Framework

The Ministry of Water, Sanitation and Irrigation (MWSI) in Kenya is the main government agency with a role in organizing the water sectors for the purposes of ensuring the whole country can access water, regulations are made and implemented and also control the consumption of water countrywide (Government of Kenya, 2019). Its major purpose is to oversee the implementation of the Water Act of 2016 which guides on how the water should be distributed and governed to serve the water needs of the people. The Water Resource Authority is tasked with monitoring Kenya's water resource consumption (Water

Resource Authority, 2018). It is responsible for managing water catchments, monitoring water quality and quantity, providing licenses for water abstraction, and making sure that water resources are used efficiently. The authority is important in preserving the balance between the various needs for water across several industries and the supply of water.

2.12 Research gap

Global studies, such as the one done by Shi *et al.* (2019), have shown that the shifting climatic patterns and human activities can impact river discharge where trends in discharge in North America and Africa have declined while those in Europe have increased. The study is useful in showing the global trend but it failed to capture localized dynamics of smaller catchments like the Moiben River catchment in Kenya, where socio-economic and land use changes serves an important role in discharge trends.

At the local level, the study of Chepkurui *et al.* (2022) on the effects of LULC shifts on river discharge in the broader Moiben and Chepkaitit watersheds have shown that farming activities and felling of trees within a watershed are the main factors affecting the flow levels of a river. This study however, did not fully consider other factors like climate variability, population changes, and socio-economic activities, on river discharge. Furthermore, Chepkurui *et al.* (2022)'s research covered a large geographical area which differ from this study that focuses specifically on the Moiben River catchment, which has a unique geographic and socio-economic setting.

There exists a clear knowledge gap in understanding how the combined effects of land use/land cover changes, climatic variability, and socio-economic activities have influenced the discharge patterns of smaller catchments like the Moiben River catchment. Previous studies have either focused on broader regions or examined individual factors in isolation, leaving limited understanding of how these variables interact at a localized scale.

This research looked at the trends in river discharge, LULC changes, and socio-economic (like population growth, agriculture, and water use) in Moiben River catchment for a deeper understanding of the localized factors affecting river discharge, which will help inform more targeted water resource management strategies.

2.13 Theoretical framework

The study was guided by the following two theories;

2.13.1 Land use transition theory

The Land use transition theory was introduced by Lambin and Meyfroidt to explain how land use patterns change over time because of socio-economic and environmental changes (Lambin & Meyfroidt, 2010). The theory states that land use changes follow an order when changing that is from the natural covers such as forests, wetlands, and grasslands to covers like farmlands because people are constantly trying to meet their food needs, their livelihoods, and settle in a safe environment. As development increases, some lands can further change from urban areas to industrial zones, while others may experience land degradation or even reforestation through conservation initiatives or changing economic priorities. These changes are caused by a range of factors such as population growth, improved technologies, changes in polices, and ecological changes such as land degradation and water scarcity. This theory emphasizes that not all changes follow a particular path because they are often shaped by local conditions, cultural settings and institutional setup that differ from one another.

Land use transition theory is important when understanding how different phases of land use changes affect water processes and water availability like in cases where converted forested land into farmland can reduce infiltration and increase surface runoff, leading to higher river discharge during rainy periods but reduced ground water in dry seasons. Increasing human infrastructures also often leads to increase in non-porous surfaces such as roads and buildings, which disrupt the natural water flow patterns and increase the risk of flooding. Increased farming activities may also result in higher water extraction for irrigation, contributing to water stress, especially during dry periods.

2.13.2 Tragedy of the commons

This theory was introduced by Garrett Hardin and the theory explains a situation where people act on their own will which are driven by their own interests to use shared resources which leads to overuse or depletion (Hardin, 1968). Every individual within the group is able to access the shared resources like grazing land, fishing areas, or water sources, which is referred as commons because everyone has ownership rights. This theory is important to this study because it illustrates how shared resources such as water resources are poorly managed and overused and it can also include poor management of the sub-catchment resources such as forests and wetlands. Over-extraction of water from rivers can cause a reduction in river discharge and also it can cause disputes because of competition from different water users like industries, farms and households hence it shows how difficult it can be in attaining sustainable and equitable water use. Water governors and policy developers can benefit from the theory because it illustrates how important it is to manage and regulate water resources effectively to avoid conflicts, contamination and deterioration.

2.14 Conceptual framework

The dependent variable which is river discharge can be influenced by independent variables such as changes that result from land uses, the amount of rainfall, population sizes and changes in temperature (Figure 2.1). River discharge can be impacted by shifts in land use like expansion of settlements, expansion of farm land, or felling of trees, for instance, turning forested lands into farmland might cause surface runoffs to increase especially during rainy seasons as forested lands tend to slow down moving water and increase infiltration which reduce river discharge compared to farm lands. The changes can also affect the natural water processes like evapotranspiration and percolation for example forested areas have a higher evapotranspiration rates that contributes more water vapor in the atmosphere thus regulating the falling of rains when compared to built-up areas where infiltration rates are lower hence causing increased surface runoffs that increase the river flows. Higher rainfall tends to increase river flow while droughts or less rainfall decrease the river flow but it can depend on the ability of the soil to retain water and the cover of the land because intense rainfall on bare grounds may lead to floods due to poor percolation. Temperature can also affect the natural water processes where the river discharge can be reduced in case of higher temperatures which increases evaporation rate while lower temperatures can maintain the flow levels because of low evaporation rate. Higher temperatures also have the ability to increase evapotranspiration rates which can potentially reduce the recharge of the ground water which can in turn affect water levels. Human population growth can affect ways in which the land can be used and competition in the use of natural resources like in cases where intensive farming is carried out to support the people’s lives, more water may be extracted leading to reduced river discharge. The topography of an area also determines the infiltration rates of water as level lands may have slower runoff leading to lower levels of river discharge due to high infiltration rate, while steep slopes may experience faster runoff and higher discharge especially during rainy seasons. Effective measures like building dams, and using sustainable farming methods may regulate river discharge and lessen flooding events along a river. Human activities like irrigation practices may cause over extraction of water from a river, which would affect the discharge levels downstream while water and land policies can control farming practices, enforce laws and promote water conservation that aim to reduce extreme effects on river flow. While policies can mitigate degradation and overuse of the natural resources, they need to be enforced and properly implemented. Traditional cultural ways of water conservation like rainwater harvesting, may be used in some communities and it can lessen the need for water from rivers thus helping restore ground water which may result in more regular river discharge. All these interactions can lead to sustainable catchment management if the needs of the environment and the people are balanced.

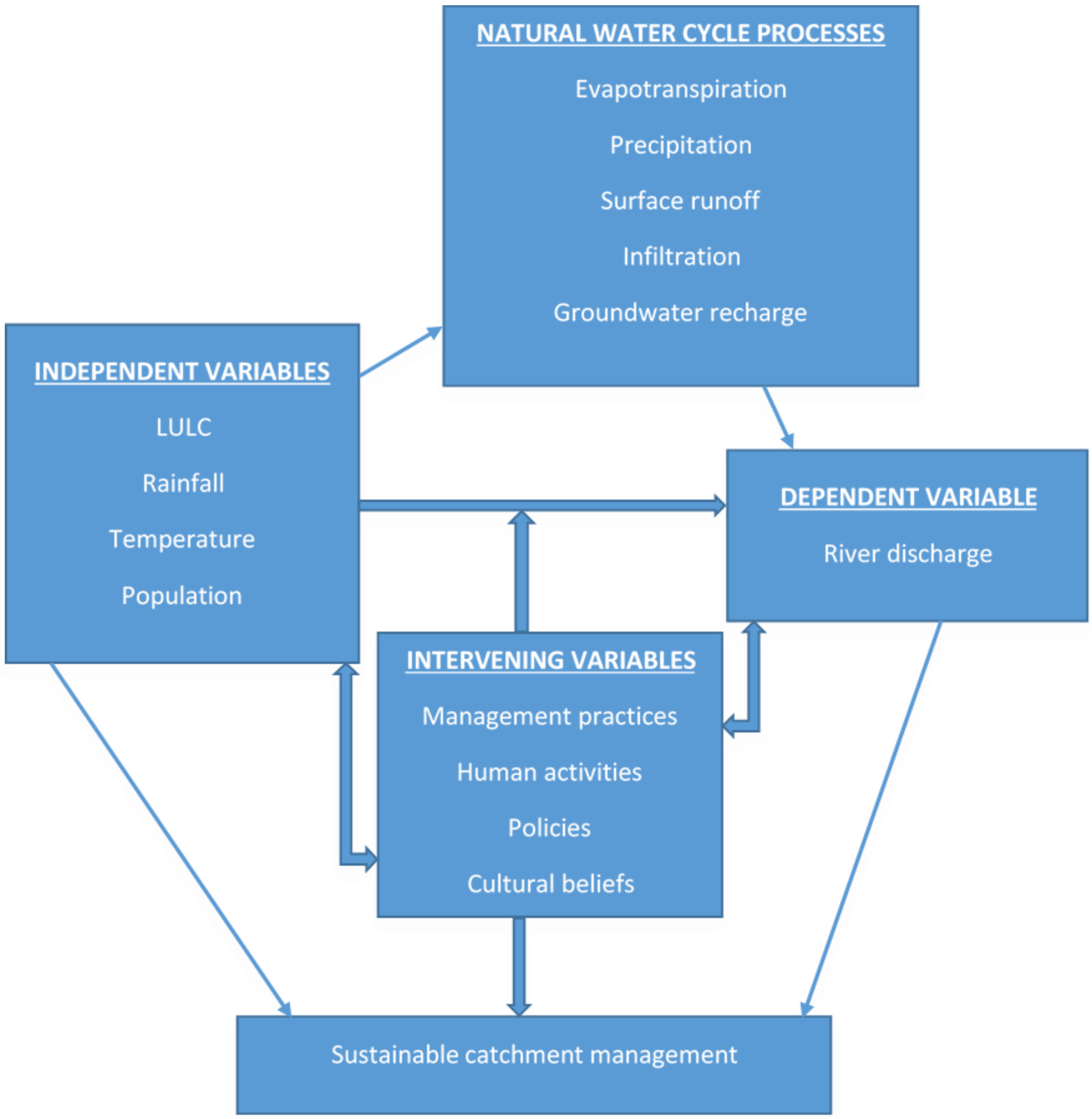

Figure 2.1: Conceptual framework

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This section contains the description of the study area, the research design, the target population, sampling procedures, data sources and description, data collection tools, and data analysis methods that were used to analyze the factors influencing the Moiben River catchment's river discharge.

3.2 Study area

3.2.1 Location

The catchment is located between longitudes 35.1°E and 35.5°E and latitudes 0.6°N and 0.9°N (Figure 3.1). The catchment covers most of Moiben Sub-county in Uasin Gishu County. It also covers some parts of Trans Nzoia and Elgeyo Marakwet Counties. The main economic activity in the catchment is agriculture because its terrain is made up of fertile plains and hills with slopes (Kiprop, 2018).

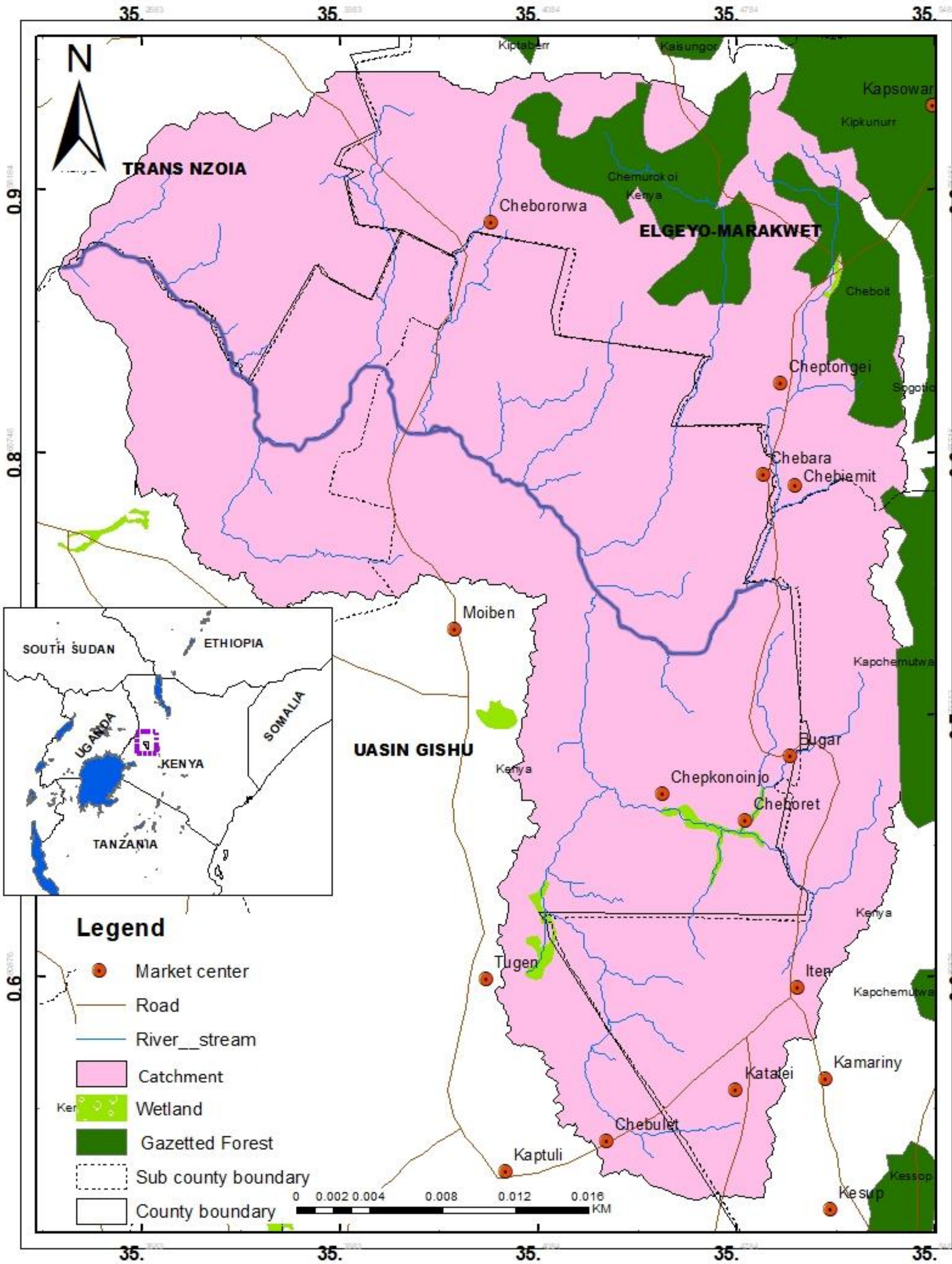

Figure 3.1: The study area map showing the Moiben River catchment

3.2.2 Climate

The catchment has a cool climate with a mean annual temperatures of about 18° C and a rising terrain of between 1500m to 2700 m above sea level (Kiptoo, 2023). The northern and southern parts of the catchment receive about 1000-1800mm of rainfall annually and the western part of the catchment is usually above 1500mm. The rainfall is common between the months of November and February while and also reliable and evenly distributed throughout the year.

3.2.3 Drainage and hydrology

Moiben River serves about 24,679 people that live in the catchment (Kiprop, 2018). The river also has tributaries which include river Tangasir which is a seasonal river, river Chebororwa and river Arbabuch.

3.2.4 Vegetation cover

The catchment has a wide grassland which has plants like the Kikuyu grass (Pennisetum clandestinum) and Red oat grass/ Kangaroo grass (Themeda triandra). Some section of the land is occupied by crops and plantations that grow few fruits (oranges, avocados and bananas) and coffee trees (Coffea Arabica) (Ngunjiri *et al.*, 2019). Man-made forests that consist of Pinus (Pinus spp) and Eucalyptus (Eucalyptus spp) are common while the natural forests has native trees like Yellowwood (Podocarpus spp) and African Pencil Cedar (Juniperus Procera). The shrub lands and bush lands, have tough species that dominate in poor soils or less rainfall like the Acacia (Vachellia tortilis) and Euphorbia (Euphorbia tirucalli). The riparian vegetation is also common along the rivers and streams.

3.2.5 Soils and geology

The soils in the catchment are both red and brown colored, clay and loam soils (Ngunjiri *et al.,* 2019). Volcanic rocks cover most of the catchment while Gneisses, schists, and quartzites rocks are in the western part of the catchment.

3.2.6 Socio-economic activities

The catchment has a rural setting with extended families and community structures. The people mostly depend on farming practices as their primary sources of income while other economic activities in the area are shaped by factors such as education levels, gender and access to important resources. (Ngunjiri *et al.,* 2019). Industrialization is also common in Eldoret which is the administrative and economic center of Uasin Gishu County and the industrial sectors include; food processing, textile, and building material industries (Oyugi & Makana, 2023).

3.2.7 Population size and distribution

The population of Uasin Gishu according to the 2019 population statistics was 1,163,183 with a population density being at 343 per km^2 and growing at a rate of 3.8%. About 24,679 people reside in the Moiben River catchment where the study was conducted (Kenya National Bureau of Statistics, 2019).

3.2 Research design

A descriptive research design was used in the study because it focuses on describing existing conditions as they are. The study aimed to examine patterns in river discharge, land use, rainfall, and human activities in the catchment. This design was chosen since it enabled collection and analysis of data without influencing any of the variables, and explained how these factors are related to water availability in the area. A mixed method approach was also used for the collection of both the quantitative and qualitative data.

3.4 Target population

To efficiently assess the challenges affecting the Moiben River catchment in providing water to Moiben residents, a target population of 24,679 that lived in the catchment was examined. This population consisted of residents from 5 sub-counties.

3.5 Sample size determination

The sample size that was used was obtained from Yamane's formula (1967) as follows;

Therefore, sample size (n) is given as:

$n = N / (1 + N (e^2))$

Where:

- n = required sample size
- N = Population size (24,679)
- e = Margin of error (typically 5.04% or 0.0504)

Calculation

Substituting the given values into the formula:

$n = 24{,}679 / (1 + 24{,}679 \times (0.0504^2))$

$n = 24{,}679 / (1 + 24{,}679 \times 0.00254)$

n = 24,679 / (1 + 62.68466)

n = 24,679 / 63.68466

n ≈ 388

According to the Kenya National Bureau of Statistics (2019), the households in the catchment was 6170. These households are distributed across seven sub-locations, which are situated within five sub-counties in the study area. The five sub-counties are Moiben, Soy, Marakwet West, Keiyo North, and Cherangany. This guided in determining the number size of households in each sub-location using proportional allocation. The formula used was;

Sample size of sub-locations= (households in each sub-location/ total households) ×Total sample size

The sample size distribution as per sub-locations in the catchment was as follows in Table

Table 3.1: Sample size distribution of Moiben River catchment

Sub-location	Population	Sample size	Percentage (%)
Kaplolo	2865	45	12
Kapsubere	3040	48	12
Suwerwa	1040	16	4
Meibeki	8577	135	35
Chebororwa	2150	34	9
Tuigoin	2947	46	12
Moiben	4060	64	16

3.6 Sampling procedures

Systematic sampling was used to select the households to be interviewed. A total of 388 households were selected from 6,170 households (KNBS, 2019) distributed across seven sub-locations within the catchment. These seven sub-locations fall within five sub-counties. The number of households selected from each sub-location was determined using Probability Proportional to Size (PPS) sampling, ensuring that sub-locations with larger populations contributed more respondents to the sample. Within each sub-location, the sampling interval was given by dividing the total number of households in that sub-location by the number of households to be sampled from it. A random starting number between 1 and the calculated interval which is 16^{th} household was selected, after which every 16^{th} household was picked until the required number for that sub-location was achieved. Purposive sampling was also used to choose key informants with in-depth knowledge and expertise in local water management, such as community leaders, KVDA and WRA officers, agricultural officers and World Vision officers.

The sampled households were within 5 sub-counties where the Moiben River catchment lies, as shown in Figure 3.2. They represent the proportional number of households per sub-county which were sampled.

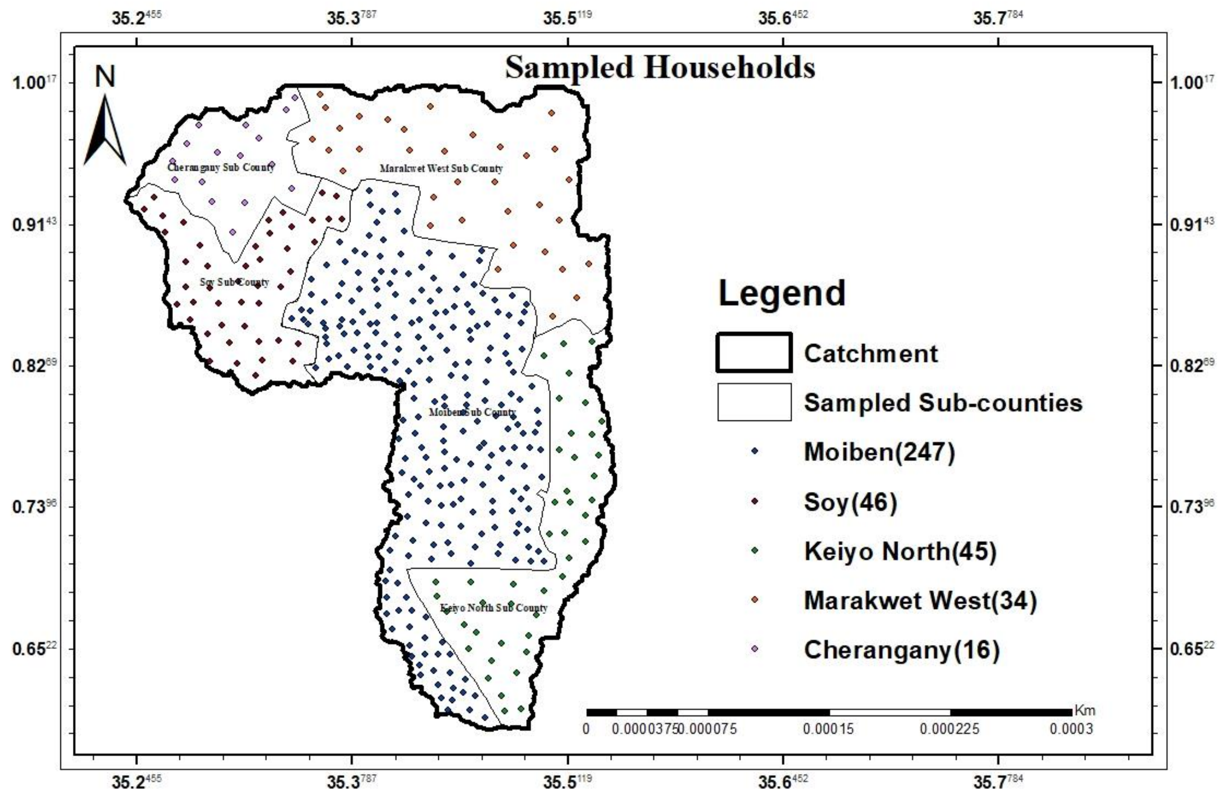

Figure 2.2: The sampled households in Moiben River catchment

3.7 Data sources and description

This study used both primary and secondary data sources to assess the factors influencing river discharge in the catchment. Data were collected using various tools and techniques, each selected to suit the specific type of information required for analysis.

