

**LAND USE, LAND COVER CHANGES AND IMPLICATIONS ON SURFACE WATER  
ACREAGE IN KOITOBOS RIVER CATCHMENT IN TRANS NZOIA COUNTY,  
KENYA.**

**BRAMWEL WOTIA SOITA**

**A Research Thesis Submitted in Partial Fulfillment of the Requirement for the Award of a  
Master of Science Degree in Climate Change Adaptation and Sustainable Development of  
Masinde Muliro University of Science and Technology**

**March, 2025**

**DECLARATION**

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented at any university for a degree or any other ward.

**Signature.....**

**Date.....**

**Bramwel Wotia Soita**

**CCA/G/03/14**

**CERTIFICATION**

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology the research thesis entitled, ” **Land Use, Land Cover Changes and their implications on Surface Water Acreage in Koitobos River Catchment in Trans-Nzoia County, Kenya.**”

**Signature.....**

**Date.....**

**Dr. Veronica Kiluva PhD.**

Department of Disaster Preparedness & Engineering Management,  
Masinde Muliro University of Science and Technology, Kenya

**Signature.....**

**Date.....**

**Prof. Samuel S. China Ph.D.**

Department of Disaster Management and Sustainable Development,  
Masinde Muliro University of Science and Technology, Kenya

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## **DEDICATION**

This work is dedicated to my wives Irine Nakhumicha and the late Alice Majuma, my sons Miracle Mukhwana, Brian and Joshua Baraka, and daughters Brenda, Favor Marjaana, my brothers Richard Nalwilisie, Robert Silicho, and my late Mum, Mama Resa Nasipwondi, who offered great support, inspiration, and encouragement.

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## ABSTRACT

Globally, many countries are facing pressure to meet the livelihood needs of their fast-increasing populations. This often leads to overuse of natural resources and consequent encroachment on fragile ecosystems such as river catchments and riparian areas, mostly in developing countries. This has resulted to unsustainable land use practices coupled with land degradation exerting pressure on land and water resources which are basic to ecosystem livelihood. Overall, this study was to assess the implication of land use, land cover changes on surface water acreage in the Koitobos River catchment between the period 1992 to 2022. Specifically assessed the extent of land use/land cover changes within the river catchment, examined the variations in surface water acreages in Koitobos River, and evaluated land use practices for sustainable land and surface water management in the study area. Land use/land cover data was based on Landsat images pertaining to the period of study, using descriptive and correlation research design. The Google Earth Engine (GEE) and Remote sensing techniques were used for acquisition of secondary data and social economic data was collected using survey questionnaires for validation feedback and ground truthing. A sample size of 384 respondents was drawn from a target population of 203,821 residents according to Kenya National Bureau of Statistics 2019, (KNBS) within the study area. The data was analyzed using SPSS software version 25 and Microsoft excel for analysis. From the findings of Land Use, Land Cover Change in the selected years, 1995, 2009 and 2022, due to data availability and consistency, showed that Agricultural Land, covered a majority area of the Catchment depicting, 26,853Ha, (58%), 32,438 Ha (70%), and 36,118Ha (77.68%) respectively. Followed by bare land area which covered 14,915 Ha (32%), 8,093 Ha, (17%) and 6175 Ha (13.28%) of the entire catchment area extremely decreases transitionally as the Agricultural land increases due to the pressure exerted on the resource. The Forest Land showed drastic decreasing trend through the transitional period from 2242 Ha (5%) to 1647 Ha (4%) and then 222 Ha (0.48%), due to increasing demand for more space by the growing population as per (KNBS) reports, which increasingly results to deforestation activities within the catchment. Water resources within the Koitobos catchment showing an increasing trend from the year, 1995, 2009, and 2022 as follows, 2332 Ha (equivalent to 5%), 3803 Ha (equivalent to 8%), and 3521 Ha (equivalent to 7.6%) and this resulted from the artificial digging of new water pans, dams and protected water points and streams. The population of the study area in 2009 was 166,524 persons and 203,821 persons in 2019, within an area of 465.3square Kilometers with residents' density of 438.0 per square kilometer. Interviews and focus group discussions (FGDs) viewed that integrated approach on sustainable land management will be key in relieving the pressure on the natural resources. The study found out that due to 2% (percent) annual population change of 2009- 2019, resulted in an increased demand for food production within the environment where arable land couldn't be expanded therefore concluded that environmental policies and laws needed to be adopted. The study therefore recommended the adoption of sustainable land use management practices that continually heal the land and conserve biodiversity by imploring catchment plans.

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## **LIST OF ABBREVIATIONS & ACRONYMS**

AFC	Agricultural Finance Corporation
AWEI	Automated Water Extraction Index
CBO	Community Based Organization
CLMBs	County Land Management Boards
CRS	Catholic Relief Services
CVA	Community Vulnerability Assessment
DEM	Digital Elevation Models
EMCA	Environmental Management Coordination Act
FGDs	Focus Group Discussions
FIRM	Forum for Integrated Resource Management
GDP	Gross domestic product
GEE	Google Earth Engine
GPS	Geographical Positioning Systems
IWRM	Integrated Water Resource Management
KFS	Kenya Forest services
KMD	Kenya Meteorological Department

KNBS	Kenya National Bureau of Statistics
KWS	Kenya Wildlife Services
LCS	Land change science
LPD	land Productivity Dynamics
LULC	Land Use and Land Cover Change
NCPB	National Cereals Produce Board
NEC	National Environment Council
NEMA	National Environment Management Authority
NGOs	Non- governmental Organizations
NLC	National Land Commissions
NPP	Net Primary Productivity
PPA	Physical Planning Act.
PPPP	Public Policies, Plans and Programs
REDD+	Reduction Emissions through Deforestation and Degradation
SCAMP	Sub catchment management plans
SDG	Sustainable Development Goals
SLM	Sustainable Land Management

SOs	Service Organizations
SOC	Soil Organic Carbon
SPSS	Statistical Package for the Social Sciences
SWAT	Soil and Water Assessment Tools
USLE	Universal Soil Loss Equation
WOCAT	World Overview of Conservation Approaches and Technologies
WRMA	Water Resource Management Authority
WRUA	Water Resource Users Association

## OPERATIONALIZATION OF TERMS

**Automated Water Extraction Index:** Is a valuable tool for identifying water bodies in satellite imagery.

**Biodiversity:** The variety of plant and animal life in the world or in a particular habitat, which is usually considered to be important and desirable.

**Bush lands:** Communities typically composed of tall, woody, self-supporting, single, and multi-stemmed plants branching at or near ground without, in most cases, clearly definable structure. The total canopy is cover >10%, with a canopy height between 2-5m.

**Catchment area:** Is a basin shaped area of land, bounded by natural features such as hills or mountains from which surface and sub surface water flows into streams, rivers and wetlands. Water flows into, and collects in, the lowest areas in the landscape.

**Drainage Basin:** It is an area of land where all water that falls on that land flows into one river.

**Environment Impact Assessment:** Means the systematic examination conducted to determine whether an activity or project will have any significant impacts on the environment, provide mitigation for the adverse impacts and optimize the positive impacts.

**Geographical Information Systems (GIS):** Is a system designed to capture, store, manipulate, analyze, manage, and present geographical data.

**Global Positioning System (GPS):** Is a network of orbiting satellites that send precise details of their position in space back to earth and are used to provide position on the earth surface.

**Implications:** the effect that an action or decision will have on something else in the future.

**Indigenous Forests:** A group of trees whose crowns are largely contiguous, the ecosystem that makes it up and a tree canopy cover of over 10% most of which are indigenous tree species.

**Land Cover:** Physical and biological cover over the surface of the earth, including water, vegetation, bare soil, and/or artificial structures.

**Land Use:** This entails the management and exploitation of the natural environment for settlement, agriculture, and industrial purposes. Land Use” means social and economic purposes for which land, including water, is managed.

**Land Use and Land Cover Changes:** Changes that occur in land use and land cover over time based on satellite imagery analysis.

**Land Use and Land Cover Trends:** Transitional changes in land use and land cover over a period.

**Net primary productivity (NPP):** The amount of carbon retained in an ecosystem (increase in biomass); it is equal to the difference between the amount of carbon produced through photosynthesis (GPP) and the amount of energy that is used for respiration (R).

**Open woodlands:** Land classified as forest with trees higher than 5 meters and canopy cover of between 10 – 40% or trees able to reach this threshold with a combined cover of shrubs and bushes.

**Plantation forests:** All areas of systematically planted, man-managed tree resources composed of primarily exotic species.

**Precipitation:** Is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. Precipitation is the main way atmospheric water returns to the surface of the Earth. Most precipitation falls as rain.

**Rainfall:** The amount of water falling in rain, snow, etc., within a given time and area. It's a measurement of how much water falls as rain in a certain period.

**Rainfall intensity:** The ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period. It is expressed in depth units per unit time, usually as mm per hour (mm/h).

**River catchment:** An area of land where water, be it from rainfall, snowmelt, or ice, collects from higher areas above it. It's usually surrounded by hills or mountains, which allows water to flow over the landscape into streams and tributaries, and down into the soil, eventually finding its way to the local river, lake, or reservoir. The water absorbed underground slowly feeds the river in drought periods.

**River flow:** Volume of water flowing on a stream at a given time.

**Runoff Coefficient:** The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). A high runoff coefficient indicates that water will move quickly over land and may lead to flash flooding.

**Trees on farm:** Trees found on privately owned farmlands.

**Water Tower:** An elevated geographical area comprising mountains, hills, and plateaus where the topography, geology, soils and vegetation support reception, retention, infiltration, and percolation of precipitation and storage as ground water, that is eventually released through springs, streams, rivers, swamps, lakes, and oceans to sustain connected biodiverse ecosystems and is harnessed for use.

**Watershed:** An area or ridge of land that separates waters flowing to different rivers, basins, or seas.

**Surface water:** Surface water is any body of water found on Earth's surface, including both the saltwater in the ocean and the freshwater in rivers, streams, and lakes. It includes any fresh water that's sent into wetlands, stream systems, and lakes.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

Land use land cover change (LULC) is key in any development because it directly reflects how humans interact with the Earth's surface, impacting crucial aspects like climate change, biodiversity, water resources, and ecosystem services, making it a critical factor to consider when planning sustainable development strategies and managing environmental impacts across any region. LULC is critical for environmental impacts such as Climate Change, where activities like deforestation and changes in land cover significantly affect carbon sequestration, contributing to greenhouse gas emissions. Also, in water quality and quantity, changes in land use can alter water flow patterns, impacting water availability and quality. Land use changes contribute to soil erosion as the removal of vegetation cover can lead to increased surface runoff, impacting agricultural productivity and downstream ecosystems. Socioeconomically, land use changes can affect agricultural productivity and food security, particularly in regions relying on subsistence farming.

Issues arising from expansion of urban areas leading to challenges like housing affordability, infrastructure needs and traffic congestion with increasing vulnerability to natural disasters like floods and landslides. Understanding the LULC dynamics will be essential for designing sustainable development plans that minimize environmental impacts and maximize resource utilization in the study area. This analysis of LULC data can help planners identify suitable areas for different development activities, like agriculture, urban expansion, and conservation and allow tracking changes for monitoring the effectiveness of conservation and development

initiatives. In summary, LULC is crucial in any development project as it provides insights into the potential environmental and social impacts of land use changes, enabling informed decision-making towards sustainable development goals. It's very significant within the United Nations (UN) framework as it influences sustainable development, climate change, biodiversity conservation, food security, and disaster risk reduction.

Marhaento et al. (2017) conducted a study on the attribution of changes in stream flow to land use change and climate change in a meso-scale tropical catchment in Java, Indonesia. The study highlighted the impact of land use and land cover changes on the river catchment and surface water. Changes in forests, arid agriculture, and urban areas were the most significant factors influencing surface runoff. In a previous study, it was determined that logging action could affect the impact of the 100-year return period rain and land use evaluation within a specific period. This evaluation was necessary to identify trends in natural change that could be used to address future mitigation requirements. (Guan et al., 2016) conducted a study on the relationship between rainfall patterns and runoff response. Mzuza et al., (2019) investigated the changes in land use and land cover of the middle Shire River catchment in Malawi, southern Africa, over a 26-year period where they employed geographic information systems (GIS) and remote sensing techniques to determine that the rate of deforestation was high, with an average annual increase of 4.3%.

Deforestation and forest degradation are caused by human activities such as expanding metropolitan areas, clearing large areas of land for agriculture, and harvesting trees for energy purposes (Zegeye, 2017). These processes are fueled by rising populations and Gross Domestic Product (GDP). Severe issues with land use/land cover changes were caused by the deforestation

in the middle Shire River basin, which was related to increased soil loss through erosion. This led to massive silt accumulation downstream. People in the catchment had no alternatives from cutting down trees for charcoal as a means of subsistence due to the devastating impact of frequent floods and droughts on crop output caused by irresponsible land management, Nyariki, (2002). Thus, other locations where comparable problems do arise could benefit from applying the integrated methodologies utilized in this study, which included geographic information systems (GIS), remote sensing, and socioeconomic considerations.

Based on studies by Kogo et al., (2020) vegetation plays an important role in protecting soil from erosion, Consequently, accelerated soil erosion could lead to watershed degradation whereby there is loss in litter production, organic matter accumulation, and root growth. Borrelli et al., (2020) believed changes in LULC and its dynamics were closely associated with human activities and increasing demand for settlement and Agricultural production imposes a threat of land degradation. The Analysis of efforts and underlying causes of forest cover change in the various forest types of Kenya, done by Rotich & Ojwang, (2021), showed that agricultural expansion and harvesting or extraction of wood for charcoal, firewood are the most dominant direct drivers of forest cover loss in Kenya.

At present, extraction of wood for charcoal and firewood are pre-dominant, particularly in the arid and semi- arid woodlands. In their studies on effects of deforestation on Water Resources, Rodríguez-Romero et al., (2018) showed that the longitudinal deterioration in water quantity in rivers reflected the cumulative effects of human activities both on the riparian and in the catchment areas. Hua, (2017), Camara et al., (2019) and James et al., (2019) corroborated this finding by confirming that this phenomenon has been reported in several studies conducted to

investigate the influence of land use and water quality in rivers in the region. Zaines et al., (2019) were of the view that turbidity increase downstream mainly originates from agricultural areas and erosion from unpaved roads. Previous studies on rivers had also indicated that the water quality can deteriorate because of the intensification of agricultural activities and clearing of forests. Agricultural expansion for subsistence and commercial farming remains key drivers in land use / land cover change in the upper Nzoia River basin resulting to both degradation and deforestation.

Research assessing the effects of alterations in land use on hydrological responses in the Koitobos river basin demonstrated that significant land use changes had occurred in the area over the last 150 years, starting from the conditions prior to human settlement. The study examined the changes occurring in the region, including the significant deforestation, depletion of wetlands and rangelands, which had been replaced by agricultural activities and urban development, Guzha et al. (2018). The study also found that land use change has a significant impact on several land surface features and processes, such as leaf area, roughness, albedo, soil moisture, energy, and water vapor exchange rates. Land use changes, such as urbanization, deforestation, and reforestation, have ongoing impacts on the interactions between groundwater and surface water.

These changes affect processes like percolation or recharge, the contribution of groundwater to streams, soil moisture, and water availability, all of which influence ecosystem services. Zaines et al., (2019) conducted research on land use on the slopes of Mt Elgon, which revealed that land use and land cover were characterized by a conflict between conservation measures and subsistence cultivation. In recent times, the area has experienced frequent occurrences of

landslides and floods, which have been triggered by heavy rainfall and the deterioration of land quality. These natural disasters resulted in loss of life and significant damage to property. The region possesses a diverse range of living organisms, which have a significant impact on the lives and economic activities of numerous individuals by providing valuable ecosystem services and products.

Over the past three decades, large areas of forest reserves had been officially “de-gazetted” and in addition, unofficially converted to other uses, mainly agriculture, and the remaining protected indigenous forests managed by Kenya Forest Services (KFS) and Kenya Wildlife Services (KWS) had been degraded by decades of logging, both legal and illegal, of valuable timber trees resulting in reduced carbon stocks and degraded biodiversity values. Forests on community trust lands under the control of local authorities continued to be degraded and destroyed through over-exploitation for timber, poles, charcoal, fuel wood and through unregulated grazing and clearance for agriculture; depicting what Hardin, (1968) calls the “tragedy of the commons”.

## **1.2 Statement of the Problem**

Despite efforts to manage the ecosystem, land use/land cover changes and its implications in the Koitobos river catchment in Trans Nzoia County have not been assessed for better development planning towards achieving environmental sustainability, and thus not been undertaken by other researchers in the study area. The essence of this study was therefore to investigate the extent of land use land cover changes in the Koitobos river catchment of Trans Nzoia County in Kenya.

Changes in land use and land cover have far-reaching effects on ecosystems and livelihoods around the world. Lambin et al., (2006) stated that these changes have significant local, regional, and global consequences for issues like increased soil erosion, disturbances in hydrological

cycles, and biodiversity loss on a global scale. According to Sultan (2016) who reviewed research on the effects of interest groups and agricultural expansion on deforestation on a local scale, land degradation processes, soil erosion, microclimatic resources, watershed runoff, and the livelihoods of local societies were all directly affected by changes in land use and land cover. Furthermore, Few et al., (2015) in their study on vulnerability and adaptation to climate change in semi-arid areas in east Africa, which is in line with the Agricultural Sector transformation and growth Strategy (ASTGS, 2019- 2029) Kenya has only 22 % arable land where most intensive crop and dairy production take place, while the rest of the land is arid and semi-arid lands (ASALs). In reference from the Agricultural Water Policy review 2018, this arable land uses 76% of water from all water resources but the water volumes are constantly reducing in rivers and other water bodies due to land use and land cover change activities.

Mt. Elgon and Cherangani ecosystems are both national and international watersheds, which support economic and ecological sectors, yet they are seriously degraded due to land use change from forest to agriculture resulting to decreased water discharge and acreage. Water quantity has drastically dropped or decreased most gauges in the catchment area resulting to challenges with water allocation because some rivers like Chepchoina, Kiptogot, Mubere which are tributaries of Koitobos river have little reserve flow. Thus, water conflicts are being reported daily to water officers. This problem stems from the abuse and poor management of forests and soils, overgrazing, extension of settlements into watershed areas, and unsuitable felling of trees for fuel wood. In an assessment of Land Use and Land Cover Changes in Kenya's Mt. Elgon Forest Ecosystem, Masayi et al., (2021) registered a significant reduction in forest cover since independence from 10% to 1.62 % because of land use change.

Ayuyo & Sweta, (2014) also validated these assertions that when the forest cover is reduced to almost zero there is an increased peak and mean stream flow in the basin, Land cover change analysis show that the agricultural area increased from about 39.6% to 64.3% between 1973 and 2001, while forest area has decreased from 12.3% to 7.0%. Considering the above-mentioned problems, it is therefore imperative to understand the hydrological processes occurring within the watershed. This foregoing shows that, despite efforts to manage the ecosystem, Land Use/Land Cover Changes on surface water acreage in the Koitobos river catchment in Trans Nzoia County are yet to achieve environmental sustainability and thus not been undertaken by other researchers in the study area. The essence of this research was therefore to investigate the implication of Land Use/Land Cover Changes on surface water acreage in the Koitobos river catchment in Trans Nzoia County in Kenya.

### **1.3 Research Objectives**

#### **1.3.1 Overall objective**

The overall objective of the study was to assess the implications of land use, land cover changes on the surface water acreage in Koitobos river catchment of Trans-Nzoia County.

#### **1.3.2 Specific objectives**

The following were the specific objectives of the study:

- i. To assess the extent of land use, land cover change in Koitobos river catchment of Trans Nzoia County Kenya.

- ii. To examine the variations in surface water acreage due to land use land cover changes in Koitobos river catchment of Trans Nzoia County Kenya.
- iii. To evaluate Land use practices for sustainable land and surface water management in Koitobos river catchment.

#### **1.4 Research Questions**

The study was guided by the following research questions.

- i. What are the land use land cover change categories in the study area?
- ii. What variations exist in surface water acreage due to land use land cover changes in the Koitobos river catchment?
- iii. What are the sound land use practices for sustainable surface water management in Koitobos river catchment?

#### **1.5 Justification**

Mt. Elgon and Cherangani ecosystems are both national and international watersheds, (Water Towers Protection 2017- 2018, 4<sup>th</sup> quarter report) which support lives, but few studies regarding them have been done especially with respect to land use, land cover changes and its implication on productive agricultural practices. Furthermore, Koitobos River, a major tributary of River Nzoia has had no research and yet it provides discharge volumes that fill the Victoria Basin, which in turn develops River Nile and hence the Mediterranean Sea. Unsustainable farming and land use practices have led to very poor ecosystem management accelerating surface runoff within the Koitobos river catchment.

Significantly, the study will add value to the existing knowledge capacity enhancement in integrated and sustainable approaches in managing water resources through sustainable land use

practices. It also will enable experts to come up with sustainable systems in managing land and water resources. The results will enhance strengthening of the water resource users for proper water management. Further, the successful completion of the study will make use of land cover and climate change scenarios for the future to determine the potential effects these will have on the catchment and hydrologic process. This would help to evaluate the watershed's water balance, such as runoff rates and volumes, and the implications of any environmental changes on the watershed. The study evidence will aid decision makers, both water and land users, to optimize water supply and demand, and to advocate for sound land use practices, while ensuring environmental sustainability. It will be significant to researchers, development partners, agencies, and policy makers in disaster preparedness and engineering management for emergency responses and food security. Data consistency and availability for selected years in the study period may result in narrowing to some few years that gives the right analytical picture.

### **1.6 Scope of the study.**

The study was conducted in Trans Nzoia County within the upper Nzoia basin covering the Koitobos river catchment area in Kwanza Subcounty and stretching to partly Endebess Sub-County along the Mt. Elgon forests and Water tower. The study covered the period from 1992 when the land settlement scheme program had fully taken off to the year 2022 for significant alterations in land use and land cover change. The study targeted a population of households within river Koitobos catchment, and its river valley, KNBS, (2019) for Kwanza sub-county, Trans-Nzoia, involving officials from non-governmental organizations together with the community and faith-based organizations in the region, and relevant government (state)

ministries such KFS, KWS, Environment water and natural resources, Ministry of Agriculture, Ministry of Roads, Ministry of Urban planning.

The area of study covered majorly the catchments within the Kwanza Sub-County of which its population largely depend on the Koitobos river water resource for domestic and farming activities. The study mainly focused on land use, land cover changes with its impacts on surface water acreages in the Koitobos river catchment, and how continually the resources can be managed through sustainable land use practices. The unit of analysis was based on the household heads and other farming community members within the catchment of Koitobos river in Kwanza Sub County, Trans-Nzoia County.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

In this chapter, literature on other scholarly works were reviewed for purposes of this study. Literature gaps on water discharge variations identified, the theoretical background and theoretical framework sections introduced key theories that underpin this research and the empirical review highlighting the past studies on the variables of the study. The chapter also includes a section on the conceptual framework and critical review of the study.

#### **2.2 Land use, land cover changes in Koitobos river catchment of Trans Nzoia County Kenya.**

##### **2.2.1 Deforestation**

The land cover classes of dense forest and barren were found to be constantly decreasing, while the land cover class of open forest was found to be constantly increasing, according to a study of land use and land cover changes in the Harenna forest and adjacent area, Bale Mountains National Park, Oromia National Regional State. The change in dense forest was because of crop production, logging, grazing, and coffee production activities, which decreased the forest density. Logging, resulting from selective cutting of suitable forest trees for timber production, decreases forest density, Morie, et al., (2007). In the case of coffee production, there was intensive thinning of forest canopy to optimize the shading. In addition, there were livestock that used to graze the area, causing damage to vegetation under the forest. These practices, apart from change in density, had great impact on biodiversity and the wildlife habitat through changing

forest cover resulting to the decrease in bare land due to conversion into agricultural and shrub land.

A study to assess the impact of land cover change in Kenya using remote sensing and hydrologic modeling on upper Njoro watershed over several decades in 1986, 1989, 2000, and 2003 which after successful simulation in this environment with land cover change analysis showed a significant loss in upland forests, primarily due to the removal of plantation forests and in addition, a large increase in small-scale agriculture, Tracy, et al., (2014).

Deforestation and cultivation alter the soil hydrological conditions on steep slopes, rendering them susceptible to saturation, Mugagga, et al., (2010). This may trigger debris flows during rainfall events. There is a need to restore forest cover on the fragile steep slopes and restrain local communities from opening new areas for cultivation on critical slopes, particularly within the protected area.

A study on the Impact of Land Use /Cover dynamics on Streamflow: A Case of Nzoia River Catchment, Kenya. The Nzoia system has its sources in the forested highlands (Mt. Elgon, Cherangani Hills, Nandi Hills and Kakamega forest). Focusing on simulating streamflow changes because of the land use/cover status as of 1973, 1986 and 2000, Odira, et al., (2010).

The runoff response because of the observed land use/cover change was tested by keeping constant all input datasets in a Soil and Water Assessment Tool (SWAT) model and varying the land use showed that with the expansion of the area under agriculture, the stream flow increases during the rainy seasons and reduce during the dry seasons, whereas when the area under forest cover is increased, the peak stream flow reduces, Odira, et al., (2010). However, when the forest cover is reduced to almost zero there was an increased peak and mean stream flow in the basin.

The annual rate of decrease from 1972 to 2004 in forest, wetland and marshy land were 91.22, 27.56 and 39.52 ha/year, respectively, Mukunda, et al., (2012).