3.7.1 Primary data sources

Primary data were collected through household questionnaires, key informant schedules and GPS for ground truthing. These provided first-hand information on socio-economic activities, local experiences with changing climate and land use shifts, and community water use practices

Household surveys using structured questionnaires were administered to sampled households within the catchment to collect data on domestic water use, agricultural practices, socio-economic activities, and local experiences with land use and climate changes. The questionnaire had both closed-ended and open-ended questions to allow for the collection of both quantitative and qualitative data. This tool was important for understanding community-level water use patterns, perceptions of both land and climate changes, and adaptation strategies within the catchment (Appendix I).

Key Informants who were the WRA and KVDA Officers, Community leaders, Agricultural officers, World Vision officers were interviewed in a semi-structured manner. Key informant interviews aided in understanding water projects, water uses and practices, agricultural activities and community engagement in water management in the catchment (Appendix II)

Global Positioning System (GPS) device was used during fieldwork to collect geo-referenced data points of various land use and land cover classes. These data points were utilized during validation of satellite images in the land use/land cover (LULC) analysis. Ground truthing helped improve the ascertaining of maps by providing real-world reference data. Coordinates were recorded for classes which were cropland, forest, bare land, surface water, rangeland, grassland and built areas**.**

3.7.2 Secondary data sources

Secondary data were obtained from relevant institutions and online sources. These included river discharge, temperature, rainfall, population, and satellite images, soil and Digital Elevation Model data.

River discharge data was obtained from the Water Resources Authority (WRA) and Kerio Valley Development Authority (KVDA), temperature and rainfall data was obtained from Kenya Meteorological Department (KMD), while population statistics was from the Kenya National Bureau of Statistics (KNBS). Remote sensing data, which is, satellite images for land use and land cover analysis was from United States Geological Survey (USGS) https://earthexplorer.usgs.gov , soil data was from the Kenya Soil and Terrain Database, https://data.isric.org and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) from United States Geological Survey (USGS) Earth Explorer for catchment delineation, was also used.

3.8 Delineation of the catchment

The Moiben River catchment was delineated using a 30-meter resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) from the United States Geological Survey (USGS) Earth Explorer. Using ArcGIS version 10.8 software, the DEM was first processed to fill sinks, after which the direction of the flow and the accumulation of the flow were generated. A pour point was placed at the river outlet to guide the watershed tool found under the spatial analyst tool and hydrology tool to outline the catchment boundary. The resulting boundary was then used for further land use mapping.

3.9 Analysis of the trends in river discharge of the Moiben River from 1995-2024

3.9.1 Data collection

The data for river discharge from 1995 to 2024 for this study was obtained from secondary data sources, which are the Kerio Valley Development Authority (KVDA) and Water Resource Authority (WRA), to show the long-term trend of river discharged from MOIBEN_1BA01 gauging station along the river.

Key informants which were the WRA officers, community leaders, agricultural officers, World Vision officers were interviewed in a semi-structured manner.

3.9.2 Data preprocessing

The data was first cleaned by identifying missing values in the data, linear interpolation technique was used to identify the missing values in the river discharge values. This involved taking the values before and after each missing point and estimating the missing value based on the assumption that the change between them was gradual. The data was also changed from daily discharge data to yearly discharge data by using mean calculation.

3.9.3 Data analysis

Linear regression analysis through time series analysis was conducted using SPSS version 29 tool to illustrate the trend of river discharge and this was done by using the river discharge data that were in form of annual averages from the year 2000 to 2023.This process involved plotting the river discharge values against time (years) and producing a trend line that shows the general direction of change over the years. Regression analysis was also performed using least square technique which produces a best-fitting line by reducing the values that vary between the actual discharge data and those that are projected.

The purpose of producing a trend line was not only to observe the trend of the discharge over time but also to statistically investigate whether these changes were significant, hence, a statistical test (t-test) was performed on the slope of the regression line to determine if the pattern was significant. A p-value of less than 0.05 was considered a significant trend. The level of change in river discharge over time was demonstrated using the coefficient of determination (R^2) produced from the analysis. This method was able to show the changes in the river discharge over the period and also gave a statistical interpretation that supported the trend.

3.10 Determination of the extent and patterns of land use and land cover change in the Moiben River catchment from 1995 to 2024.

3.10.1 Data collection

Remote sensing satellite images from LANDSAT 5(1995), LANDSAT 8(2004), and LANDSAT 8(2014) which had a resolution of 30 meters from United States Geological Survey (USGS) https://earthexplorer.usgs.gov and Sentinel-2 (2024) which had a resolution of 10 meters from Copernicus Open Access were used in this study to produce the LULC maps of the catchment (Table 3.2). The images were obtained in January, February, and March when the cloud cover percentage was low. These images were obtained after every ten years from 1995 to 2024.

The key informant data used were obtained at the same time when collecting data for objective one.

Table 3.2: The satellite data

Dataset Type	Satellite Sensor	Platform	Path/Row	Spatial Resolution (m)	Date of Acquisition	Reference
Satellite Imagery	LANDSAT 5 TM	Landsat Program (USGS)	169/060	30	Jan–Mar 1995	United States Geological Survey(USGS), https://earthexplorer.usgs.gov
Satellite Imagery	LANDSAT 7 ETM+	Landsat Program (USGS)	169/060	30	Jan–Mar 2004	United States Geological Survey(USGS), https://earthexplorer.usgs.gov
Satellite Imagery	LANDSAT 8 OLI/TIRS	Landsat Program (USGS)	169/060	30	Jan–Mar 2014	United States Geological Survey(USGS),

						https://earthexplorer.usgs.gov
Satellite Imagery	Sentinel-2 MSI	Copernicus (European Space Agency)	Tile 36MVE	10	Jan–Mar 2024	Copernicus Open Access Hub, https://scihub.copernicus.eu
DEM	SRTM 30m	USGS		30	2024	United States Geological Survey(USGS), https://earthexplorer.usgs.gov

3.10.2 Data processing

Geometric correction was performed on all the satellite images to ensure that all the features were at their correct real world coordinates. This process helps remove the spatial distortions that occurs when the sensors move, the changes in terrain or because of the curved nature of the Earth. The control points on the earth surface were generated using United States Geological survey (USGS) images which were useful in the correction process. The images were then rectified and projected to the Universal Transverse Mercator (UTM) coordinate system for the purposes of consistency in all the satellite images and enabling easy and accurate overlay with other satellite images which have similar coordinate system.

Atmospheric correction has a role of ensuring that the images are free from the manipulations caused by clouds, dust and water vapors in the atmosphere. This process was done for all the images to ensure that the reflectance from the surface features were accurate with the help of atmospheric correction algorithms that adjusts the unprocessed image values to accommodate atmospheric distortion.

The different levels of the brightness of individual images were balanced using radiometric correction. This process involved balancing the differences in the sun intensity and sensor errors which manipulate the visual appearance of the image.

Cloud and shadow masking technique was also used to eliminate the areas affected by clouds and shadows. A mask was created to identify and avoid these areas from the analysis and thus allowing only the clear parts of the images to be analyzed.

3.10.3 Data Analysis

Satellite images were grouped in the periods 1995, 2004, 2014, and 2024 to allow individual classification using supervised classification to produce four LULC maps. The classification process was guided by the training samples obtained for each image to show the different land covers of each year and they were used train the algorithm for classification by giving it known land cover types like the rangeland, bare land and surface water. The algorithm used was Maximum Likelihood Classification (MLC) to classify the satellite images as this is the common algorithm in most supervised classification and also it is effective when classifying multi-spectral data. Maximum Likelihood Classification (MLC) is widely preferred in supervised classification because of its high accuracy levels and it can facilitate change detection effectively when comparing land cover categories for different periods of time (Chughtai *et al.*, 2021).For example, in a study by Alam *et al.*, (2020) in the Kashmir Valley, where Maximum Likelihood Classification was used to map land use changes over a long period of time and it was found that the major shifts were commonly caused by human activities in the area. This method places individual pixel to the class it is most likely to belong according to the given probabilities that assumes that the statistical allocation of each class in the training samples has a normal distribution. The classification also reduced the errors that occur during the classification process by classifying each image individually for all the four images. The changes in land use and land cover over the period in the catchment were then demonstrated in different maps to show the comparisons and allow further interpretation. The analysis was done using ArcGIS version 10.8 software.

3.10.4 Ground truthing using GPS

Ground truthing was done to confirm the accuracy of the classified images from the real images on the land uses from the actual ground. Some points from the study area was selected and then these points were visited to observe the land cover types that are in these points are seen from the images such as forest, grassland and bare land. At each selected point a handheld GPS device was used to confirm the coordinate location of the land cover in that site. Direct observations were also used to identify the land cover types on these sites. Field notes were utilized to get details such as the type of vegetation, and the human activities on the selected sites. A total of three hundred and ninety two ground truth points were collected across the catchment to represent the sample of all the major land cover types and two hundred and seventy four of these reference points were then used in the classification process to improve the accuracy of the land cover maps and the other remaining one hundred and eighteen reference points were also used further in the accuracy assessment process to compare the classified results with the actual ground data.

3.10.5 Validation and accuracy assessment

Kappa coefficient was used to compare the ground truth data with the actual ground data by considering the chances for random compatibility to show the accuracy of the classified land use/land cover (LULC) maps created. The correct and incorrectly classified pixels of the land covers were displayed in a confusion matrix and used to calculate the Kappa coefficient. The matrix included rows representing the classified LULC classes and columns representing the reference (ground truth) classes. Kappa Coefficient (κ) measured the compatibility between the classified data and reference data while accounting for chance agreement (Foody, 2020). It is given by:

$\kappa = (Po - Pe) / (1 - Pe)$, where

Po (Overall accuracy) = (Sum of Diagonal Elements) / (Total Samples)

Pe (Expected accuracy) = [(Row Total × Column Total) for each class] / (Total Samples) ^2

3.11 Evaluation of the significant factors influencing river discharge in the Moiben River catchment.

3.11.1 Data collection

Data on household characteristics, demographic trends, and population density was obtained from the 2019 Kenya National Bureau of Statistics census report and aided in estimating the population for the years 1995, 2004, 2014, and 2024 using a growth rate of Uasin Gishu County which is 3.8% (Kipsang *et al.*, 2018). The information on water usage, agricultural practices, income levels, and other important socio-economic characteristics was collected through household interviews utilizing questionnaires. The development projects, land use changes, and other economic activities in the catchment, were gathered from key informant interviews. The temperature and rainfall data were obtained from the Kenya Meteorological Department (KMD) from the year 1995 to 2024. Using the same sources from objectives two, satellite imagery from LANDSAT 5, 8, and Sentinel were used for land use and land cover change assessment to ensure consistency and compatibility in this research. Similar to objective one, river discharge data was obtained from Kerio Valley Development Authority (KVDA) and Water Resources Authority (WRA). Key informant data used was obtained similar to objective one.

Hydrological modelling was also performed using Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) to simulate the flow response of water in the river under scenario of rainfall events using a 30-year return period which helped to show the peak discharge the catchment that would be generated under the current physical and land use conditions.

3.11.2 Data preprocessing

In addition to the previously preprocessed data on river discharge and land use/land cover change, temperature and rainfall data was converted from daily data to annual averages using annual mean calculation. Linear interpolation technique was used identify the missing values of rainfall and temperature data. This involved taking the values before and after each missing point and estimating the missing value based on the assumption that the change between them was gradual. This method was applied to monthly data for rainfall and temperature data from 1995 to 2024 separately, using records provided by Kenya Meteorological Department. Once the gaps were filled, the results were checked to make sure the data looked consistent and could be used reliably in the analysis. Socio-economic data collected using household questionnaires was entered into Excel spreadsheet where double-entry verification was performed on the responses to check for data entry errors.

3.11.3 Data analysis

Descriptive analysis was used to present socio-economic characteristics of respondents, trends in land use and land cover changes, and river discharge patterns.

Pearson correlation was used to evaluate the relationship of the dependent variable, river discharge, and various independent variables such as population, land use/cover classes and climate factors (temperature, rainfall). The analysis was conducted using SPSS Version 29.

Hydrological modelling was done using Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) from United States Geological Survey (USGS) Earth Explorer which had a resolution of 30 meters (Figure3.3). It had an elevation that ranged from 1847 meters, which was at the pour point, to 2853 meters above sea level.

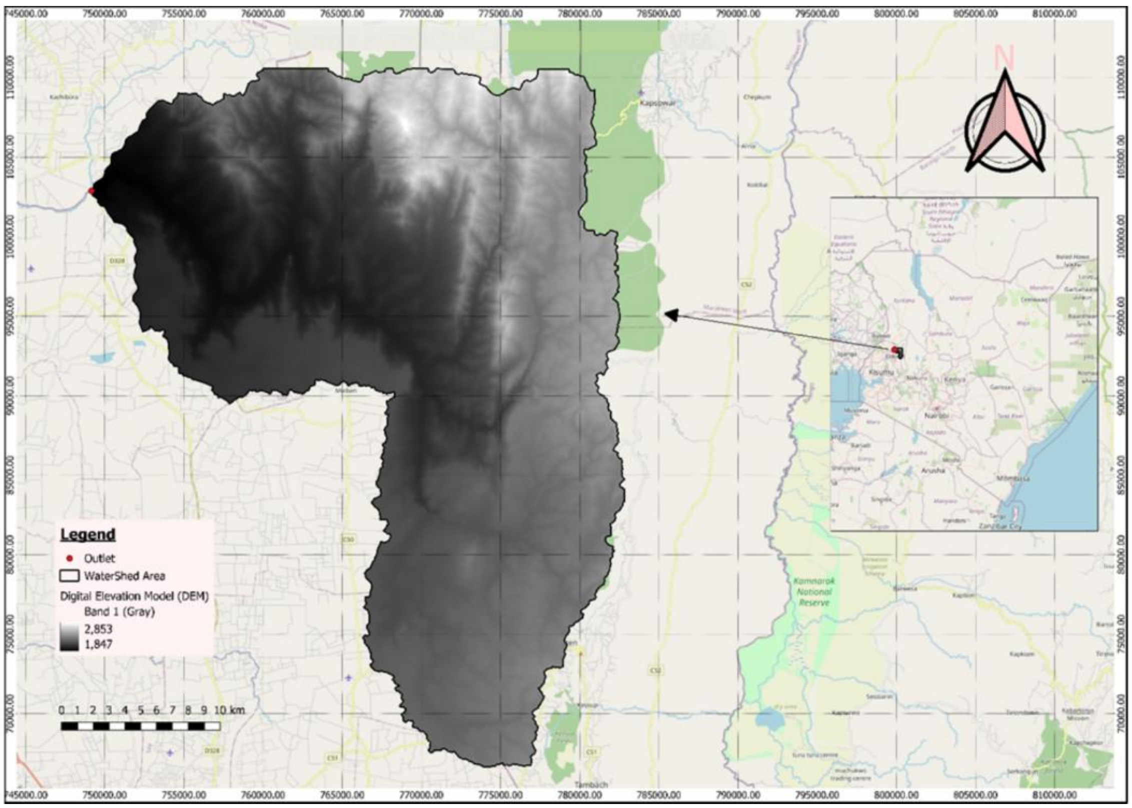

Figure 3.3: The DEM of the Moiben River catchment

Land use data was obtained from the classified land use maps which were analyzed in objective 2. Rainfall data was obtained from Kenya Meteorological Department (KMD) from the year 1995 to 2024 while soil data was from the Kenya Soil and Terrain Database, https://data.isric.org .

The catchment was then delineated to define the boundary and the catchment was divided into smaller sub-basins as shown in Figure 3.4

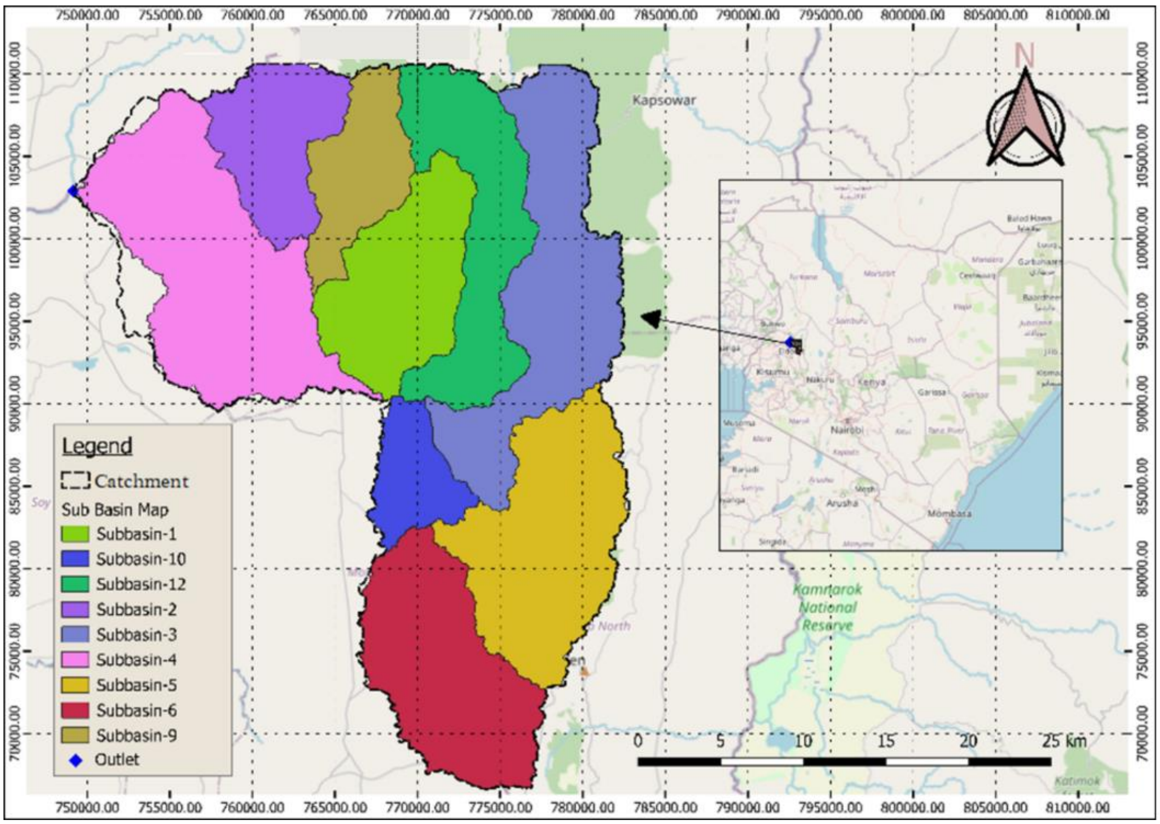

Figure 3.4: The sub-basins in the Moiben River catchment

ArcGIS tool version 10.8 was used in determining the Curve Numbers (CN) for each sub-basin which was derived using land use/land cover data and soil hydrologic using zonal statistics and overlay techniques and Flow lengths (L), which shows the longest flow path between a sub-basin and the outlet was extracted using the Flow Length tool. The slope tool helped to calculate the average slope of each sub-basin and it was recorded in percentage (%) because it is important in calculating the Time of Concentration (Tc).The slope shows how the land terrain influences the speed of runoff. The initial abstraction (Ia) which refers to the amount of rainfall that is lost before surface runoff start to infiltrate the soil, was also calculated, after which the Time of concentration (Tc) and Lag time was calculated using the formula from Natarajan & Radhakrishnan ,2019) ;

$$Tc = [L^{0.8} \times (S + 1)^{0.7}] / [1{,}140 \times Y^{0.5}]$$

$$Lag = 0.6 \times Tc$$

Where:

L = lag, h

Tc = time of concentration, h

ℓ = flow length, ft

Y = average watershed land slope, %

S = maximum potential retention, in

$$S = (1000 / CN) - 10$$

(American Units; $0 < CN < 100$)

The analysis used the following parameters in Table 3.3 below. The curve number (CN) values ranged between 19.92 and 23.99, indicating moderate differences in land cover and hydrologic soil conditions. Basin areas varied considerably, with the largest being Subbasin-4 (157.44 km^2) and the smallest Subbasin-10 (33.73 km^2), suggesting spatial diversity in catchment size and runoff potential. Flow lengths ranged from 13.74 km in Subbasin-10 to 36.05 km in Subbasin-3, while basin slopes (Y %) varied between 6.17% and 22.95%, reflecting differences in topography that influence flow velocity and concentration time. The time of concentration (TC) ranged from 15.81 hr to 44.30 hr, corresponding to lag times between 9.48 hr and 26.58 hr, indicating that steeper and smaller basins responded more quickly to rainfall. Initial abstraction values were between 6.34 in and 8.04 in (161–204 mm), showing slight variations in surface storage and infiltration characteristics across sub-basins.

Table 3.3: The parameters for hydrological modelling

Sub-Basin	Area (km²)	CN (ArcGIS Pro)	Flow Length (km)	Flow Length (ft)	Basin Slope (Y)	Y (%)	S	TC	Lag (Hr)	Lag (min)	Initial Abstraction (in)	Initial Abstraction (mm)
Subbasin-5	121.42	23.01	22.59	72512.30	0.08	8.90	33.45	27.08	16.25	975.08	6.69	169.94
Subbasin-6	107.14	22.37	27.99	89841.55	0.06	6.16	34.70	39.60	23.76	1425.82	6.94	176.28
Subbasin-3	131.18	23.84	36.04	115677.36	0.15	15.14	31.92	29.22	17.53	1052.22	6.38	162.19
Subbasin-10	33.73	21.18	13.73	44081.95	0.08	8.69	37.19	19.78	11.87	712.33	7.43	188.97
Subbasin-12	93.75	23.98	28.90	92743.08	0.22	22.95	31.69	19.79	11.87	712.70	6.33	160.99
Subbasin-1	86.17	21.27	21.31	68406.37	0.13	13.65	37.00	22.35	13.41	804.91	7.40	187.99
Subbasin-9	51.85	22.58	18.75	60169.85	0.20	20.05	34.28	15.80	9.48	569.02	6.85	174.17
Subbasin-2	61.78	21.41	16.94	54360.25	0.18	18.47	36.69	15.90	9.54	572.45	7.33	186.40
Subbasin-4	157.44	19.92	35.51	113973.72	0.08	8.81	40.19	44.29	26.57	1594.70	8.03	204.17

These parameters enabled the running of the HEC-HMS model as shown in Figure 3.5 in the different sub-basins. Each sub-basin represents a distinct hydrological unit characterized by specific parameters such as area, curve number, slope, flow length, and time of concentration. The model structure demonstrates how rainfall-runoff relationships were defined and how flow contributions from each sub-basin combine to form the total discharge at the catchment outlet.

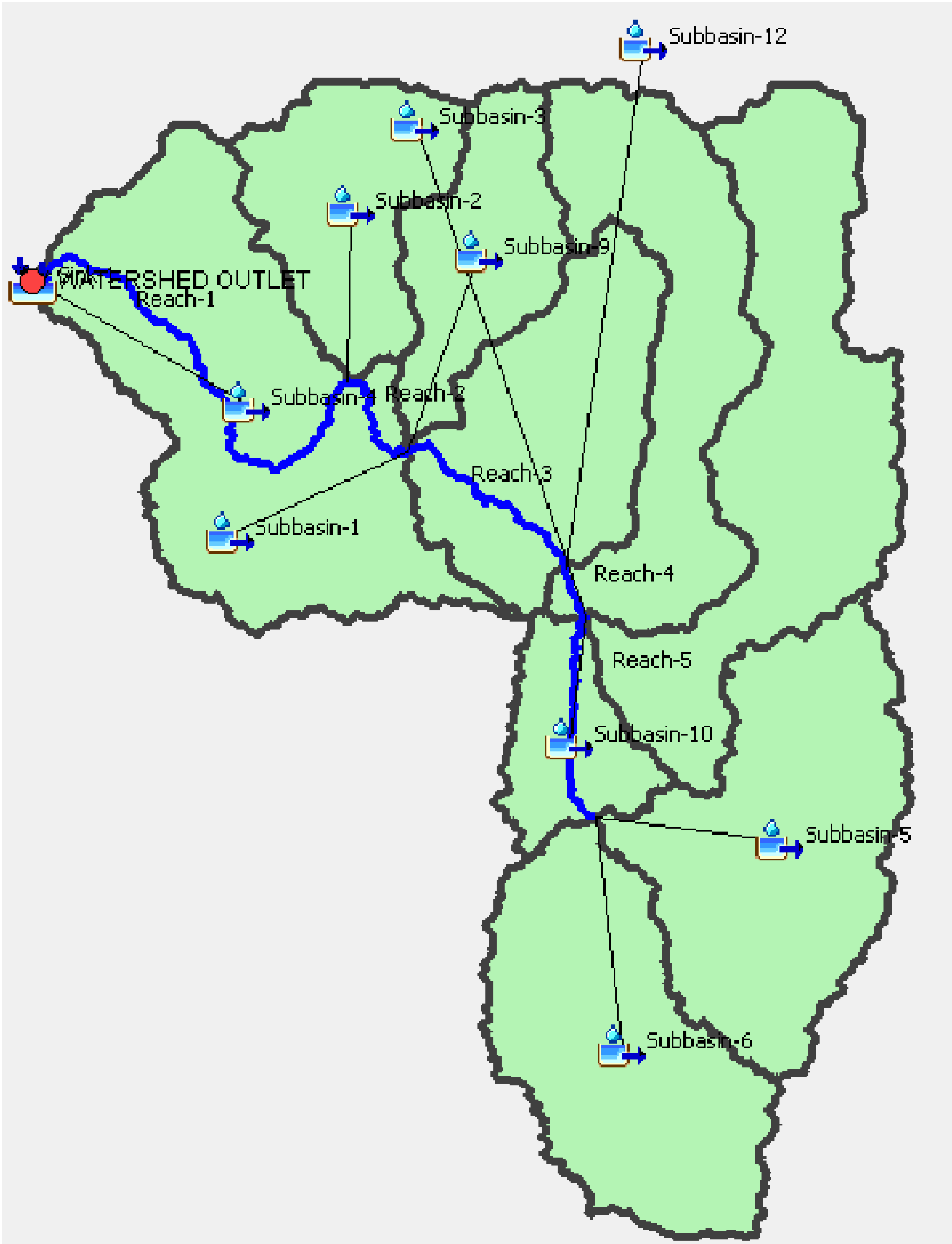

Figure 3.5: The HEC-HMS model

3.11.4 Calibration, validation and sensitivity analysis

Ground truthing and accuracy assessment for land use were done the same way as in objective 2. The same fifty-six GPS points and field observations were used again to check the accuracy of the land cover classification. This helped keep things consistent and reliable across both objectives.

The model was calibrated using secondary discharge data from the MOIBEN_1BA01 gauging station for the period January to June 2024 to adjust the Curve Number (CN), initial abstraction, and lag time for the simulated hydrographs to match the secondary data. The performance of the model was also assessed during the calibration period, January to June 2024, using the coefficient of determination (R^2) calculated as:

$R^2 = 1 - [\Sigma (Q_{obs,i} - Q_{sim,i})^2] / [\Sigma (Q_{obs,i} - \bar{Q}_{obs})^2]$ where:

Q_{obs} = observed discharge at each time i, Q_{sim} = simulated discharge at each time i, $\bar{Q}_{obs}$ = mean of observed discharges, and

An R^2 value of 0.82 was achieved, which was an acceptable agreement between the observed and simulated flows (Fanta & Tadess, 2022).

Validation was conducted for the period July to December 2024 using the calibrated model without further parameter changes to compare to secondary discharge data by visually inspecting the hydrographs and calculating the Percentage Bias (PBIAS) as:

Bias = [(Sum of simulated) - (Sum of observed)] ÷ (Sum of observed) × 100%

The validation confirmed that the model was reliable at 15.7%, which is acceptable and is considered good (Barbosa *et al.*, 2019).Sensitivity analysis was performed using Subbasin-

5 to show how the important parameters influenced the peak discharge and the Curve Number (CN), initial abstraction, and lag time parameters were used in this case. The CN, which is generated from the characteristics of the land uses and soil, became the most sensitive parameter where an 8.6% increase in CN led to a 12.2% increase in peak discharge, while a decrease in it caused a reduction in peak flow by 10.7%. Initial abstraction showed moderate sensitivity, with a ±17.7% change resulting in approximately ±7.5% variation in peak discharge. Lag time had an impact on the timing and magnitude of peak flows, where a ±20% change caused a ±13% shift in discharge; therefore, this showed that accurate CN and abstraction estimation is important for return period-based simulations.

3.12 Validity and reliability of research instruments

Content validity was used to ensure that every important aspect of the study topics was fully covered by the questions. Construct validity was also applied by carrying out a preliminary investigation to verify that the tool effectively represented the required structures. Content validity was achieved by designing the questionnaires and interview schedules to comprehensively address all aspects of the study objectives and variables. The instruments were reviewed by academic supervisors and experts in environmental information systems to confirm the relevance, clarity, and adequacy of the items. Construct validity was established through a pilot study involving 10% of the target population in an area with similar characteristics to the study site, and the feedback obtained was used to refine and improve the tools before the main data collection. Reliability was assessed using Cronbach’s Alpha, which measures internal consistency of the questionnaire items. The computed Cronbach’s Alpha coefficient was 0.82, exceeding the acceptable threshold of

0.70 by Izah *et al. (*2023), indicating that the research instruments were reliable and capable of producing consistent results.

3.13 Ethical consideration in research involving human participants

A license permit from NACOSTI was obtained, and permission to conduct the research was secured from the local administration of Moiben Sub-County. The details of the study to the respondents, clarifying that it was conducted for academic purposes only, were provided. The respondents were also informed of their free will to participate or decline at any time. Therefore, their privacy, cultures, and beliefs were protected at all times.

CHAPTER FOUR

RESULTS

4.1 Introduction

This section contains the findings of collected and analyzed data from Moiben River catchment. The findings of the river discharge trend, changes in LULC and the factors affecting river discharge are presented in the chapter in form of tables, maps, graphs and pie charts.

4.2 Background information of respondents

The section below contains the background information of the respondents in the catchment;

4.2.1 Demographic characteristics of the respondents

The respondent's demographic characteristics are important for understanding how different social and economic groups in the catchment use and manage land and water resources. These characteristics also help explain how such activities may affect river discharge and are summarized in Table 4.1. The percentage of the respondents consisted of females (47.9%) and male (52.1%). Most of these percentage respondents were aged between 30 to 40 years (36.1%) and 41 to 50 years (28.4%). Regarding education levels, most of them had secondary education (39.2%) and primary education (21.9%) while those that advanced to University were few (13.7%). Farming was the common occupation (70.1%) while others included teaching (6.7%) and civil duty (4.1%). The household sizes mainly ranged between 3 to 5 people (53.9%) and 5 to 6 people (42.5%). The people had their monthly income commonly between 10,000 and 20,000 Kenyan shillings (42.0%) and 20,000 to 30,000 Kenyan shillings (17.8%).

Table 3.1: Demographic characteristics of the respondents

Demographic characteristics	Attribute	Frequency	Percent Frequency
Age(years)	<30	15	3.9
	30-40	140	36.1
	41-50	110	28.4
	51-60	90	23.2
	>60	33	8.5
	Total	388	100.0
Gender	Female	186	47.9
	Male	202	52.1
	Total	388	100.0
Level of education	No formal education	14	3.6
	Primary	85	21.9
	Secondary	152	39.2
	Tertiary	84	21.6
	University	53	13.7
	Total	388	100.0
Occupation	Casual worker	16	4.1
	Civil servant	26	6.7
	Farmer	272	70.1
	Teacher	36	9.3
	Total	388	100.0
if others specify	Carpenter	3	0.8
	Doctor	2	0.5
	Electrician	1	0.3
	Engineer	2	0.5
	Hair dresser	6	1.5
	Mason	7	1.8

	Nurse	2	0.5
	Plumber	6	1.5
	Tailor	8	2.1
	Welder	1	0.3
	Total	388	100.0
Household size (number of people)	< 3 people	7	1.8
	3-5 people	209	53.9
	6-10 people	165	42.5
	> 10 people	7	1.8
	Total	388	100.0
Monthly income (in Kenyan shillings)	<10,000	75	19.4
	10,001-20,000	163	42.0
	20,001-30,000	69	17.8
	30,001-40,000	30	7.7
	40,001-50,000	23	5.9
	More than 50,000	28	7.2
	Total	388	100.0

4.2 Discharge trend of Moiben River from 1995 to 2024

The trend in river discharge and the seasonal variability are illustrated in the sections below;

4.2.1 Annual trends in river discharge

The mean annual discharge between 1995 and 2024 shows considerable variability, with values generally ranging between 2.0 and 4.6 cubic meters per second (m^3/s). From 1998 and 2011 was the period that recorded higher discharge, while 2001 and 2015 recorded the least discharge. (Figure 4.1). A linear regression analysis of annual mean discharge yielded the equation Q_t=0.8534.t+112.96, indicating a slight increasing trend with a projected discharge of 3.50 m^3/s in the year 2024. This trend was not statistically significant, at the 0.05, (R^2= 0.0221, p = 0.530).

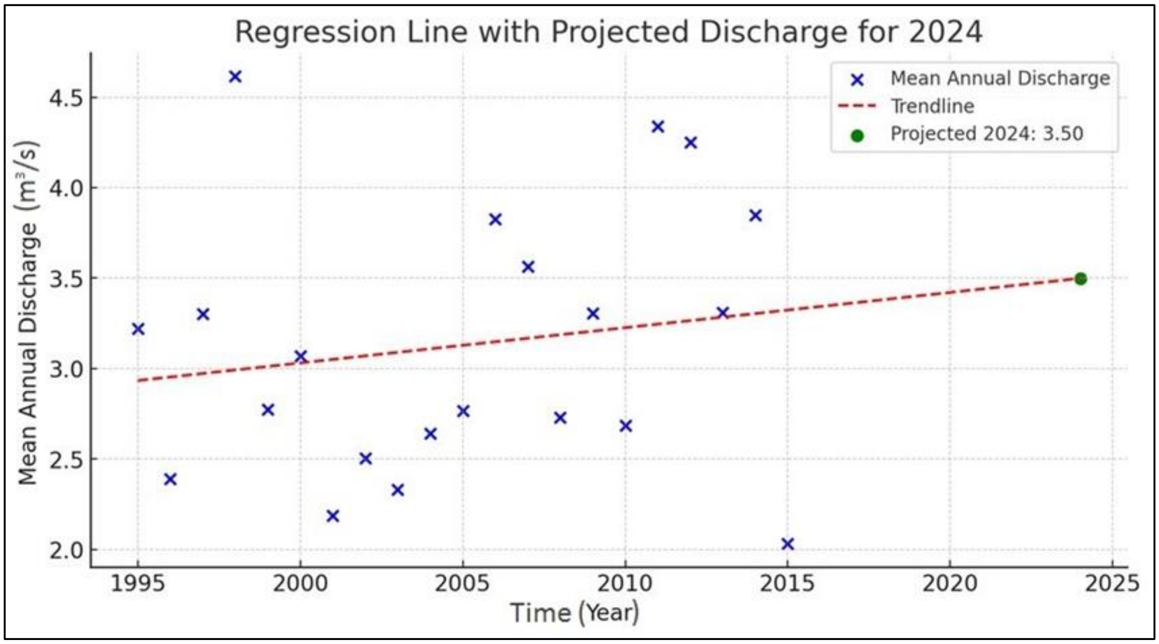

Figure 4.1: Annual trend of river discharge in Moiben River catchment from 1995 to 2024

4.2.2. Seasonal variability in river discharge

The averages seasonal discharge for the two seasons (wet and dry) were plotted in (Figure 4.2). The average amount of discharge of wet season was the highest (1.25 m^3/s) with a standard deviation of (0.12 m^3/s) while the dry seasons had the lowest discharge of (1.07 m^3/s) and the spread of the data having an average of **(**0.41 m^3/s).

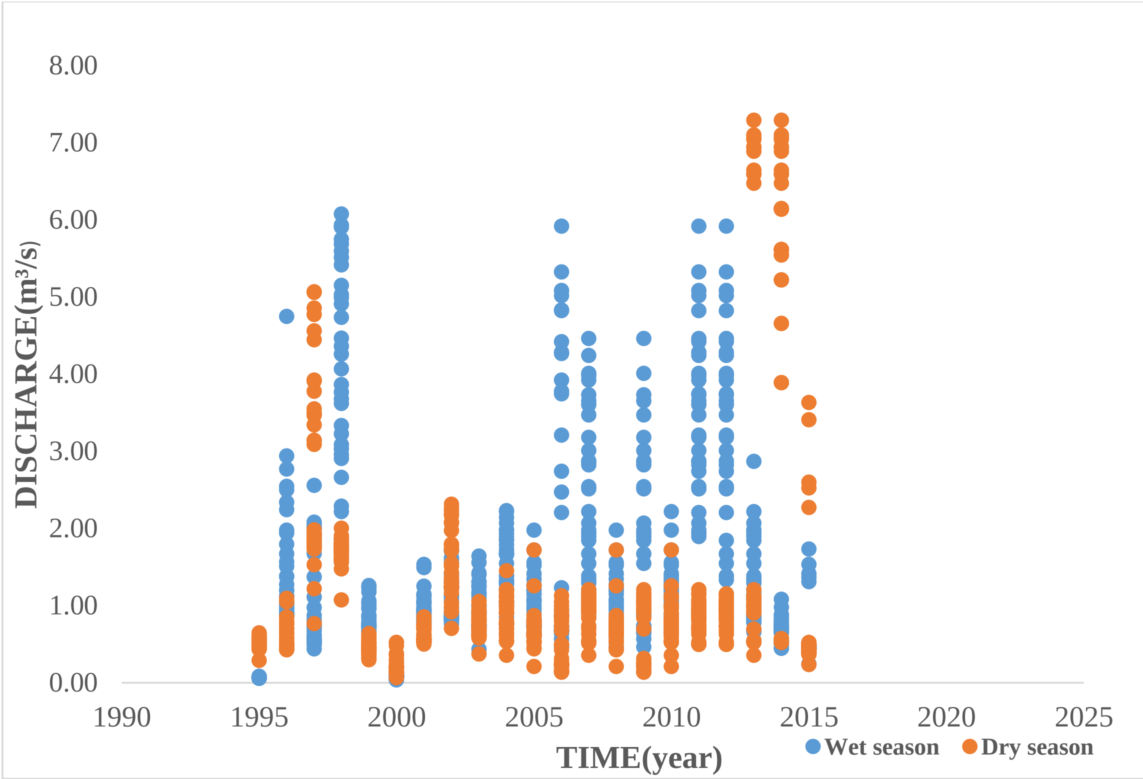

Figure 4.2: Seasonal variability of river discharge in Moiben River catchment

4.2.3 Changes in river flow patterns

The percentage responses on the changes in river flow patterns over the past 20 years were mainly unpredictable flow patterns (55.4%) and reduced river flows (19.3%) while the least were increased river flows (2.6%) and no significant changes (1.5%) as illustrated in (Figure 4.3).

Key Informants described noticeable changes in the flow of the river all year round. During rainy season, the river often floods, damaging crops and, in some cases, washing away small bridges. In the dry season, the water level drops so low that the riverbed is exposed. They pointed out two main reasons for this: the increase in horticultural farming along the river and the clearing of trees to make room for more farmland. These activities, they said, have disrupted the natural flow of water in the catchment.

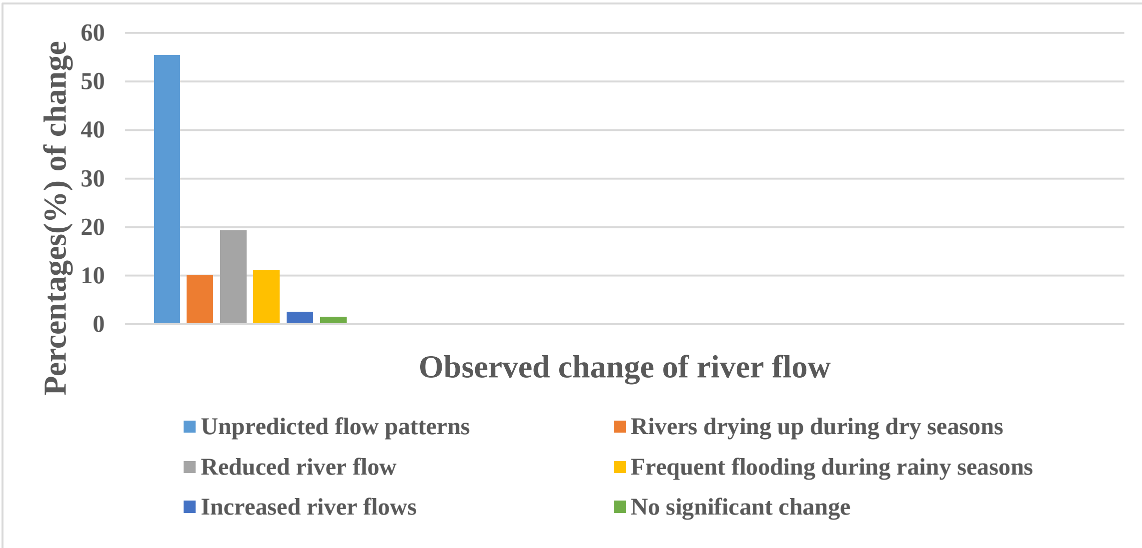

Figure 4.3: Community responses concerning changes in river flow patterns in Moiben River catchment

4.3 The extent and patterns of land use and land cover change in the Moiben River catchment

The Table 4.2 shows LULC areas in hectares and percentages for the years 1995, 2004, 2014, and 2024. Cropland is by far the largest land use, growing steadily from about 44,672 hectares (51.5%) in 1995 to nearly 67,400 hectares (77.7%) in 2024. The next biggest land covers are forest and rangeland. Forest area fluctuated, starting around 26,487 hectares (30.5%) in 1995, reducing to about 20,972 hectares (24.2%) in 2004, and then increased to roughly 27,088 hectares (31.2%) by 2024. Rangeland was steady, ranging from just under

9,478 hectares (10.9%) in 2004 to nearly 11,843 hectares (13.7%) in 2024. Built area and bare land take up the least space but have shown the biggest percentage increases. Built area expanded from about 693 hectares (0.8%) in 1995 to over 3,650 hectares (4.2%) in 2024, showing that settlements and infrastructure have been spreading. Bare land also grew, though it still covered less than half a hectare, from 0.014 hectares (0.00002%) in 1995 to about 0.38 hectares (0.0004%) in 2024. In short, from 1995 to 2024, cropland expanded a lot while forest and rangeland stayed important but fluctuated. Built area and bare land grew too, even if they covered much less area overall.

Table 4.2: Land use/ land cover trends in hectares and percentage (%) from 1995 to 2024

	Year			
	1995	2004	2014	2024
Surface water	82.59 (0.10)	76.50 (0.09)	99.41 (0.11)	98.62 (0.11)
Bare land	0.014 (0.00002)	0.245 (0.00028)	1.609 (0.00185)	0.3787 (0.00044)
Cropland	44672.40 (51.48)	58874.23 (67.86)	66538.01 (76.68)	67399.49 (77.67)
Grassland	3.7421 (0.004)	3.3129 (0.004)	3.9158 (0.004)	3.6314 (0.004)
Rangeland	11009.67 (12.69)	9478.25 (10.93)	12023.74 (13.86)	11843.28 (13.65)

Forest	26487.42	20972.38	27612.93	27087.56
	(30.53)	(24.17)	(31.83)	(31.22)
Built area	693.20	1452.36	1531.08	3650.05
	(0.80)	(1.67)	(1.77)	(4.21)
Total land area	86741.16	86741.16	86741.16	86741.16
	(100.00)	(100.00)	(100.00)	(100.00)

The figures in parentheses represent the percentages.