According to the ministry of forestry and wildlife reports on the analysis of drivers and underlying causes of forest cover change in various forest type of Kenya released in 2013, it was evident that since 1990, the forest cover has reduced from 3,708,000 hectares to 3,467,000 hectares by 2010. Based on the related reports, it is expected that the forest cover will be lower in the next five years. Mango, et al., (2011) conducted a study in Kenya aimed at establishing the land use and climate impacts on the hydrology of the upper Mara River basin and in their study, they established that between 1990 and 2010, in east Africa, 13 million hectares of forestland was converted to agricultural land after population increased in the same period. Relative to Twesingye's, et al., (2011), Mango, et al., (2011) also suffers the same research gap of evaluating to predict land use land cover changes in the Koitobos river catchment to provide mitigation measures to the expected changes.

Kwawaldah, (2016) used the Ca-Markov model to evaluate land use land cover change by using two, land use land cover of 1999 and 2014 obtained from satellite images. In this study it was established that barren, rangeland, and agricultural land would undergo more changes, which would in turn change the land cover and hence the water volumes in water channel. Kumar et al, (2015) corroborated these findings after conducting a study aimed at predicting future land use land cover changes of Vijayawada city using Remote Sensing and GIS and predicted that by 2040, there will be a 28.42% increase in built up areas, decrease by 11.67% in dense vegetation, decrease in open land by 14.31%. The researchers noted that there would be a 50.21% increase in built up areas, most of which will be expansion into forests and protected land.

Katana, et al., (2013) undertook a study on Athi River, Kenya with an aim of detecting and predicting land use land, cover changes in the upper river valley using Cellular Automat-Markov Model. The prediction was made between 2010-2030 based on the 1984-2010 trends. In their findings, the researchers detected that agricultural and urban land increased by 8.67% and 23.70% respectively. On the other hand, open/closed woody vegetation, forests, and rangeland decreased by 9.98%, 2.52%, and 19.88% respectively. The evaluations made between 2010-2030 indicate that agricultural and built-up lands will increase by 5.61% and 7.66% respectively, while rangelands, woody vegetation, forests will decrease by 6.42%, 6.62% and 0.22% respectively. In conclusion, Katana, et al., (2013) stated that in the future agricultural expansion, urban sprawl and related development will account for most of the land use, land cover changes.

The study by Katana, et al., (2013) did not consider the surface water because of land use land cover changes, which this study seeks to establish. Furthermore, only one model, Cellular Automat-Markov Model was used while in this study, Google Earth Engine (GEE), technology will be used in establishing the extent of land use land cover changes and planning for sustainable use for the coming generations.

### **2.2.2 Farming activities**

Land cover change analysis has shown that the agricultural area has increased from about 39.6 to 64.3% between 1973 and 2001, in the upper river Nzoia Basin, while forest area has decreased from 12.3 to 7.0%. Results from the calibrated model showed that generally, runoff was highest from agricultural lands, followed by shrubland, grasslands, and forest. The study found that land cover changes would explain a variation in runoff of around 55-68% in the absence of climate change. In contrast, a 30- 41% variation in runoff was explained by climatic change alone,

unaffected by changes in land cover. According to Githui et al., (2009), changes in land cover have had a more significant impact on runoff than climate change. The annual rate of increase from 1972 to 2004 in agricultural land and settlements was 181.96, 9.89 ha/year, respectively, Mukunda, et al., (2012).

A study conducted in Ethiopia examined the changes in land use and land cover, as well as the effects of *Jatropha* on soil fertility. The study found that throughout the specified years, there was an increase in agricultural land, bare ground, and built-up land cover. This rise came at the expense of bush and shrub land, as well as degraded bushy grass field. Ayele, et al., (2011). Additionally, it was demonstrated that farming operations provide the primary means of subsistence, but their lack of efficient control methods also makes them the primary cause of watershed degradation. To address degradation in catchment areas, it is important to implement measures that involve active participation in planning and management. This should include improved coordination, the promotion of alternative livelihoods, and a thorough review of policies and regulations that may be ineffective. It is also crucial to enforce existing legal and policy frameworks, adopt an ecosystem-based approach to catchment conservation, and establish a national coordinating body within the decentralized governance system of the country, Sakataka, et al., (2012).

### **2.2.3 Settlement and Urbanization**

A study on Evaluating change detection techniques for monitoring land-cover changes established that the area of soil cover decreased from 51.95 km<sup>2</sup> in 1990 to 32.24 km<sup>2</sup> in 2000, due to the urban growth from 0.68 km<sup>2</sup> in 1990 to 9.50 km<sup>2</sup> in 2000 and land reclamation (vegetation growth) from 0.59 km<sup>2</sup> in 1990 to 11.48 km<sup>2</sup> in 2000, Hafez et al., (2011).

According to research on land use land cover change detection using remote sensing data and GIS tools, the Northwest district saw a comparatively large rise in both population and built-up area, Rajender et al., (2011). Buildings and roads ate away almost 10,000 hectares of farmland in Delhi over the course of 19 years, increasing the city's built-up area to 18%. Up to 1987, these farmlands were mainly located in Delhi's northwest and western parts. Urbanization also resulted in the loss of forest areas. During the study period, Rajender et al., (2011), recorded the loss of almost 11,000 hectares of forest area, including both open and deep forest. A study that utilized satellite-derived maps to examine watershed dynamics and land use/cover patterns from 1972, 1990, 1999, and 2005 found that residential/industrial development, settlement proximity, and other biophysical and socio-economic drivers had an impact on the watershed's land use/cover patterns, causing agricultural and settlement areas to expand linearly.

In contrast, eucalyptus tree plantations, annual crops and bare land/open grassland cover increased at a rate of 2.8, 12.5 and 24.8 ha per year, respectively. Correspondingly, bare land/open grassland increased by 344.5% at the expense of shrinking shrub grasslands and expanded into uninhabited areas, Ayele, et al., (2011).

Based on the statistics released by the Kenya National Bureau of Statistics, KNBS, (2019), it is expected that by the year 2030, Kenya will have surpassed the 50 million marks as the total number of persons. By the same period, it is expected that the population within major cities will have doubled, and this means cities will grow inwards (intensification) and outwards (sprawl). Both forms of growth will alter land use and land cover because of industrialization, increased pollution, and increased demand for food production, which will give rise to expansion of human activities to natural vegetation such as forests and other protected lands.

Maitima, et al., (2010); and Morie, et al., (2007), in their study on expansion of agricultural land and grazing of animals estimated that if the culture of expanding agricultural land and pasture for animals continues, then most countries especially developing economies will not achieve sustainable development goals.

Mango et al., (2011), conducted a study in Kenya aimed at establishing the land use and climate impacts on the hydrology of the upper Mara River basin and in their study, they established that between 1990 and 2010, in east Africa, 13 million hectares of forestland was converted to agricultural land after population increased in the same period. In this study it was established that barren, rangeland, and agricultural land would undergo more changes, which would in turn change the land cover and hence the water volumes in water channel. Kumar, et al., (2015), corroborated these findings after conducting a study aimed at predicting future land use land cover changes of Vijayawada city using Remote Sensing and GIS and predicted that by 2040, there will be a 28.42% increase in built up areas, decrease by 11.67% in dense vegetation, decrease in open land by 14.31%. The researchers noted that there would be a 50.21% increase in built up areas, most of which will be expansion into forests and protected land.

#### **2.2.4 Population growth**

The main reasons for the changes in land use and land cover can be attributed to the following: rising population pressure and all the problems that come with it, including a lack of land tenure security and inadequate infrastructure development, as well as unfavourable government policies. Ayalew, et al., (2008). In the Blue Nile and A wash basins of Ethiopia, Kuhar Michael and Lenche Dima conducted a comparative study on land use and land cover change, drivers, and impact. They found that although there were sporadic variations in the amount of land

changed, the overall rate of change over the entire analysis period (1972–2005) was found to be 0.8% per year, which led to a net increase in land use and land cover change, Oumer, et al., (2009).

A study on livelihood activities and wetland conservation in the upper Nzoia river basin, western where results showed that population pressure and consequent intense and widespread land cultivation has led to changes in the biophysical features such as land fragmentation, narrowed river channels depletion of vegetation cover and deterioration in water quality and quantity, Sakataka, et al., (2012). The extension of agriculture around the world is being propelled by rising populations and the rising need for agricultural output. The loss of biodiversity, land degradation, and overexploitation of delicate ecosystems are all consequences of these expansions. Kipkulei et al., (2022), set out to determine what variables in Kenya's Trans Nzoia County are responsible for land use/land cover changes (LULCCs) and the subsequent growth of farmland.

According to the National Population Census reports of 2009, released by the Kenya National Bureau of Statistics, Kenya had a population of 37.71 million people. After 10 years, Kenya's population increased to 47.6 million, Kenya National Bureau of Statistics, (2019). From the outlook, it is projected that come 10 years, the Kenya's population is projected to be at 57.5 million (2029). By the same period, it is expected that the population within major cities will have doubled, and this means cities will grow inwards (intensification) and outwards (sprawl). Both forms of growth will alter land use and land cover because of industrialization, increased pollution, and increased demand for food production, which will give rise to expansion of human activities to natural vegetation such as forests and other protected lands.

It should be noted that Agriculture supports 70% of livelihoods of Kenyans, while manufacturing and service sectors accounts for the remaining percentages. Even though Kenya is not an industrialized country, impacts of industrialization emanating from human activities pose a great threat to natural resources and organic habitats.

According to research by Kipkulei et al., (2022), on the topic of cropland expansion and its drivers in Trans Nzoia County, Kenya, the world's population is rising, and with it, the demand for agricultural production. As a result, land is being expanded all over the place. The loss of biodiversity, land degradation, and overexploitation of delicate ecosystems are all consequences of these expansions. Using Landsat data to define the temporal land use/land cover changes (LULCCs) over a 30-year period and to estimate cropland expansions using change detection, this study set out to uncover the reasons driving these changes and the subsequent expansion of farmland in Kenya's Trans Nzoia County.

### **2.3 Surface water acreage variations due to land use land cover changes.**

Surface water is the volume of water flowing through a river channel. This is the total volume of water flowing through a channel at any given point and is measured in cubic meters per second (cumecs). The surface water from a drainage basin depends on precipitation, evapotranspiration, and storage factors.

The surface water, according to Mubea, et al., (2010), changes with the alteration in seasons and land cover. Climatic changes and increased human activities along a river channel and around a catchment area determine the river surface water per given time. In their works that purposed to determine the long-term hydrological influence of Land use, land cover change in the Little

River watershed in Tennessee, Mubea, et al., (2010), used SWAT to simulate water discharge volumes in watersheds in national parks and in stream flow surrounding urban areas. There was no stream flow increase in watersheds found in national parks because land use land cover changes were minimal. On the other hand, there was a more than 10% increase in stream flow surrounding urban areas. In urban areas, surface water had 34.6% decline in sediments and 10% decrease in nutrients from 1984 to 2010.

This study by the researcher, on assessing land use/ land cover change, seeks to not only consider the implications of land use, land cover changes on surface water acreage, but will also establish the extent to which these changes affect the environment. Furthermore, this study will evaluate surface water variations in relation to land use, land cover changes for a given period.

Olang and Furst., (2011), in their work on that purposed to determine the influence of land cover change on flood peak surface water, and runoff volumes in the Nyando River basin in Kenya, established for surface run-off that, in the 14 sub-catchments, in the upper river level where deforestation was high, surface water volumes increase between 30-47% during peak discharge time. In the entire study period, other surface water volumes increased by 16% to 10% because of the low extent or low rate of land use, land cover changes. Although the study by Zhu and Li (2014) established the connection between land use land cover changes, it failed to establish the extent of land use land cover changes implications on surface water, as this study will.

### **2.3.1 Precipitation influence on surface water variation**

The hydrological cycle and its processes are essential to the provision of livelihoods of organisms. Freshwater, estuarine ecosystems and human beings depend on water resources; however, intense pressure on land use and climatic change affect water channels, Jiongxin Xu,

(2013). Dominant factors including temperature, precipitation, and agricultural activities have contributed immensely towards affecting the surrounding rivers and stream water, and quality. Most importantly, land use, which changes land cover, contributes greatly towards influencing water volumes variations in water sources and channels, Matshakeni, (2016).

Water quantity has drastically dropped or decreased most gauges in the catchment area resulting to challenges with water allocation because some rivers like Muberi, and Kaibei which originate from North-Western slopes of Mt. Elgon and Sikubu and Chemususu tributaries in the middle and lower reaches draining the wetland areas in the Koitobos river catchment with little reserve flows bringing up water conflicts being reported daily to water officers. This problem stems from the abuse and unsustainable management of forests and soils, overgrazing, extension of settlements into watershed areas, and unsuitable felling of trees for fuel wood. In an assessment of Land Use and Land Cover Changes in Kenya's Mt. Elgon Forest Ecosystem, Masayi, et al., (2021), registered a significant reduction in forest cover since independence from 10% to 1.62 % because of land use change. Ayuyo, et al., (2014), also validated these assertions that when the forest cover is reduced to almost zero there is an increased peak and mean surface water /stream flow in the basin.

Precipitation is a primary factor that influences surface water levels. When it rains, the water that falls on the land surface can either infiltrate into the ground or flow over the surface into rivers and streams. The amount of rainfall and its intensity can significantly affect the volume of water that reaches the river. For instance, heavy rainfall can cause a rapid increase in surface water levels to decrease significantly, Renatus, et al., (2023).

### **2.3.2 Human activities influence surface water variations.**

Numerous studies have been conducted to establish a relationship between human activities, climatic changes, and natural factors and water channel volumes, but limited studies have been published regarding land use, land cover changes in relation to surface water volume variations. It should be noted that surface water variations might not be recognized within a season, it takes time for researchers to record changes in water volumes on a river or lake basin, Zhang, et al., (2014).

These changes reflect an increased risk for decreased water quality, reduction in groundwater recharge and subsequent decline in the aquifer, as well as related impacts to the local ecology Tracy, et al., (2014). Land cover change analysis in Tanzania, showed that the agricultural area had increased from about 39.6 to 64.3% between 1973 and 2001, while forest area decreased from 12.3 to 7.0%. Results from the calibrated model showed that generally, runoff was highest from agricultural lands, followed by shrubland, grasslands, and forest.

The study on land use, in the upper Nzoia basin, found that land cover changes would explain a variation in runoff of around 55-68% with the absence of climate change. In contrast, a 30- 41% variation in runoff was explained by climatic change alone, unaffected by changes in land cover. This demonstrates that changes in land cover have had a more significant impact on runoff than climatic changes, Githui, et al., (2009). The most common types of surface water pollution are agriculture, sewage, and wastewater (including stormwater runoff), oil pollution and radioactive substances. The agricultural sector consumes a lot of fresh water and is the leading source for water degradation. Gutters and drains quickly transfer water to rivers, leading to a rapid increase

in surface water. Due to more water entering the river channel in a shorter period, the river has more energy increasing the amount of erosion and transportation.

The runoff response because of the observed land use/cover change was tested by keeping constant all input datasets in a SWAT model and varying the land use showed that with the expansion of the area under agriculture, the stream flow increases during the rainy seasons and reduce during the dry seasons, whereas when the area under forest cover is increased, the peak stream flow reduces. However, when the forest cover is reduced to almost zero there was an increased peak and mean stream flow in the basin, Odira, et al., (2010).

In reference from the Agricultural Water Policy review 2018, arable land uses 76% of water from all water resources but the water volumes are constantly reducing in rivers due to land use and land cover change activities. Mt. Elgon and Cherangani ecosystems are both national and international watersheds, which support economic and ecological sectors, yet they are seriously degraded due to land use change from forest to agriculture resulting to decreased surface water.

Land use, channelization, and dams can have a tremendous effect on water velocity and volume. However, in an urban setting, vegetation is usually converted to streets, parking lots, and concrete. This type of stream is referred to as “flashy” because water enters and exits the stream much faster than streams in more vegetated areas. Additionally, the land use around it, is mostly agricultural, so runoff from cleared, non-forested land is higher and contributes to a higher surface water.

### **2.3.3 Natural activities influence surface water variations.**

Guzha, et al., (2018) found that land use change has a significant impact on various land surface features and processes, including leaf area, roughness, albedo, soil moisture, energy, and water vapor exchange rates. Land use changes such as urbanization, deforestation, and reforestation continue to have an impact on groundwater-surface water interactions, including percolation or recharge, groundwater contributions to streams, soil moisture, and water availability, all of which influence ecosystem services.

The temperature of water indeed impacts its flow rate, although the specific effect depends on various factors. In general, as the temperature of water increases, its viscosity decreases, resulting in a lower resistance to flow, Skyla, et al., (2013). This lower viscosity can lead to an increase in the water flow rate. Vegetation absorbs water and releases it to the atmosphere through evapotranspiration and increases the water storage capacity of soil, making it like a sponge. This allows the soil to store water during dry periods and will increase your flow. Vegetation also adds surface roughness to the stream channel, streambanks, and flood plain, which will slow down the stream discharge. Removing vegetation from the land or replacing it with concrete removes that surface roughness and the absorption of water into the soil, allowing a dramatic increase in discharge in a short period of time.

## **2.4 Evaluation of Land use practices for Sustainable land and surface water management in Koitobos river catchment.**

### **2.4.1. Sustainable land Management Practices (SLMs)**

Sustainable land management (SLM) comprises measures and practices adapted to biophysical and socio-economic conditions aimed at the protection, conservation and sustainable use of resources (soil, water and biodiversity) and the restoration of degraded natural resources and their ecosystem functions. Land resource planning – the systematic assessment of land potential – is needed to help land users select, adapt and put SLM options (biological, agronomic and structural) into practice in an integrated way in each farm or wider landscape with the aim of maintaining productivity and restoring degraded land.

The selection of appropriate SLM practices and approaches is an important step in ensuring the effectiveness of land management and restoration. SLM has central roles in Ecosystem Restoration ecosystems, through combating land degradation while generating multiple co-benefits including climate change mitigation, resilience, improved biodiversity and enhanced production. In terms of land degradation neutrality –WOCAT (2021), a central component of ecosystem restoration – SLM works to avoid, reduce and reverse land degradation.

SLM includes practices to prevent land conversion and protect vulnerable lands, prevent and mitigate land degradation and restore degraded soils, control soil erosion, improve soil-water storage, manage soil organic matter for soil carbon sequestration, manage and enhance soil fertility, promote integrated soil–crop–water management and integrated agroforestry and agro-silvopastoral systems, improve crop–water productivity and manage soil salinity in irrigated

dryland agriculture. "Restoring Life to the Land – The Role of Sustainable Land Management in Ecosystem Restoration" prepared jointly by UNCCD Secretariat and WOCAT, 2021.

SLM technologies are physical practices on the land that control land degradation and enhance productivity. SLM practices not only help to restore soil fertility and conserve moisture, Murphy, et.al., (2018), but are also critical in climate change mitigation and adaptation, Branca, et al., (2013), and food security enhancement. Sustainable rural development should therefore be about the enhancement of rural livelihoods through the protection and enhancement of livelihood systems and assets, promoting and securing access to these assets, and promoting diversification on the use of these assets. SLM should address sustainable development through the protection, enhancement and use of natural assets, thus breaking the vicious cycle of land degradation and poverty.

Sustainable land management is the use of land resources such as soils, water, animals and plants to produce goods to meet changing human needs while assuring the long-term productive potential of these resources, and the maintenance of their environmental functions. Sustainable land management also entails the foundation of sustainable agriculture, and a strategic component of sustainable development and poverty alleviation and seeks to harmonize the often-conflicting objectives of intensifying economic and social development, while maintaining and enhancing the ecological and global life support functions of land resources, Mwangi, (2007).

Land-use and land-cover change, as one of the main driving forces of global environmental change, is central to the sustainable development debate. It has impacts on a wide range of environmental and landscape attributes, such as the quality of water, land and air resources, ecosystem processes and function, and the climate system itself through greenhouse gas fluxes.

Moreover land-use change has important implications on sustainable livelihood of local communities, Kaimowitz & Angelsen., (1998). However, knowledge of recent changes in land use, driving forces and implications of changes within the context of sustainable development is limited, Lambin et al., (1997).

In Kenya, farmers, especially those living in marginal environments and in areas with low agricultural productivity, depend directly on genetic, species and ecosystem diversity to support their way of life. As a result of this dependency, any impact that climate change has on natural systems will threaten their livelihoods, food intake and health. There are six situations, which make Kenya particularly vulnerable to climate change: surface water resources, especially in international shared basins where; there is a potential for conflict and a need for regional co-ordination in water management; food security, at risk from declines in agricultural production; natural resources productivity and intensified land use, SRA, (2006).

Climate change may offer new opportunities for sustainable land management by enhancing rainfall or growing periods in some places or through creating markets that might pay farmers for improved sustainable land management practices, Gautam., (2006). Sustainable land management can also reduce vulnerability to climate change and increase people's ability to adapt and in many cases can contribute to climate change mitigation through improved carbon sequestration and reduced greenhouse gas emissions, Cline, (2007); Pender, (2008).

Land degradation leads to a steady shrinking of the natural assets and ability of the land to provide goods and services for human welfare. The assets that get depleted include clean water, arable land, fuel wood, and timber, biodiversity for various uses including herbal medicine, fisheries and grazing resources. Decrease in ability to provide environmental services is

manifested in silted lakes and rivers, dry catchments areas, polluted air, climate change leading to longer and more frequent droughts, WRI et al, (2007).

Often this environmental entitlement loss occurs needlessly, because planners of irrigation projects fail to consider the potential impacts of upstream water diversion on downstream users of water and land, Barbier et al., (2007).

The important proximate causes of land degradation have been cited as; Conversion of forests, woodlands, and bush lands which are ill-suited to permanent agriculture; Overgrazing of rangelands; Excessive exploitation of natural habitats (e.g. harvesting for fuel wood in woodlands); and unsustainable agricultural practices (e.g., farming on steep slopes without sufficient use of soil and water conservation measures, excessive tillage, declining use of fallow without application of soil nutrients, Pender., (2008).

## **2.5. Environmental policies in relation to Land Use Land Cover Change (LULCC).**

Environmental policies and laws in a country determine the extent to which land use around a catchment area and/or along the banks of a water channel, influence land cover. Increase in population calls for an increase in food production in an environment where arable land cannot be expanded.

### **2.5.1 The Environmental Management and Co-ordination Act (EMCA, 2019)**

This legislation establishes criteria for promoting environmentally sustainable development and mandates the inclusion of Participatory National Environment Plans in development planning. These plans must incorporate sectoral coordination and connections, as well as measures for environmental conservation. Furthermore, it is necessary to conduct an environmental impact

assessment for any development initiatives that have the potential to cause adverse environmental effects. The Act mandates the conduct of annual environmental audits with explicit mitigation measures for comprehensive projects, Kimani & Musungu, (2010). To broadly oversee the environment, the Act establishes two administrative entities: the National Environment Council (NEC) and the National Environment Management Authority (NEMA). NEC is responsible for developing policies, establishing national objectives, and fostering collaboration among stakeholders. On the other hand, NEMA's mission is to oversee and coordinate all things pertaining to the environment. It is important to observe that the Act establishes NEMA (Section 7) as the organization responsible for carrying out the requirements of the Act. The Environmental Impact Assessment and Audit Regulations, (2003), require lead agencies to conduct Strategic Environmental Assessments (SEA) on all public policies, plans, and programs (PPPP). During the Strategic Environmental Assessment (SEA) process, the potential significant impacts of a Public-Private Partnership Project (PPPP) on the environment are identified, described, assessed, and documented. All possible consequences and affects, including secondary, cumulative, synergistic, short-term, medium-term, long-term, permanent, and/or temporary impacts, should be thoroughly examined.

### **2.5.2 The Forest Act, Cap 385 of 2023**

This statute has relevance to the planning and construction industry and the legislation facilitating the creation, management, and oversight of forests in Kenya. It promotes the preservation of many forms of plant life, so making a significant contribution to the increase of green spaces in urban settings, Kimani & Musungu, (2010). The Forest Act applies to designated forest areas known as Forest Reserves. It specifically addresses the processes of gazettelement, boundary changes, and de-gazettelement of Forest Reserves (Section 4). Additionally, it includes

provisions for the establishment of Nature Reserves within Forest Reserves and the regulation of activities within these Nature Reserves (Section 5). Although these measures exist, it is important to highlight that the designation of areas as protected forests is under the jurisdiction of the Physical Planning Act Cap 286, which governs land use planning. This may lead to a disagreement on the hierarchy of laws.

In addition, the Act grants local authorities and the state the authority to govern the development and utilization of property, including private property, for the benefit of the community or country. On the other hand, land use planning offers a framework for combining various land uses to promote the well-being of a wide range of areas, particularly in ecologically significant regions with differing property rights systems. Forest management has an impact on the changes in land use and land cover within catchments. The demand to develop urban areas puts pressure on forests, although efforts are made to ensure that resources are maintained in a sustainable manner.

Nevertheless, the enlargement of the developed regions that would encroach upon any officially designated forest would need following the degazettement procedures outlined in the Forests Act. In addition to state woods, the Act grants forest officers the right to make arrests in local authority forests and provisional forests. The Act grants forest officials the authority to prosecute individuals to effectively safeguard forests and prevent unauthorized encroachment. In addition, the new Act has increased the severity of sanctions to enhance deterrence.