The series of LULC maps for 1995, 2004, 2014, and 2024 reveal a gradual but significant transformation in the catchment over time (Figure 4.4). The LULC maps from 1995 to 2024 show a clear increase in cropland, which occupy the largest area in size in most maps. Cropland expanded progressively from 1995 through 2024, with its spatial extent covering more of the catchment over time.

Forest cover decreased between 1995 and 2004, then increased again in 2014 and remained relatively stable in 2024. Rangeland size reduced between 1995 and 2004, increased by 2014, and shows a slight decrease in 2024.Built area expand steadily across the four maps, with noticeable growth seen from 2014 to 2024. Bare land increases from 1995 to 2014, then declines slightly in 2024 with limited visibility across the maps. Surface water remains sparse and shows minimal visible change across all years. Grassland appeared in small, scattered patches in 1995 and remains consistent throughout the study period, though dominated by cropland by 2024.

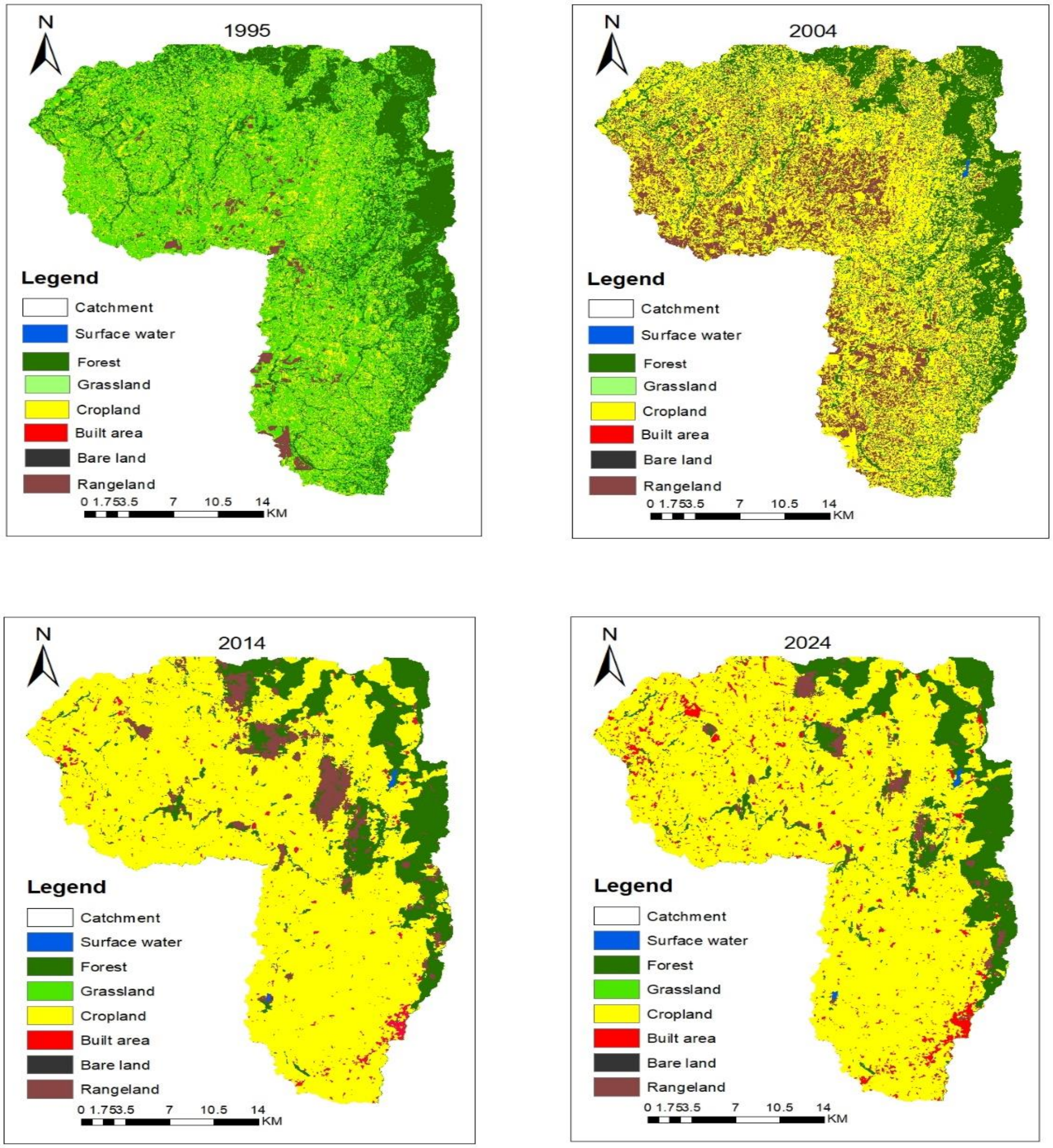

Figure 4.4: Land use/ land cover in the Moiben River catchment from 1995-2024

4.3.1 Change in land cover /land use from 1995-2024

Table 4.3 illustrates the percentage changes in different LULC types from 1995 to 2024, along with changes during the periods 1995–2004, 2004–2014, and 2014–2024. Over the period from 1995 to 2024, cropland increased the most, by about 26.8%. This growth was significant between 1995 and 2004, with a 16.4% increase, then slowed to 8.8% from 2004 to 2014, and only 1% from 2014 to 2024. Forest area changed by 6.6% overall, but this included a decrease of 6.4% between 1995 and 2004 before recovering with a 7.7% increase from 2004 to 2014 and a small decrease of 0.6% from 2014 to 2024. Built area grew by 4.3% from 1995 to 2024, mostly between 2014 and 2024 when they increased by 3.3%. Surface water, bare land, and rangeland all showed much slight changes, less than 1% over the all period. Grassland remained almost unchanged, with minimal variation close to zero.

Table 4.3: Percentage land use /land cover change from 1995 to 2024

Land Use Classes	1995–2024 (%)	1995–2004 (%)	2004–2014 (%)	2014–2024 (%)
Surface water	0.02	-0.01	0.03	-0.01
Forest	6.59	-6.36	7.65	-0.60
Grassland	-0.01	-0.01	0.01	-0.01
Cropland	26.79	16.37	8.83	1.00
Built area	4.26	0.87	0.09	3.30
Bare land	0.42	0.27	0.16	-0.01
Rangeland	0.96	-1.77	2.93	-0.19

4.3.2: Accuracy assessment.

Table 4.4 shows the Kappa coefficiency of 0.924 which in in the accepted range for LULC classification accuracy of between 0.7 and 1.0 (Abdelkareem *et al.,* 2018). The Kappa value of 0.7 means that the level of agreement of the predicted and performed classification is accepted, making the classification algorithm used for this study very reliable (Yaghoobi *et al.,* 2022). Furthermore, the overall accuracy level of the classification was 94% thus supporting the validation of the classification results. According to Li *et al.,* (2022), when the overall accuracy level of a remote sensing classification is more than 85%, it shows that the results are dependable to be used for other applications. The user and producer accuracies for the various land use classes ranged between 0.74 and 0.92, with the highest values observed in surface water (0.92) and built-up areas (0.82), while cropland, rangeland, and forest exhibited moderate accuracies between 0.70 and 0.75. The classification results from this study are therefore reliable for further analysis of LULC changes, their influences on water availability and land use planning.

Table 4.4: Accuracy assessment

Classes	Surface water	Bare land	Cropland	Grassland	Rangeland	Forest	Built Area	Total	U-Accuracy	Kappa
Surface water	12	0	0	0	0	1	0	13	0.92	
Bare land	0	15	2	0	1	0	0	18	0.83	
Crop land	0	1	14	2	1	0	1	19	0.74	
Grassland	0	0	2	13	1	0	1	17	0.76	
Rangeland	0	1	1	1	14	2	0	19	0.74	
Forest	1	0	0	0	2	12	1	16	0.75	
Built Area	0	0	1	1	0	1	14	17	0.82	
Total	13	17	20	17	19	16	17	100		
P-Accuracy	0.92	0.88	0.70	0.76	0.74	0.75	0.82			
Kappa										0.924

4.3.3 Observed changes in land use or land cover over the past 30 years in the area

The observed percentage responses from the communities in the catchment on the changes of LULC over the past 30 years are believed to be caused by increased farming activities (49%), deforestation (45%) and urban growth (6%) as shown in Figure 4.5

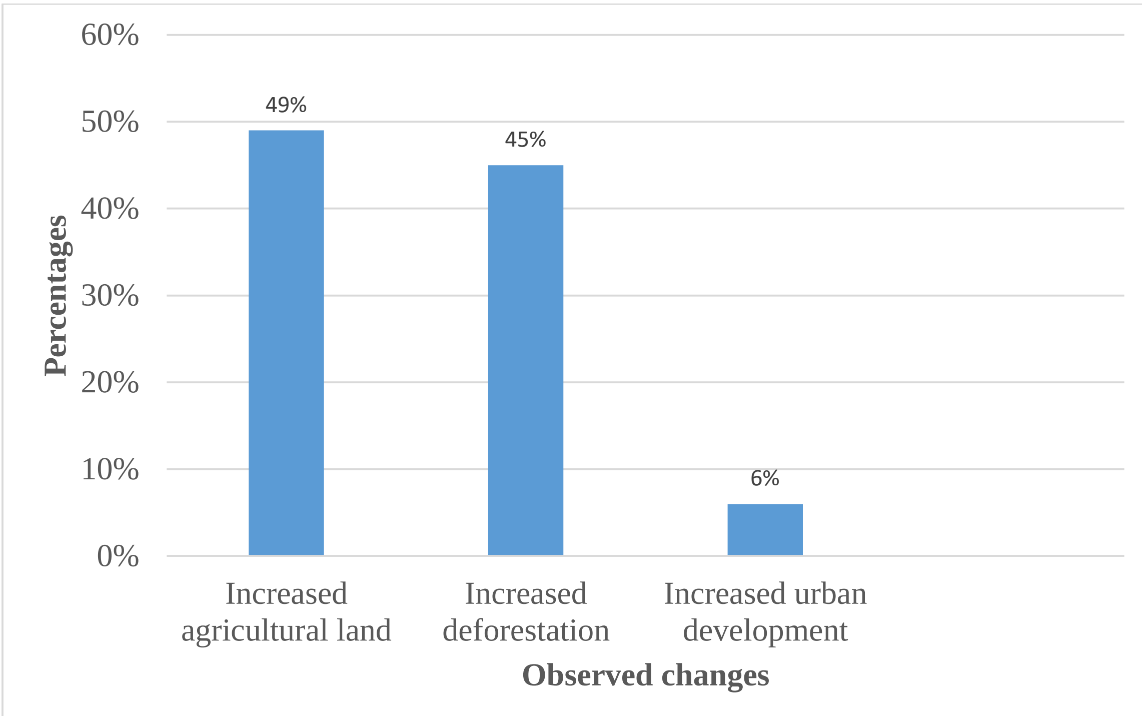

Figure 4.5: Observed land use and land cover changes over the past 30 years

Investigating the drivers of LULCC is vital in understanding the causes of change in the environment which aids in sustainable land use and formulation of relevant land use policies. The percentages of main drivers of LULCC as indicated by the respondents were population growth (82.20%) and agricultural expansion (72.20%), while the minor drivers were climate change (19.60%) and industrial activities (0.30%) as presented in Figure 4.6.

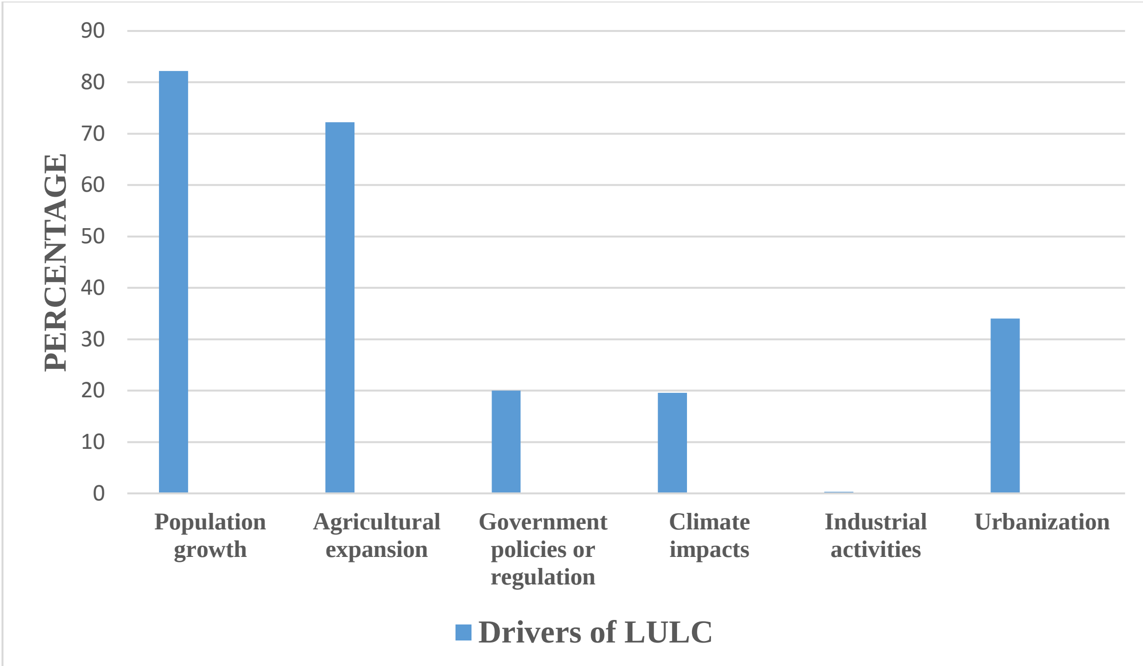

Figure 4.6: Observed main drivers of land use/land cover changes by the respondents

Key Informants mentioned that current practices in the catchment include the proposed Meibeki Valley Project, along with various individual farming activities. They highlighted several human activities taking place in the area, including the construction of the Chebara Dam in the year 1999 and farming practices such as the irrigation of horticultural crops along the riverbanks. One major initiative mentioned was the 15 Billion National Government Tree Growing and Restoration Campaign, which aims to restore degraded land and improve the general conditions in the catchment.

4.4 The factors that have significant impact on river discharge in Moiben River catchment

This objective outlines the key human and environmental factors influencing the river discharge in the catchment, and it presents various factors, their correlation results and the modelling output of peak discharge in the catchment in a 30-year return period;

4.4.1 Perceptions of respondents on the causes of climate change

The sections below demonstrates the perception of the respondents concerning climate change which has influence on river discharge;

a) Main causes of climate change in the area

Community views regarding causes of climate change are important in the development of mitigation measures that aids in the resilience of the community. A number of respondents highlighted deforestation (48%), agricultural expansion (35%) and urbanization (17%) to be the common causes of the changes in climate in the area as shown in Figure 4.7.

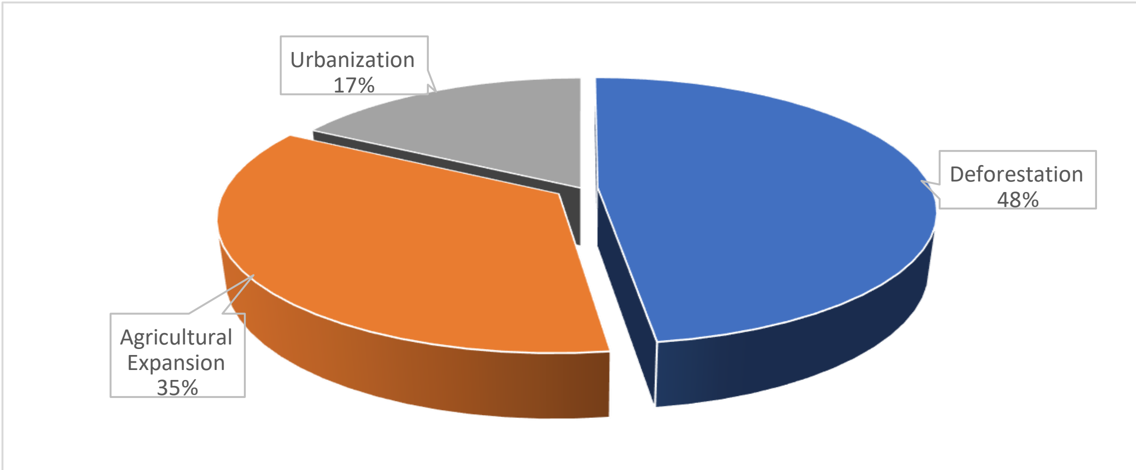

Figure 4.7: The main causes of climate change in Moiben River catchment

b) Observed changes in temperature and rainfall trends

In Table 4.5, community observations of temperature and rainfall help in understanding the influence of climate variation and a valuable source of comparative data for meteorological data obtained. A majority percentage of respondents (86.3%) reported that temperatures have increased, with 80.4% noting more frequent hot days and nights as an indicator. About 34.0 % of respondents observed that rainfall intensity has increased, while 67.5% stated that rainfall events have become shorter but with increased intensity. In general, (85.1%) described rainfall patterns as erratic and unpredictable.

Table 4.5: Observed changes in temperature and rainfall trends in Moiben River catchment

Question	Attribute	Frequency	Percentage Frequency
Any noticed changes in temperature trends over the past 30 years?	Decrease in temperature	42	10.8
	Increase in temperature	335	86.3
	No significant change	11	2.8
	Total	388	100.0
What specific changes in temperature patterns have you observed?	Colder days and nights	31	8.0
	Hotter days and nights	312	80.4
	More frequent cold spells	8	2.1
	More frequent heat waves	25	6.4
	No noticeable changes	12	3.1
	Total	388	100.0
Have there been changes in the intensity or frequency of rainfall in your area over the past 20 years?	Increased intensity of rainfall events	132	34.0
	Decreased intensity of rainfall events	130	33.5
	Less frequent rainfall	99	25.5
	More frequent rainfall	21	5.4

	No noticeable changes	6	1.5
	Total	388	100.0
Have you noticed changes in the duration of rainfall periods?	Longer rainy seasons with lighter rainfall	120	30.9
	No significant change	6	1.5
	Shorter rainy seasons with heavier rainfall	262	67.5
	Total	388	100.0
How would you describe changes in rainfall patterns in your area?	Longer dry spells followed by intense rain	51	13.1
	More consistent and predictable	1	0.3
	More erratic and unpredictable	330	85.1
	No significant changes	6	1.5
	Total	388	100.0

c) Effects of forest cover change on local climate conditions

Figure 4.8 illustrates the percentages of the effects that change in forest cover size has on local climate conditions which serves to inform the extent to which deforestation and reforestation has influenced temperature and rainfall trends, which in turn impact water resources. About 47% of the respondents reported that reduced forest cover led to increased temperatures, while 40% believed that it caused a decrease in rainfall. A smaller portion

(4%) associated the change with lower temperatures, and 1% felt that there was no noticeable effect.

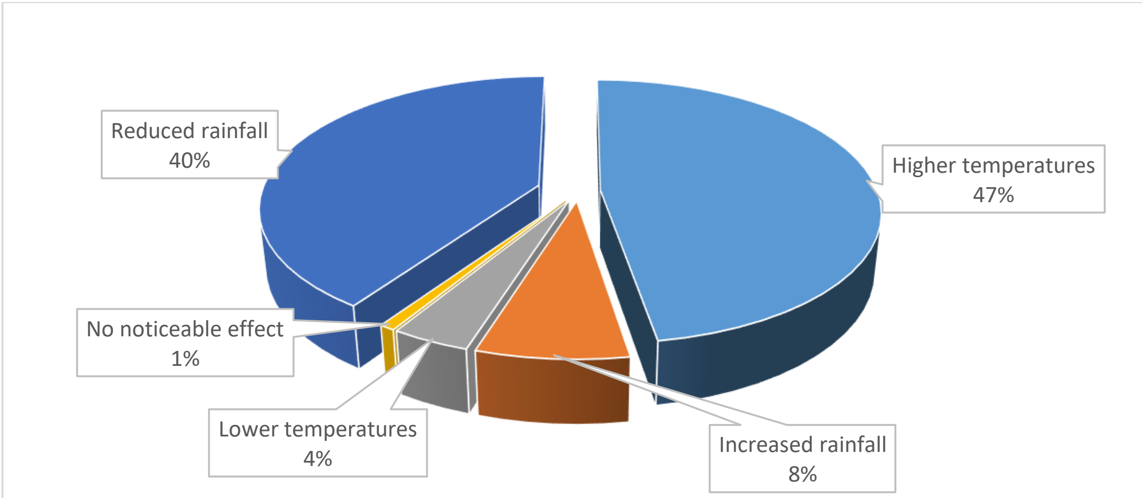

Figure 4.8: Perceptions of households on the effects of forest cover change on local climatic conditions

4.4.2 Water usage and management

The sub-topics below illustrates the usage of water and management practices that exists in the catchment;

a) Water source and usage by the respondents

Understanding water sources and usage help assess supply and demand of water in the area. Majority of the respondents depended on rivers (39.80%) and wells (16.70%) as their main water sources. Streams (3.60%) and springs (3.30%) are the least depended water source as shown in Figure 4.9.