### **2.5.3 National Land Commission Act, 2022**

The National Land Commission Act, 2019, enacts the creation of the National Land Commission as the primary overseer of public land. The Act additionally requires the Commission to establish County Land Management Boards (CLMBs) with the objective of overseeing the management of

public land at the county level. As to the January 2022, status report from the National Land Commission (NLC), the Commission has implemented actions and strategies to prevent the unauthorized occupation and sale of public land owned by the county and national governments. NLC has taken steps to reclaim unlawfully occupied public land by providing legal assistance to resident associations in their lawsuits against private developers. The NLC (2022), instructed and informed the Counties to promptly reclaim lands with encroachments by completing their inventories. Since most of the infill construction that impacts the city's environment occurs on encroached land, the NLC's move will provide planning authorities in the impacted regions with an opportunity to conduct appropriateness studies for the development of those spaces.

#### **2.5.4 Physical and Land Use Planning Act, Cap 286, 2019.**

The Physical Planning Act, Cap 286 confers explicit authority over development control issues in metropolitan areas. The provision allows for the development of national, regional, and local standards, policies, and strategies for physical planning, Kimani and Musungu, (2010). The physical planning legislation enables the creation and execution of physical development plans and related objectives. The Act grants Local Authorities the authority to regulate and restrict the use and development of land and buildings in a systematic manner. This includes controlling the division of land, reviewing, and approving development proposals, ensuring the proper execution of approved physical development plans, and creating by-laws to regulate zoning and preserve open spaces, parks, urban forests, and green belts in accordance with the approved plans, Kimani and Musungu, (2010).

## **2.6 Theories of Land Use Land Cover Change (LULC)**

### **2.6.1 Defining land, land cover, and land use.**

The meaning and characteristics of land, land cover, and land use can differ depending on the specific purpose and context in which they are being discussed. These concepts are strongly connected to each other. This analysis utilized the Theory that defines Land as a distinguishable portion of the Earth's terrestrial surface that includes all aspects of the biosphere directly above and below this surface, European Commission, (2001). It includes the temperature, soil, topography, surface hydrology, and human settlement patterns and physical outcomes of human activities that are close to the Earth's surface. Land can be categorized into two domains: land in its pristine state and land that has been altered by humans to serve a specific purpose or a variety of purposes. The idea of land encompasses a range of functions, including environmental, economic, and social aspects, as described by Hubacek et al. (2002). Land serves multiple crucial functions in relation to environmental challenges, including acting as a medium for soil, a natural filtration system for clean water, and a habitat for diverse wildlife and plant species. Furthermore, land serves as a connection between climate, hydrological, and atmospheric systems. In terms of economics, land is responsible for the allocation of production activities, infrastructure, housing, and capital assets. Landowners possess social significance on a societal level. Hubacek, et al., (2002) state that land is one of the three classic production inputs. Although the phrases land cover and land use are commonly used interchangeably, they do not have the same meaning. Lambin et al. (2006) and Ellis et al., (2010), provide a definition of land cover as the characteristics of the land surface and the layer just below it. This includes the physical and biological elements that cover the earth's surface, such as water, vegetation, bare soil, and artificial structures. Alternatively, Lambin, et al., (2006) provides a more inclusive

definition of land use, which pertains to the planned utilization or control of the land cover type by humans.

- i. Land cover classification, as specified by the European Commission in 2001, is the procedure of categorizing land cover and land use classes using clearly defined diagnostic criteria. A classification is a systematic framework that included the names of classes, the criteria used to differentiate them, and the interrelationships between the classes. The information was obtained either through ground surveys or by Remote Sensing (RS). The creation of a land use categorization can be approached in two main ways: the functional approach and the sequential approach. These approaches can be defined as follows: The functional approach involves describing land based on its socioeconomic purpose and can be applied to various land use objectives, including agriculture, forestry, and settlement. Functional land uses can be implemented either at a certain moment or within a brief timeframe.
- ii. The sequential technique, often known as the sequence of operations approach, was originally developed for the purpose of categorizing agricultural land. Land use is defined as a sequence of human activities aimed at obtaining products and/or advantages from land resources. It necessitates prolonged observation.

### **2.6.2 Theories of Land use/ land cover change**

Several theories of land use change aim to elucidate the patterns and dynamics of transitioning from one land use type to another. These ideas seek to provide insights into the underlying causes and mechanisms driving these transitions. The causality and purpose behind land use change are intricately linked, however current models often fail to consider both aspects

simultaneously. Most theories regarding land use change are situated within the broader theoretical framework of the economic discipline, as well as environmental and spatial changes.

Land use change theories can be categorized into three primary classifications.

- the urban and regional economic theories,
- the sociological (political economy) theories,
- Nature-society (human-nature) theories, which address mainly the human role in causing global environmental change.

According to Lepers et al. (2005), most of the literature on land cover change (LCS) focuses on human conversion of natural land to human use or changes in management practices of ecosystems dominated by humans. However, Reenberg et al., (2007) and Afify et al., (2011) argue that LULC change is now an important part of strategies for managing resources and tracking environmental changes.

### **2.6.2.1 Theoretical Review - Land Use Change Processes**

Theories of land use change processes include land use spillovers, such as land sparing and rebound effects, and land use transitions, such as forest transitions. Middle-range theories are contextual generalizations that describe causal mechanisms and the conditions that trigger them. These theories can help build generalized knowledge of land systems and support sustainable social-ecological systems. Land use economics is a field that studies the relationship between land use, transportation, and economic activities in urban areas. It analyzes how households, developers, and landlords make decisions based on economic principles, Tekola et al., (2012). Land-use change models are tools to support analyses, assessments, and policy decisions concerning the causes and consequences of land-use dynamics; by providing a framework for the

analysis of land-use change processes and making projections for the future land-use/cover patterns and these are in line with the study undertaken on land use /land cover changes in Koitobos River catchment.

The land cover classes of dense forest and barren were found to be constantly decreasing, while the land cover class of open forest was found to be constantly increasing, according to a study of land use and land cover changes in the Hareenna forest and adjacent area, Bale Mountains National Park, Oromia National Regional State. The change in dense forest was because of crop production, logging, grazing, and coffee production activities, which decreased the forest density. Logging, resulting from selective cutting of suitable forest trees for timber production, decreases forest density, Cazzolla Gatti et al., (2015). In the case of coffee production, there was intensive thinning of forest canopy to optimize the shading. In addition, there were livestock that used to graze the area, causing damage to vegetation under the forest. These practices, apart from change in density, had great impact on biodiversity and the wildlife habitat through changing forest cover resulting to the decrease in bare land due to conversion into agricultural and shrub land. A study to assess the impact of land cover change in Kenya using remote sensing and hydrologic modeling on upper Njoro watershed over several decades in 1986, 1989, 2000, and 2003 which after successful simulation in this environment with land cover change analysis showed a significant loss in upland forests, primarily due to the removal of plantation forests and in addition, a large increase in small-scale agriculture, Baldyga et al., (2004).

Deforestation and cultivation alter the soil hydrological conditions on steep slopes, rendering them susceptible to saturation, Mugagga et al., (2012). This may trigger debris flows during rainfall events. There is a need to restore forest cover on the fragile steep slopes and restrain local communities from opening new areas for cultivation on critical slopes, particularly within

the protected area. A study conducted by Odira et al., (2010), on the Impact of Land Use /Cover dynamics on Streamflow: A Case of Nzoia River Catchment, Kenya. The Nzoia system has its sources in the forested highlands (Mt. Elgon, Cherangani Hills, Nandi Hills and Kakamega forest).

Land cover change analysis has shown that the agricultural area has increased from about 39.6 to 64.3% between 1973 and 2001, while forest area has decreased from 12.3 to 7.0%. Results from the calibrated model showed that generally, runoff was highest from agricultural lands, followed by shrubland, grasslands, and forest. The study found that land cover changes would explain a variation in runoff of around 55-68% in the absence of climate change. In contrast, a 30- 41% variation in runoff was explained by climatic change alone, unaffected by changes in land cover. According to Githui et al., (2009), changes in land cover have had a more significant impact on runoff than climate change. The annual rate of increase from 1972 to 2004 in agricultural land and settlements was 181.96, 9.89 ha/year, respectively, Behera et al., (2012).

Land degradation, irregular rainfall, soil moisture stress, the rejection of conventional methods for improving soil fertility, and the ineffectiveness of inorganic fertilizers have all worked together to reduce Lenche Dima's crop yields. Furthermore, there has been a reported decline in the number of crop varieties planted from nine to four, which has constrained the output possibilities, Ali., (2009). A study conducted in Ethiopia examined the changes in land use and land cover, as well as the effects of *Jatropha* on soil fertility. The study found that throughout the specified years, there was an increase in agricultural land, bare ground, and built-up land cover. This rise came at the expense of bush and shrub land, as well as degraded bushy grass field, Ayele, (2011). Additionally, it was demonstrated that farming operations provide the primary

means of subsistence, but their lack of efficient control methods also makes them the primary cause of watershed degradation.

To address degradation in catchment areas, it is important to implement measures that involve active participation in planning and management. This should include improved coordination, the promotion of alternative livelihoods, and a thorough review of policies and regulations that may be ineffective, Bass & Mayers, (2013). It is also crucial to enforce existing legal and policy frameworks, adopt an ecosystem-based approach to catchment conservation, and establish a national coordinating body within the decentralized governance system of the country, Roy et al., (2011).

#### **2.6.2.2 Empirical review**

Empirical review is an approach to assessing the evidentiary value of a research area. It involves selecting a cross-section of studies for replication and evaluating their replicability. The goal assesses the extent of land use, land cover change in Koitobos river catchment of Trans Nzoia County Kenya which was to incorporate strength of evidence as researchers refine theories and plan new investigations in the research area. It allowed for integration of qualitative and quantitative approaches to assess and enable planning for environmental sustainability within the catchment. Land use and land cover (LULC) change is a global environmental concern that affects the human survival environment, food safety, and the Earth's water-land-carbon cycle. These theories are in line with the study undertaken especially on settlement and population increase determine the change and transitions in land use, Mubea & Menz., (2012).

A study on Evaluating change detection techniques for monitoring land-cover changes established that the area of soil cover decreased from 51.95 km<sup>2</sup> in 1990 to 32.24 km<sup>2</sup> in 2000, due to the urban growth from 0.68 km<sup>2</sup> in 1990 to 9.50 km<sup>2</sup> in 2000 and land reclamation

(vegetation growth) from 0.59 km<sup>2</sup> in 1990 to 11.48 km<sup>2</sup> in 2000, Afify., (2011). According to research on land use land cover change detection using remote sensing data and GIS tools, the Northwest district saw a comparatively large rise in both population and built-up areas. Buildings and roads ate away almost 10,000 hectares of farmland in Delhi over the course of 19 years, increasing the city's built-up area to 18%. Up to 1987, these farmlands were mainly located in Delhi's northwest and western parts. Urbanization also resulted in the loss of forest areas. During the study period, Marques & Marques., (2020), recorded the loss of almost 11,000 hectares of forest area, including both open and deep forest. A study that utilized satellite-derived maps to examine watershed dynamics and land use/cover patterns from 1972, 1990, 1999, and 2005 found that residential/industrial development, settlement proximity, and other biophysical and socio-economic drivers had an impact on the watershed's land use/cover patterns, causing agricultural and settlement areas to expand linearly. In contrast, eucalyptus tree plantations, annual crops and bare land/open grassland cover increased at a rate of 2.8, 12.5 and 24.8 ha per year, respectively.

Correspondingly, bare land/open grassland increased by 344.5% at the expense of shrinking shrub grasslands and expanded into uninhabited areas, Daniel., (2008). The main reasons for the changes in land use and land cover can be attributed to the following: rising population pressure and all the problems that come with it, including a lack of land tenure security and inadequate infrastructure development, as well as unfavorable government policies, Ayalew et al., (2008). In the Blue Nile and A wash basins of Ethiopia, Kuhar Michael and Lenche Dima conducted a comparative study on land use and land cover change, drivers, and impact. They found that although there were sporadic variations in the amount of land changed, the overall rate of change

over the entire analysis period (1972–2005) was found to be 0.8% per year, which led to a net increase in land use and land cover change, Oumer et al., (2020).

A study on livelihood activities and wetland conservation in the upper Nzoia river basin, western where results showed that population pressure and consequent intense and widespread land cultivation led to changes in the biophysical features such as land fragmentation, narrowed river channels depletion of vegetation cover and deterioration in water quantity, Sakataka & Namisiko, (2014). The extension of agriculture around the world is being propelled by rising populations and the rising need for agricultural output. The loss of biodiversity, land degradation, and overexploitation of delicate ecosystems are all consequences of these expansions, Lal., (2001), set out to determine what variables in Kenya's Trans Nzoia County were responsible for land use/land cover changes (LULCCs) and the subsequent growth of farmland.

## **2.7. The Google Earth Engine (GEE) technique in Land use, land cover change assessment**

GEE - Google Earth Engine (GEE) is a web-based Cloud Computing and geospatial processing platform based on geo-information applications for large-scale geospatial data processing and analysis. This platform provides free access to huge volumes of satellite data for computing and offers support tools to monitor and analyze environmental features on a large scale. Such facilities have been widely used in numerous studies about land management and planning. It allows users to apply image processing and geospatial analysis algorithms using Python and JavaScript to large geospatial datasets stored in the cloud.

The geospatial data available within the GEE platform is remote sensing data collected by satellite sensor systems. The data are organized in collections (catalogues), for different geographical areas, time periods, types of sensors or bands of the electromagnetic spectrum used. It is accessed and controlled through an Internet-accessible application programming interface

(API) and an associated web-based interactive development environment (IDE) that enables rapid prototyping and visualization of results, Gorelick, et al., (2017).

The GEE platform has been vital and helpful in research especially for global forest cover change by a team led by University of Maryland's Matt Hansen (2013), used Earth Engine to survey over a decade of global tree cover extent, loss, and gain. To conduct such extensive analysis, Earth Engine performed computations in parallel across thousands of machines, as well as automatically managed data format conversion, reprojection and resampling, and image-to-pixel metadata association.

The platform has also been used by the European Commission's Joint Research Centre (JRC) (2016), to develop high-resolution maps of global surface water occurrence, change, seasonality, recurrence, and transitions. The study, published in Nature, analyses Landsat images collected over the past three decades to identify both permanent and seasonal water bodies. Understanding these changes was vital for ensuring the security of our global water supply for agriculture, industry, and human consumption; for assessing water-related disaster reduction and recovery.

It was also very useful in global forest watch, which was an initiative of the World Resources Institute, being a dynamic online forest monitoring system designed to enable better management and conservation. Global Forest Watch uses Earth Engine to measure and visualize changes to the world's forests; users can synthesize data from over the past decade or receive alerts about possible new threats in near-real-time. Having been launched in 2014, it's now being used by corporations, non-profits, governments, and indigenous groups for applications as diverse as protecting against illegal logging and ensuring supply chain transparency.

GEE has been used in a wide variety of research areas. In a demonstration study, Padarian, et al., (2015); successfully showed the ability of GEE to generate continuous soil prediction and classification of categorical data at a speed 40 – 100 times faster compared with conventional DSM using a desktop workstation.

Having a huge collection of temporal data and faster computing power makes GEE a powerful tool for analyzing land use land cover change. This was exploited by Nyland, et al., (2018); when they mapped land cover changes in the Lower Yenisei River region. There is hardly any work that has been done using GEE to monitor vegetation changes within rangeland areas globally not to mention Kenya, despite the huge potential. This study will be the first and going to use a similar method used by Huang, et al., (2017), in mapping major land cover dynamics in Beijing.

Google Earth Engine has made it possible for the first time in history to process vast amounts of satellite imagery, identifying where and when tree cover change has occurred rapidly and accurately at high resolution. Global Forest Watch would not exist without it. For those who care about the future of the planet, Google Earth Engine is a great blessing! - Dr. Andrew Steer, President, and CEO of the World Resources Institute

For the analysis of remote sensing information that can be used in water resources management, we have used the Automated Water Extraction Index (AWEI). AWEI is a valuable tool for identifying water bodies in satellite imagery.

The AWEI value is calculated using the following bands:

- BLUE (B2).
- GREEN (B3).
- NIR (B8).

- SWIR1 (B11).
- SWIR2 (B12).

The difference between reflectance in the blue band and reflectance in the green band is used to identify water bodies. Water has a higher reflectance in the blue band than in the green band. Therefore, AWEI values greater than 0, indicate the presence of water.

AWEI - automatic water extraction index in binary mode calculates value 0 or 1 depending on the areas where water is found. In general, the blue and green bands are used to identify water bodies in satellite images because they are sensitive to blue and green light, which are reflected by water in a characteristic way.

NIR stands for near-infrared. It is a region of the electromagnetic spectrum that lies between the visible spectrum and the infrared spectrum. In satellite imagery, NIR is used to identify a variety of features, including vegetation, soil, snow, and water.

SWIR1 and SWIR2 are shortwave infrared (SWIR) bands that are used in satellite imagery to identify a variety of features, including water bodies, vegetation, soil, and snow. The Automatic Water Extraction Index (AWEI) uses the difference between reflectance in the SWIR1 band and reflectance in the SWIR2 band to identify water bodies.

The formula for calculating the AWEI is as follows:

$$AWEI = 4 * (GREEN - SWIR2) - (0.25 * NIR + 2.75 * SWIR1) \dots\dots (1)$$

Where;

AWEI = Automatic Water Extraction Index

SWIR = Shortwave Infrared

NIR = Near-Infrared

## **2.8. Remote sensing (RS) and Geographic information systems (GIS) techniques.**

Analysing a variety of phenomena using technology is the goal of remote sensing (RS) and geographic information systems (GIS) research. The term "remote sensing" refers to the practice of gathering data about the Earth's surface from a distance using a device, usually an airplane or a satellite in orbit, to analyse the collected information. A geographic information system (GIS) is a computer-based tool for collecting, storing, analysing, and displaying geographical data. Natural resource assessments and environmental change monitoring both make heavy use of these two methods, which are frequently employed in tandem. Using geographic information systems (GIS), time series analysis of remote sensing data, and the development of various digital models and analyses, social scientists can better understand the spatial and temporal dynamics of various social phenomena in relation to their environmental contexts. With a focus on remote sensing, this article first surveys GIS in general and then delves into the ways in which the two methods might work in tandem to solve various problems. It goes on to say that social scientists doing ecological and environmental studies can benefit from using remote sensing and GIS.

Remote Sensing allows for the observation and analysis of water bodies, precipitation, and snow cover, offering significant knowledge on hydrological processes. Remote sensing improves water resource management and flood forecasting by detecting changes in water levels and identifying potential flood dangers. Remote sensing has revolutionized the ability to study the Earth by providing many measurements of biological and physical processes. This has great importance for range management, Tueller, (1989). Recently, there have been significant advancements in

data collecting and accessibility, as well as increases in spatial and spectral resolution, and temporal frequency. These advancements allow for better differentiation of various biophysical and physical characteristics.

The ongoing acquisition and application of land remote sensing data provide significant advantages in analysing and comprehending human influences on the environment, managing Earth's resources, performing national security operations, and organizing and executing various scientific, economic, and social activities. Remote sensing is a valuable tool in rangeland management. It can be used to map rangeland fires, assess vegetation health and biomass, calculate rain use efficiency, measure net primary productivity (NPP), evaluate forage availability, and analyse changes in land use and land cover, Reeves et al., (2016). The improvement in remote sensing data and technology has brought about remote sensing “Big Data”. The remote sensing “Big Data” not merely refers to the volume and velocity of data that outstrip storage and computing capacities, but also the variety and complexity of remote sensing data.

There are several aspects and features of the remote sensing “Big Data” that include: the huge volume and rate of remote sensing data, the diversity of remote sensing data and the complexity of remote sensing data especially the higher dimensionality brought about by remote sensing sensors and technologies customized for different earth science disciplines, Ma, et al., (2015). It is almost impossible to handle remote sensing “Big Data” in a common workstation hence the need for a powerful computing tool such as Google Earth Engine.

An Accuracy Assessment was carried out to verify that the results of the categorization matched the actual data. To complete this procedure, reference data was utilized with aerial photographs

obtained and ground truth GPS points randomly collected from the ground, as the study also made use of data from Google Earth, which includes an archive of images spanning the study period. We then calculate the total accuracy, the number of users, and the number of producers for each land use and land cover category identified for the research years (1992 – 2022).

$$K = \frac{n \times x - \sum(U_1 \times P_1) + \dots + (U_n \times P_n)}{n^2 - \sum(U_1 \times P_1) + \dots + (U_n \times P_n)}$$

Where k is the kappa coefficient

n is the total sum of reference points

X is the sum of correctly classified pixels (In the diagonal)

U is the sum of reference point for every class in row

P is the sum of classified points for every class in the column.

With other assessment tools including Confusion matrix, errors of omission and commission.

## 2.9. Conceptual Framework

This is a visual depiction or schematic illustration of the correlation between variables in a research study conducted by Mugenda, et al., (2003). It aids in determining the intended correlation between the variables. Within the conceptual framework, we will examine the independent variables that demonstrate changes in land use, specifically in deforestation and farming activities, as well as the factors that drive these changes. The dependent variables we will consider include variations in the volume of surface water discharge. Additionally, we will explore the relationship with intervening variables, such as government policies.

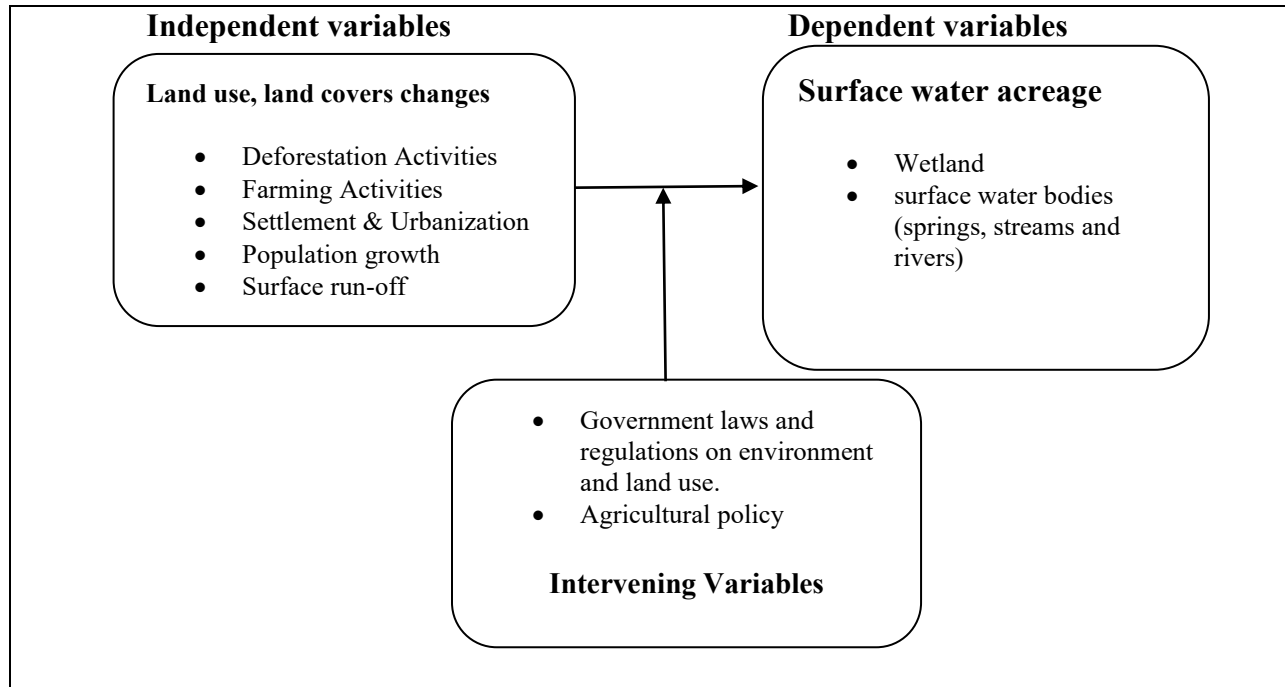


Fig. 2. 1: Conceptual framework of the study

Source: (Researcher, 2024)

## 2.10 Summary of the chapter

A study examining the effects of changes in land use and land cover has demonstrated that activities such as urbanization, deforestation, and reforestation have ongoing impacts on the interactions between groundwater and surface water. These changes affect processes such as percolation, recharge, the contribution of groundwater to streams, soil moisture, and ultimately, the availability of water. These effects, in turn, have implications for ecosystem services, Nejadhashemi., (2009). A separate investigation of changes in land use revealed that the primary trend in the research region between 1995 and 2006 was the conversion of forested areas into agricultural land due to invasion, Mugagga et al., (2010).

A further investigation on the impact of deforestation on water resources revealed that the decline in water quality in the river was a result of the combined effects of human activities in

both the riparian and catchment areas, Masese, et al., (2012). Recurrent interplay between driving forces have led to generalizable patterns of change despite the various causes of land-use change. Although these sequences had varying outcomes in individual circumstances, their recognition provided some prediction capability through comparison with similar paths in comparable regional and historical contexts. The study will investigate the land use, land cover change implications on surface water acreage within the Koitobos river catchment in Trans Nzoia County, Kenya, that has not been considered in the previous studies undertaken.

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.0 Introduction**

This chapter presents the study area and location, study population, research design, methodology, sample size and Sampling strategy, data collection, data analysis and presentation, reliability and validity of data collection instruments, and ethical considerations.