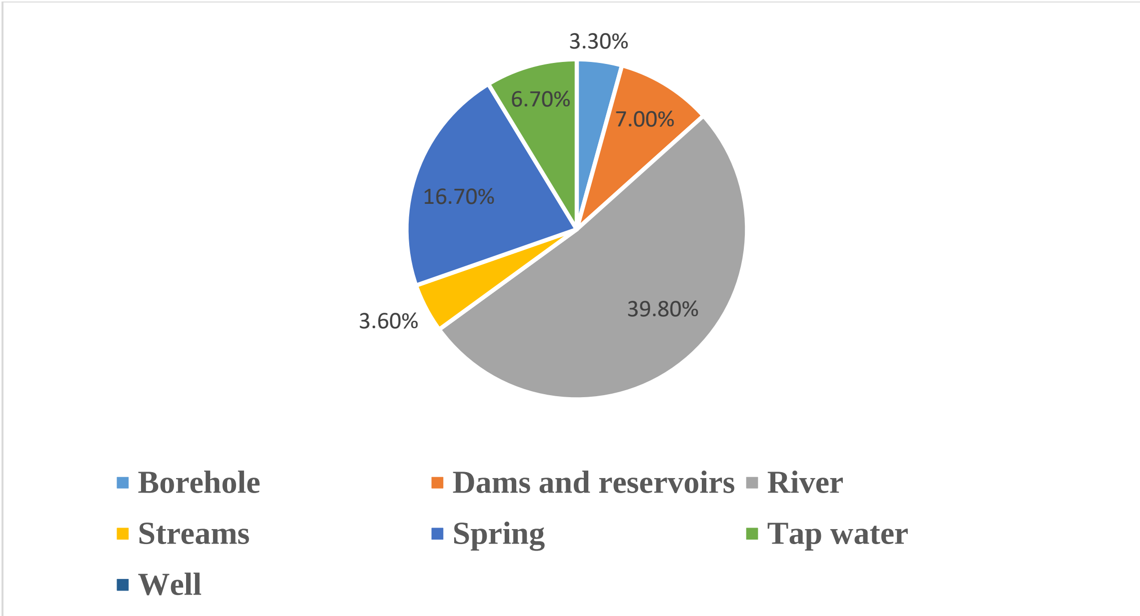

Figure 4.9: The main water sources for residents in Moiben River catchment

The volume of water used for household each day for domestic purposes and the distance from the water sources have been presented in (Table 4.6) and it serves as key indicators of water accessibility in the catchment. Large percentage of people consumed between 100-300 liters of water each day (57.2%), while a small percentage used less than 100(0.5%).A majority percentage of them also lived within 100 to 500 meters (52.4%) from their water sources while the least exceeded 1500 meters (1.6%).

Table 4.6: Water usage by the respondents in Moiben River catchment

Question	Attribute	Frequency	Percent Frequency
On average, how many liters of water does your household use per day for domestic purposes	<100 liters	2	0.5
	100-300 liters	222	57.2
	301-500 liters	144	37.1
	501-700 liters	17	4.4
	>700 liters	3	0.8
How far is your primary water source from your home (in meters)?	<100 meters	103	27.5
	100-500	196	52.4
	501-1000	71	19.0
	1001-1500	12	3.2
	>1500	6	1.6
	Total	388	100.0

b) Water shortages and coping strategies

Understanding water shortages and how the community deals with them is important because it reveals the local coping strategies and resilience to water stress in the catchment. The percentage of community members that faced water shortages for domestic use were 1.5% with most of them having started in 2020 between January and March. Some of the percentages of the recommended solutions to curb it included harvesting rain water (38.4%), using water storage tanks (25%) and moving to alternative water sources (17.3%) as presented in Table 4.7.

Table 4.7: Water shortages and coping strategies

Question	Attribute	Frequency	Percent Frequency
Have you experienced water shortages for domestic use?	No	382	98.5
	Yes	6	1.5
	Total	388	100.0
If yes, when did you start	2011	1	16.7
	2015	1	16.7
	2017	1	16.7
	2020	2	33.3
	2022	1	16.7
	Total	6	100.0
If yes, which months is water scarcity for domestic use severe?	January-March	5	83.3
	October-December	1	16.7
	Total	6	100.0
What have you done or doing to address scarcity?	Installed water storage tanks	97	25.0
	Installed water-efficient appliances	2	0.5
	Moved to alternative water sources (e.g., boreholes, wells)	67	17.3
	Participated in community water conservation initiatives	3	0.8

	Practiced rainwater harvesting	149	38.4
	Reduced water usage (e.g., shorter irrigations)	17	4.4
	Reused grey-water (e.g., for gardening)	53	13.7
	Total	388	100.0

c) Community initiatives and NGOs related to water management

NGOs and community projects related to water management highlights the community efforts and external support in enhancing sustainable water resource use in the catchment. Majority of residents living within the catchment were not aware of the any government (national/county) programs for water management and conservation (94.8%). The percentage that were aware (5.2%), noted that they were aware of County government projects (60%) and Tachasis Community water project (20%). A low percentage (0.8%) could also identify NGOs driven projects in the area which was World Vision. (Table 4.8).

Table 4.8: Community and NGOs driven to water initiatives

Question	Attribute	Frequency	Percentage Frequency
Are you aware of any government (national/county) programs in your area that aim to improve water availability and management/conservation?	No	368	94.8
	Yes	20	5.2
	Total	388	100.0
If yes, who are they?	County government project	12	60.0
	Kapsoni water project	2	10.0
	Meibeki water project	2	10.0
	Tachasis water project	4	20.0
	Total	20	100.0
Are you aware of any NGO programs in your area that aim to improve water availability and management/conservation?	No	383	98.7
	Yes	3	0.8
	Total	388	100.0
If yes, who are they?	World Vision	3	100.0
	Total	3	100.0

4.4.3 Agricultural practices

The information concerning agricultural practices in the catchment has been illustrated below;

a) Land size and irrigation

Land size and irrigation practices information help determine the extent of agricultural activity and how it affects water demand in the catchment. The bigger percentage of the farmers in the catchment owned land of size 5 to 10 acres (47.7%) and greater than 15 acres (18.0%) while the least had between 11 to 15 acres (16.8%). The percentage of the land under agriculture was less than 5 acres (42.3%) while those greater than 15 acres were the least under agricultural practices (8.5%) as seen in Table 4.9. The percentage of those that practiced irrigation were few (8.8%) and mostly utilized small farm sizes of 1 acre (70%), while irrigation practices were mostly started in 2010 to 2013(32.4%).

Table 4.9: Land size and irrigation

Question	Attribute	Frequency	Percentage Frequency
What is the total size of your land (acres)?	< 5 acres	68	17.5
	5-10 acres	185	47.7
	11-15 acres	65	16.8
	>15 acres	70	18.0
	Total	388	100.0
What size of your land is under agriculture (acres)?	< 5 acres	164	42.3
	5-10 acres	149	38.4
	11-15 acres	42	10.8
	>15 acres	33	8.5
	Total	388	100.0
Do you practice irrigation?	No	354	91.2
	Yes	34	8.8
	Total	388	100.0
If yes, what size of your land is under irrigation (acres)?	1 acre	24	70.6
	2 acres	6	17.6

	3 acres	2	5.9
	4 acres	1	2.9
	5 acres	1	2.9
	Total	34	100.0
Which year did you start irrigation?	2007-2010	6	17.6
	2010-2013	11	32.4
	2013-2016	9	26.5
	2016-2019	4	11.8
	2019-2022	4	11.8
	Total	34	100.0

b) Source of water for irrigation

Identifying the source of irrigation water is essential for evaluating dependence on particular water source and the possible effects of agricultural activities on catchment's water supply. The percentage of water sources for irrigation within the catchment are mostly rain water (92.3%) and river (4.6%) as indicated in Table 4.10. The amount of water used for irrigation is mostly ranges between 2000 to 4000 liters (61.8%) while the common irrigation method used is flood irrigation (70.6%).

Table 4.10: Source of water for irrigation

Question	Attribute	Frequency	Percentage Frequency
What is the source of the water you use for irrigation?	Rain	358	92.3
	Borehole	2	0.5
	Dams and reservoirs	7	1.8
	River	18	4.6
	Springs	3	0.8
	Total	388	100.0
If others specify	Stream	2	50.0
	Well	2	50.0
	Total	4	100.0
How much water do you use for irrigation (liters)?	<2000 liters	4	11.8
	2000-4000 liters	21	61.8
	4001-6000 liters	8	23.5
	>6001 liters	1	2.9
	total	34	100.0
What method of irrigation do you use?	Flood irrigation	24	70.6
	Sprinkle irrigation	7	20.6
	Surface irrigation	3	8.8
	Total	34	100.0

c) Water scarcity

Understanding the limitations of water supply is important when assessing how resilient the community is in irrigating their crops. The percentage of households that practice irrigation and have faced water scarcity were (97%) especially between the months of January and March (99.7%). There was low technology uptake as evidenced (0.5%) of farmers adopting greenhouse farming (Table 4.11).

Table 4.11: Water scarcity and technology uptake

Question	Attribute	Frequency	Percentage Frequency
Have you experienced water scarcity for your irrigated crops?	Yes	33	97.
	No	1	2.9
	Total	34	100.0
If yes, which months is water scarcity for the crops more severe?	January-March	387	99.7
Have you adopted any new technologies or practices to improve water use efficiency in farming?	Yes	2	0.5
	No	388	99.5
	Total	388	100.0
If yes, please describe	I use greenhouse technology	2	100.0

4.4.4 Livestock kept and their water source

The demand of water for watering animals and the strain of water sources can be understood by looking at the type and number of animal and their corresponding water sources in the area. All the farmers in the study area kept livestock and the percentage of the common animals were cows (93.8%) and sheep (57.5%). The percentage of water sources for these livestock were mostly watered from dams and reservoirs (34.5%), river (33.8%) and spring (20.6%), (Table 4.12).

Table 4.12: Livestock kept and source of water

Question	Attribute	Frequency	Percentage Frequency
Do you keep livestock?	Yes	388	100.0
If yes, which ones	Cow	364	93.8
	Goats	170	43.8
	Sheep	223	57.5
	Poultry	119	30.7
	Total	388	100.0
What is the main source of water for livestock?	Rain	21	5.4
	Boreholes	17	4.4
	Dams and reservoirs	134	34.5
	River	131	33.8
	Springs	80	20.6
	Tap water	5	1.3
	Total	388	100.0

a) Water demand and scarcity for livestock

The water demand for livestock helps assess the overall water needs in the catchment, as water scarcity for animals compete with other important water uses. Some of the percentages of farmers that owned livestock and experienced water scarcity for their animals (3.6%) were majorly in 2015(0.6%), 2017(0.6%) and 2020(1.0%). This was common more so in the months of January to March (92.8%), (Table 4.13).

Table 4.13: Water scarcity for livestock in Moiben River catchment

Question	Attribute	Frequency	Percentage Frequency
Have you experienced water scarcity for your livestock?	No	372	95.9
	Yes	14	3.6
	Total	388	100.0
If yes, when did it start (which year)	2000	1	0.3
	2005	1	0.3
	2010	1	0.3
	2011	1	0.3
	2012	1	0.3
	2013	1	0.3
	2015	2	0.6
	2017	2	0.6
	2020	3	1.0
	2022	1	0.3
If yes, which months is water scarcity for livestock more severe?	January-March	13	92.8
	October-December	1	7.2
	Total	14	100.0

4.4.5 Correlation of significant factors impacting river discharge in the Moiben River catchment

The significant factors impacting river discharge such as climatic factors and population alongside various land uses have been presented and correlation analysis between these factors have also been demonstrated in the sections below;

a) Climatic conditions of the catchment from 1995 to 2024

The analysis of climate data from 1995, 2004, 2014, and 2024 as shown in Figure 4.10 and 4.11. The highest annual mean temperature was recorded in 2024 to be 25.22ºC while the minimum annual average temperature was experienced in1995 was 11.35ºC. The top annual rainfall average was measured in 2020 as 1959.61 mm while the lowest annual average rainfall which was experienced in 2020 was 979.98 mm.

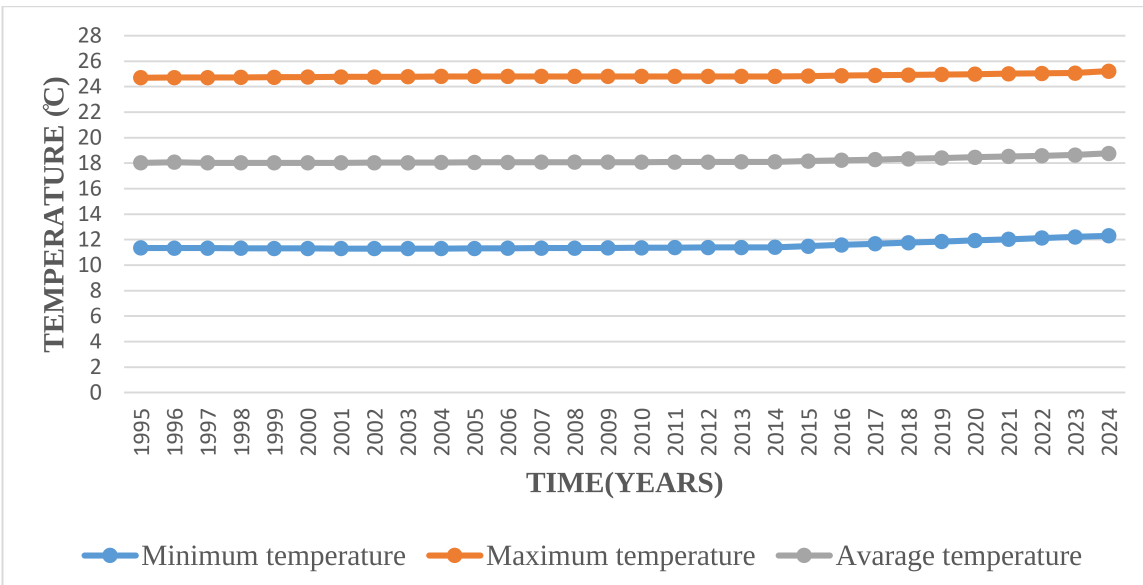

Figure 4.10: Average annual temperature of Moiben River catchment from 1995 to 2024

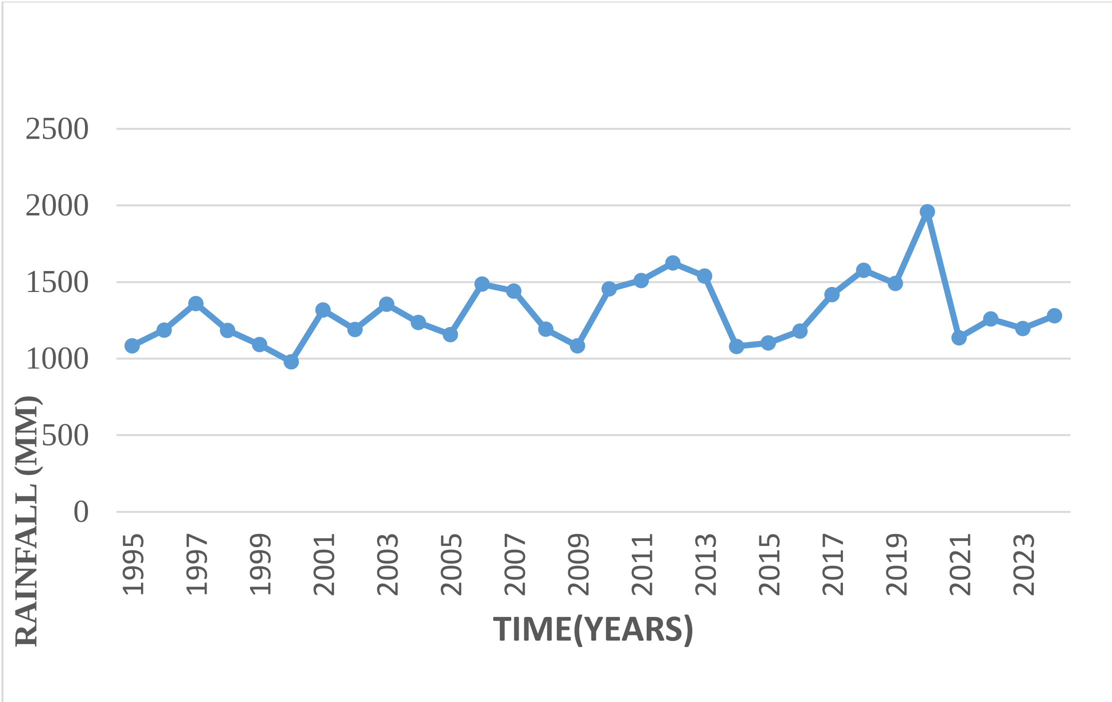

Figure 4.11: Average annual rainfall of Moiben River catchment from 1995 to 2024

b) Human population in the catchment from 1995 to 2024

The population distribution of the catchment was obtained from the 2019 Kenya National Bureau of Statistics census report and using the growth rate of Uasin Gishu County which is 3.8% the population for the years 1995, 2004, 2014, and 2024 was obtained (Figure 4.12). The population has grown over the years with 1995 having the least population (15,341) and 2024 having the highest population distribution (27,227).

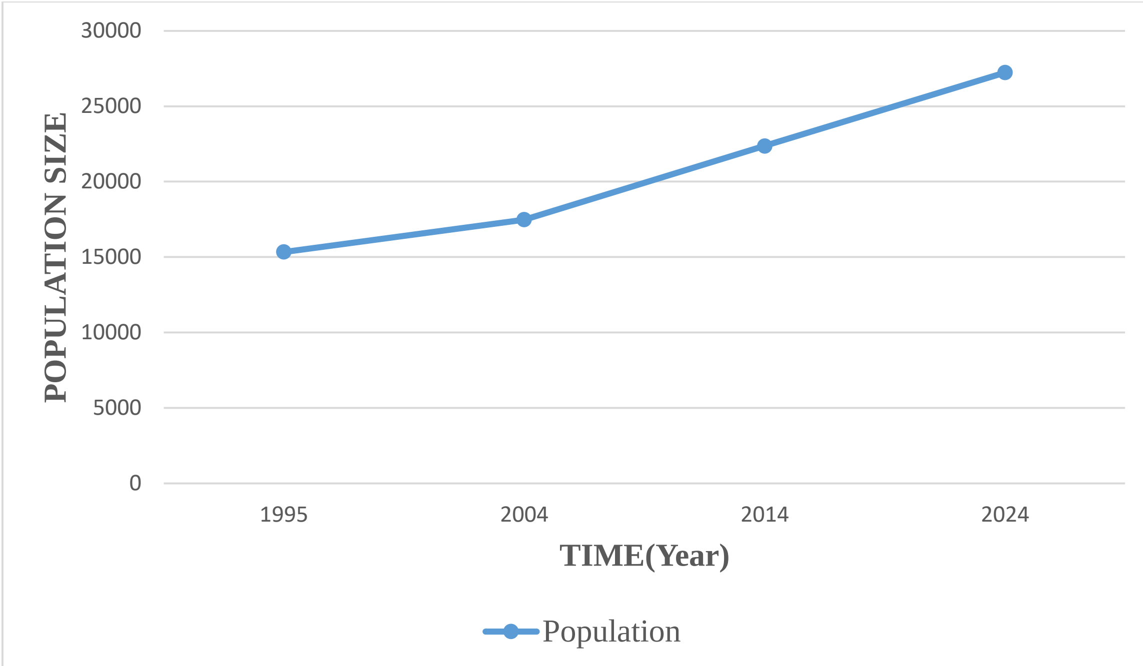

Figure 4.12: Human population change in Moiben River catchment from 1995 to 2024

c) Correlation between river discharge and the significant factors influencing river discharge

The correlation analysis (Table 4.14) presents Pearson correlation coefficients, with the values in parentheses representing their corresponding p-values (significance levels using $p < 0.05$ as the threshold for statistical significance). These correlations were used to examine the relationships between environmental and anthropogenic factors in the catchment over time. Population showed a very strong positive correlation with time ($r = 0.990$, $p = 0.010$), indicating a significant increase in population over the study period. Similarly, built area ($r = 0.914$, $p = 0.086$) and cropland ($r = 0.922$, $p = 0.078$) also showed strong positive correlations with time, reflecting notable expansion in settlements and agricultural land, though these were not statistically significant at the 0.05 level. River discharge had a moderate positive linkage with time (r= 0.470, p= 0.530), though the relationship was not statistically significant. Land cover types such as forest (r= 0.964, p= 0.036) and rangeland (r= 0.983, p= 0.017) showed strong positive and statistically significant correlations with river discharge at the 0.05 level, while grassland (r= 0.941, p= 0.059) and surface water (r= 0.901, p= 0.099) were not statistically significant at the 0.05 level, suggesting that changes in these land covers influence river discharge in the catchment. In addition, population and built-up area had a strong positive correlation (r = 0.925, p = 0.075), indicating that population growth has driven settlement expansion. A positive correlation was also seen in population and temperature (r = 0.945, p = 0.055) which was not statistically significant at the 0.05 level, implying that rising population may be contributing to increased local temperatures.

Table 4.14: Pearson correlation coefficients and p-values between climate, land use/ land cover, river discharge and population in the catchment

Variable	Time	Max. Temp	Rainfall	Min. Temp	River discharge	Population	Surface water	Forest	Grassland	Cropland	Built Area	Bare land	Rangeland
Time	1	.926(.074)	.751(.249)	.880(.120)	.470 (.530)	.990 (.010)	.805(.195)	.373(.627)	.152(.848)	.922(.078)	.914 (.086)	.437 (.563)	.577(.423)
Max. Temp(ºC)		1	.944(.056)	.994 (.006)	.328 (.672)	.945(.055)	.662 (.338)	.325(.675)	.-008(.992)	.733 (.267)	.996 (.004)	.079(.921)	.482 (.518)
Rainfall (mm)			1	.974 (.026)	.167 (.833)	.793 (.207)	.460 (.540)	.248(.752)	-.144(.856)	.479(.521)	.948 (.052)	-.244 (.756)	.345(.655)
Min. Temp(ºC)				1	.292 (.708)	.909(.091)	.612 (.388)	.318(.682)	-.039 (.961)	.655 (.345)	.991 (.009)	-.023 (.977)	.455 (.545)
River discharge(cubic meters)					1	.541 (.459)	.901 (.099)	.964 (.036)	.941 (.059)	.344(.656)	.247 (.753)	.649 (.351)	983 (.017)
Population (count)						1	.845(.155)	.473 (.527)	.226 (.774)	.864 (.136)	.925 (.075)	.396 (.604)	.654 (.346)
Surface water(ha)							1	.822 (.178)	.708 (.292)	.694 (.306)	.602 (.398)	.673 (.327)	.938(.062)
Forest(ha)								1	.917 (.083)	.161(.836)	.243 (.757)	.427(.573)	.968 (.032)
Grassland (ha)									1	.071 (.929)	-.094 (.906)	.622 (.378)	.871 (.129)
Cropland (ha)										1	.733 (.267)	.632 (.368)	.402(.598)
Built Area (ha)											1	.035 (.965)	.405 (.595)
Bare land(ha)												1	.561(.439)
Rangeland(ha)													1

A significant correlation was observed $p< 0.05$ (2-tailed)

4.4.6 The modelling output

The modelling output using the 30-year return period showed that the peak discharge in the catchment over the period 1995 to 2024 was in July, 2024 where the peak discharge was at 87.9m^3/s and the volume was at 3.02m^3(Table 4.15).This results is important because it forms a foundation for understanding the current hydrological behavior of the catchment under existing land use and climatic conditions. The results further indicate that the discharge increased progressively from the upper to the lower sub-basins as runoff from different contributing areas accumulated downstream. Larger sub-basins such as Subbasin-5, Subbasin-3, and Subbasin-12 recorded relatively higher discharges due to their larger drainage areas and greater runoff contribution, while smaller sub-basins such as Subbasin-10 exhibited lower discharges. The simultaneous time of peak at 6 July 2024, 06:30 across all sub-basins suggests a uniform response to a widespread rainfall event within the catchment. This concurrence implies that the catchment has a high runoff response, possibly due to reduced vegetation cover, compacted soils, or increased impervious surfaces that accelerate surface flow. The output is therefore important for identifying flood-prone areas, understanding the spatial variability of runoff, and assessing how land use and climatic factors influence hydrological responses.

Table 4.15: The modelling output

Hydrologic Element	Drainage Area (KM^2)	Peak Discharge (M^3/S)	Time of Peak	Volume (MM)
Subbasin-5	121.6	20.5	6 July 2024, 06:30	5.89
Subbasin-6	107.5	7.3	6 July 2024, 06:30	1.71
Reach-5	228.6	27	6 July 2024, 06:30	3.76
Subbasin-3	131.8	19.5	6 July 2024, 06:30	5.14
Subbasin-10	37.1	1.3	6 July 2024, 06:30	0.76
Reach-4	393.5	46.4	6 July 2024, 06:30	3.79
Subbasin-12	95.8	15.9	6 July 2024, 06:30	6.24
Reach-3	487.2	60.5	6 July 2024, 06:30	4.09
Subbasin-1	86.8	7.4	6 July 2024, 06:30	2.05
Subbasin-9	51.9	6.2	6 July 2024, 06:30	3.56
Reach-2	625.9	71.9	6 July 2024, 06:30	3.6
Subbasin-2	70.1	6.9	6 July 2024, 06:30	2.98
Reach-1	687	76.3	6 July 2024, 06:30	3.38
Subbasin-4	164.8	11.6	6 July 2024, 06:30	1.45
Sink-1	867.4	87.9	6 July 2024, 06:30	3.02

Figure 4.13 shows the contributions of individual sub-basins which lead to peak discharge in 2024 in the catchment. This is important as it highlights the spatial differences in runoff generation and it identifies the sub-basins that contributed more to peak flows.

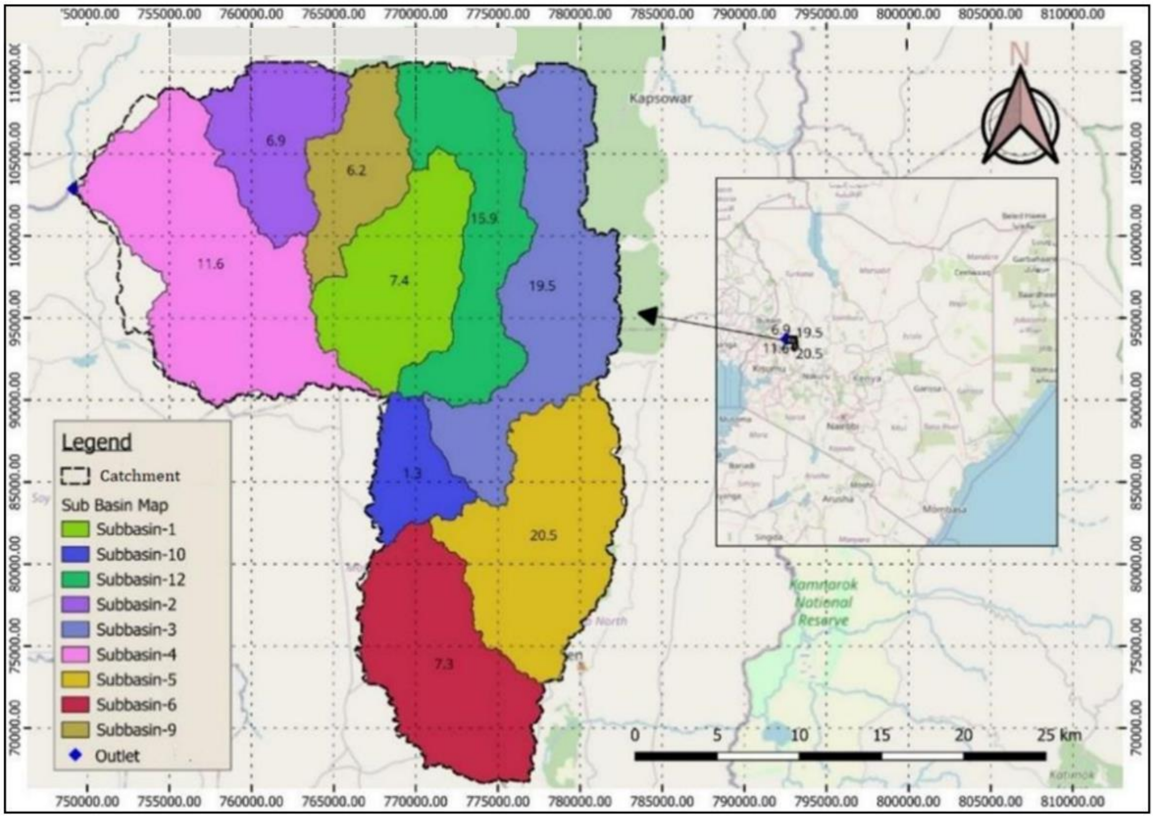

Figure 4.13: The contributions of discharge from each sub-basin

The distribution of land use types for the peak year of 2024 was overlaid with the discharge values that were contributed by each sub-basin in Figure 4.14. This helped to illustrate the dominant land use type within each sub-basin and how it influenced the overall peak discharge value for the catchment. This is important as it highlights the spatial differences in runoff generation and identifies the sub-basins that contributed more to peak flows. Understanding these variations is important because it indicates which areas have higher runoff potential and are therefore more susceptible to flooding or soil erosion. Such information can guide targeted land and water management interventions, such as reforestation, soil conservation, and improved drainage systems in high-contributing sub-basins.

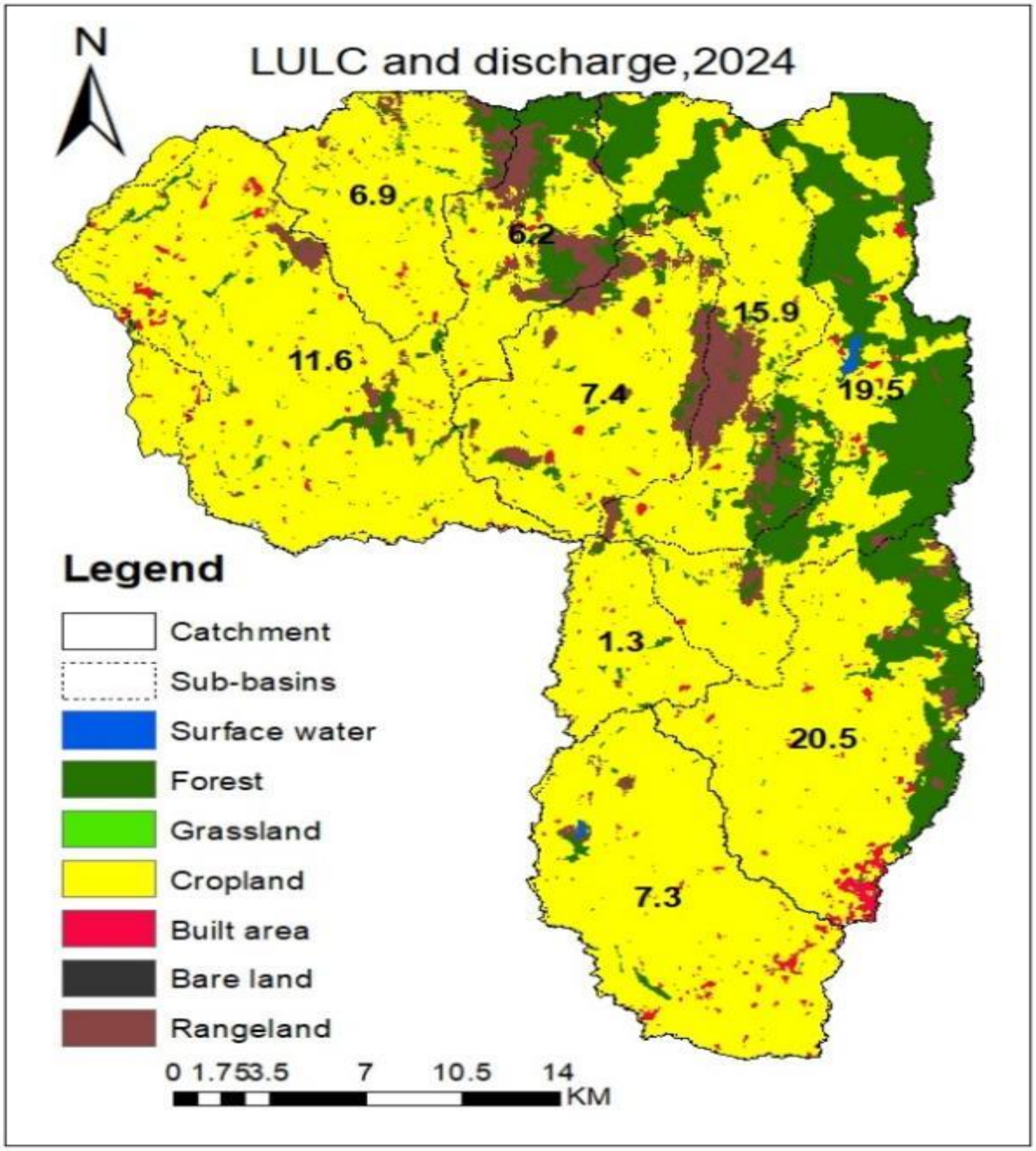

Figure 4.14: Land use and land cover types in each sub-basin

4.5 Water scarcity measures and solutions

The following are some of the water scarcity measures and solutions that exist in the catchment;

4.5.1 Training or education on water conservation practices and government role

The percentage response on whether the community had been trained or educated on water conservation practices showed that many of the respondents have never been trained or educated (93.8%) and as for those who had been trained (6.2%), they majorly mentioned having knowledge on rainwater harvesting (3.6%). The recognized government initiative was Tachasis water project (1%) and the County initiative was County government water project (40.5%) as illustrated in Table 4.16.

Table 4.16: Training or education on water conservation practices and government role

Question	Attribute	Frequency	Percentage Frequency
Have you received any training or education on water conservation practices?	No	364	93.8
	Yes	24	6.2
	Total	388	100.0
If yes, what did you learn?	Efficient irrigation techniques	1	0.3
	Rainwater harvesting	14	3.6
	Soil and water conservation	6	1.5
	Water recycling	4	1.1
	Total	388	100.0
	No	382	98.5

Are there any national government initiatives to address water scarcity issues in the area?	Yes	4	1.0
	Total	388	100.0
If yes, what are they?	Tachasis water project	4	100.0
	Total	4	100.0
Are there any county government initiatives on water scarcity issues in the area?	No	346	89.2
	Yes	42	10.8
	Total	388	100.0
If yes, what are they?	County government project	17	40.5
	Kapsoni water project	2	4.8
	Kaptik water project	16	38.1
	Meibeki water project	5	11.9
	Sugut water project	2	4.8
	Total	42	100.0
What role should the national government play in addressing water scarcity issues in your area?	Increase funding for water projects	98	25.3
	Enforce water conservation policies	134	34.5
	Build more water infrastructure	112	28.9
	Collaborate with communities	64	16.5
	Total	408	100
Are there any local organizations or groups actively working to improve water management/conservation?	No	387	99.7
	Yes	1	0.3
	Total	388	100.0
If yes, who are they?	Lake Victoria North basin	1	0.3
	Total	388	100.0

If yes, how effective have they been?	Need improvement	1	0.3
	Total	388	100.0
Have you received any training or education on water conservation practices?	No	384	99.0
	Yes	4	1.0
	Total	388	100.0

4.5.2 Strategies for better planning and management of water scarcity

The percentage responses on environmental challenges faced by the people in the catchment were mainly poor water quality (68.3%) and reduced water quantity (51.5%). The people also mentioned that the current state of management policies needed improvement (48.2%). For the community to be fully involved in water conservation, it was suggested that they could be encouraged to participate in local water management committees (40.7%). It was also reported that the common challenges in the area over the past 2 decades was reduced forest cover (53%) and increased agricultural land (46.9%) as shown in Table 4.17.

Table 4.17: Environmental management and strategies

Question	Attribute	Frequency	Percentage Frequency
How do the mentioned environmental challenges relate to water management?	Poor water quality	265	68.3
	Reduced water quantity	200	51.5
	Increased water scarcity	180	46.4
	Increased frequency of flooding	2	0.5
What are your thoughts on the current state of water management policies in your area?	Effective	111	28.6
	Need improvement	187	48.2
	Not effective	90	23.2
	Total	388	100.0

How can community involvement be improved in water resource management?	Increase awareness and education.	73	18.8
	Encourage participation in local water management committees.	158	40.7
	Implement community-led water conservation projects.	72	18.6
	Offer incentives for sustainable water use.	62	16.0
	Involve youth and schools in water management efforts.	40	10.3
What are the most significant changes you have observed in the catchment over the past 20 years?	Decrease in forest cover	295	53.0
	Increase in agricultural land	261	46.9
	More frequent water shortages	1	0.2
	Total	557	100

4.5.3 Strategies for better water management at the community level

The community had suggestions on possible ways of improving water availability and management which are important for policy recommendations on governance and land resources planning in the catchment (Figure 4.15). Majority of the respondents emphasized the need to strengthen community water conservation initiatives (24.2%) and promote reforestation (19.3%). A smaller percentage suggested adopting efficient irrigation systems (6.7%) while others proposed enforcing water management regulations (6.4%).

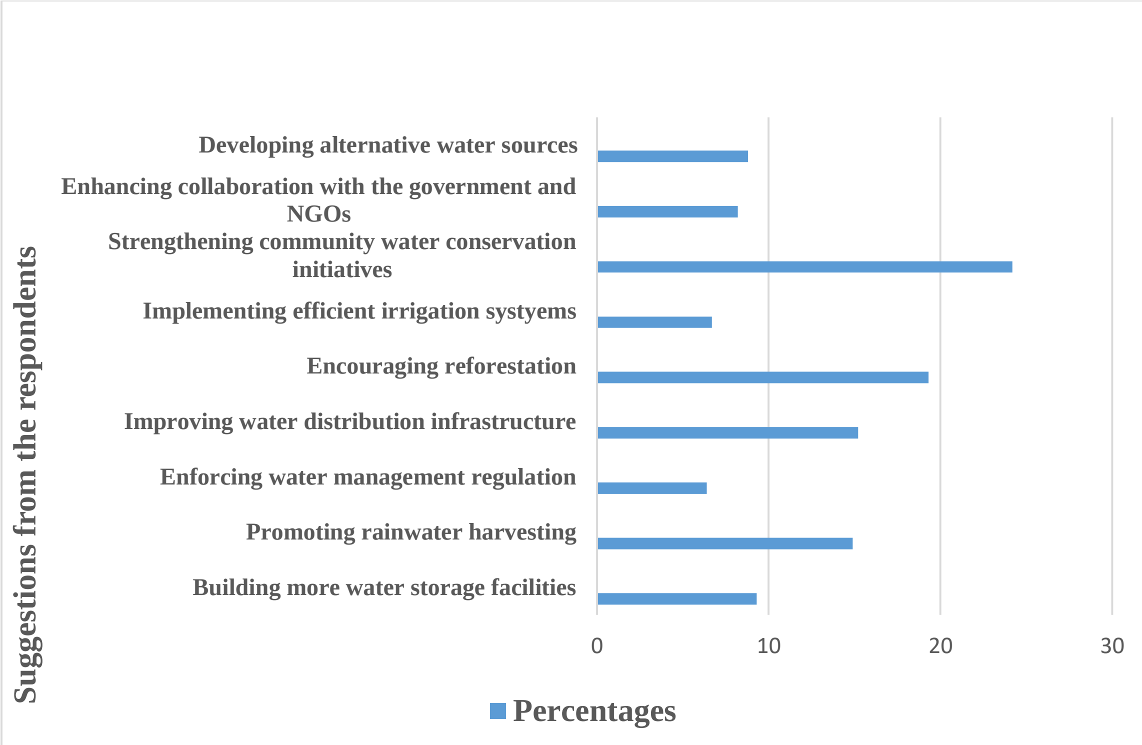

Figure 4.15: Strategies for better water management at the community level

Key Informants shared that several water-related projects have taken place in the catchment. One of them is a County water program that involves the donation of solar panels used to pump water from the river into storage tanks provided by the County government of Uasin Gishu. These tanks, which range in capacity from 10,000 to 50,000 liters, are located in seven different village centers across the catchment. About ten years ago, World Vision also supported water access in the area by constructing water tanks and supplying water pipes, benefiting places like Meibeki and Kaptik. However, the NGO is no longer active in the region, and much of the water infrastructure they helped establish are now dilapidated in maintenance. A major challenge identified by key informants is that there are very few government projects aimed at improving water access, and as a result, many community members are not even aware of them. To improve water availability, they suggested stronger collaboration among stakeholders and enforcement of laws protecting riparian areas. They also emphasized the importance of conserving forests, noting their role in regulating temperature and rainfall.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents discussions of the findings from this study. The results of river discharge trend, LULC change and the factors affecting river discharge are discussed here.

5.2 The trend of river discharge in the catchment

The discharge trend between 1995 and 2024 revealed noticeable fluctuations, with some years such as 1998 and 2011 experiencing higher flows and others recording much lower values (2001 and 2015). The linear regression line showed a slight increasing trend, with a projected discharge of 3.50 m^3/s by 2024 but the trend was not significant. Additionally Pearson correlation of river discharge and time revealed a moderate increase in flow over time, which is not statistically significant at reinforcing the regression results, thus proposing that other various external factors are responsible rather simple increase or decrease over the years.

The fluctuations of river discharge in the catchment suggest that other interconnected factors such as changes in rainfall pattern, LULC changes and human activities are responsible. Studies of similar river basins across East Africa indicate that change in rainfall patterns is a major driver of river flow changes. Research by Gebrechorkos *et al.* (2019) and Nsubuga *et al.* (2019) found that rainfall in East Africa has been fluctuating because of climate change, leading to inconsistent river discharge trends. It could be possible that what is observed in Moiben River catchment is a reflection of the broader region, where specific years' experience heavier rainfall and increased river flow, while others experience prolonged dry periods which is similar to this catchment.

The discharge during the wet seasons (1.25 m^3/s) was high compared to dry seasons (1.07 m^3/s) which is a common phenomenon in areas where natural vegetation has been cleared suggesting other influences such as climate change or increased farming be playing a bigger role than only time. This was backed up by Key Informant who mentioned that the river flow is not stable but fluctuating with higher discharge during the rainy period and sometimes it causes floods along the areas near the banks while dry season the discharge is very low which are mainly caused by deforestation. The changes in LULC, particularly deforestation and agricultural expansion, are the major possible contributors altering runoff and groundwater recharge which impact river discharge. A study by Rwigi *et al.* (2024) on Kenyan river basins found that high rates of discharge during the rainy seasons and reduced discharge during dry seasons is caused by deforestation due to lower groundwater retention. Similar changes in the Moiben River catchment, where natural vegetation is decreasing, could be contributing to its fluctuating discharge, where wet season flows are more pronounced, but dry season flows remain low.

Another important possible factor is water extraction rates for irrigation and domestic use where Nyakundi *et al.* (2023) found that many Kenyan rivers have been declining during dry season flows due to increased water extraction, even when rainfall trends remain stable. Key Informants informed that the farming of horticulture crops using flood irrigation along Moiben River is common during the dry months of October to February which could explain why dry-period discharge was low over time.

The changing weather such as the occurrence of El Niño and La Niña may be affecting the levels of discharge in the river. The fluctuating discharge trends in the Moiben River maybe a reflection of what is happening globally where there is rapid changing of climatic conditions. Opere, (2021) found that the periods when El Niño occurs, it increases the amount of rainfall thus leading to increased river discharge while the periods La Niña occurs there are more droughts which leads to reduced river flows.

The management practices available in the catchment could be responsible for shaping the river flow patterns. Some of the projects in the catchment that exist along the Moiben River are the Meibeki valley irrigation project and the National Agricultural value chain development project and they could be influencing the observed discharge trends. Research by Sang, (2022) on Kenyan rivers found that some of the practices and projects like irrigation practices, the building of reservoirs and dams along rivers, and conservation projects available in an area often modify the original flow of a river by altering the dry and wet season flows.

The study utilized linear trend analysis where the discharge over time was observed, while this may have not fully captured the complexities of a river system, other advanced modeling techniques, like those explored by Salih *et al.* (2021), suggest that a combination of various factors like rainfall, land use changes and temperature may affect the flow of a river. The weak positive correlation found from this study may suggest that other factors such as changes in LULC, increased abstraction and deforestation, other than time are causing these fluctuations.

Some respondents (55.4%) observed that the flow of the river had become more unpredictable over 20 years ago while others observed that the level of water had dropped

(19.3%). Other smaller percentages of respondents noticed that there were occurrence of frequent flooding especially during the rainy seasons (11.1%) while smaller streams dried up faster during the dry months (10.1%). Some of them also observed that river flows had increased (2.6%) and very few observed that the flow had no much change (1.5%). These observations were noticed by individuals who have stayed in the catchment for longer time and they are probably because of the changing rainfall patterns and other human activities such as deforestation and increased farming activities along the riverbanks. This can be supported by Taye *et al.* (2021), who identified that river flows are mostly affected by various factors like felling of trees, land degradation, and the changing climatic conditions which causes the river flow patterns to be less predictable in many areas. Similarly, Mohammed *et al.* (2022) observed that in the cases of extended droughts, water levels in rivers reduce while increased rainfall makes flooding more frequent.