#### **3.1 Description of Study Location**

##### **3.1.1 Location**

The study was undertaken in Trans Nzoia County within the upper Nzoia basin covering the river Koitobos catchment area in Kwanza Subcounty and stretching to partly Endebess Sub-County and along the Mt. Elgon forests and water tower. The Koitobos river catchment is in the western part of Trans-Nzoia County, Kenya between Latitude 1,0'00" to 1,11'00" and Longitudes 34,40'00" and 34,90'00". The elevation of the catchment varies between 1792 m above the mean sea level to 4221 m in the upper parts. With a study population of 203,821 residents.

##### **3.1.2 Farming**

It has rich natural resources such as mixed forests (Eucalyptus, bamboo trees). Maize is recorded as the main crop in the watershed. Other crops include short term cereals (wheat, sorghum and millet), horticultural crops (tomatoes, Irish potatoes, kales, cabbages) and legumes (cowpeas and beans). The upper part of the subbasin covers part of Mt. Elgon National Park which is a protected area for mammals and flora. Trans Nzoia County is considered the food basket of Kenya due to its suitable climate for agriculture.

### **3.1.3 Rainfall**

Koitobos River Catchment (KRC) experiences a bimodal rainfall pattern. The rain season starts in March to end of May (MAM). This is followed by a short rainfall period (July–September) while December–March is a dry period. The rains in this sub-basin are influenced by hydrological dynamics in Mt. Elgon in the West and Cheranganyi hills in the North-East. The foothill of Mt. Elgon experiences more annual average rainfall of about 1270 mm than the lowland areas which experience annual average rainfall of about 1016 mm due to differences in attitude, with a maximum of 1549 mm having been recorded. The wet season is characterized by night temperatures of up to 19 °C rising to about 25.6 °C during the day.

### **3.1.4 Climate**

The catchment is drained by Koitobos river which drains an area of approximately 825 sq.km starting from Mt Elgon. It discharges into Nzoia River a few kilometers from Kitale town, which is the headquarter of Trans Nzoia County. The river is joined by small tributaries such as Muberi, and Kaibei which originate from the North-Western slopes of Mt. Elgon. In the middle and lower reaches, it is joined by other intermittent tributaries that drain wetland areas such as Sikubu and Chemususu during the wet seasons. The location of the study area is presented in Fig. 3.1.

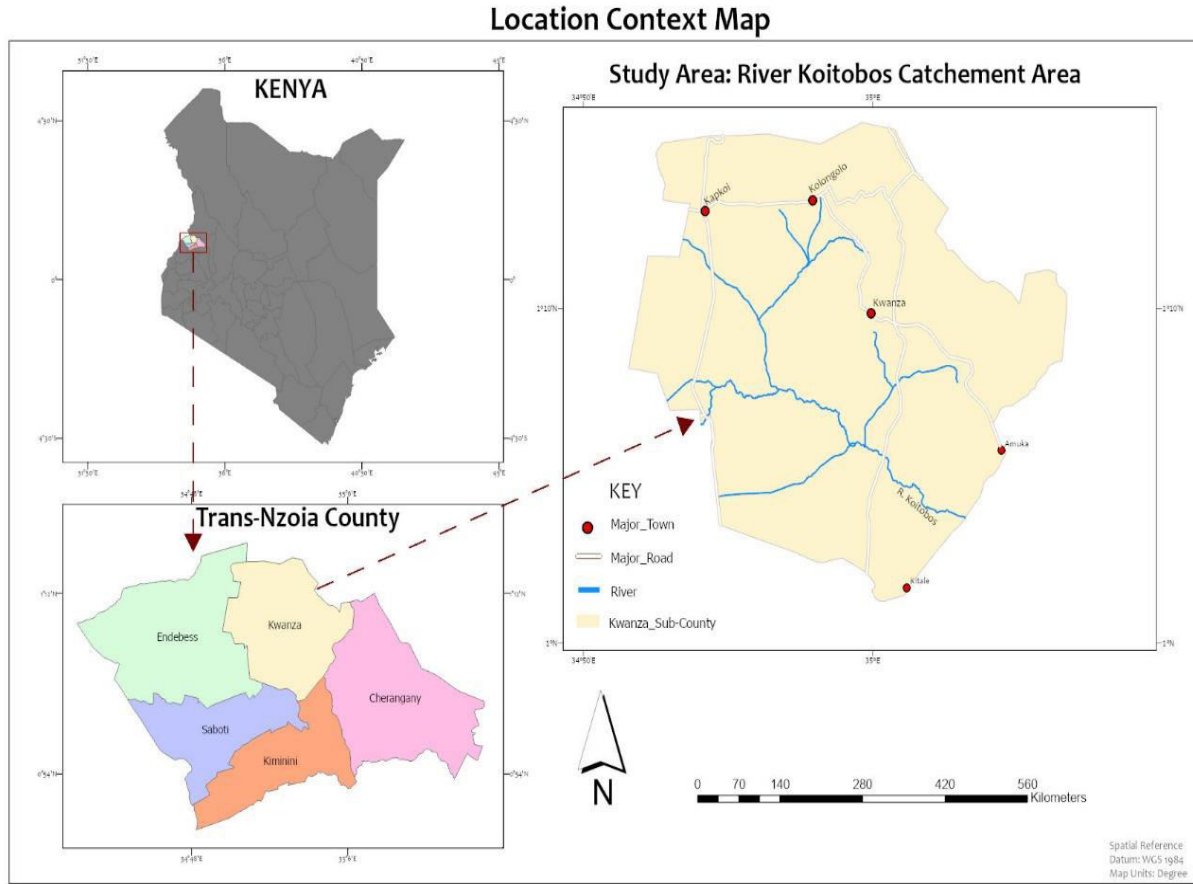


Fig. 3. 1: Location of the Koitobos river catchment.

### 3.1.5 Soils,

Soils in the Upper parts of Koitobos River Catchment are Ferralsols, which are weathered soils characterized by low nutrient levels. The Ferralsols are interspersed with deep and red Nitisols soils containing some good percentage of organic matter. The basin has several urban centers though most of the population resides in rural areas. Most farms in KRC are privately owned and the sizes have been decreasing to smaller sizes due to land tenure rights that have driven subdivision of land amongst family. Large corporations that own large-scale farms; Agricultural

Development Corporation [ADC], Kenya Seed Company, Kenya Seed Driers, Western Seed and Kenya Cooperative Creameries, and Panacol Flower International Limited.

There is an increasing emergence of urban centers in the catchment particularly after devolution in 2013, even though most of the population resides in rural areas. Urban centers in this watershed include Endebess and Kitale Town. The catchment also hosts part of Mt. Elgon Game Park and Mt. Elgon National Reserve. Most farms in Koitobos River Catchment (KRC) are privately owned and the sizes have been decreasing to smaller sizes due to land tenure rights that have driven subdivision of land amongst family members. Large corporations that own large-scale farms; Agricultural Development Corporation [ADC], Kenya Seed Company, Kenya Seed Driers, Western Seed, Kenya Cooperative.

### **3.2. Study population**

According to reports from the Ministry of Agriculture, Trans-Nzoia County, River Koitobos catchment, and its river valley supports the population of approximately 203,821, KNBS, (2019) residents for Kwanza sub-county, Trans-Nzoia, together with officials of non-governmental organizations, community-based organizations (CBOs) and Faith Based Organization (FBOs) in the region, and relevant state ministries were derived to provide information through FGDs of 0 participants and KIIs of 21 participants. This implied that the target population was 203,821; a sample was drawn from this figure to form sampling units. The area of study covers majorly the catchments within the Kwanza Sub-County of which its population largely depend on the Koitobos river water resource for domestic and farming activities.

### 3.3. Research Design

The choice of the research design was determined by the indicators within every specific objective looking for during the study as stipulated in table 3.1.

Table 3. 1: Objectives, variables, and research design were adopted in the study.

Specific Objective	Indicators	Research Design
To assess the extent of land use, land cover change in Koitobos river catchment, Trans Nzoia County Kenya.	<ul style="list-style-type: none"> <li>• Deforestation activities</li> <li>• Farming activities</li> <li>• Settlement and Urbanization</li> <li>• Population growth</li> <li>• Surface run off</li> </ul>	Google Earth Engine techniques and GIS & Remote sensing techniques from (USGS). Cross-sectional survey with questionnaires.
To examine the variations in surface water acreage due to land use land cover changes in Koitobos river catchment, Trans Nzoia County Kenya.	<ul style="list-style-type: none"> <li>• Surface water acreage</li> <li>• Wetlands</li> <li>• Surface water bodies (springs, streams and rivers)</li> </ul>	Google Earth Engine techniques and GIS & Remote sensing techniques through (USGS). Cross-sectional survey with questionnaires.
To evaluate land use practices for sustainable surface water management in Koitobos river catchment.	<ul style="list-style-type: none"> <li>• Conservation Agriculture</li> <li>• Soil &amp; water management measures.</li> <li>• Afforestation activities</li> </ul>	Evaluation research design by survey questionnaires.

As indicated in table 3.1, the choice of these research designs was justified by the fact that the study area had over the last 40 plus years, undergone land use transformation from dominant large-scale grain and dairy farming to medium to small-scale mixed farming. In the subsequent expansion and transformation of farming, watersheds have come under increasing cultivation pressure due to a rise in immigration of land-seekers and business, people from different ethnic, cultural, and economic backgrounds in Kenya. Besides the different approaches to land use and livelihood searches, it is evident that other socio-economic demographic variables appear to have

a strong bearing on the biophysical transformations witnessed in riparian ecosystems in recent years.

This study targeted officers from government departments, non-governmental organizations, traders, and service providers in category one. In the second category, the study targeted farmers (landowners), local community members, focus group discussion members. Government departments, government organizations, websites, and reports provided statistics about their population.

### **3.4 Sampling Technique and Sample size**

The researcher utilized a judgmental or purposive sampling methodology, which is applicable to both quantitative and qualitative investigations. Purposive sampling was particularly relevant when exploring and understanding the audience and this entailed using common sense and the best judgment in choosing the right habitations and meeting the right number of people for the purpose of the study and especially when focusing on extreme cases.

In determining the sample size for a finite population, the researcher used the Krejcie & Morgan (1970), Table for Determining Sample Size from a Given Population as shown in Table 3.2 which provides the sample value of any range of study population available.

The ever-increasing need for a representative statistical sample in empirical research has created the demand for an effective method of determining sample size. To address the existing gap, Krejcie & Morgan (1970) came up with a table for determining sample size for a given population for easy reference which was constructed using the following formula for determining sample size.

*Formula for determining sample size*

$$S = x^2 NP(1 - P) + d^2(N - 1) + x^2 P(1 - P)$$

$S$  = required Sample size

$X^2$  = the table value of Chi- Square for 1 degree of freedom at the desired confidence level

(3.841)

$N$  = population size

$P$  = population proportion (assumed to be 50 since this would provide the maximum sample size)

$d$  = the degree of accuracy expressed as a proportion (0.5)

Table 3. 2: Krejcie & Morgan (1970), Table for Determining Sample Size from a Given Population

<i>N</i>	<i>S</i>	<i>N</i>	<i>S</i>	<i>N</i>	<i>S</i>	<i>N</i>	<i>S</i>	<i>N</i>	<i>S</i>
10	10	100	80	280	162	800	260	2800	338
15	14	110	86	290	165	850	265	3000	341
20	19	120	92	300	169	900	269	3500	346
25	24	130	97	320	175	950	274	4000	351
30	28	140	103	340	181	1000	278	4500	354
35	32	150	108	360	186	1100	285	5000	357
40	36	160	113	380	191	1200	291	6000	361
45	40	170	118	400	196	1300	297	7000	364
50	44	180	123	420	201	1400	302	8000	367
55	48	190	127	440	205	1500	306	9000	368
60	52	200	132	460	210	1600	310	10000	373
65	56	210	136	480	214	1700	313	15000	375
70	59	220	140	500	217	1800	317	20000	377
75	63	230	144	550	225	1900	320	30000	379
80	66	240	148	600	234	2000	322	40000	380
85	70	250	152	650	242	2200	327	50000	381
90	73	260	155	700	248	2400	331	75000	382
95	76	270	159	750	256	2600	335	<b>100000</b>	<b>384</b>

NOTE: "*N*" is the population size

"*S*" is the sample size

Source : Krejcie, Robert & Morgan, 1970.

Based on the target population as given in section 3.2, the target population for Koitobos river catchment of Kwanza Subcounty in Trans Nzoia County was 203,821, KNBS, (2019) residents. Using the Krejcie & Morgan (1970), Table for determining sample size, the desired sample size was 384 as per the study population. While during the administration of the survey questionnaires the response was 312 which was used as the N sample in this study analysis.

The research conducted interviews with 21 key informants comprising of Village leaders (farmers) (3), National government officers (3 Chiefs), County government officers (Lands, Agric, Water, Health, Education)-5, 2 NGOs- Vi and World Vision, Parastatals- (NEMA, KWS, KFS, WRA, KMD)-5. WRUA officials (2) and 1- Trader.

Table 3. 3: Shows the sampling strategy of the study showing the population, method, and size.

Study Population Units	Sampling Method	Sample Size
• Key Informant Interviews (KII)	Stratified random with proportional allocation and purposive	<b>21 persons</b> –Village leaders (farmers) (3), National government officers (3 Chiefs), County government officers (Lands, Agric, Water, Health, Education)-5, 2 NGOs- Vi and World Vision, Parastatals- (NEMA, KWS, KFS, WRA, KMD)-5. WRUA officials (2) and 1- Trader.
• Landowners /Households and residents	Stratified random with proportional allocation	384 participants
• FGD Members	Quota	3 FGDs with total 30 participants in different locations (Each FGD having 8-12 members) drawn from the residents and service providers.

Source –Field data, (2024)

The purposive selection of key informants aimed at drawing representation from business, the farming community, policy makers and institutions in the farming and environmental conservation fields within and outside the study area. The information to be gathered covered the

key socio-economic parameters and the overall livelihood characteristics of the communities, as well as specific land use practices.

Proportionate stratified random sampling was used in selecting catchments and households. In addition, quota sampling was used in selecting participants in the individual watershed FGDs. Quota sampling was used in selecting vulnerable individuals in households to discuss community-wide vulnerability issues.

### **3.5. Data collection and Instruments,**

For socio-economic aspects, the study used a combination of descriptive survey, cross-sectional, Google Earth Engine (GEE) techniques and Remote sensing and Geographic information systems (GIS) techniques for getting secondary information and analysis and social economic data being collected using survey questionnaires for validation feedback and ground truthing. The survey design permitted assessment of deforestation and encroachment activities, Agricultural activities (farming practices), Settlement and Urbanization, population growth in relation to land use land cover changes, variability in rainfall in relation to surface runoff and precipitation, human and natural activities, and environmental policies in place.

The researcher employed both quantitative and qualitative approaches to data collection, analysis, and presentation. Historical design assisted in exploring, explaining, and understanding the past about the subject from data already available. The aim was to collect relevant information that provided baseline data upon which land use cover change, forestry, and agriculture would be determined for future development planning. The cross-sectional design was used to determine the extent of deforestation activities, agricultural activities (farming practices), settlement and urbanization together with other natural processes such as landslides

and mudslides within the catchment for the period. Further, cross-sectional design was used to examine variations in rainfall, precipitation, human and natural activities within the catchment because of land use land cover changes.

### 3.5.1 Data Collection Instruments

Primary data was collected through structured questionnaires, key informant interviews, focus group discussions, observation checklist, and community vulnerability assessments. While secondary data was collected through the review of literature from Libraries, on-line and off-line browsing of international journals and peer-reviewed articles.

Table 3. 4: Primary data collection, organization and data collection instruments for study population units

Study Population Units	Sampling Method	Sample Size	Data Collection Instruments	Appendix number
Service Providers (NGOs, other dev. Partners, local opinion leaders and public members)	purposive	21	Key informant Interviews	III
Landowners/Farmers	Stratified random	384	Survey Questionnaires	II
FGD Members	Quota	30	FGD	IV
<b>TOTAL</b>		<b>435</b>		

Source –Field Data, (2024).

### 3.5.2 Data collection and Processing Tools and Techniques.

The tools and techniques used in this study included:

1. Digital camera for capturing images of both biophysical changes and anthropogenic features.
2. GPS for capturing geographical coordinates and mapping biophysical changes.
3. GEE tools for tracking land cover and land use change in the catchment.

4. Remote sensing (RS) techniques.

5. Existing maps generated by different actors in the conservation and natural resource use institutions (e.g., KWS, NEMA, WRA, and Ministry of Lands & Surveys) to locate water catchments and the river channel.

### **3.5.2.1 Primary Data**

Primary data was sourced through questionnaires, key informant interviews, focus group discussions, observation checklist, and community vulnerability assessments and is summarized as follows:

#### **a) Questionnaires**

The survey questionnaire (Appendix II) was to be administered to the targeted sampled 384 persons in all the 5 clusters (by category) and proportionate (by size i.e., large, medium, and small) catchments. This sought to capture important data from the sample units.

#### **b) Key Informant Interviews**

They were purposively selected and interviewed (Appendix III). The interviews probed for qualitative information to evaluate trends in behavior, as well as perspectives in livelihood activities and wetland conservation. The interviews were thematically analyzed in line with the study objectives.

To avoid possible biases among the various professional and other stakeholders, a total of 21 local community members in the study area were selected by quota sampling and interviewed. These comprised of Village leaders (farmers) (3), National government officers (3 Chiefs), County government officers (Lands, Agric, Water, Health, Education)-5, 2 NGOs- Vi and world

Vision, Parastatals- (NEMA, KWS, KFS, WRA, KMD)-5. WRUA officials (2) and 1- Trader in the study area.

### **c) Focus Group Discussions (FGDs)**

Focus Group Discussions (FGD) were held for each of the 3 sampled sub catchments (Appendix IV) where a total of 30 participants were involved. These were composed of 8-12 participants, selected by quota sampling from among the respondent units, in consultation with key informants. Each FGD sought to collect qualitative information regarding their experiences, attitudes and preferences on land use and land cover change in the study area. Prior to its commencement, the researcher outlined the purpose and format of the discussion, stressing that although all participants' views were important, consensus views and ranking carried greater weight. Probing strategies were applied to elicit fuller and clearer responses from the participants. The useful views and suggestions emanating from the FGDs were used in evaluating options for sustainable land use and conservation as well as confirming results obtained from questionnaires and interviews.

### **3.5.2.2 Secondary Data**

Secondary data was collected through the review of literature from Libraries, on-line and off-line browsing of international journals and peer-reviewed articles. Official documents reviewed included annual reports and policy papers and publications of the Ministries of Agriculture, Planning and National Development, Water, Environment and Natural Resources, and Lands and Settlement. Reports and publications from Parastatal Agencies of Governments and civil society organizations with project undertakings in the Koitobos River catchment were also consulted. Publications of Government such as the Constitution, Commission reports, Acts of Parliament

and Sectoral Policy Papers were reviewed. This was undertaken through reviews to corroborate and justify attained results presented from analysis.

**a). GEE tools for tracking land use and land cover change in the catchment.**

GEE - Google Earth Engine (GEE) as a web-based Cloud Computing and geospatial processing platform based on geo-information applications for large-scale geospatial data processing and analysis was used to through Land Degradation Neutrality (LDN) techniques in processing the LULCC in the study area of Koitobos river catchment. This platform provided free access to satellite data for computing and offers support tools to monitor and analyze land use, land cover change features that were important for the study. It allowed the researcher to apply image processing and geospatial analysis algorithms using Python and JavaScript to large geospatial datasets stored in the cloud.

The geospatial data available within the GEE platform is remote sensing data collected by satellite sensor systems and organized in collections (catalogues), for different geographical areas, time periods, types of sensors or bands of the electromagnetic spectrum used. Was able to access maps and data analyzed systematically as projected for the study area identified.

**b). Remote sensing (RS) and Geographic information systems (GIS) techniques.**

The research was facilitated by incorporating Landsat photos along with other data, such as ground truth data and high-resolution photos from Google Earth, to establish five distinct land use land cover classifications. The categories encompassed are agriculture, barren land, forest, developed/built-up areas, and water bodies.

Agricultural land was selected for sample training based on its high reflectance in the near-infrared region, which is between wavelengths 0.7 and 1.3  $\mu\text{m}$ , as well as other feature

interpretation aspects like pattern, tone, and shape. Because chlorophyll absorbs light between 0.45 and 0.67  $\mu\text{m}$ , healthy plant is an excellent visible-light energy absorber. It is critical to use band combinations that clearly reflect agriculture in satellite photos downloaded during months when crops in the region are fully developed. Areas with crops were identified using Feature Interpretation components. The pattern, tone, and shape all pointed to agricultural regions. Spectral reflectance and feature interpretation were combined to create training sites for supervised classification.

For forested regions, the Spectral reflectance is varied for trees and crops. When compared to crops, trees exhibit more visible-light absorption and near-infrared spectral reflectance. Thus, while agricultural regions displayed a paler shade of red in the false colour composite, wooded areas had a much deeper red. Training sites for supervised categorization were developed using band combinations. Forests and other land uses can be identified using the band combinations shown in Table 3.5.

Water bodies encompassed regions containing rivers, streams, water pans, lakes, and dams. Water exhibits light absorption in the near infrared and mid infrared spectra, resulting in a darker appearance. The areas of water were discovered by analysing the band combinations specified in the table. In contrast, training locations were created with true colour composites, where water elements are depicted as blue.

The developed/built-up land cover encompassed areas that were occupied by structures and other forms of settlement. The identification of built-up regions for the establishment of training sites was conducted near urban areas due to the high population density. Despite the problem of developed areas blending with other land use types, a specific combination of bands was utilized

to clearly depict the built-up areas, as demonstrated. Developed land being quantified transitionally across the study period within the Koitobos river Catchment.

Bare land is defined as an area devoid of any vegetation and used neither for crop production nor any other purpose. Soil primarily covered these places. Differentiating them from other land use land cover was made easier by their spectral reflectance, which differed from that of vegetation, croplands, and other land uses. The study identified several kinds of land use and land cover, and the table below displays the band combinations used to analyse them. For all land use land cover identification, false colour composites were useful, save from a few specific band combinations for each class type.

Table 3. 5: Band combinations for each land use category.

<b>Landsat Land use/ land cover</b>	<b>Landsat 5 (1995)</b>	<b>Landsat 7(2009)</b>	<b>Landsat 8 (2022)</b>
Agriculture	5 4 1 / 4 3 2	4 3 2	6 5 2
Forest	7 4 2 / 4 3 2	7 4 2 / 4 3 2	5 6 2
Water Bodies	7 5 3 / 4 3 2 / 7 4 2	1 4 7 / 1 2 3	5 6 4
Developed/ Built up Areas	3 2 1 / 4 3 2	3 2 1	7 6 4
Bare Land	4 5 1 / 4 3 2	4 5 1 / 4 3 2	5 6 4

(Source – RS Data, 2024)

From the result findings, it was realized that the Built-up areas or developed have highly expanded all through transitions within the years 1995 to 2022 thus from moving from 321/432 to 764 as per the assessment bands. This was attributed to the need for economic development and urbanization in the Koitobos river catchment area and thus exerting pressure on the land resource for food production under agriculture to meet the growing population demands for food

supplies. This has resulted in the consistent reduction in the forest land from 742/432 in 1995 to 562 in the year 2022. Agriculture space has slightly increased in acreage from 1995 to 2022 but being because of competing population needs for sustenance. Here surface water has also shown signs of reduction during the research period from 753/432/742 which was very high to 564 in the year 2022 thus contributing a lot to the availability of surface water required for agricultural activities.

### **3.6. Data Analysis Techniques and Presentations**

#### **3.6.1 Primary data**

Quantitative data collected using structured questionnaires was analyzed using Statistical Package for Social Science, SPSS with Microsoft excel applications and the findings were presented in tables and charts. The findings were in descriptive statistics, which is usually in percentages and frequencies. Qualitative datasets collected using key informant interviews, focus group discussions and community vulnerability assessments were analyzed using thematic content analysis where findings were grouped into themes and sub-themes for easy analysis and understanding. After the qualitative data was analyzed, it was tabulated for simplicity and understanding and presentation.

#### **3.6.2 Secondary Data**

Data collected from publications, reports, journals, books, was analyzed in relation to the study objectives, and other secondary data sources analyzed using Google Earth Engine (GEE) and Remote sensing (RS) techniques which detects changes, maps trends, and quantifies the differences on the Earth's surface. GEE is widely applied in land use and land cover research and now available for commercial use and remains free for academic and research use. This also

included LULC error matrix analysis tools such as producer accuracy %, user accuracy %, overall accuracy %, omission error, commission error and Kappa coefficient applications.

### **3.7. Reliability and Validity of Data Collection Instruments**

Reliability is a measurement tool's accuracy or precision, Orodho, (2013). Cronbach's Alpha was calculated on the computer to check the consistency of the research equipment; the results showed a reliability value of 0.712. As noted by Mugenda & Mugenda (1999), a reliability value of 0.7 or higher is considered acceptable for use in research because it indicates a high degree of interitem consistency. Experts in disaster management reviewed the instruments to determine their reliability and their capacity to respond to the objectives.

### **3.8. Ethical Considerations**

The National Commission for Science, Technology, and Innovations (see appendix), the local administration, and the elders were consulted for permission to conduct research. Along with their identity, each respondent was notified of the confidentiality of the information they provided. They were also informed that the information provided could only be utilized for academic purposes, as the study was conducted solely for academic purposes. The identity of the respondents was kept confidential, and they were specifically requested not to provide their names. The obtained data were placed in a secure location that only the researcher and his or her supervisors could access. They will be destroyed upon the conclusion of this investigation. To eliminate all forms of compulsion, each participant was free to withdraw from the study. Due to the academic nature of the study, they were not promised any monetary or other rewards in exchange for their participation. The survey was carried out between October 2021 and February 2022 for data collection and the units of analysis based on household heads and other farming

community members in the catchment of Koitobos river in Kwanza Sub County, Trans-Nzoia County.

### **3.9 Limitations and Delimitations of the Study**

The study area by geographical coverage is wider and therefore required a bigger sample size to have a wider representation. The researcher, however, was limited to a smaller sample size but well distributed and widely spread.

Secondly, it is human nature that people tend to glorify themselves and as such, some information could be exaggerated especially on land use cover activities and programs. The researcher alleviated this by ensuring that the respondents are drawn from all sectors of the target population. Collecting data from a large group, which might not have knowledge on data collection, may lead to errors influencing the outcome of the study. The researcher alleviated this by conducting a pilot study and by corroborating responses with available data and information from the government ministries.

Due to the geographic location of the study, respondents were sparsely populated and therefore data collection was a bit problematic because of long distance of travel, and topography of the region that required more time. To solve this problem, the researcher worked with trained local research assistants who internalized the data collection tools to hasten getting information from the community and faster reach out to more respondents within the study location.

The Google Earth Engine (GEE) techniques utilization limits you on the years due to availability of accurate data for analysis to provide enough support during projections and planning of development activity execution especially 1995, 2009 and 2022. These significant years settled

on could provide consistent data that could be used for planning, comparison, analysis and projections unlike the other years within the period that couldn't offer consistent data.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

#### **4.1 Introduction**

This chapter contains result analysis, presentation, interpretation of the data collected as well as discussions of findings based on the study objectives as captured through the Google Earth Engine (GEE) techniques, and Remote sensing techniques and those captured from the social economic survey questionnaire tools employed in the fields.

#### **4.2 Extent of land use, land cover changes (LULCC) in the Koitobos river catchment.**

This section stipulates the results from application of different tools such as GEE, & Remote Sensing techniques and socio-economic survey questionnaires.

##### **4.2.1 Land use land cover changes results using the GEE techniques:**

This presents the acreage of land use, land cover generated using the Google earth Engine techniques for the study area of Koitobos river catchment.

##### **4.2.1.1 Deforestation activities within the period of 2001 – 2021**

The table stipulates acreage of deforestation in Koitobos river catchment generated from Google Earth Engine techniques for the period 2001 - 2021. These range of years were considered due to availability of consistent data for analysis and development planning purposes; however, the period of study was 1992 through to 2022.

Table 4. 1: Deforestation Activities for a period of 20 years within Koitobos River Catchment

Year	Hectares (Ha)
2001	7.614
2002	4.827
2003	28.648
2004	5.761
2005	6.793
2006	3.031
2007	14.5
2008	19.129
2009	3.665
2010	11.888
2011	4.469
2012	19.189
2013	16.804
2014	9.312
2015	7.24
2016	81.542
2017	137.198
2018	25.92
2019	63.146
2020	72.808
2021	41.6

(Source – GEE data, 2024)



Fig. 4. 1: A Bar Graph Showing Deforestation Cover (Ha) Over Time for the Period 2001 to 2021 in the Koitobos River Catchment

From the findings within the Koitobos river catchment, there has been increasing deforestation practices in the area that may have been attributed to the increasing population demanding food and need to increase the agricultural land to meet the food supply needs. Fragmentation of farming parcels and encroaching into the existing protected areas of vegetation and even extending to riparian areas for farming activities.

Land use changes from forestry to agriculture is increasingly from year to year within the Koitobos river catchment to catch up with the increasing demands of the residents in the area. The year 2016 and 2017 had great significance of deforestation activities in the Koitobos river catchment in the transition period of 2001 – 2022 where the activity scaled to about 138 hectares (Ha) of forested land which contributed to the highest percentage of land degradation.

#### 4.2.1.2 Land use/ land cover changes realized by residents of the Koitobos River Catchment

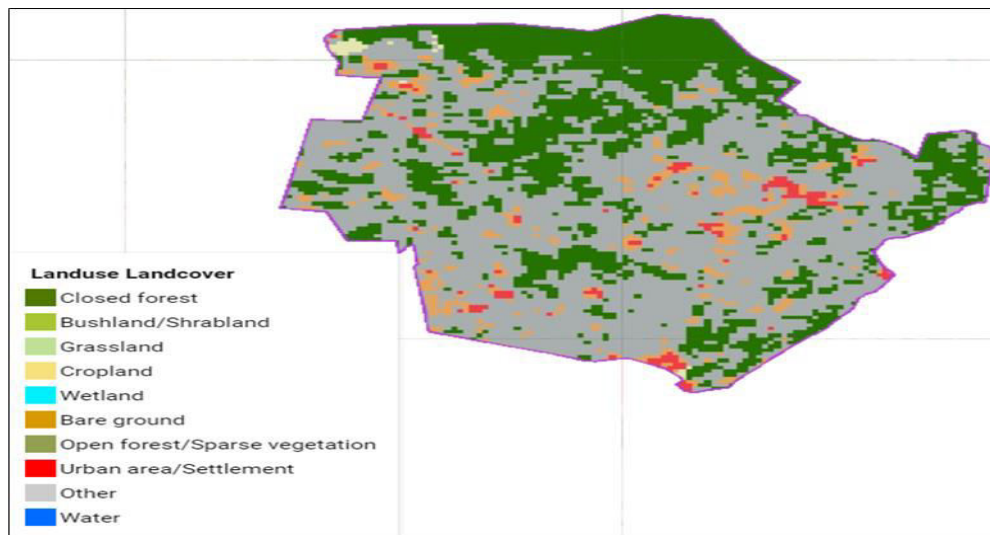


Fig. 4. 2: Land use/ land cover changes between 2001 to 2022 realized by residents of the Koitobos River Catchment.

(Source – GEE data, 2024)

During the study period of 2001 – 2022, cropland cover, and urban area / settlement have gradually increased at the expense of closed forest, open and sparse vegetation, grassland, wetland, and water bodies within the Koitobos river catchment. These changes in land use have had an implication on the surface water acreage within the area. As the cropland cover and settlement increases with their land use cover decreasing, water bodies in the catchment have dried up and reducing in acreage affecting the human activities that are dependent on it, as a key resource. Decrease in closed forest and open/ sparse vegetation in the catchment contributes to shrinking of the wetlands and drying up of the surface water bodies.

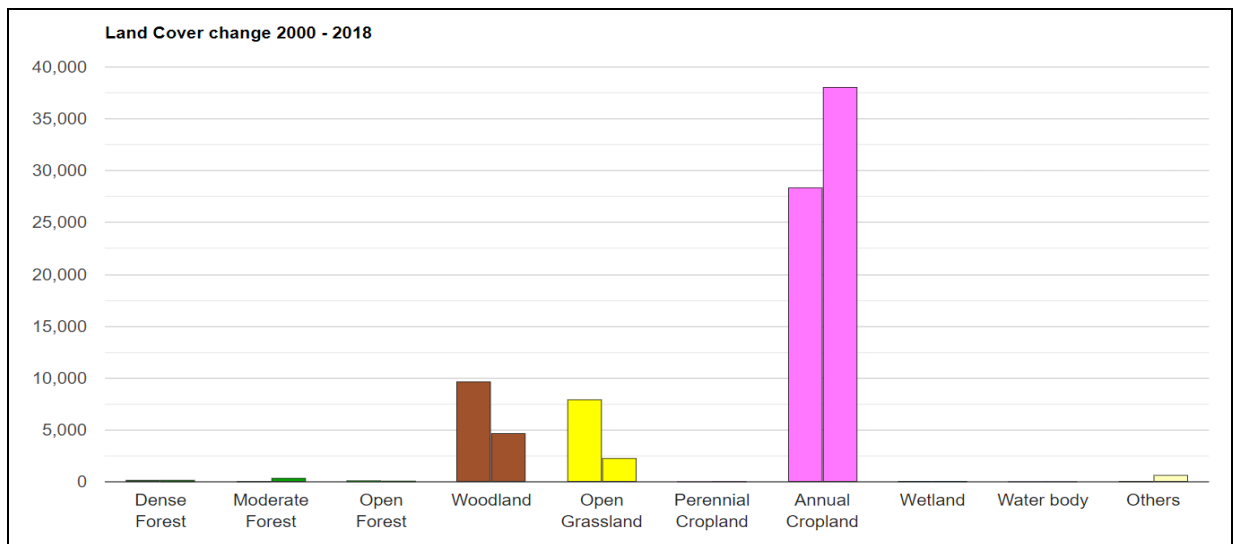


Fig. 4. 3: Land use, land cover changes, 2000 and 2018, in the Koitobos river catchment.

From the observations displayed through the distribution in the map, land use changes under annual cropland area greatly changed when compared in the year 2000 and 2018. This was attributed to the high demand of the increasing population within the catchment in need of food which forces the expansion of annual cropland increasing within the catchment. The forest cover in the catchment is drastically fading away which calls for environmental policy enhancement.

Table 4. 2: Land cover transitions in 2021 in Koitobos river catchment

LC	Value (Area- Ha)	%age
Forest	6,798.69	14.6
Shrubland	6,058.93	13
Grassland	5,453.61	11.7
Cropland	27,510.06	59.2
Artificial	603.531	1.3
Wetland, Water body and Other land	55.570	0.2
<b>TOTAL</b>	<b>46,480.39</b>	<b>100.0</b>

(Source – GEE data, 2024)

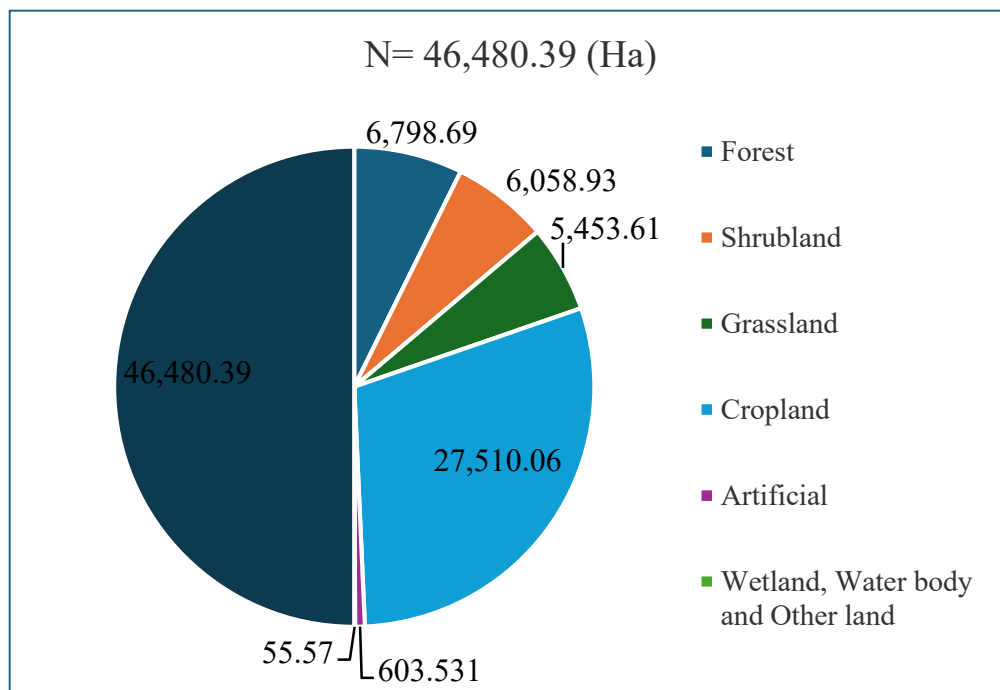


Fig. 4. 4: Land cover in 2021 within the Koitobos river catchment.

(Source – GEE Data, (2024))

From the findings shown above the figure 4.4 within the Koitobos river catchment depicts that, there has been increasing deforestation practices in the area that is attributed to the increasing population demanding food and need to increase the cropland to meet the food supply needs. Cropland 59.2% of the total catchment area, Forest being 14.6%, Shrubland 13% and Grassland covering 11.7% of the total area of the catchment. Fragmentation of farming parcels and encroaching into the existing protected areas such as forests, shrublands and grasslands and even extending to riparian areas for farming activities.

Observations showing that in the 32-year period between 1972 and 2004 shrub-grassland and riverine trees covers had decreased at a rate of 21.5 and 16.3 ha per year respectively. Riverine trees suffered the greatest devastation from riparian encroachment and by 2004 have been reduced to only 16% of their cover in 1972, Ayele, *et al.*, (2011). Land use changes from forestry to agriculture are increasingly from year to year within the Koitobos river catchment to meet the increasing demands of the residents in the area.

#### **4.2.2 Land use/ land cover change results using Remote sensing (RS) techniques.**

The research was facilitated by incorporating Landsat photos along with other data, such as ground truth data and high-resolution photos from Google Earth, to establish five distinct land use land cover classifications. The categories encompassed are agriculture, barren land, forest, developed/built-up areas, and water bodies.

##### **4.2.2.1 Agriculture land cover**

Agricultural land being quantified transitionally from 1995, 2009 and 2022 as 26,853 hectares (58%), 32,438 hectares (70%) and 36,118 hectares (77.68%) respectively in coverage within the Koitobos river Catchment. This shows the agricultural land cover drastically increasing through

the study period. The increase being attributed to various factors within the Koitobos river catchment especially the aspect of pressure exerted on land resource in demand of food by the ever-growing population.

#### **4.2.2.2 Forest land cover**

The forest land cover was quantified transitionally from 1995, 2009 and 2022 as 2242 hectares (5%), 1647 hectares (4%) and 222 hectares (0.48%) respectively in coverage within the Koitobos river Catchment, showing the forest cover drastically reducing through the study period. This attributed to cutting down of forest to create space for settling the growing population in the area.

#### **4.2.2.3 Water Bodies land cover**

Water bodies encompassed regions containing rivers, streams, water pans, lakes, and dams. Water resources within the Koitobos catchment showing an increasing trend from the year, 1995, 2009, and 2022 as follows, 2332 Ha (equivalent to 5%), 3803 Ha (equivalent to 8%), and 3521 Ha (equivalent to 7.6%) and this resulted from the digging of new water pans, dams and protected water points and streams contributing to increased aspect.

#### **4.2.2.4 Developed/ Built up land cover.**

The developed/built-up land cover encompassed areas that were occupied by structures and other forms of settlement. Developed land being quantified transitionally from 1995, 2009 and 2022 as 154 hectares (0.0%), 514 hectares (1.0%) and 459 hectares (0.99%) respectively in coverage within the Koitobos river Catchment. This shows the developed land cover slightly increasing through the study period. The increase being attributed to various factors within the Koitobos river catchment especially the aspect of pressure exerted on land resource in demand of space for built up in settling food by the ever-growing population.

#### **4.2.2.5 Bare land cover**

Bare land is defined as an area devoid of any vegetation and used neither for crop production nor any other purpose and primarily covered by soils. Bare land cover, being quantified transitionally from 1995, 2009 and 2022 as 14,915 hectares (32%), 8093 hectares (17%) and 6175 hectares (13.28%) respectively in coverage within the Koitobos river Catchment, showing the bare land cover drastically reducing through the study period. The decrease being attributed to various factors within the Koitobos river catchment especially the aspect of pressure exerted on bare land in demand of space for built up in settling the ever-growing population, food production needs and new water pans for supply in the area.

From the result findings, it was realized that the Built-up areas or developed have highly expanded all through transitions within the years 1992 to 2022, having been attributed to the need for economic development and urbanization in the Koitobos river catchment area and thus exerting pressure on the land resource for food production under agriculture to meet the growing population demands for food supplies. This has resulted in the consistent reduction of forest land. Here surface water has also shown signs of reduction during the research period in the catchment thus contributing a lot to the inadequate surface water for agricultural activities.

#### **4.2.3 Demographic characteristics of respondents in Koitobos river catchment.**

These results include gender, marital status, age group, Occupation (sources of income), household size, Size of land, years of farming experience, settlement pattern, level of educational, and aggregate annual income of the land users.

#### 4.2.3.1 Questionnaire Return Rate

In this study 384 questionnaires were distributed which was 100% of the total questionnaires needed. From this only 312 questionnaires were returned which is 81.3% questionnaire return rate. All the items in the questionnaire were responded to, presenting a 100% response rate.

#### 4.2.3.2 Gender.

Gender is the state of being male or female in relation to the social and cultural roles that are considered appropriate for men and women. You can use gender to refer to one of a range of identities that includes female, male, a combination of both, and neither. Some people refer to the fact that a person is male or female as his or her gender. Women are sometimes denied opportunities solely because of their gender.

The respondents were called upon to indicate their gender and the results indicated in figure 4.5.

Majority of the respondent's 63.5 % (198) were male while 36.5% (114) of them were female.

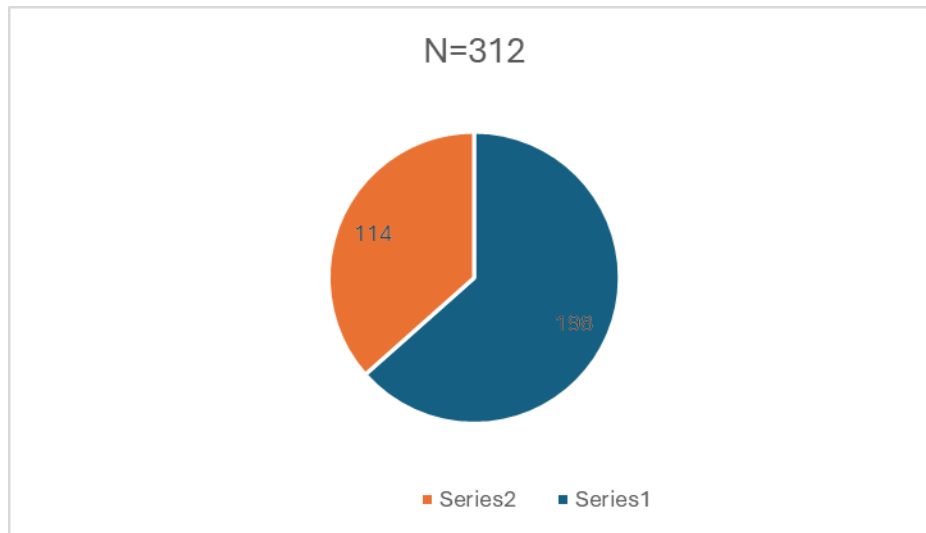


Fig. 4. 5: Gender response in relation to LULCC in Koitobos river catchment

This result of 63.5 % (198) males and 36.5% (114) females implied that there were more males interviewed than female within the catchment due to the culture of male dominance in the decision making at community level. Majorly land ownership is embedded to the male and any major decision undertaken on land use land cover changes are mostly undertaken by them. The female most of the time work on the land and access resources from it but limited in decisions pertaining land use. The results were backed up by the FGD respondents, 61% (18) males and 39% (12) females, who also indicated that within the community the male were dominant than female. The study was supported by Ayoola et al. (2023) in their research on the variability of land tenure, land rights, and land acquisition methods among male and female farmers in the irrigation sector of Gombe and Bornu States, Nigeria. The study found that most respondents (95.3%) were male, while 4.7% were female.

The study found that women have a higher level of participation in agriculture within the gender groups that were examined. Inheritance is the prevailing form of land ownership for both females and males. Males in the research area have a greater number of plots and larger farm sizes compared to females. Suggestions include the necessity of integrating gender perspectives into the process of reforming land use systems, promoting awareness among land users to actively participate in farmers organizations, and prioritizing the adoption of agricultural practices that are more conducive to women. These should be the primary areas of concentration for extension services.

About 63.5 percent of the respondents were males compared to 36.5 percent of female respondents. This is an indication of the existence of male dominance in decision making

regarding the household business. However, this dominance is not that pronounced as the ratio fits perfectly in the gender ration requirements as stipulated by the Kenyan Constitution, 2010.

#### 4.2.3.3 Marital Status

The study sought to find out the marital status of the respondents within the catchment and the findings are presented in figure 4.6.

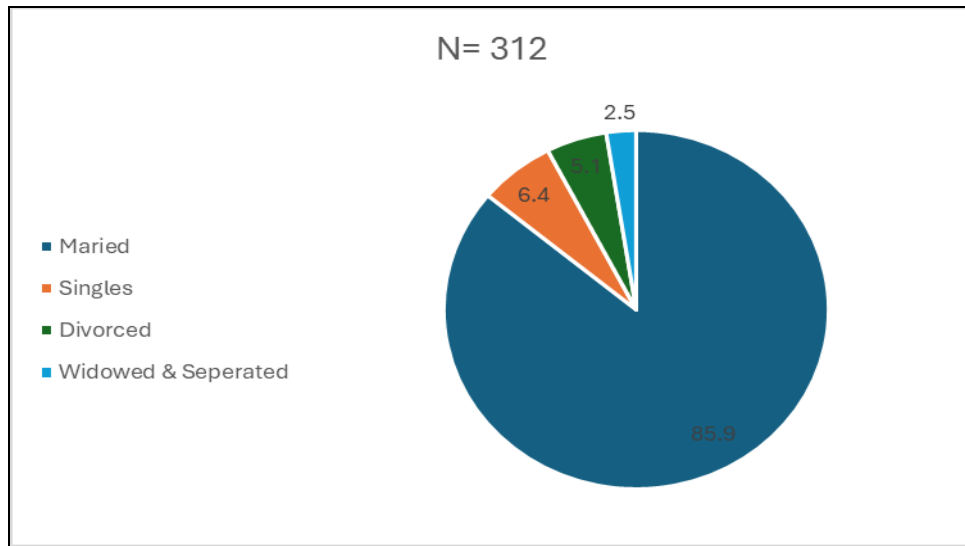


Fig. 4. 6: Marital Status response in relation to LULCC in Koitobos river catchment.

The survey found that most of the respondents, specifically 85.9% (268 individuals), were married. Among the married respondents, 55.8% practiced monogamy while 30.1% practiced polygamy. Additionally, 6.4% (20 individuals) were single, 5.1% (16 individuals) were divorced, 2.5% (8 individuals) were widowed, and the other respondents were separated. The distribution of marital status among respondents was heavily biased towards married individuals, with 85.9% falling into this category. Thus, with a significant proportion of married participants, it is reasonable to anticipate improved decision-making and coordination of land use affairs, because of the synergistic responsibilities performed by both spouses. The FGD respondents corroborated

the findings, indicating that males held dominance in position over females within the community. Furthermore, this study aligns with Ayoola et al., (2023) research on the variability of land tenure, land rights, and land acquisition methods among male and female farmers in the irrigation sector of Gombe and Bornu States, Nigeria. Ayoola et al. found that the distribution of marital status among respondents was heavily skewed towards married individuals, with 91.0% falling into this category. Comment from FGDs,

*“Given the significant number of married participants, it is logical to predict that decision making, and coordination of land-related issues would be improved because of the complementary responsibilities played by both spouses in the community”.*

#### 4.2.3.4 Age Group

The study sought to find out the age group status of the respondents within the catchment and the findings are presented in figure 4.7.

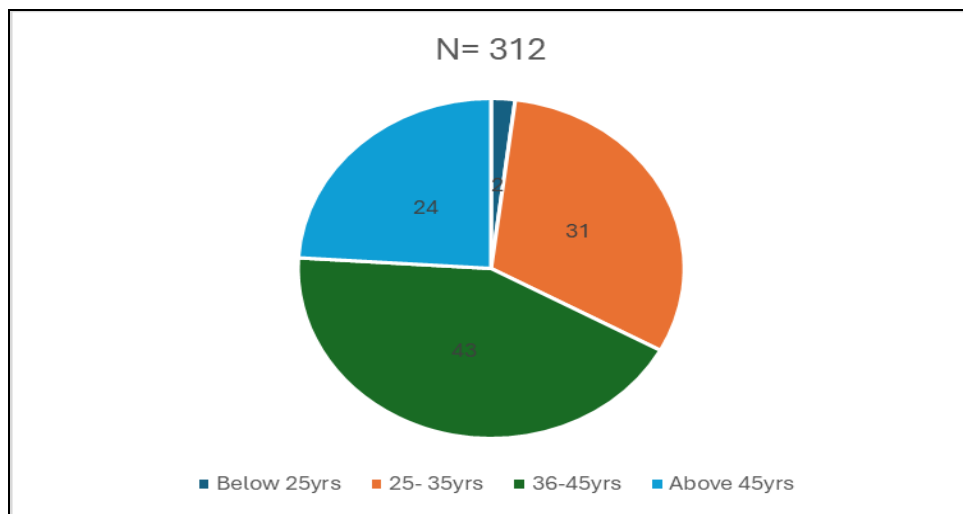


Fig. 4. 7: Age group response in relation to LULCC in Koitobos river catchment

The study indicated that the majority of the respondent's 42.9% (134) were between **36-45** years, 31.4% (98) of them were between 25-35 years, 23.7% (74) of them were above 45 years while only 1.9% (6) of them were below 25 years. The results demonstrate that, due to cultural norms in the research region, most landowners and farmers were middle-aged individuals, with a vanishingly small percentage being 25 and younger. In addition, the results corroborate those of Ayoola et al. (2023) regarding the land tenure, rights, and acquisition methods of male and female farmers in the irrigation sector of Gombe and Bornu states, Nigeria. In that study, 29.0% of the participants were between the ages of 31 and 40, while 17.0% were between the ages of 20 and 30, 16.3% were between 41 and 50, 16.3% were between 51 and 60, and 19.3% were above 60. However, respondents in the under-20 age range made up a tiny fraction of the total (3.0%). From the study findings, it was evident that farmers aged over 35 years of age comprising of 67% (209) with an assumption that they were mature to explain the contribution of land subdivision to the process of land use transformation in the study area. However, the study noted that majority of farmers owning land in the study are aged between 36- 45 years, and that most of the original landowners had died and the current agricultural landowners acquired their land through inheritance. Oluoch and Kosura (2008), opined that the age of a farmer may explain the exposure to farming practices, level of exposure to new technologies in farming and thereby use of land. Similarly, as agricultural landowners become older, there is a likelihood of subdividing land to fulfill the socio-cultural practices such as land inheritance.