In general, the discharge pattern of this catchment fits to the observed trends of other rivers in East Africa where there is higher river discharge during rainy seasons and lower river discharge during dry seasons (Gebrechorkos *et al.*, 2023). But the weak positive correlation in the linear trend analysis suggests that other reasons such as climate variability, land use changes, and human practices, are also affecting the river discharge other than time alone.

5.3 The Land use patterns and land cover change in the catchment

The catchment's land uses have shifted in the past thirty years due to both environmental and anthropogenic factors. Grassland and rangeland have decreased over the years, while built area, bare land, surface water and cropland have increased. Forest cover has also slightly increased within the period 2014-2024. Surface water has increased over time, probably because of human practices like building of dams. Built areas have increased indicating increase in settlements. These changes could be as a result of socio-economic advancement, conservation initiatives, and agriculture.

The growing agricultural sizes of land is similar with broader trend in Kenya, Key Informant also mentioned the growing horticulture irrigation in the catchment, where priority needs for food security required by growing population have led to increased croplands. Agricultural expansion is the main cause of change in many catchments and the findings resonates with research done by Oduor *et al.* (2023) and Opiyo *et al.* (2022) in Thiba and Migori catchments in Kenya. The reduction of grassland and rangeland fit the research done by Langat *et al.* (2021), who noted that croplands and tree plantations usually get replaced by croplands which ultimately affects the soil stability and biodiversity.

The changes in forest size lies between relationship between restoration efforts and deforestation because forest has reduced by only 0.6% from 2014 to 2024 compared to 6.36% in the early years from 1995 to 2004. According to Onyango *et al.* (2020), previous deforestation was probably caused by the need for farming land, settlement land, and firewood for fuel, which is similar to other East African forests. Forest cover has reduced by only 0.6% in recent years, which could mean that conservation efforts, afforestation initiatives and land management regulations are beginning to pay off. This was backed by Key Informant who mentioned that the proposed government initiative known as 15 Billion National Government Tree Growing and Restoration Campaign. Mansourian &

Berrahmouni (2021), believe that efforts from the community and the government in reforestation initiatives assisted in reversing previous deforestation.

Improved land use, whether by reforestation, soil conservation, or efficient agricultural practices, is shown by the reduction of bare land in recent years from 200 4 to 2014. According to Ndungu *et al.* (2023), improved management efforts such as afforestation and smart agriculture are frequently associated with a decrease in Kenya's bare land. Opiyo *et al.* (2022) warns that even in regions that are under cultivation, inadequate land management techniques can cause soil deterioration, despite the apparent benefits of less bare land.

Surface water fluctuations are probably because of a combination between human activities such dam construction and changing climatic patterns. Among the human activities mentioned by key informant is the construction of Chebara Dam along the river in the year 1999. Similar trends were noted by Onyango *et al.* (2020) in Kenyan catchments, where the shift in rainfall patterns and rising agricultural practices cause variation in water availability. The recent decreases however could be due to over extraction and sedimentation or it may be reflecting better conservation.

The decline of grassland and rangeland indicates a possibility of increase in farming activities or planted forestry. According to Langat *et al.* (2022), comparable shifts have been observed throughout East Africa, where land that was formerly covered in grass and bushes is now being used for crop farming or tree plantations. Future land usage planning must consider the ecological effects of this shift, especially with regard to biodiversity and water infiltration.

The steady growth of rural population is reflected in the increased built area. According to Ndungu *et al.* (2023), as the population increase, infrastructural development also grows thus contributing to the gradual spread of built area, even in rural areas. This trend indicates the need to look into the impacts of the growing development that it has impacted on the land resource even if it is still small in comparison to cropland.

Over time, the changes in land use have not been consistent as indicated in Figure 4.4. Before the attempts to restore the forest vegetation in recent years, a large amount of land was cleared between 1995 and 2004, most likely for farming activities or the growth of settlements. This trend is same with more general results from land use research done in other parts of Kenya, which emphasize that degradation and restoration cycles are brought about by shift in the land usage, economic status, and policies (Oduor *et al.*, 2023; Mansourian & Berrahmouni, 2021).

These finding have demonstrated that the catchment's land use changes are similar to those of other catchments in Kenya and other comparable regions globally. Conservation and land management regulations have contributed to the alteration of the landscape, even when agricultural expansion continues to be a key cause of change. Although the reduction of bare land from 2014 to 2024 by 0.01% may indicate improvements in land management, the reduction of rangeland and grassland raises questions about the stability of the ecosystem. Future sustainable land use will depend on finding ways to control human innovations, agricultural practices, and environmental protection.

A huge number of respondents (94.8%) noticed major changes in LULC over the past 20 years. Most noted increased in agricultural practices (49%) and deforestation (45%). This was buttressed by Key informant who mentioned that the proposed Meibeki valley irrigation project which is aimed to increase agricultural practices in the catchment. Some also noted more infrastructure development, such as roads and buildings, while urban expansion was less frequently mentioned.

The majority believed that what is causing these changes is population increase (82.2%), urbanization (32.7%) and agricultural expansion (72.2%). The minor drivers included climate change (19.6%) and government policy (20.4%) such as the Physical and Land Use Planning Act, 2019 which directs on how land is zoned for particular use. This shows that as population grows, they utilizing more land for housing and farming at the cost of forests. Betru *et al.* (2019) believe that the main drivers of land cover change in many developing countries are agriculture and population growth. Deforestation and urbanization are rapidly changing the environment, impacting local temperatures and biodiversity, as noted by Alemu *et al.* (2021).

5.4 The factors that have significant impact on river discharge in the catchment

The following are some of the significant factors that impacts river discharge in the catchment;

5.4.1 Changes in rainfall and temperature

Most respondents reported that temperatures increased over the past two decades (86.3%). Hotter days and nights were also mentioned (80.4%), others noting an increase in heat waves (6.4%). A few respondents observed colder days (8%) or felt that temperatures had not changed much (3.1%). This is supported by *Opiyo et al.* (2022) research which found that increased temperatures and unreliable rainfall are already impacting farming and water availability in semi-arid regions.

Rainfall has also changed over the past 20 years. Some respondents have experienced rainfall which are more intense (34%), while others felt that rainfall has decreased (33.5%) overall. Those that felt that rainy seasons were shorter than before with heavier downpours were noted (67.5%), while some mentioned that longer dry spells before intense rain arrives (30.9%). Some of them also felt that rainfall remained consistent (1.5%). This is similar to research done by Dunning et al. (2018) which confirms that climate variability has changed the rainfall patterns in many regions where short and intense rains are more pronounced than before.

Most respondents believed deforestation (48%) was the key cause of climate variability in the region, followed by agricultural expansion (35%) and urban growth (17%). The results point out the high level of local awareness on how human activities are influencing the surrounding. While expansion of farm lands and cities disturbs natural ecosystems, the cutting of trees decreases the land's capacity to hold moisture. Educated individuals or those with information on agricultural and environmental issues had better understanding on these links more than those who were less educated of the people.

These results are supported by a research from Ofori *et al.* (2020), which highlighted that the main cause of climate variability in developing countries is deforestation. Gebreyesus *et al.* (2021), demonstrated that cutting trees for agriculture and urbanization leads to higher temperatures and changing rainfall patterns by reducing vegetation cover, which lowers evapotranspiration and disrupts the local climatic balance.

Concerning the effects of forest changes on local climate variations, majority observed rising temperatures (47%), while reduced rainfall followed (40%). Others observed increased rainfall (8%) or cooler temperatures (4%), while very few felt that forest reduction had no impact on the local climate (1%). These responses reinforced what Key informants have long warned about forests playing a key role in regulating temperature and rainfall. When tree cover is lost, the land becomes drier, temperatures rise, and rainfall patterns become less stable. Wolff *et al.* (2018) found that in places where there is high rate of deforestation, it is usually associated with increased temperatures. It has also been supported by Wang *et al.* (2020) who also reported areas that have lost most of its tree cover often receive very little rainfall compared to areas where the tree covers has been restored or conserved meaning that there is a connection between forests and climate stability.

5.4.2 Water usage and management

The findings from the household interviews pointed out that various factors like the sizes of households, the social and economic levels and the presence of water infrastructure in the catchment influences the usage of water and management efforts in the catchment. The people in the catchment got their water mainly from the river and wells while most of those who were educated had connected piped water to their homes. The people who lived far from the rivers had coped by digging wells and those that were affected by water scarcity mostly during the dry seasons had coped by harvesting rainwater and storing them in tanks. Key Informants recognized the efforts of both government and non-governmental organizations (NGOs) in improving water accessibility but the awareness rate of these initiatives are still low among the residents of the catchment which may have limited their effectiveness in addressing water security.

The dependence on rivers and wells as the main water sources is similar to what is happening in most rural settings where there is less or no piped water. A study by Ayele and Teshome (2020) confirms that poor water infrastructural development in Ethiopia has forced the residence of that place to rely on natural water sources similar to what is happening in the catchment since the river is the key source of water. In Kenyan water sources, Deresse, (2023), argues that dependence on rivers and wells alone increases the chances of households being vulnerable to seasonal water shortages, pollution of the water and contaminating waterborne diseases especially during dry months.

Muthoni *et al.* (2021) believes that there exists relationship between water use and socio-economic factors meaning that educated households tend to prioritize in hygiene and invest in water infrastructure compared to uneducated households. Likewise, the report of this research aligned with results from a research by Adeyeye *et al.* (2020), which illustrated that high income households probably afforded to install water storage tanks which made them not to be affected by water shortages while lower-income households often depend on direct water sources, making them more vulnerable to changes in seasonal water availability.

Seasonal water shortages in some parts of the catchment mirrors the situation in East Africa, where the changing climatic conditions have affected many water sources (Gabiri *et al.*, 2020). Opiyo *et al.* (2022) mentioned that the majority of people who are more likely to be affected by water scarcity are those that depend only on rain water as their main water source. Kipkorir and Mugo (2018) found that choosing rain water harvesting as an alternative water source usually occurs when there is limited awareness and financial challenge which allow the use of modern methods such as greenhouse farming.

Most of the respondents were not aware of the efforts the government and NGOs were doing in providing water security, but a Key Informant recalled a water program implemented by World Vision about ten years ago. It is a common problem in rural setting where there is low awareness, involvement and communication which results to lack of visibility of such initiatives. Research by Kariuki and Ngugi (2019) align with this by mentioning that most people don't get to be part of water initiatives because they are not involved or they lack information about the projects. Similarly, Maina *et al.* (2021) ascertains that the level of education an individual has acquired play a huge role in enabling them to be part of conservation and resource management programs like water conservation projects. The findings also suggests that targeted outreach campaigns, direct communication to the people, and community involvement in water projects could enhance the impact of existing water initiatives in Moiben River catchment.

5.4.3 Agricultural practices

In the catchment most of the farmers have below 10 acres of land while few farmers have land exceeding 15 acres. The households who owned larger pieces of land, only utilize a portion under cultivation and for those that lived near the river used their land for irrigation practices. Kadigi *et al.* (2019), explores this further by mentioning that the sizes of land in Sub-Sahara under irrigation mainly depends on the farmer's capability to finance it and other farming services provided by the government. According to research by Rahman *et al.* (2020), this is a rampant issue in that majority of developing countries, such as South Asian where farmers find it difficult to implement irrigation techniques because of their high prices.

Factors such as income and education affected the size of owned land, as better financial stability tended to lead to bigger land while adoption of sustainable water practices depended on level of awareness and financial capacity.

The majority of farmers relied on rainwater for irrigation because it is more affordable. Even among those who practiced irrigation, most chose flood irrigation due to its low cost. This makes the people to be vulnerable as they over depend on rain water especially with the changing climate leading to reduced agricultural productivity during dry spells. Future production of agricultural produces may be seriously affected by over dependence on rain water given the current changes in climatic conditions. Gebrehiwot *et al.* (2022), mentioned that small-scale farmers such as those in East Africa have no resources for alternative water sources. Just like Li *et al.* (2021) observed, less developed countries would choose traditional farming systems because they can afford it.

Most farmers who don’t have farms near the river primarily rely on rainfall for farming. The changing climatic conditions are more likely to affect them, hence highlighting the need for better planning. January to March was the most challenging period for most farmers as this is a dry season in the catchment. Furthermore, the fact that nearly none of the farmers had adopted new water-saving technologies suggests that either they do not see the need or they lack the means to implement them. This finding is confirmed by a study by Mugambi *et al.* (2023), where many small farmers do not consider water challenges to be a critical issue until they are personally impacted by drought. Similarly, Kadyampakeni *et al.* (2020) noted that shifting rainfall trends have already started to affect agricultural productivity, even though many farmers do not consciously recognize water challenges.

5.4.4 Livestock water sources

Cattle were the common livestock owned by farmers interviewed (93.8%), followed by sheep (57%), goats (43.8%), and poultry (30.7%). The livestock were watered from rivers and dams, while tap water and boreholes were the least utilized.

The choice of water source for farmers depended on the season. During the rainy season they watered from ponds and dams while during the dry season they watered them from rivers and reservoirs. This trends are similar to what were noted by Adaawen *et al.* (2019) in dry areas causing farmers to change their water sources seasonally and also Moyo *et al.* (2020) pointed out that most farmers in these areas migrate looking for water for the livestock especially with the changing rainfall patterns.

The dry months from January to March was when some farmers complained about the water scarcity problems for their livestock and they believe that it might be the effects of the shifting weather patterns which is affecting the supply of water. This could probably suggest that some farmers are already feeling the effects of water scarcity, especially those who rely on water sources that change seasonally. If current trends continue, this issue is to increase given the changes in climate which affect water availability. This viewpoint is corroborated by Tsegaye *et al.* (2022), who note that while some farmers have coped well with the seasonal changes in water supply, some are still susceptible especially during dry seasons. Hadebe *et al.* (2021) also mentioned that livestock farmers need to shift to modern water management techniques as impacts of climate change are increasing.

5.4.5 Correlation between climate, LULC, river discharge and population

The findings on climate variability, LULC, river discharge, and population trends in the Moiben River catchment showed that environmental changes that have been experienced in the area are cause by both environmental and anthropogenic influences. Over the study period, temperatures has increased and with a strong correlation with time, which was not statistically significant, and this could be probably because of the global warming experienced worldwide. This warming trend also aligns with world climate patterns reported by the IPCC (2021) where temperature in most areas is increasing rapidly due to urbanization and industrialization. This warming trend emphasizes the importance of focusing on future scenarios using river discharge as a critical indicator to understand potential impacts on water availability and guide necessary interventions. Meanwhile, rainfall levels showed a moderate correlation, which was not statistically significant, suggesting potential water shortages that could impact agriculture, ecosystems, and livelihoods.

Changes in LULC reflected growing demands for agricultural expansion and urban growth. Cropland, bare land and forested areas have expanded, while grassland, and rangeland have declined. This could suggest that there have been afforestation and reforestation efforts in some parts of the catchment but also it shows the impact of human activity on natural vegetation covers. Forest and rangeland were statistically significant, and grassland was not statistically significant but had a strong correlation with river discharge and this suggests that the changes in natural vegetation has an impact on the fluctuation of river discharge. This is in line with Chepkurui *et al.* (2022) who confirmed that the changes of natural vegetation caused by human activities in a watershed such as farming are likely to impact the discharge levels of a river. Increased rate of rainfall has a positive correlation with increased forest cover and increased surface water availability, but it also had a positive relation with increase in bare land, suggesting that it could be due to soil erosion or deforestation. Zhu *et al.* (2019), emphasize that climate variability and land-use decisions are key in shaping the vegetation and the overall cover changes in a place and thus supporting the findings.

Urbanization was related to population growth and this was concluded from the strong correlation between the expanding settlements and the increasing population numbers in the catchment which was not statistically significant. This is a common trend in rapidly developing areas, where urban expansion causes the natural lands to be utilized for settlements and infrastructures development leading to pressure on water resources within the occupied lands (Mukherjee *et al.*, 2018). A research of UN-Habitat, (2022) has noted that similar challenges in other growing urban areas and thus emphasizing the need to consider the importance of sustainable practices to balance the growth with environmental protection.

River discharge patterns had positive but moderate correlation with time which was not statistically significant, which indicates that the seasonal river flow fluctuations remained relatively stable, however, given the ongoing shifts in land use and climate variability, future shifts in discharge patterns cannot be ruled out. The absence of a strong link between river discharge and all the land cover changes suggests that while some land uses were related to the changes in river discharge, other factors, such as groundwater recharge, soil infiltration rates, and water extraction help regulate the water flow. Similar finding by Wang et al. (2020) has demonstrated that hydrological processes are influenced by multiple combined natural and anthropogenic factors rather than being dictated to only land cover changes.

5.4.6 The simulated discharge in the catchment

The simulation resulted during the highest peak discharge in July 2024 with 87.9 m^3/s of discharge among the simulated events of 30 years, was contributed more by subbasin-5(20.5 m^3/s) and less by subbasin-10 (1.3 m^3/s) (Figure 4.15). This high peak discharge suggests that the combined effect of land use shifts such as increased farming practices and changing weather conditions could have caused it. The increase in peak discharge aligns with finding that revealed that the conversion of natural vegetation to farmlands reduces infiltration and increases surface runoff, as demonstrated by Revell *et al.* (2021) who found that the plantation of woodland reduces the peak flow compared to non-porous or cultivated land. These findings also are supported by Masood et al. (2023), who found that increased rains under future climate scenarios will rise from 21% to 28% by the end of the century and together with land cover changes they will increase the inflows and stream flows of catchments as their calibrated HEC-HMS model showed that the flow is strongly influenced by both climate and land use shifts.

The period 1995 to 2024 had greater change in cropland from 51.48% to 77.67% and built-up areas from 0.80% to 4.21% and this could mean that the vegetation cover reduced and non-porous surfaces increased hence causing increases surface runoff. This is also supported by the HEC-HMS findings where Subbasin-5 and Subbasin-3, which are dominated by cropland and built area (Figure 4.16), recorded the highest peak discharges of 20.5 m^3/s and 19.5 m^3/s respectively while sub-basins with lower peak discharges such as Subbasin-10 (1.3 m^3/s) may have retained more natural cover or experienced less land degradation. The findings suggest that increased farming practices and human settlement growth have caused faster and higher surface runoff, which may raise the risk of flooding during heavy rains. This has been supported by Kayitesi *et al.*, (2022), who demonstrated that land uses in tropical areas have greatly shifted over the past decades because the need for land is growing and it is causing the people to convert forested lands to farm lands and people's homes which influences the natural water balance components like percolation and evaporation. Adeyeri *et al.*, (2020), also support this findings that shows that changes that are seen in the river discharge are contributed by the human activities that change the environment and it can combine with change in rainfall patterns to cause the variations.

These findings calls for the need for an integrated land and water conservation efforts in the catchment in that the continuous expansion of urbanization, felling of trees, and increased farming activities can be replaced by sustainable practices such as afforestation programs, improved water conservation efforts, and climate-resilient urban planning which will help maintain the ecological balance and securing long-term water availability.

5.5 Water conservation and management

The sections below contains some of the water conservation and management efforts in the catchment;

5.5.1 Water conservation and management strategies

Water storage tanks (31%) and rainwater harvesting (45%) were the most widely utilized water conservation methods, whereas drip irrigation and other modern technologies were not utilized. This implies that even when aware of these modern technologies the farmers still choose the cheaper traditional methods. This can be attributed to either lack of awareness or finances among the small scale farmers

This is simmilar to a research by Alemu *et al.* (2021), which highlight that depending on rainwater by small scale farmers of Africa is because it is cheaper compared to modern technologies. Gebretsadik and Namara (2022) reinforced this by mentioning that even when modern technologies are available, its implementation cost and lack of awareness discourage its adoption.

5.5.2 Existing water scarcity measures and solutions

The findings from the study found that most people had no training on sustainable water use (93.8%), few had knowledge on practices such as rainwater harvesting (3.6%) and soil and water conservation (1.5%). Insufficient knowledge on sustainability is a critical issue in the continued struggle with water shortages. While some respondents (89.2%) mentioned that the National Government had not done much to address water scarcity, a small number (1.0%) still recognized initiatives such as Tachasis Water Project. Many residents however felt they are not well supported even with some County government initiatives, such as the Kaptik and Meibeki Water Projects.

The people emphasized that they needed stronger water conservation policies (34.5%), as well as better infrastructure (28.9%), and more funding for water projects (25.3%). The catchment also had no local organization that deals with water conservation making the situation even worse as these results are comparable with research by Kimani *et al.* (2022) and Ochieng *et al.* (2020), who stressed that managing water resources effectively requires a combination of enforcement of policies, improving in water connection, and involving the community in water projects. For such progress to be made, it requires the public to be educated, the government to take more action and different stakeholders coming together in initiatives. Lack of such efforts will continue to make communities face water shortages and even harder for them to adapt with the shifting climate and unpredictable weather patterns.

The findings portray a concerning trend of increased environmental challenges that include declining quality of water and increasing water scarcity which affects water management thus requiring adequate mitigation measures. Increased felling of trees and the increased farm land in catchment is the main cause of declining forest cover in the catchment as it has been replaced by croplands. This is because many locals believe that the current water management policies are not adequate (23.2%), while some think they are successful (28.6%) and near half said they need to be improved (48.2%).

Respondents emphasized that they need to be involvement more in water projects and be informed through education in local water management while others suggested to be offered incentives for sustainable water use and engage the young people and schools in conservation initiatives. Some Key Informants informed on the proposed National Agricultural Value Chain Development project in the catchment which target farming practices and encourages sustainable land and water use as the solution to sustainability. These views align with findings by Moyo *et al.* (2020) and Opiyo *et al.* (2021), who believe that community involvement and education programs help in water conservation and it leads to long-term water sustainability.

5.5.3 Suggestions for improving water availability and management

The reasons for Kenya's increasing water problems are closely related to those in the Moiben River catchment where deforestation and increased farming activities are changing the environment, where soil's capacity to retain water is reduced causing increase in surface runoff, reducing the quality of water and thus escalating water scarcity. This call for government cooperation, reinforcement of regulations, and community involvement for sustainable land use and water conservation.