#### **4.2.3.5 Occupation (Source of income)**

The study sought to find out the occupational status of the respondents within the catchment and the findings are presented in figure 4.8. The N value being 312 due to the number of responses received during the survey questionnaire execution.

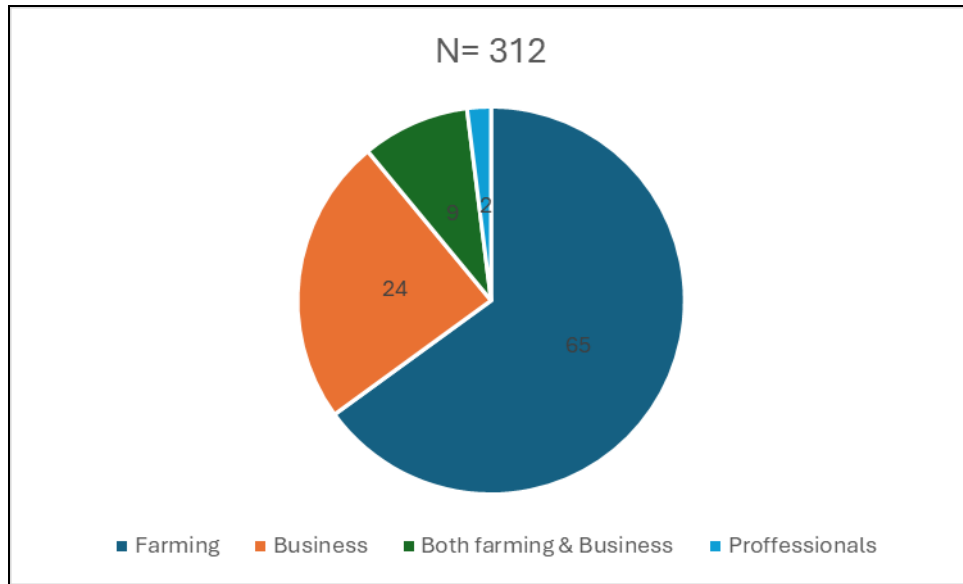


Fig. 4. 8: Occupation status response in relation to LULCC in Koitobos river catchment

The findings of the study showed that majority of the respondents' 64.7% (202) were farmers, 23.7% (74) were both farmers and businessmen, 9% (28) of them businessmen while only 2.6% (8) percent of them stated other professions. These explains that the major daily activity in Koitobos river catchment was land cultivation due to farming as majority being farmers and thus enhancing their knowledge in sustainable land use management practices is very key to help in managing the Koitobos river water resource that is important for agriculture. Also, findings indicated that majority of the respondent's 67.3% (210) had sold land in the last five years while only 32.7% (102) of them stated the contrary showing that land fragmentation is very high resulting to great effects on the water resource through siltation and sedimentation resulting from the reduced soil surface cover with increased surface runoff. More frequently cultivated land alters the soil structure, diminishing its water holding capacity which escalates the risk of soil erosion.

#### 4.2.3.6 Household Size

The study sought to find out the household size status of the respondents within the catchment and the findings are presented in figure 4.9.

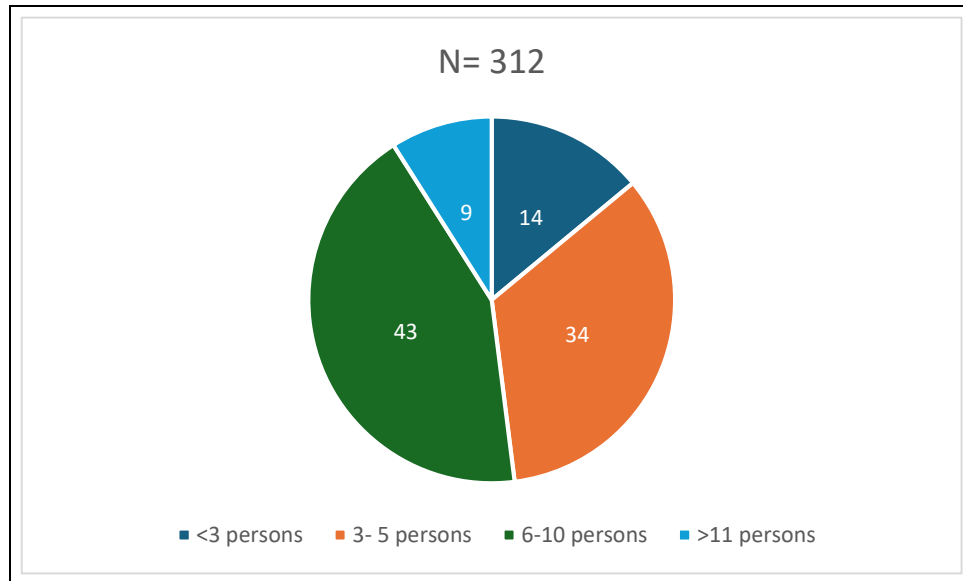


Fig. 4. 9: Household size response in relation to LULCC in Koitobos river catchment

Source: Field Survey, 2024

The participants were requested to specify the number of individuals in their household. The majority, including 42.7% (134) of respondents, indicated a group size of 6-10 individuals. 34.1% (106) of respondents reported a group size of 3-5 individuals, while 13.8% (44) reported a group size of less than three individuals. Additionally, 9.4% (28) of respondents reported a group size exceeding 11 individuals. The findings indicated that the majority of households have a family size of between 3-10 accounting for about 76.8 percent (240) of the respondents. Households with over 10 members account for about 9.4 percent of the respondents and under 3 members are 13.8 percent of the respondents. Kiswii, et al. (2022) conducted a study on the

household land size and land use for sustainable food and livelihood security in Maize farming systems of Uvuu Sub-location, Makueni county. Their findings revealed that most households have a family size of between 4-6 accounting for about 63.6 percent of the respondents. Household with 10-12 members account for about 4.7 percent of the respondents. The relatively big household size could be as result of high life expectancy and fertility rates in the entire county. These relatively large household sizes imply many mouths in need of food thus affecting the food security of individual households. In addition, since tradition requires land to be subdivided to individual heirs, the big household sizes affect the land sizes of subsequent farms.

This distribution illustrated the wide range of variation in the number of individual households in the studied area. Such variability may result in certain families gaining an advantageous or disadvantageous position in terms of land ownership and utilization. The FGD respondents corroborated the findings, indicating that the household size within the community ranged from 6 to 10 individuals. This contributes significantly to land fragmentation, as the limited land is subjected to increased pressure demands.

Furthermore, the household densities result in reduced land sizes as parents subdivide their parcels to their sons. In addition, there have been increased settlements because of the big household sizes in the catchment area. These settlements reduce the land available for agricultural production hence impacting negatively on the food and livelihood situation of the households. Moreover, household size influences land use allocations as for instance, with many mouths to feed, households are forced to allocate bigger sections of their land to food production. The households with small sizes have the privilege of allocating big proportions of their farms to commercial farming.

#### 4.2.3.7 Size of Land

The study sought to find out how much land the respondents owned, and the findings are presented in figure 4.10.

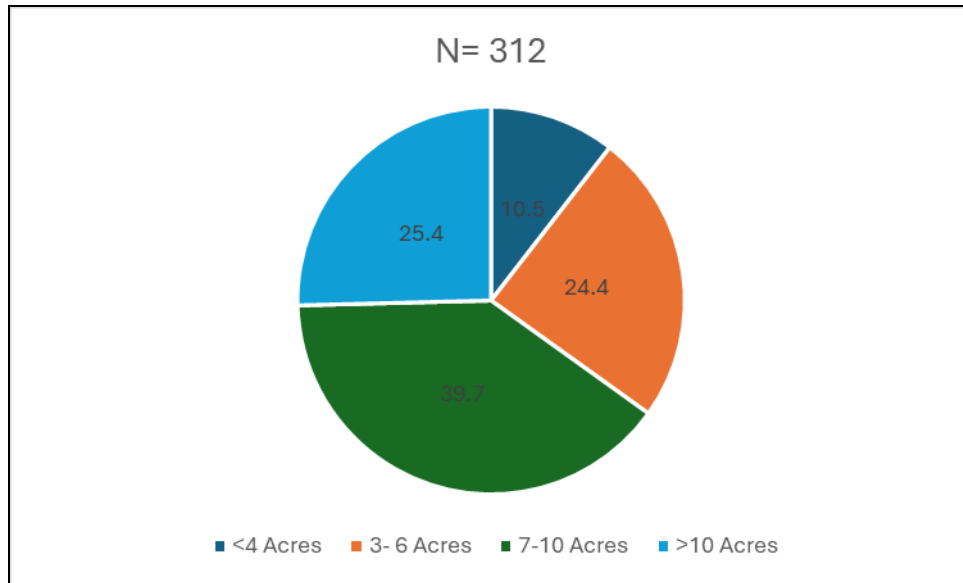


Fig. 4. 10: Land sizes response in relation to LULCC in Koitobos river catchment

Source: Field Survey, 2024

The findings of the study revealed that most of them 39.7% (124) had 8-10 acres of land, 25.4% (79) of them had over 10 acres, 24.4% (76) of them had 4-7 acres, while 10.5% (33) had 4 acres and below of land. In line with land size, the respondents were further asked whether they had ever sold land in the last five years. The findings indicated that the majority of the respondent's 67.3% (210), had sold land in the last five years while only 32.7% (102) of them stated the contrary. Land sub-division through selling contributes to land use, land cover change conversion tending to be increased built up with settlement and agriculture due to food supply

demands as pressure mounts on the land resource. Selling land significantly affects land use and land cover by changing the ownership and intended purpose of the land, potentially leading to transformations such as converting natural areas into developed land for residential, commercial, or industrial use, altering the landscape and impacting ecosystems depending on the new land use practices applied by the new owner.

#### 4.2.3.8 Duration of farming in the study area.

The study sought to find out the household size status of the respondents within the catchment and the findings are presented in figure 4.11.

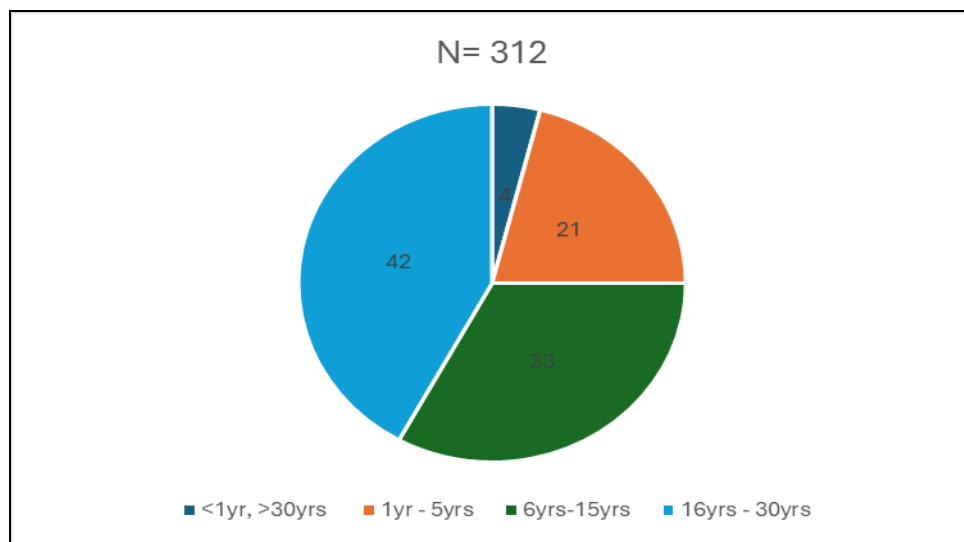


Fig. 4. 11: Duration of farming response in relation to LULCC in Koitobos river catchment

Source: Field Survey, 2024

The respondents were asked to state the duration of time they had undertaken farming in the study area and results indicated that majority of the respondent's 42% (131) had undertaken active farming in the study area between 16-30 years, 33% (103) stated 6-15 years, 21% (66) of

them stated 1-5 years while 4% (12) of them stated less than one years and over 31 years. Thus, having stayed long enough to attest of the land use land cover variations in the study area due to being there for a period of 16 – 30 years to be able to provide tangible information that can easily be verified. The respondents in the study region, due to their extensive farming expertise, are expected to be useful assets in land management and other associated concerns in the study area.

#### 4.2.3.9 Education Level

The study sought to find out the household size status of the respondents within the catchment and the findings are presented in figure 4.12.

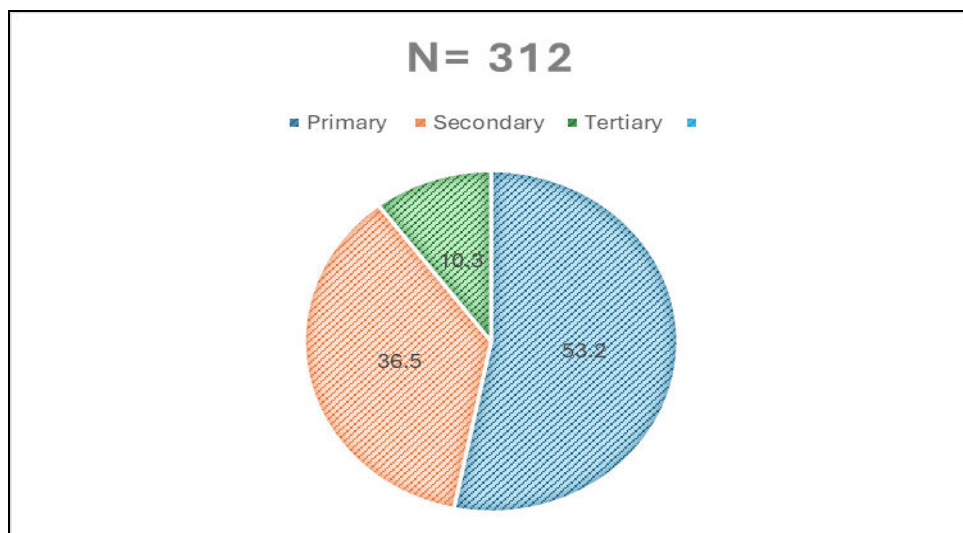


Fig. 4. 12: Education level response in relation to LULCC in Koitobos river catchment.

Source: Field Survey, 2024

On the education level, the study findings revealed that the majority of the respondent's 53.2% (166) had attained primary education, 36.5% (114) of them having acquired secondary education while only 10.3% (32) stating tertiary education. The study findings showed that the majority of the respondents have acquired the basic level of education and thus able to understand any land

use management strategy that can be brought on board for the sustainability of land management practices. The study findings align with Ayoola et al.'s (2023) research on the variability of land tenure, land rights, and land acquisition methods among male and female farmers in the irrigation sector of Gombe and Bornu States, Nigeria as it revealed that a significant majority of the respondents (72.0%) had received some form of formal education, while a considerable proportion (24.7%) had informal education, and a negligible proportion (3.3%) had no education. The outcome illustrated a situation where a knowledgeable agricultural community is anticipated to be well-informed, adaptable, and open to new ideas, assuming all other factors remain constant.

Moreover, households with members who have attained tertiary level of education tend to have access to better job opportunities. This off-farm income generating activities enables the households to acquire additional land parcels and more knowledgeable on sustainable land and water management measures.

#### **4.2.3.10 Level of income**

The respondents were interrogated on their salary scales and the response was as follows; Dependents were 13.5% (42), less than KES 3000 were 17.9% (56), between KES 3000 and KES 9000 were 44.2% (138), between Ksh 10,000 and Ksh 29,000 were 13.5% (42) and salary above Ksh 30,000 10.9% (34). From the study findings, it showed that a larger percentage of respondents earn a monthly income of less than 10,000 shillings to be able to support the acquirement of the basic household needs in the study area, accumulating to an annual income of less than KES. 100,000. However, a sizeable proportion of the respondents, 75.6% (236) reported annual farm incomes of below KES 100,000, with Only 24.4% (76) of them having

annual income above KES 100,000.00 per annum. This shows that general farming has not been taken up as an important source of farm income among the respondents in the study area and thus contributing to their living standards that require some sustainable interventions for upscaling.

#### 4.2.3.10 Farming systems and Methods

The study found out that different farming systems and methods were used in Koitobos river catchment among them being cultivation across the contours 58.4% (182) and along the contour 6% (19) other farming practices identified was the traditional method of broadcasting 0.6% (10). Different farming methods used include manual method 11.7% (37) and mechanized method 23.3% (73) as shown in figure 4.13.

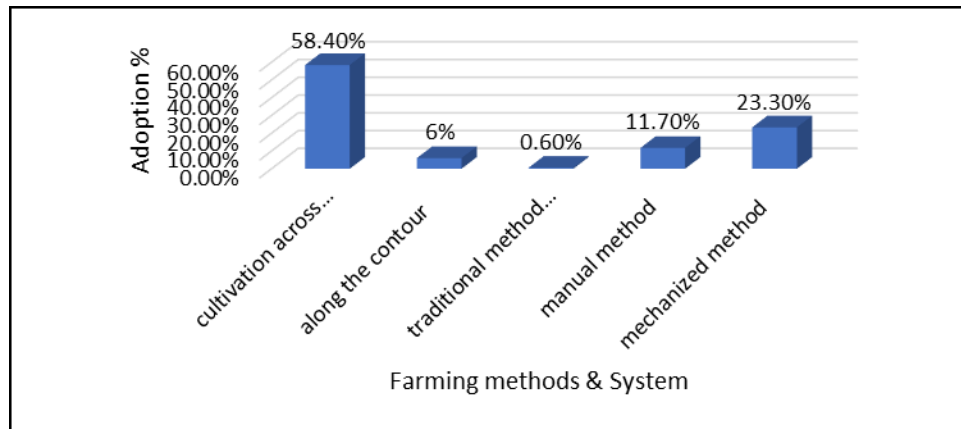


Fig. 4. 13: Farming systems and methods within Koitobos river catchment.

Source: Field Survey, 2024

#### 4.2.3.11 Ploughing times and cropping seasons.

The study also evaluated the number of times farmers ploughed their land and the number of seasons they plant their crops, and it was noted that most of the respondents ploughed their farms

twice 75.6% (236) and planted two seasons 69.9% (218). Frequent ploughing of soil or land promotes soil degradation as nutrients are easily washed away due to loosening surface and resulting in low land productivity which calls for more land to meet the food demands of the growing population.

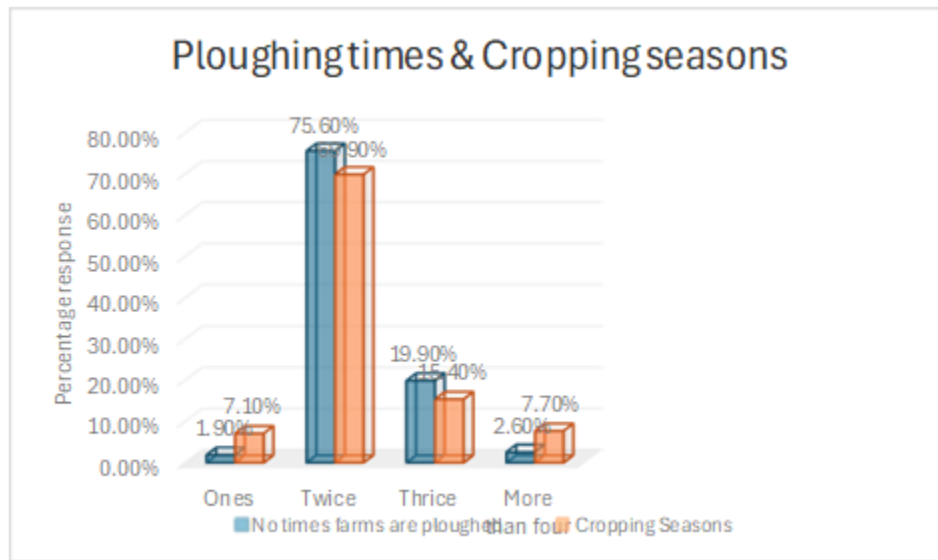


Fig. 4. 14: Ploughing times and cropping seasons.

Source: Field Survey, 2024

The findings are summarized in table 4.3.

Table 4. 3: Ploughing times and cropping seasons.

	No times farms are ploughed	Cropping Seasons
Ones	1.9%	7.1%
Twice	75.6%	69.9%
Thrice	19.9%	15.4%
More than four (4)	2.6%	7.7%

#### 4.2.3.12 Land cover

The study also evaluated the types of trees grown in Koitobos river catchment and it was realized that Cyprus and Eucalyptus which are not for environmental conservation were preferred as

long-term trees posing great risk to the environment, while sesbania and calliandria were preferred as short-term trees. Trees availability on the farm and within the catchment reduces the pressure on the natural forest within the catchment for enhanced land use cover changes.

Table 4.4 and 4.5 summarize the types of trees grown in Koitobos river Catchment.

Table 4. 4: Long term trees

		Long-term trees					
		Eucalyptus	Cyprus	grevillea	Elgon teak	Others	Total
Tree growing	yes	75.30%	76.90%	80%	89.50%	90%	80%
	no	24.70%	23.10%	20%	10.50%	10%	20%
Total		100%	100%	100%	100%	100%	100%

Table 4. 5: Short term trees

		Short-term trees				
		Sesbania	Syzygium	Calliandra	others	Total
Tree growing	yes	78.1%	80%	100%	60%	78.1%
	no	21.9%	20%	0	40%	21.9%
Total		100%	100%	100%	100%	100%

Source: Field Survey, 2024

#### 4.2.3.13 Farming practices practiced.

In evaluating farming practices in Koitobos river catchment, the study analyzed various farming practices, and their summary is as tabulated in table 4.6.

Table 4. 6: Farming practices undertaken.

Practice	% of those who practice	% of those who don't practice
Bush clearing	92.3	7.7
Irrigation	26.3	73.3
Grazing	78.8	21.2
Fallowing	9	91
Tree growing	77.6	22.4
Fish growing	19.2	80.8

Source: Field Survey, 2024

How they were applied as shown in figure 4.15.

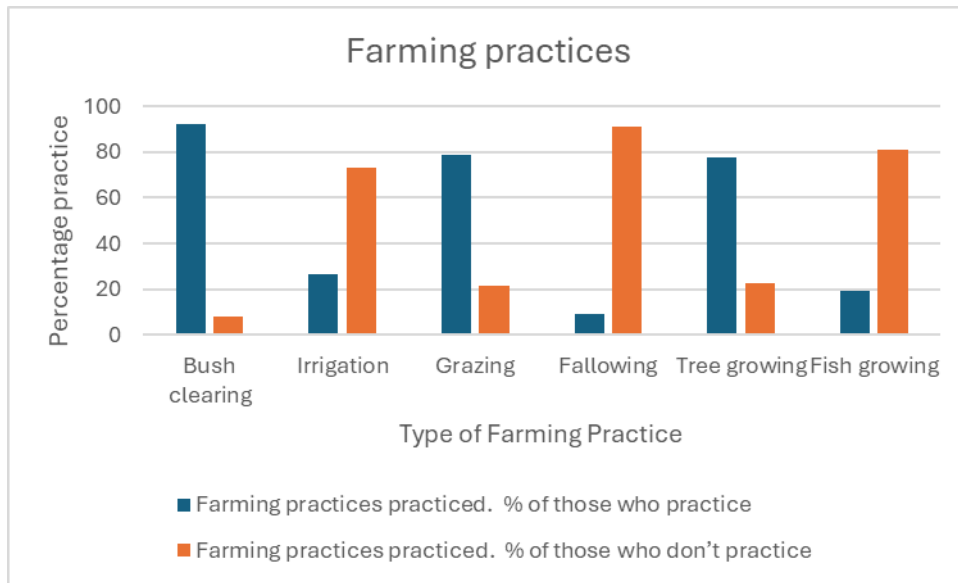


Fig. 4. 15: Farming practices undertaken within the catchment.

Out of the 312 respondents, a large proportion practiced bush clearing (92.3%), open grazing (78.8%) and tree growing at (77.6%) while the least applied farming practices were fallowing (9%). Bush clearing has proved a rampant land use activity undertaken in the Koitobos catchment area due to expansion for agricultural activities for production and land subdivision or fragmentation to meet the increasing demands of the growing population.

#### 4.2.3.14 Soil conservation Measures

To investigate the land use land cover changes within Koitobos river catchment, the study investigated soil conservation measures adopted by residents. A sample of 312 inhabitants were engaged and their responses analyzed as shown in figure 4.16.

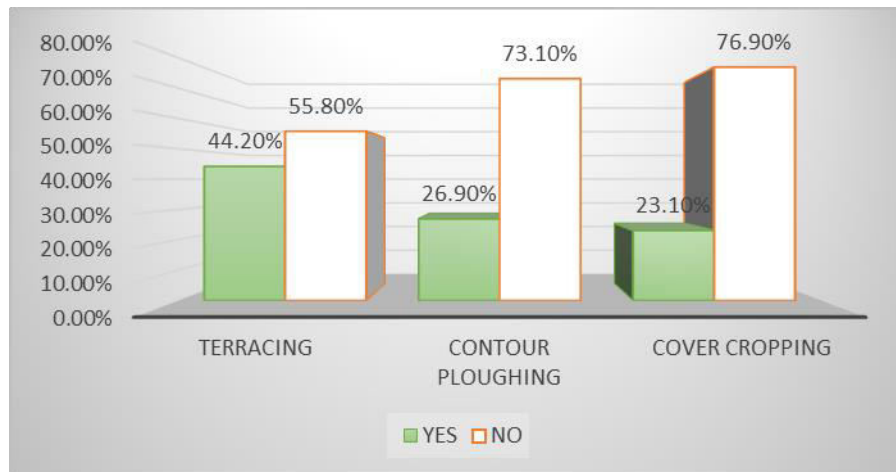


Fig. 4. 16: Soil conservation measures within Koitobos river catchment

From the findings it was deduced that, 44.2% were practicing terracing while 55.8% did not have any knowledge on terracing and therefore were not practicing this soil conservation measure, 26% of the respondents were practicing contour ploughing while 73.8% lacked knowledge in this soil conservation measure. A paltry 23.1% of the farmers had cover crop on the land meaning most farmers lacked knowledge in conservation agriculture (76.9%).

#### 4.2.3.15 Changes realized by respondents.

Respondents had different views on different parameters set for changes, among them being land size where 55% (172) noted that land had reduced while 45% (140) land had increased in size. On land prices, 23% (72) reported having no knowledge on land prices while 77% (240) said that land prices had increased. It was noted that 55% (172) of respondents noted an increase in food

harvest with 40% (125) and 5% (15) noting a decrease and not being aware respectively. Transport was suggested by many as a factor that was difficult to access with 91% and 9% showing difficult and easy respectively. Extension support was very low with 84% of the respondents not being able to access extension services at the right time or with need. According to the respondents the feeling on vegetation cover was that it had reduced since the ratio of deforestation and afforestation is not directly proportional.

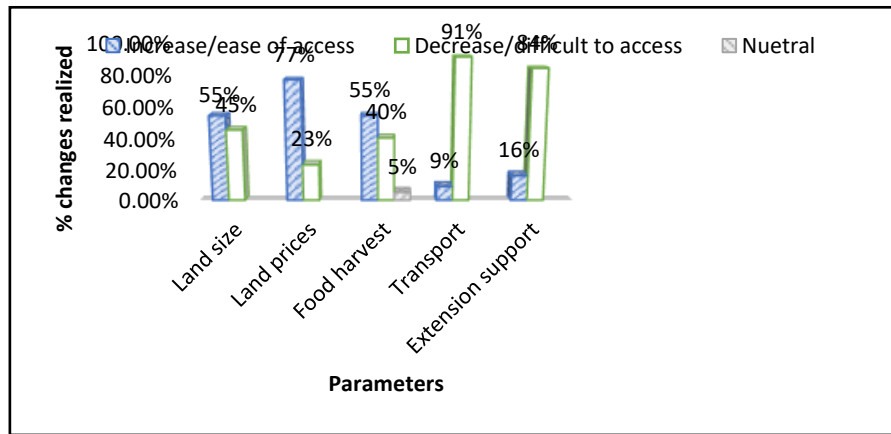


Fig. 4. 17: Land use changes realized by respondents.

Respondents had different views on different parameters set for changes, among them being household land size where 54.5% noted that land had reduced while 45.5% land had increased in size. On land prices, 23.1% argue that the prices had reduced due to lack of knowledge awareness on prices while 76.9% argue that land prices had increased. It was noted that 54.5% of respondents noted an increase in food harvest with 40.4% and 5.1% noting a decrease and not being aware respectively. Transport was suggested by many as a factor that was difficult to access with 91% and 9% showing difficult and easy respectively. Extension support was very low with 84% of the respondents not being able to access extension services at the right time or

with need. According to the respondents the feeling on vegetation cover was that it had reduced since the ratio of deforestation and afforestation was not directly proportional.

#### 4.2.3.16 Source of water and farm water harvesting methods

The study realized that the main source of water used by the residents of Koitobos river catchment was from boreholes 38.5% (120), river 37.8% (118) springs 21.8% (68) and wells 1.9% (59). 38.5% (120) of the respondent's harvest water in their farms using ditches and cut off drain system.

#### 4.2.3.17 Micro-irrigation system and source

Out of the 312 respondents, 78.2% (244) acknowledged irrigation practice and identified the sources of water being 31% (76), 9% (22) and 60% (146) river, harvested water, and boreholes respectively. The findings were further represented as shown in the pie chart in figure 4.18.

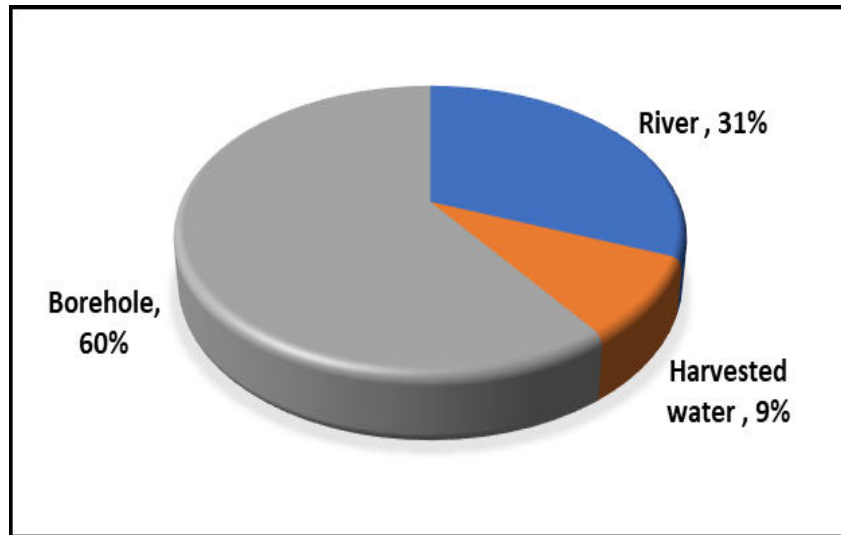


Fig. 4. 18: Water sources for irrigation

#### 4.2.3.18 Availability of water throughout the year due to land use land cover changes

In analyzing availability of water in Koitobos river catchment, the study realized that out of the 312 respondents, 54% (169) of the population experienced water drying from there springs, 35% (109) attest that the rivers had water throughout the year while 11% (34) were not aware if the river dried or not. The data was further analyzed and represented as shown in table 4.7.and figure 4.19.

Table 4. 7: Water Availability throughout the year.

Type	Response from survey	Percentage (%)
Seasonal springs	169	54
Permanent rivers	109	35
Neutral	34	11
Total	312	100

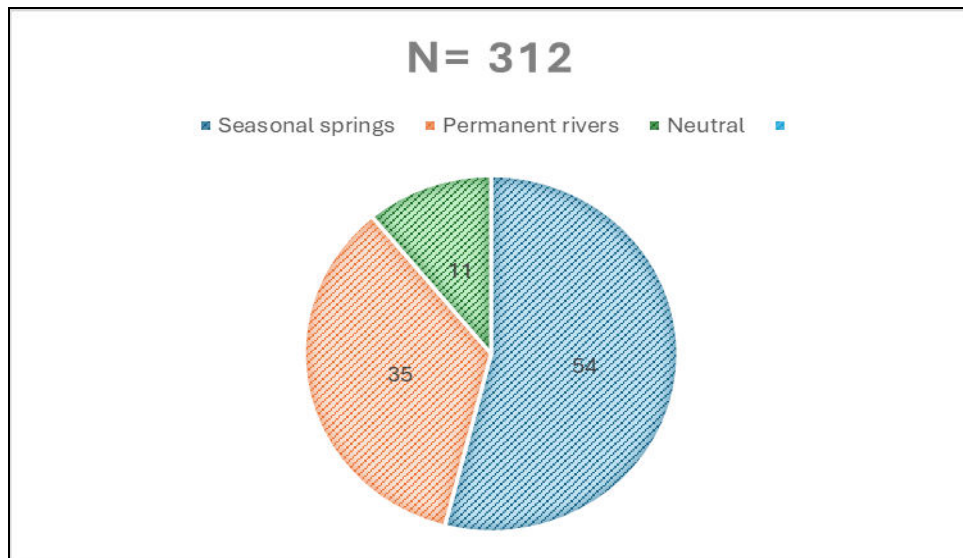


Fig. 4. 19: Availability of water throughout the year.

#### 4.2.3.19 Flooding incidences within Koitobos river catchment.

The findings of the study revealed that flooding was the main disaster experienced in Koitobos river catchment. 69.2% (216) of the respondents had experienced flooding over the past 40 years

with the frequency being higher 2001 and 2010. However, it was revealed that flooding trend had increased over time due changes in land use and land cover with the period 1981 and 1990 showing the list frequency though an increasing trend was depicted over the years. Figure 4.20 summarizes the flooding pattern in Koitobos river catchment.

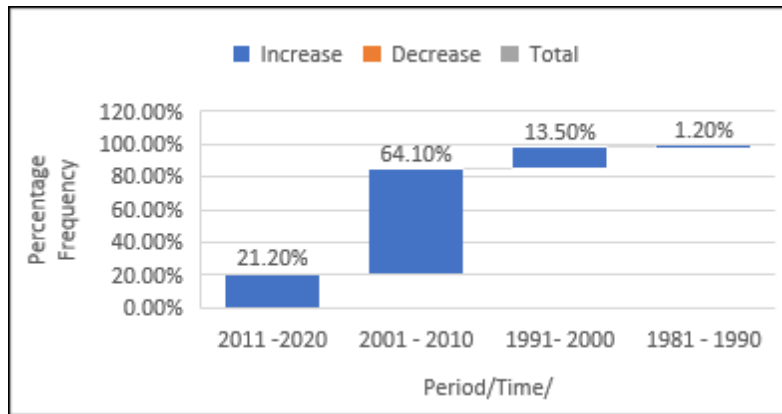


Fig. 4. 20: Flooding incidences within Koitobos river catchment.

#### 4.2.3.20 Environmental protection measures

The study found out that there were different environmental measures put in place in Koitobos river catchment. The main ones included, building of gabions 15% (47), Planting trees along the riverbanks 68% (212), establishment of soil conservation structures 11% (34) and protection of springs for better environment 7% (22). The findings were further analyzed as represented in figure 4.21.

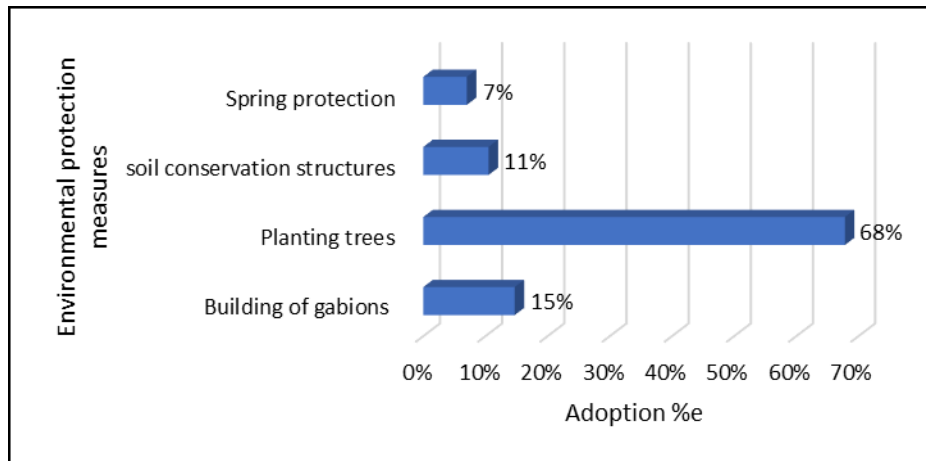


Fig. 4. 21: Environmental protection measures.

### **4.3 Variations in surface water acreage in Koitobos river catchment due to land use land cover changes of Trans Nzoia County Kenya.**

This section presents the results from application of different tools such as GEE, GIS & Remote Sensing techniques and socio-economic survey questionnaires on the variations of surface water acreage in the Koitobos catchment due to land use, land cover changes.

#### **4.3.1 Surface water variation observations in Koitobos river catchment using the GEE techniques:**

This presents the surface water variations in acreage because of land use, land cover changes generated using the Google earth Engine techniques in Koitobos river catchment.

**4.3.1.1 Land Productivity Spatial Temporal Changes (LPSTC) (2001-2022) from the land use transition charts – RCMRD**

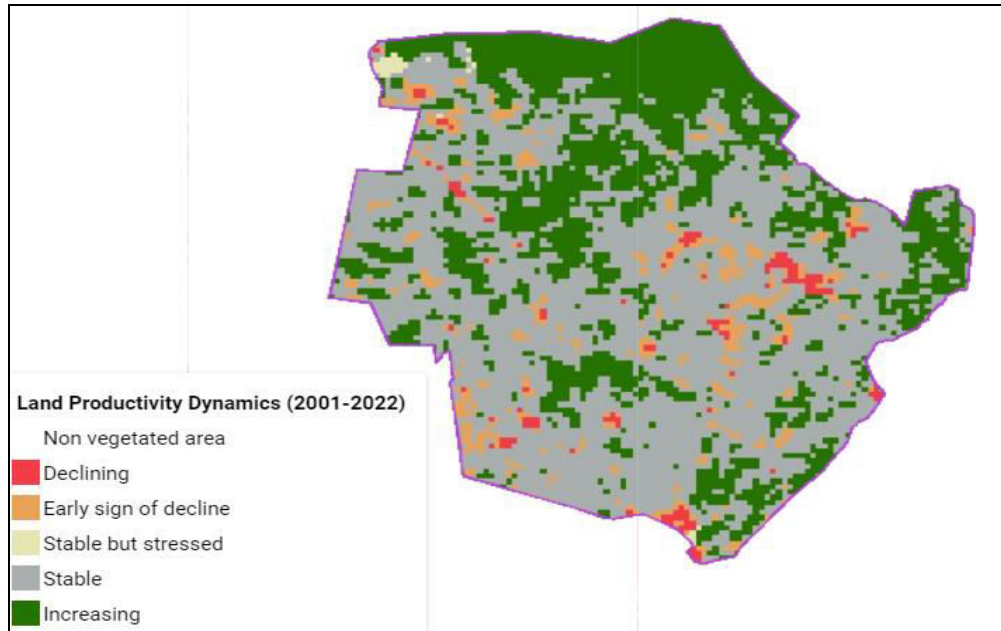


Fig. 4. 22: Land productivity spatial temporal changes Map within the Koitobos river catchment.

From the results depicted by the land Productivity spatial temporal changes map, table 4.8 and the pie- chart (figure 4.23), has increasingly changed towards from stability to risen degaradation within the Koitobos river catchment. Land use, land cover change has increasingly affected the land productivity spatial temporal changes within the Koitobos river catchment and thus contributing to environmental degradation.

Table 4. 8: Land Productivity spatial temporal changes within the Koitobos river catchment

Land Productivity spatial temporal changes (LPD)	Area (Ha)	%age
Declining	893.272	1.9
Early sign of decline	2,892.23	6.2
Stable but stressed	178.848	0.4
Stable	27,317.98	58.8
Increasing	15,198.06	32.7
<b>TOTAL</b>	<b>46,480.39</b>	<b>100.0</b>

(Source – GEE Data, 2024)

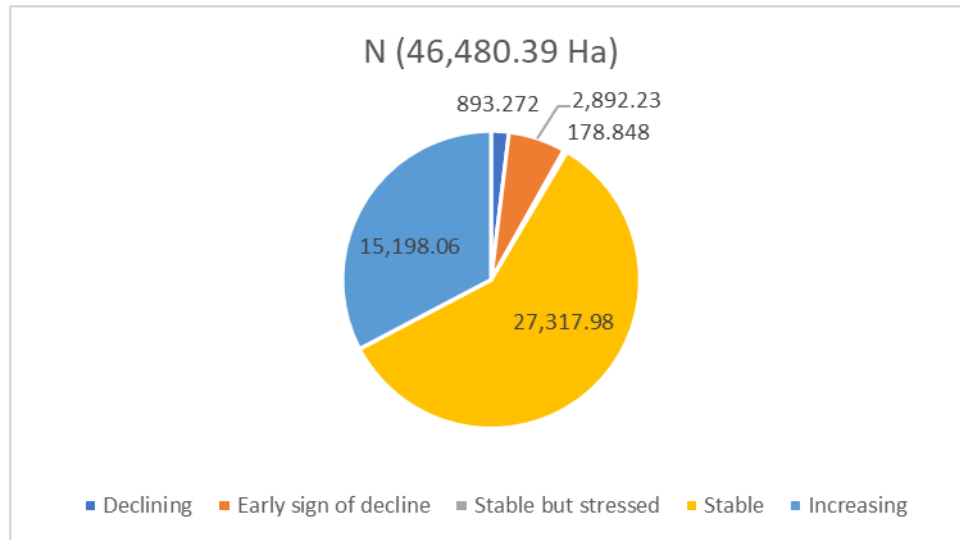


Fig. 4. 23: Land productivity spatial temporal changes Pie chart in the Koitobos river catchment.

(Source – GEE Data, (2024))

From the findings shown above the figure 4.23 within the Koitobos river catchment depicts that, there has been increasing situation of land productivity dynamics from land use practices in the area that is attributed to the increased pressure on the limiting land resources into diverse land cover changes. Stable variations are depicted from the area at 58.8%, due to stabilized population growth with increasing variations due to the increasing degradation at 32.7% within the catchment. This negatively affects the availability of surface water in the Koitobos river catchment which is dependent on this resource for domestic and farming activities for sustaining the growing population.

#### 4.3.2 Surface water variation observations in Koitobos river catchment using Remote sensing (RS) techniques

This exhibits the area of land use and land cover changes produced using GIS and Remote Sensing (RS) techniques in the Koitobos river watershed.

#### 4.3.2.1 Land use land cover change of Koitobos river catchment in hectares.

The study's goal was to find out how much land use and land cover changed in the Koitobos river basin. To do this, the final land use and land cover maps for 1995, 2009, and 2022 were used to number the acres of all the different types of land use and land cover that were found.

Table 4.9 Land use land cover of Koitobos river coverage in hectares and percentages compared to the total coverage of the Koitobos Catchment.

Table 4. 9: Land Use Land cover of Koitobos river Catchment

LULC Class / Year	1995		2009		2022	
	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)
Agriculture	26853	57.8	32438	69.8	36118	77.70
Bare land	14915	32.1	8093	17.4	6175	13.29
Developed/ Built up	154	0.3	514	1.1	459	0.99
Forest	2242	4.8	1647	3.5	222	0.48
Water	2316.39	5	3788.39	8.2	3506.39	7.54
<b>TOTAL</b>	<b>46,480.39</b>	<b>100</b>	<b>46,480.39</b>	<b>100</b>	<b>46,480.39</b>	<b>100</b>

(Source – RS &GIS Data, 2024)

From the findings of Land Use, Land Cover Change in the years, 1995, 2009 and 2022, in the Koitobos River catchment showed that Agricultural Land, covered a majority of the Catchment with an area of 26,853Ha, (58%), 32,438 Ha (70%), and 36,118Ha (77.68%) respectively when transitioning through the years of the entire Catchment thus showing a drastic increased changes in area on the same, followed by bare land area which covered an area of 14,915 Ha (32%), 8,093 Ha, (17% ) and 6175 Ha (13.28%) of the entire Catchment area as shown in the table which drastically decreases transitionally as the Agricultural land increases due to the pressure exerted on the resource.

The Forest Land had shown a drastic decreasing trend through the transitional period from 2242 Ha (5%) to 1647 Ha (4%) and then 222 Ha (0.48%), and this due to increasing demand for more space by the growing population which increasingly results to deforestation activities of unplanned cutting down of trees within the catchment. Water resources within the Koitobos catchment showing an increasing trend from the year, 1995, 2009, and 2022 as follows, 2316.39 Ha (5%), 3788.39 Ha (8.2%), and 3506.39 Ha (7.54%) and this resulted from the digging of new water pans, dams and protected water points and streams contributing to increased aspect. Also reduced abstraction from the river for irrigation purposes contributing to some amount of area covered within the catchment by water resources.

Agricultural land in the years 1995, 2009, and 2022 spread all over the Catchment separated by patches of bare lands, water, and forests. Showing that in this transitioning period of 1995, 2009 and 2022 years, the major land use land cover changes was Agriculture land covering 58%, 70% and 77.68% of the entire area coverage within the Koitobos River catchment. This was due to the increasing demand for food supply of the ever-growing population as depicted by the KNBS reports in every transition having been corroborated by Katana, (2013) in their study on Athi River, detecting and predicting land use land, cover changes in the upper river valley using Cellular Automat- Markov Model, who stated that in the future agricultural expansion, and related development will account for most of the land use, land cover changes.

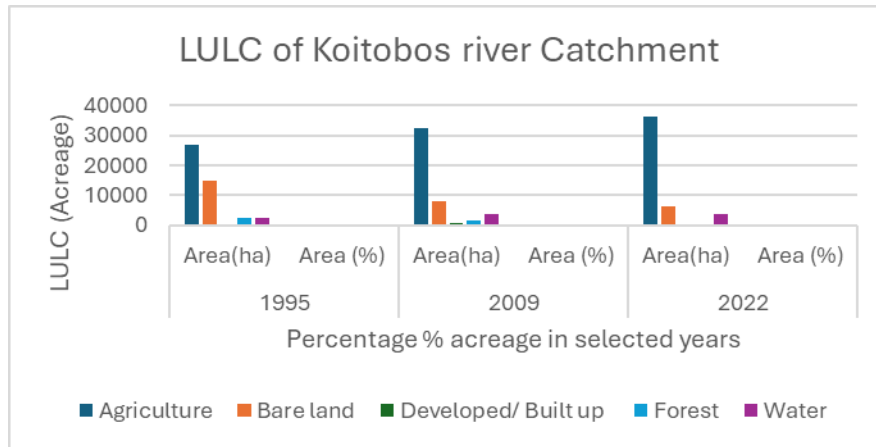


Fig. 4. 24: Showing LULC of Koitobos River Catchment.

#### 4.3.2.2 Land use land cover map for year 1995

Agricultural land occupied 26,853 Hectares (Ha) in 1995, which accounted for 58% of the total area of the Koitobos river catchment. Most of the land was used for agriculture, with the remaining portion being bare ground, which made up 14,915 Hectares (Ha), or 32% of the total Catchment. The remaining land in the Catchment region was developed or built upon, with the forest and water covering 0% and 5% respectively. In 1995, agricultural land was dispersed throughout the catchment, with sections of forest and bare land serving as barriers. The analysis reveals that in the current year, the predominant alteration in land use and land cover was the expansion of agricultural land, which now encompasses 58% of the total catchment area.

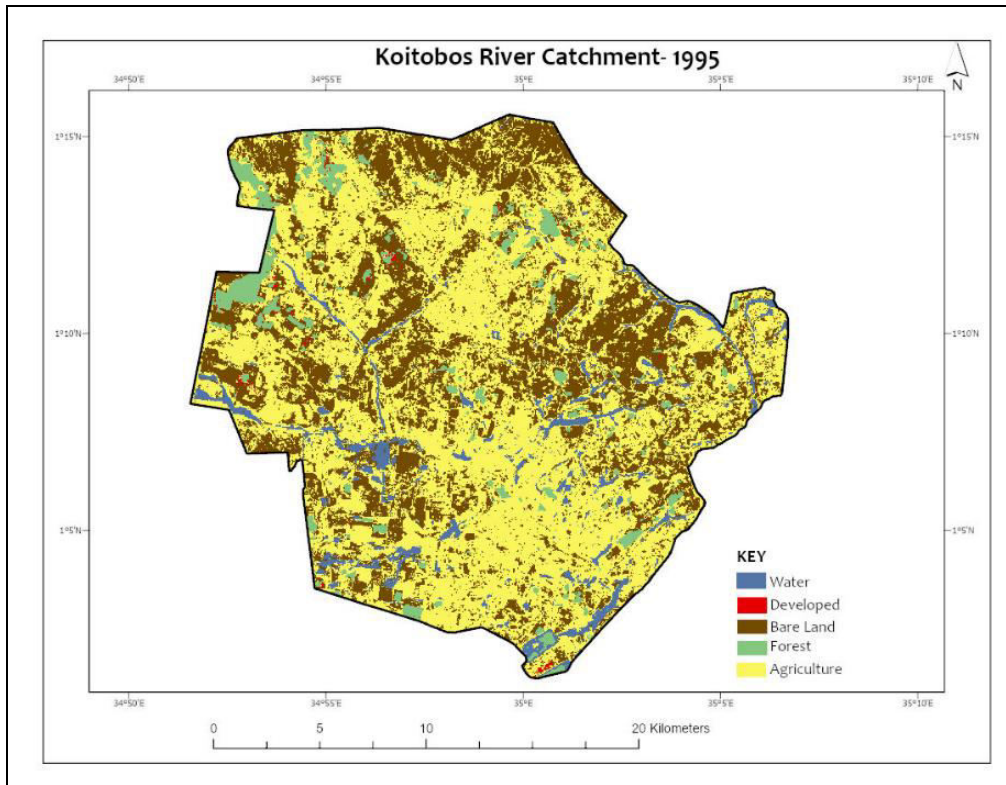


Fig. 4. 25: LULC map for the year 1995 within Koitobos River catchment

#### 4.3.2.3 Land use land cover map for year 2009

As shown in the data, most of the Catchment area in 2009 was agricultural land with an area of 32,438 Ha, or 70% of the total. Bare land covered 8,093 Ha, or 17% of the Catchment area. A total of 8% of the catchment area was covered by water, 1% by developed/built up land, and 1% by forest land. In 2009, the Catchment was covered in agricultural land with areas of undeveloped territory in between. Evidence indicating 70% of the catchment area was devoted to agricultural use this year, the most significant change in land cover type. As shown in each transition by the KNBS reports, this was caused by the ever-increasing demand for food supply caused by the constantly growing population.