Some respondents stressed the importance of strengthening local water conservation initiatives, highlighting the necessity of cooperation in safeguarding and managing water resources. Forests regulate the hydrological cycle and also helps in controlling soil erosion and restoring ground water, therefore it should be restored. Food and Agriculture Organization (FAO, 2021) noted that forests help in maintaining water availability while reducing impacts like floods and droughts.

Another suggestion was upgrading the water distribution infrastructure. While Key Informants recognized the water distribution program from the County government, many respondents noted that outdated or inadequate water systems contribute to losses and unequal access. A study by Mwangi *et al.* (2022) reinforce this, showing that inefficient distribution networks in many rural areas worsen water scarcity. Rainwater harvesting was emphasized to be an efficient method, especially during dry periods. As to Opiyo *et al.* (2022), communities that have opted to harvest rainwater as a mitigation measure to the changing natural water sources are more secure because of the increasing cases of water scarcity.

Another issue raised was the need for better water storage facilities because bigger storage can guarantee a more consistent supply of water and it can also help the people endure longer dry seasons. The respondents also recommended some other sources of water such as underground reservoirs and drilling boreholes to compliment the water from the river which is their main water source. This aligns with Kimani and Wekesa (2020), who believe that communities that have alternative water sources are more resilient to the effects of prolonged droughts and famines which dries up water sources.

Collaboration among various stakeholders is important for improving water management as mentioned by Key Informants and it can be achieved by allocating funds, providing skills, and disseminating information, which aim for conservation and water distribution initiatives. Whenever the government and community work together with an aim for achieving sustainable solutions in local water management practices, there is usually increased chances of success as illustrated by Ochieng *et al.* (2020).

The respondents also mentioned adoption of irrigation systems as a strategy to reduce the use of the current flood irrigation method in farming practices as it is unsustainable. When farmers adopt modern irrigation methods like greenhouse farming they can be able to increase their agricultural yields and reduce the amount of water wasted (Muthoni *et al.*, 2021). But, most of the small farmers sometimes are not able to get these modern technologies because of financial problems and inability to operate them which means there is need for training programs and funds from the government.

Key Informants reported the challenges in the catchment such as water pollution of the river, wastage and over-extraction of water, and they recommended that the available water management regulation be strictly enforced to address these problems. Nyongesa *et al.*, (2022), believe that when the community is fully aware and have the right capacity for sustainable water management it becomes easier for the existing regulations to be enforced and responsible water use being met.

These strategies mentioned by the community and the Key Informants are recognized by international research where sustainable water management involve plans that involves getting governmental support, improving water infrastructure , engaging in conservation initiatives, and the people having technical capacity for modern irrigation methods (UNESCO, 2021).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The chapter concludes the findings of river discharge patterns, land use changes, and the social and economic factors driving resource use in the catchment. It also provides recommendations for improving water management and conservation and the recommendations for further studies.

6.2 Summary of findings

Objective 1: To analyze the trend in river discharge of the Moiben River from 1995 to 2024

The River discharge in the catchment between 1995 and 2024 revealed fluctuations in the mean annual discharge ranging between 2.0 and 4.6 m^3/s. Although the linear regression equation ($Qt = 0.8534t + 112.96$) suggested a slight increasing trend, the results were not statistically significant ($R^2 = 0.0221$, $p = 0.530$). This indicates that despite observable variations over the years, there was no consistent long-term increase in discharge. Seasonally, the wet season recorded higher discharge (1.25 m^3/s) compared to the dry season (1.07 m^3/s), showing clear seasonal differences in flow volume. Community responses confirmed that river flow patterns have become increasingly unpredictable (55.4%) with a general perception of reduced flows (19.3%) over the past two decades, primarily due to land use changes and agricultural expansion along the riverbanks. Key

Informants also reported flooding during rainy seasons and extremely low flows in dry periods, largely attributed to increased horticultural irrigation and deforestation.

Objective 2: To determine the extent and patterns of land use and land cover change in the Moiben River catchment from 1995 to 2024

Land use and land cover analysis showed that cropland dominated the catchment throughout the study period, expanding from 44,672 ha (51.5%) in 1995 to 67,399 ha (77.7%) in 2024, an overall increase of 26.8%. Forest cover fluctuated, initially declining between 1995 and 2004, but later recovering to 27,088 ha (31.2%) by 2024, marking a 6.6% overall increase. Rangeland showed minor variations, while built-up areas had a slight rise from 0.8% to 4.2%, reflecting growing settlements and infrastructure. The LULC maps confirmed a steady expansion of cropland and urban areas, with slight recovery in forest cover. Accuracy assessment indicated high reliability of classification (Kappa = 0.924; overall accuracy = 94%), confirming dependable results. Community feedback linked the observed land cover changes to increased farming activities (49%), deforestation (45%), and urbanization (6%), driven mainly by population growth (82.2%) and agricultural expansion (72.2%). Major development projects and initiatives such as the Chebara Dam and National Government Tree Restoration Campaigns were also highlighted as contributing factors.

Objective 3: To evaluate the factors that have significant impact on river discharge in Moiben River catchment

The results revealed that among the analyzed factors, forest cover and rangeland had a statistically significant influence on river discharge in the catchment, with correlation coefficients of $r = 0.964$ ($p = 0.036$) and $r = 0.983$ ($p = 0.017$), respectively. This indicates that areas with higher forest and rangeland cover are associated with more stable river discharge, highlighting the important role of vegetation in regulating hydrological balance through enhanced infiltration, evapotranspiration, and flow regulation.

Population also showed a significant positive correlation with time ($r = 0.990$, $p = 0.010$), demonstrating rapid growth over the study period. Although it has a direct relationship with river discharge, it was not statistically significant, the strong link between population, built-up area, cropland expansion, and temperature rise implies indirect effects on discharge through intensified land use shifts, increased farming activities, and increased water demands.

Climatic factors, particularly temperature and rainfall variability, were found to have a marked influence on river discharge. Rising temperatures contribute to higher evapotranspiration rates and increased water losses, while irregular rainfall patterns alter surface runoff and groundwater recharge, both of which directly affect stream flow volume and timing. Periods of prolonged drought reduce base flow, whereas heavy rainfall events increase surface runoff, leading to fluctuations in discharge levels.

Water use for domestic, livestock, and agricultural purposes further contributes to the modification of discharge patterns. Increased irrigation, livestock watering, and household consumption have led to higher rates of abstraction, reducing the volume of water available in the river during dry seasons.

From the hydrological modelling results, the simulated peak discharges showed that rainfall intensity and land cover characteristics significantly influence flow magnitudes during extreme events. Catchments with reduced vegetation and increased impervious surfaces exhibited higher runoff peaks, indicating the sensitivity of discharge to land cover dynamics. The modelling outcomes validated the observed correlations by demonstrating how land use changes and rainfall events combine to alter discharge responses within the Moiben River catchment.

6.3 Conclusion

This study examined the transformation of the Moiben River catchment by analyzing river discharge trends, land use changes, and factors influencing hydrological characteristics.

The trend analysis showed that river discharge has fluctuated over the years, with the 2024 event recording the highest discharge in a 30-year return period. The variations are linked to changing rainfall patterns, human activities, and increased water use for agriculture and domestic needs.

The land use and land cover assessment revealed an expansion of farming and settlements and a decline in natural vegetation, particularly grassland and rangelands. Deforestation, once a major concern, has slightly reduced due to ongoing conservation and reforestation initiatives. These land use changes are largely driven by population growth, agricultural expansion, and urbanization.

The study also found that socio-economic and environmental factors such as farming practices, water use, conservation measures, and limited infrastructure significantly influenced the river discharge. Dependence on rainfall and inefficient irrigation methods persist, while water conservation technologies remain underutilized. Seasonal fluctuations, weak policy enforcement, and inadequate awareness continue to affect sustainable water resource management.

Overall, the findings emphasize the need for integrated and sustainable water management strategies that balance human demands with environmental conservation in the Moiben River catchment.

6.4 Recommendations

The study made the following recommendations;

a) Land Use and Land Cover Management

The National Environment Management Authority (NEMA) and County governments should stop the unsustainable land uses by strictly enforcing land use policies such as prohibiting cultivation within riparian zones. Sustainable land management techniques including terracing, regulated grazing, and maintaining a minimum of 30% vegetation or tree cover within the catchment should be promoted to the farmers and landowners. This vegetation threshold can enhance infiltration, reduce surface runoff, and stabilize base flow, thereby improving river discharge stability. Legislative bodies should ensure that existing land use regulations are monitored and implemented through participatory approaches, engaging local communities in conservation efforts.

b) Sustainable water resource management

Since water use and agricultural practices were found to have a significant influence on river discharge, the Ministry of Water and Sanitation should promote water-saving methods such as low-flow household fixtures and efficient irrigation systems. Farmers and cooperatives must switch from traditional irrigation systems, such as flood irrigation, to more efficient methods like drip and greenhouse irrigation. These water-efficient ways ensure crops receive enough water without over-extracting the river. In addition to improving irrigation, farmers should be supported in exploring alternative income-generating activities to reduce overdependence on farming, especially in water-scarce periods. Education programs and knowledge-building programs should be organized to educate communities on viable alternative livelihoods such as agroforestry, beekeeping, eco-tourism, and small-scale businesses. This diversification can enhance resilience and reduce pressure on water resources.

c) Alternative water sources

The County Government, in collaboration with the National Government, should prioritize the restoration and extension of water distribution networks. Over-dependence on the river as a primary water source increases pressure on discharge, especially during dry seasons. Therefore, the development of alternative sources such as boreholes, protected springs, roof catchments, and small dams should be accelerated. NGOs and government agencies should support community-based water storage systems such as tanks and pans that capture rainfall during wet seasons, ensuring a steady water supply even in periods of scarcity.

d) Climate change adaptation strategies

The study established that temperature had a significant negative impact on river discharge, underscoring the need for climate adaptation interventions. Farmers should adopt climate-smart farming systems that improve soil structure and moisture retention, such as mulching, conservation tillage, and the use of drought-resistant crops. The Kenya Forest Service (KFS) and local communities should implement afforestation and reforestation along degraded riparian areas and hill slopes to moderate temperature effects and enhance catchment resilience. The Kenya Meteorological Department should also strengthen the dissemination of local weather and early warning information to guide water use and agricultural decisions.

6.5 Recommendations for further research

This research analyzed the temperature and rainfall trends and their influences with river discharge in the Moiben River catchment. Further research should investigate the future effects of climate change using future climate forecasts, as this study performed historical trend analysis. The future research should combine climate models with hydrological models to predict the possible impacts of different climate scenarios on the discharge. This modelling technique will help in improving early warning systems, help create climate-resilient catchment management measures, and contribute to sustainable water resource management.

The catchment also recorded an increase in cropland from 51.48% to 77.67% and built area from 0.80% to 4.21% from the year 1995-2024 and these findings has influenced the river discharge of the catchment based on modelling results which have shown that the peak discharge in a 30-year return period is 2024. It is recommended that future studies should explore the impact of different land use scenarios on hydrological responses in the catchment such that the study could assess how further increases in built area or continued crop farming in the area might influence surface runoff and peak discharge. Running such simulations would provide important information that can shape future land use decisions that might affect water flow patterns, and can support more informed planning for sustainable catchment management.

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APPENDICES

Appendix I: Household questionnaires for Moiben River catchment

COUNTY ____

LOCATION _____________________________________

SUB-LOCATION______________________________DATE (D/M/Y): ____________________________

GPSX___________________________GPSY____________________Z_______________ _____

Section A: Demographic

1. Age: ……. (Years)

2. Gender:

i) Male
ii) Female

3. Level of Education:

i) No formal education
ii) Primary
iii) Secondary
iv) Tertiary
v) University

4. Occupation:

i) Farmer
ii) Teacher
iii) Civil servant
iv) Casual worker
v) Others (specify) ….

5. Household Size: (number of people) ….

6. Monthly Income (in Kenyan Shillings):

i) Less than 10,000
ii) 10,000 - 20,000
iii) 20,001 - 30,000
iv) 30,001 - 40,000
v) 40,001 - 50,000
vi) More than 50,000

Section C: Water Usage and Management

7. On average, how many liters of water does your household use per day for domestic purposes? ….

8. What is your main water sources?

i) River
ii) well
iii) borehole
iv) spring
v) dams and reservoirs
vi) tap water
vii) Any other (specify)……

9. How far is your primary water source from your home (in kilometers)? ….

10. a) Have you experienced water shortages for domestic use:

i) Yes
ii) No

b) If yes,

i) When did you start experiencing this? ….
ii) Which months is water scarcity for domestic use severe?

January-March

April-June

July-September

October-December

11. What have you done or doing to address water scarcity?

i) Installed water storage tanks
ii) Practiced rainwater harvesting
iii) Reduced water usage (e.g., shorter showers, fewer irrigations)
iv) Reused grey water (e.g., for gardening)
v) Participated in community water conservation initiatives
vi) Installed water-efficient appliances
vii) Purchased water from vendors
viii) Moved to alternative water sources (e.g., boreholes, wells)
ix) Others (specify)….

12. a) Have you participated in any community initiatives related to water management?

i) Yes
ii) No

b) If yes, please describe……

13. a) Are you aware of any government (national/county) programs in your area that aim to improve water availability and management/conservation?

i) Yes
ii) No

b) If yes, who are they?

14. a) Are you aware of any NGO programs in your area that aim to improve water availability and management/conservation?

iii) Yes
iv) No

b) If yes, who are they?

Section D: Agricultural Practices

15. What is the total size of your land (acres)? ……

16. What size of your land is under agriculture (acres)? …..

17. a) Do you practice irrigation?

i) Yes

ii) No

iii) b) If yes, what size of your land is under irrigation (acres)? ….

18. Which year did you start irrigation? …..

19. What is the source of the water you use for irrigation?

i) River

ii) Springs

iii) Dams and reservoirs

iv) Boreholes

v) Tap water

vi) Others (specify)…

20. How much water do you use for irrigation (liters)? ……

21. What method of irrigation do you use?

i) Flood irrigation

ii) Drip irrigation

iii) Sprinkle irrigation

iv) Surface irrigation

v) Subsurface irrigation

vi) Others (specify)….

22. Which year did you start irrigation? …..

23. How much water do you use under irrigation (liters)? ……

24. a) Have you experienced water scarcity for your irrigated crops?

i) Yes

ii) No

b) If yes,

i) When did it start? ……

ii) Which months is water scarcity for the crops more severe?

January-March

April-June

July-September

October-December

25. a) Have you adopted any new technologies or practices to improve water use efficiency in farming?

i) Yes
ii) No

b) If yes, please describe……….

26. What are some of the water conservation and management strategies that you practice?

i) Rainwater harvesting
ii) Use of water storage tanks
iii) Reduced water use for irrigation
iv) Rely on alternative water sources (e.g., boreholes, rivers)
v) Practice mulching to retain soil moisture
vi) None
vii) Others (specify) …….

27. a) Have you noticed changes in the types of crops that grow well in your area over the past 20 years?

i) Yes
ii) No

b) If yes, please explain……

28. a) Do you keep livestock?

i) Yes
ii) No

b) If yes, which ones

i) Cows
ii) Goats
iii) Sheep

iv) Poultry

v) Others (specify) …….

29. a) What is the main source of water for livestock?

i) River

ii) Boreholes

iii) Dams and reservoirs

iv) Springs

v) Tap water

vi) Others (specify) ……

b) Has the source of water for livestock changed over time?

i) Yes

ii) No

c) Explain ……

30. a) Have you experienced water scarcity for your livestock?

iii) Yes

iv) No

b) If yes,

iii) When did it start? ……

iv) Which months is water scarcity for livestock more severe?

January-March

April-June

July-September

October-December

Section E: Perceptions of Climate and Land Use Change

31. Have you noticed any changes in river flow patterns, such as flooding or drying up, over the past 20 years?

i) Increased drying up of the river during dry seasons

ii) More frequent flooding during the rainy season

iii) Unpredictable flow patterns (e.g., sudden floods or dry periods)

iv) Reduced river flows

v) Increased river flows

vi) No significant changes in river flow

vii) Others (specify) ……

32. What are the main causes of climate change in your area?

i) Deforestation

ii) Agricultural expansion

iii) Urbanization

iv) Industrial activities

v) Other (specify)…….

33. Have you noticed any changes in temperature trends over the past 20 years?

I) Increase in temperature

ii) Decrease in temperature

iii) No significant change

IV) other (specify) ……

34. What specific changes in temperature patterns have you observed?

i) Hotter days and nights

ii) Colder days and nights

iii) More frequent heat waves

iv) More frequent cold spells

v) No noticeable changes

vi) Other (specify) ……

35. Have there been changes in the intensity or frequency of rainfall in your area over the past 20 years?

i) Increased intensity of rainfall events

ii) Decreased intensity of rainfall events

iii) More frequent rainfall

iv) Less frequent rainfall

v) No noticeable changes

vi) Other (specify) ……

36. Have you noticed changes in the duration of rainfall periods?

i) Shorter rainy seasons with heavier rainfall

ii) Longer rainy seasons with lighter rainfall

iii) No significant change

iv) Other (specify) ……

37. How would you describe changes in rainfall patterns in your area?

i) More erratic and unpredictable

ii) More consistent and predictable

iii) Longer dry spells followed by intense rain

iv) No significant changes

v) Other (specify) ……

38. a) Have you observed any significant changes in land use or land cover in your area over the past 20 years?

i) Yes

ii) No

b) If yes, what specific changes in land use/land cover have you noticed?

i) Increased agricultural land

ii) Increased deforestation

iii) Increased urban development

iv) Expansion of infrastructure (e.g., roads, buildings

v) Increased reforestation or natural vegetation

vi) No significant changes

vii) Others (specify) ……

39. What do you think are the main drivers of land use/land cover changes in your area?

i) Population growth

ii) Agricultural expansion

iii) Urbanization

iv) Industrial activities

v) Government policies or regulations

vi) Climate change impacts

vii) Others (specify)….

40. How have changes in forest cover affected local climate conditions (e.g., rainfall, temperature)?

i) Reduced rainfall
ii) Higher temperatures
iii) Increased rainfall
iv) Lower temperatures
v) No noticeable effect
vi) Others (specify) …….

Section F: Water Scarcity Measures and Solutions

41. a) Have you received any training or education on water conservation practices?

i) Yes
ii) No

b) If yes, what did you learn?

i) Efficient irrigation techniques

ii) Rainwater harvesting

iii) Soil and water conservation

iv) Water recycling

v) Other (specify) ….

42. a) Are there any national government initiatives to address water scarcity issues in the area?

i) Yes
ii) No

b) If yes, what are they?

43. a) Are there any county government initiatives on water scarcity issues in the area?

iii) Yes
iv) No

b) If yes, what are they?......

44. What role should the national government play in addressing water scarcity issues in your area?

i) Increase funding for water projects

ii) Enforce water conservation policies

iii) Build more water infrastructure

iv) Collaborate with communities

v) Other (specify) ……

45. a) Are there any local organizations or groups actively working to improve water management/conservation?

i) Yes
ii) No

b) If yes,

i) Who are they? …..
ii) How effective have they been?
a) Very effective
b) Need improvement
c) Not effective

Section G: General Observations

46. What impact does population growth have had on water availability in your area?
i) Reduced water availability due to increased demand
ii) No noticeable impact
iii) Other (specify) ….

47. a) What are the main environmental challenges facing the Moiben River catchment?

i) Deforestation
ii) Soil erosion
iii) Water Pollution
iv) Over-extraction of water
v) Cultivation of riparian areas
vi) Other (specify)….

b) How do they relate to water management?

i) poor water quality
ii) Reduced water quantity
iii) Increased water scarcity
iv) Increased frequency of flooding
v) Other (specify)……

48. What are your thoughts on the current state of water management policies in your area?

i) Effective
ii) Need improvement
iii) Not effective
iv) Any other (specify)…..

49. How can community involvement be improved in water resource management?

i) Increase awareness and education
ii) Encourage participation in local water management committees.
iii) Implement community-led water conservation projects.
iv) Offer incentives for sustainable water use.
v) Involve youth and schools in water management efforts.
vi) Other (specify)……

50. What are the most significant changes you have observed in the Moiben River catchment over the past 20 years?

i) Decrease in forest cover

ii) Increase in agricultural land

iv) More frequent water shortages

v) Other (specify) …….

51. What suggestions do you have for improving water availability and management in your community?

i) Build more water storage facilities

ii) Encourage reforestation

iii) Implement efficient irrigation systems.

iv) Promote rainwater harvesting.

v) Improve water distribution infrastructure.

vi) Strengthen community water conservation initiatives.

vii) Enforce water management regulations.

Viii) Enhance collaboration with government and NGOs.

Ix) Develop alternative water sources.

x) Other (specify) ……

Section H: General Comments

52. Please provide any additional comments or suggestions regarding water resource management in the Moiben River catchment. ……..

Thank you for your cooperation.

Appendix II: Key Informants Interview Schedule

INTRODUCTION

Please describe your role and responsibilities within your organization/community.

How long have you been involved in water/agricultural management activities in the Moiben River catchment?

Project manager Meibeki water project

What is the current projects in the catchment?

How many liters of water is drawn for the project?

What is the capacity of tanks for these projects?

What is its goals and achievements?

Are there any other future proposed projects?

WRA officer

What is the role of your organization in water management?

What are some of the policies in place for water management in the catchment and how effective are they?

According to your records, how is the state of river discharge for Moiben River over the past 20 years?

Agricultural officer

What are the agricultural projects in the catchment?

What size of land is under irrigation in the catchment?

How much water is withdrawn from the river yearly for irrigation?

Can you describe the current practices used for water management in the catchment?

How effective do these practices are in managing water resources?

What impact have land use and land cover changes had on water availability and quality?

What policies or regulations are currently in place to manage water resources in the Moiben River catchment?

How well do you think these policies are being implemented and enforced?

Are there any gaps or weaknesses in the current policy framework that need to be addressed?

World vision

How long have you been active in the catchment?

What are the current project in the catchment?

What are the achievements of these projects?

Are there other proposed projects or underway?

What are some of the achievements and failures of these projects?

Thank you for your cooperation.

Appendix III: NACOSTI RESEARCH PERMIT

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