The below map shows the land use land cover map for the year 2009.

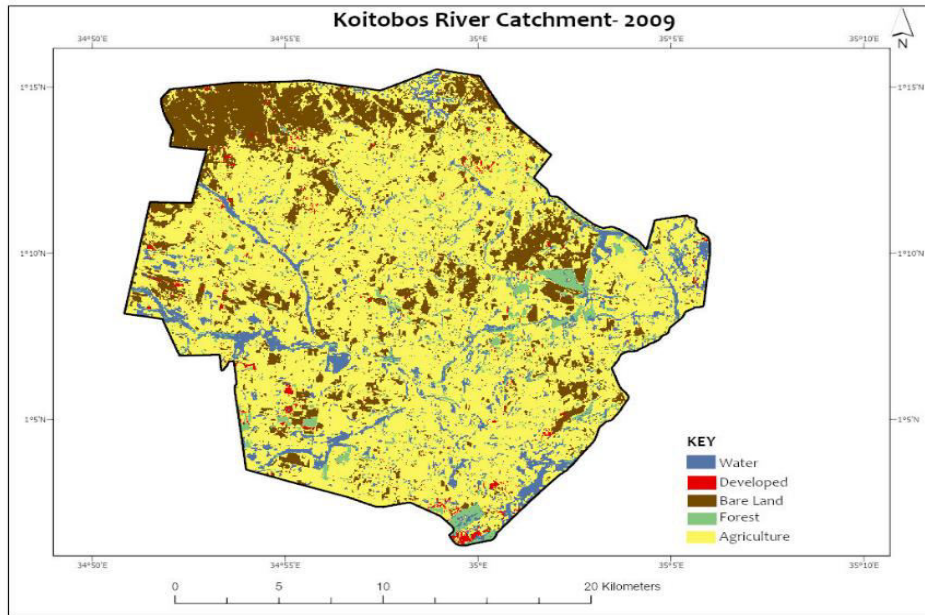


Fig. 4. 26: Land use land cover map for year 2009

Land utilization within the catchment as shown from the satellite imagery within the Koitobos river catchment in the stipulated year of assessment.

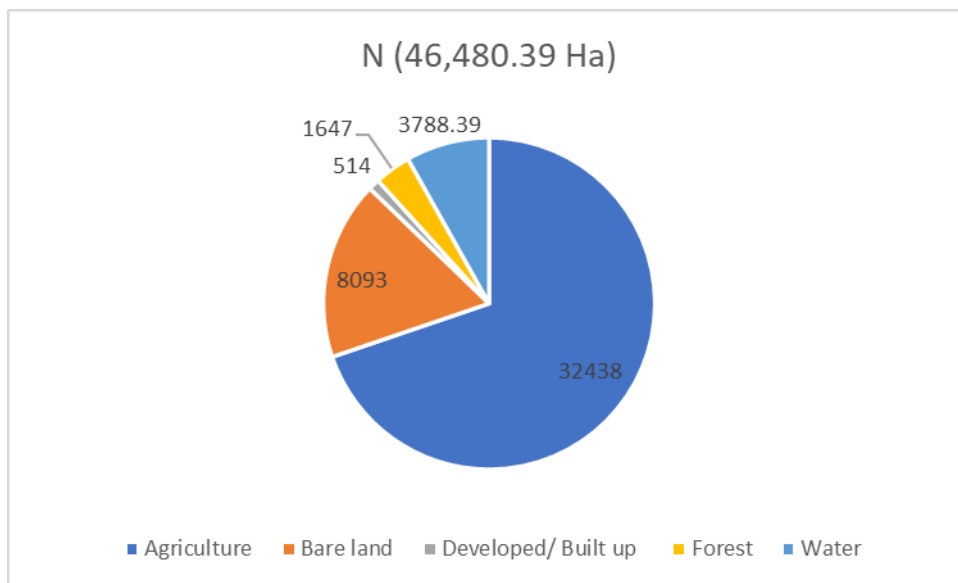


Fig. 4. 27: Land use land cover changes Pie chart for year 2009

#### 4.3.2.4 Land use land cover map for year 2022

Agricultural land occupied 36,118 Hectares (Ha) in 2022, which accounts for 77.68% of the total Catchment area. At 6,175 Ha, bare land accounted for 13.28 percent of the catchment area, behind just 0.99 percent of developed/built up land, 0.48 percent of forest land, and 7.57 percent of water. Compared to 27 years ago, when they were largely contained in the city core, the built-up areas have migrated extensively throughout the Catchment. As seen by patches that extended everywhere, the amount of forested area and bare ground had decreased significantly compared to the previous year's survey. Agricultural land accounted for 77.68% of the catchment area, indicating that this year there were significant changes in land use and cover. For the year 2022, the map displays the land cover and land usage.

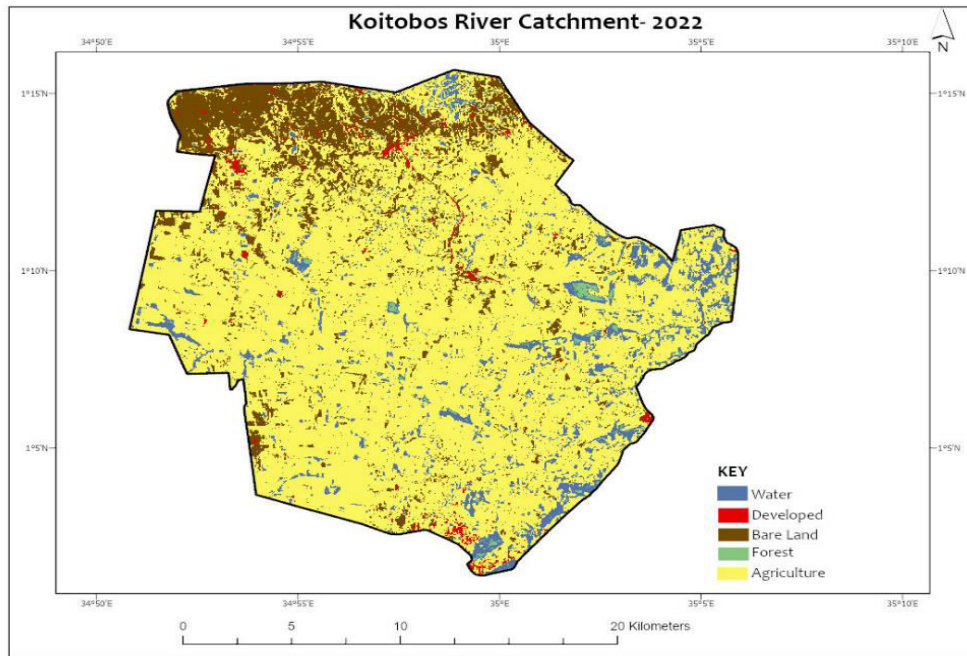


Fig. 4. 28: Land use land cover map for year 2022.

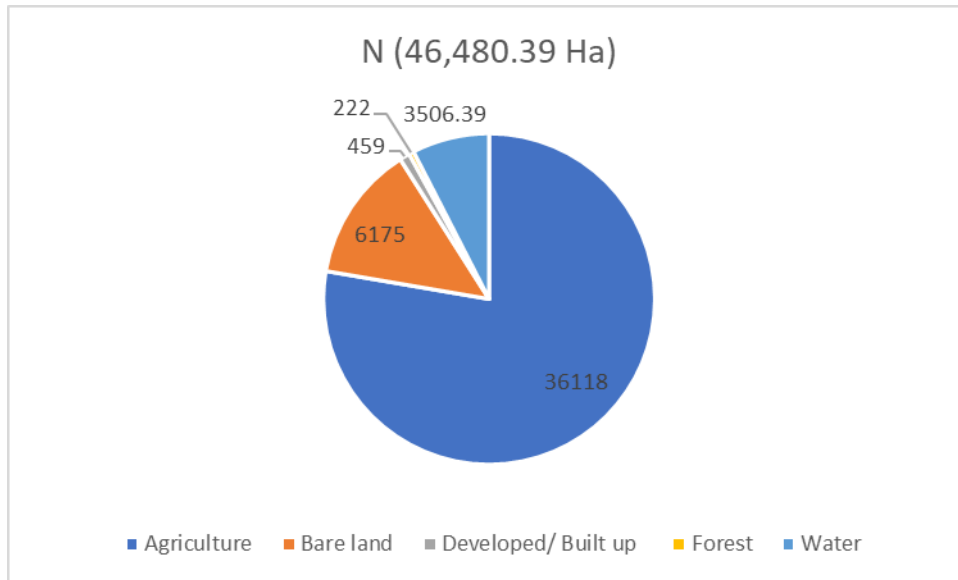


Fig. 4. 29: Land use land cover pie chart for year 2022.

#### 4.3.2.5 Accuracy assessment results for the year 1995

An Accuracy Assessment was carried out to verify that the results of the categorization matched the actual data. To complete this procedure, reference data was utilized with aerial photographs obtained and ground truth GPS points randomly collected from the ground, as the study also made use of data from Google Earth, which included an archive of images spanning the study period. We then calculated the total accuracy, the number of users, and the number of producers for each land use and land cover category identified for the research years (1992 – 2022). During this period of assessment, the study settled on 1995, 2009 and 2022 within the period due to availability of consistent data for analysis especially on seasons across these years.

$$K = \frac{n \times \sum(U_i \times P_i) + \dots + (U_n \times P_n)}{n^2 - \sum(U_i \times P_i) + \dots + (U_n \times P_n)}$$

Where k is the kappa coefficient

n is the total sum of reference points

X is the sum of correctly classified pixels (In the diagonal)

U is the sum of reference point for every class in row

P is the sum of classified points for every class in the column.

With other assessment tools including Confusion matrix, errors of omission and commission.

Table 4. 10: Shows the producers and users accuracy for years 1995, 2009 and 2022 respectively.

Class Name	Reference Total (Col-1)	Classified Total (Col-2)	Correct Number (Col-3)	Producers Accuracy (%) = (Col-3)/ (Col-1)	Users Accuracy (%) = Col-3/ Col-2
Water	10	9	7	70	78
Developed/ Built Up	10	9	7	70	78
Bare land	10	11	8	80	73
Forest	10	13	8	80	62
Agriculture	17	15	15	88	100
<b>Total</b>	<b>57</b>	<b>57</b>	<b>45</b>		

**Note:** Producers' accuracy = Total Correct number/Total Reference

User's Accuracy = Total Correct/ Total Classified

The accuracy evaluation results are expressed in terms of producer and user accuracies. The accuracy of the producer indicates an error of omission, whereas the accuracy of the consumer indicates an error of commission.

Table 4. 11: Shows the Accuracy assessment results for the year 2009.

<b>Class Name</b>	<b>Reference Total =Col-1</b>	<b>Classified Total= col-2</b>	<b>Correct Number= Col-3</b>	<b>Producers Accuracy (%) = Col-3/ Col-1</b>	<b>Users Accuracy (%) = Col-3/ Col-2</b>
Water	10	12	9	90	75
Developed	10	8	8	80	100
Bare land	10	8	7	70	88
Forest	21	11	9	43	82
Agriculture	17	22	20	118	91
<b>TOTAL</b>	<b>68</b>	<b>61</b>	<b>53</b>		

(Source – RS & GIS Data, 2024)

The Table shows the accuracy assessment results for the classification output of the year 2009 represented in terms of producers and user’s accuracies.

Table 4. 12: Shows the Accuracy assessment results for the year 2022.

<b>Class Name</b>	<b>Reference Total =Col-1</b>	<b>Classified Total= col-2</b>	<b>Correct Number= Col-3</b>	<b>Producers Accuracy (%) = Col-3/ Col-1</b>	<b>Users Accuracy (%) = Col-3/ Col-2</b>
Water	10	12	9	90	75
Developed	10	11	9	90	82
Bare land	10	10	8	80	80
Forest	10	8	8	80	100
Agriculture	23	22	20	87	91
<b>TOTAL</b>	<b>63</b>	<b>63</b>	<b>54</b>		

(Source – RS & GIS Data, 2024)

The Table shows the accuracy assessment results for the classification output of the year 2022 represented in terms of producers and user’s accuracies.

#### 4.3.2.6 Accuracy assessment results for the years 1992 - 2022.

An Accuracy Assessment was carried out to verify that the results of the categorization matched the actual data. To complete this procedure, reference data was utilized. In addition to aerial photographs obtained and ground truth GPS points randomly collected from the ground, the study also made use of data from Google Earth, which includes an archive of images spanning the study period. We next calculated the total accuracy, the number of users, and the number of producers for each land use and land cover category identified for the research years.

Table 4. 13: Shows the Overall accuracies and Kappa coefficient.

	1995	2009	2022
Overall Accuracy	78.95	77.94	85.71
Kappa Coefficient	73.42	82.99	81.42

(Source – RS & GIS Data, 2024)

The overall accuracies represent the proportion of correctly identified samples out of the total number of samples. On the other hand, the Kappa coefficient assesses the agreement between the interpreted image and the reference data. The Kappa coefficient indicated that the percentages of 73.42, 82.99, and 81.42 for the years 1995, 2009, and 2022, respectively, were within the acceptable range. These percentages represented high scores in terms of accuracy computation.

#### 4.3.3 Socio economic and demographic responses in relation to variations in surface water from LULCC in Koitobos river catchment.

##### 4.3.3.1 Source of water and farm water harvesting methods

The main source of water used by the residents was from boreholes (38.5%), river (37.8%) springs (21.8%) and wells (1.9%). 38.5% of the respondent's harvest water in their farms using ditches and a cut off drain system.

#### 4.3.3.2 Change in Agricultural practices for the last thirty years.

Table 4. 14: Change in Agricultural practices for the last thirty years.

Farming practices	Increased %	Constant %	Reduced %
Clearing bush/grass (slash, burn, direct plough)	32	12.6	55.4
Irrigation	14.1	48.1	37.8
Grazing	60.9	23.1	16
Fallowing	1.9	45.5	52.6
Tree growing	51.9	32.7	15.4
Fish farming	7.1	68.6	24.3

Source: Field Survey, 2024

In the catchment during the period of study, open livestock grazing rated the highest which resulted to high degradation of surface water resources which as followed by bush clearing /grass (slash, burn, direct plough) that are unsustainable land use practices that highly lead to degradation. Drainage rated the highly reduced at 79.5% and this may have resulted from the reduced surface water resources in the catchment due to land use land cover changes. Irrigation practice has reduced drastically due to inadequacy of water for abstraction in the catchment that has become scarce.

#### 4.3.3.3 Flooding incidences within the Koitobos river catchment.

Disaster experienced in the area is flooding. 69.2% (216) of the respondent experienced flooding with the table below showing the level of affected in percentage for different years. 53.2 percent experienced flooding twice with 55.8% recording an increase change in flooding patterns.

Table 4. 15: Experience with flooding

Time	Percent
1-10 years ago,	21.2
11-20 years ago,	64.1
21-30 years ago,	13.5
over 31 years	.6

Source: Field Survey, 2024

Table 4. 16: Times experienced with flooding.

Times experienced	Percentage	Change	Percentage
Once	3.2	Increased	55.8
twice	53.2	No change	32.1
thrice	32.7	Decreased	12.1
four times	7.7		
more than five times	3.2		
Total	100.0		

Source: Field Survey, 2024

Flooding has frequented in the Koitobos river catchment due to the land use land cover changes and application of the unsustainable land management practices. The experience of 64.1% (200) attests to the frequent disaster of flooding in the catchment and this is because of land use land cover changes.

#### 4.3.3.4 Surface water flow in the Koitobos river catchment due to land use land cover changes.

Table 4. 17: Surface water variations.

		Frequency	Percentage (%)
Valid	Increasing variations	212	68
	Constant	72	23
	Decreasing variations	28	9.0
	Total	312	100.0

Source: Field Survey, 2024

The findings from the respondents showed an increasing variation in the Koitobos river catchment surface water of 68% (212), with 23% (72), showing that no variations had been seen in the flow rate and 9% (28), having observed a decreased flow rate which is attributed to the land use land cover change within the catchment. The variations in the Koitobos river flow rates were attributed to land use land cover changes due to shift from forest cover to open agricultural land that accelerates the surface runoff resulting to increased variations in river flow as no

substance can hold water to reduce runoff. Reduced variations on their farms to the river channels was attributed to increasing take of sustainable land management practices within their farms and thus controlling the surface runoff.

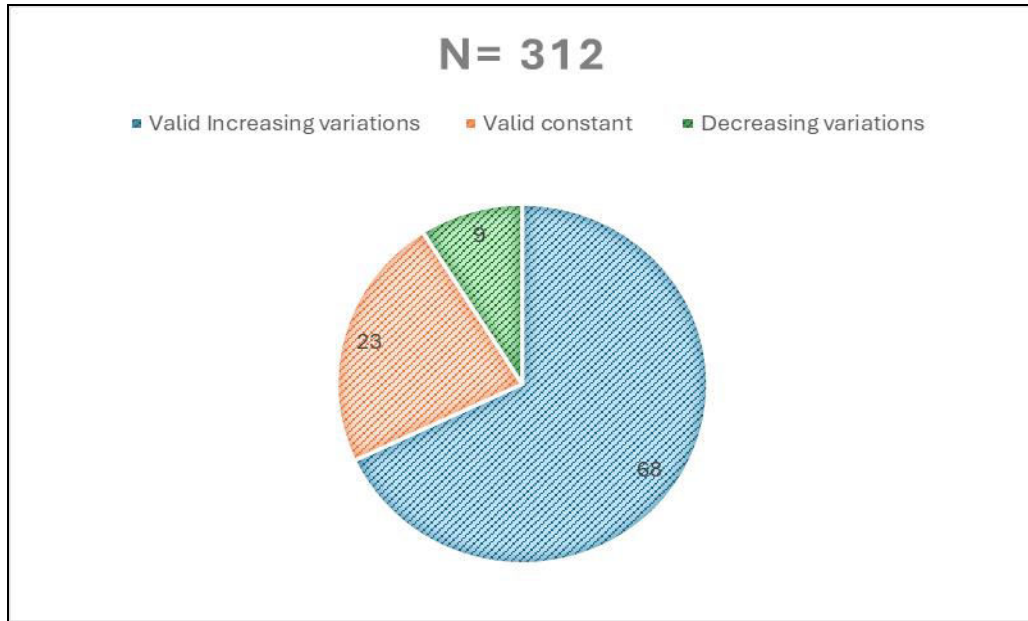


Fig. 4. 30: Surface water variations in Koitobos river catchment.

#### 4.4. Land use/land cover changes evaluation on surface water.

This section stipulates the results from application of the socio-economic survey questionnaires which offers the residents perspective of the situation and the anticipation of the future to help in coming up with the sustainability strategies for livelihoods management in the Koitobos river catchment. Looks into how land use land cover changes in the Koitobos river catchment contribute to surface water availability.

#### 4.4.1 Demographic characteristics of respondents in Koitobos river catchment

This section presents the feeling of the community residents and their views on the future scenario in aspects of land use land cover changes in Koitobos river catchment. Responses on what needs to be done for a better environment and community resilience in the catchment.

##### 4.4.1.1 Response towards the future development of the area

From the study, farming systems, road networks and social status/ standards of living had 56.4% (170), 16.7% (52), and 32.1% (100) responses towards improvement respectively, while road networks and social standards was considered to deteriorating within the catchment and thus affecting the community livelihoods of residents. Figure 4.31 shows a summary of different responses towards different development project objectives.

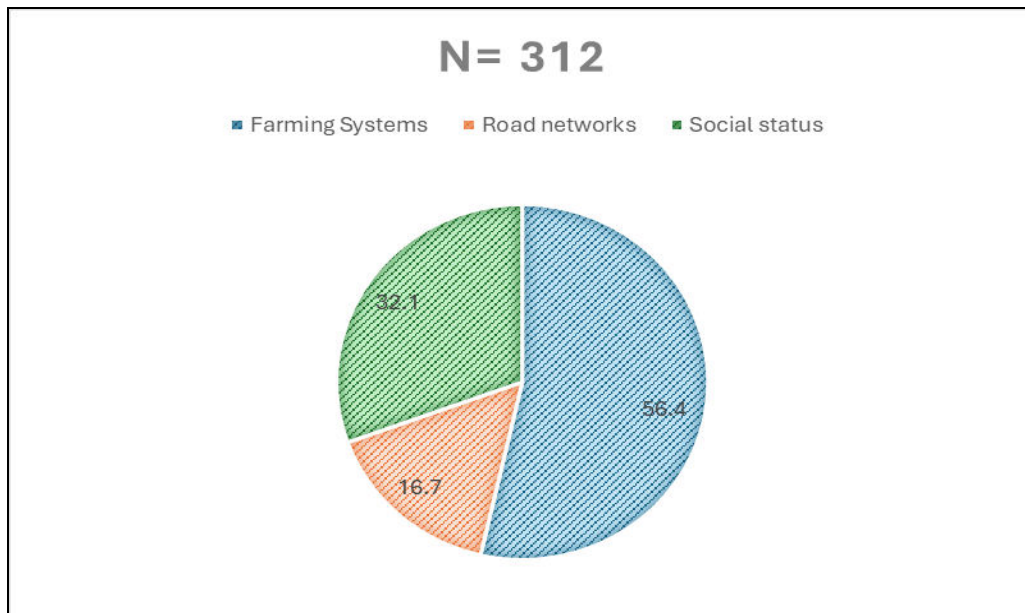


Fig. 4. 31: Response towards the future development of the Catchment area.

#### 4.4.1.2 Programs/projects on integrated land use measures awareness initiated within the catchment.

The study showed that 41.7% (130) of the respondents were aware of programs initiated on integrated land use measures by development agents and other service providers within Koitobos river catchment 30.8% (96) were not aware of such programmes while 27.6% (86) never knew anything. Of those who were aware they noted that 55% of the projects were run by the government, 40% of the projects were run by the non-governmental organizations while 5% were run by faith and Community based organizations. The findings were further represented as shown in figure 4.32.

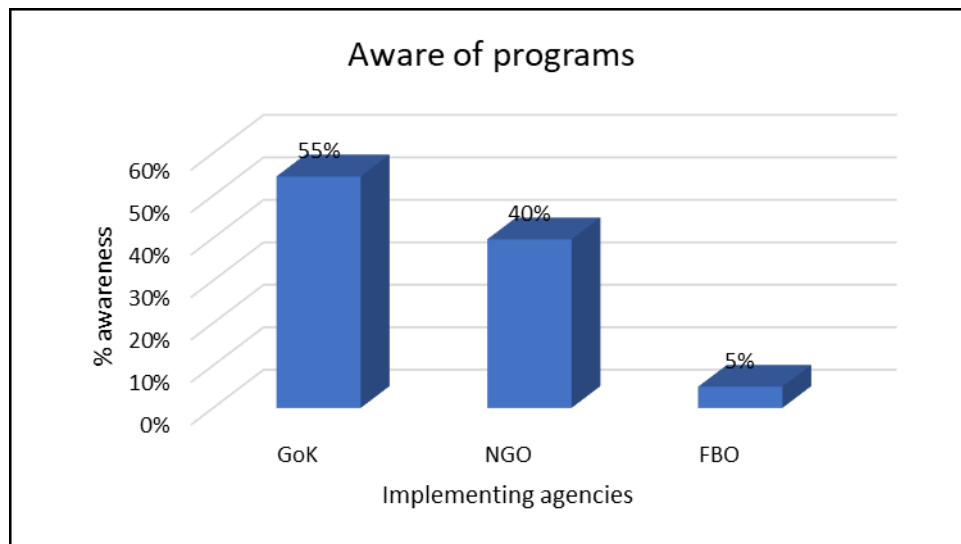


Fig. 4. 32: Response towards the awareness of programs within the area of study.

#### 4.4.1.3 Surface water acreage changes experienced by respondents.

From the study, 47% (147) of the respondent revealed that the frequency of experiencing surface water acreage changes will be very high while 53% (165) of the respondent perceived moderate and low frequency within the Koitobos river catchment. Findings are as shown in the summary table 4.18.

Table 4. 18: Surface water acreage changes experienced by respondents.

	Frequency	Percentage	
Valid	1	18	5.8
	2	28	9.0
	3	118	37.8
	4	132	42.3
	5	16	5.1
	Total	312	100.0

Source: Field Survey, 2024

#### 4.4.1.4 Farming systems and Methods of farming

Different farming systems are undertaken Koitobos river catchment, among them being cultivation across the contour 90.4% (282) and along the contour 9% (28) other farming practices identified was the traditional method of broadcasting 0.6% (2). Different farming methods used include manual method (16.7% (52) and mechanized method 83.3% (260). This contributes much to the change in land use and land cover within the catchment of the river Koitobos.

#### 4.4.1.5 Ploughing times and cropping seasons.

The table below shows the number of times farms are ploughed and number of seasons they plant their crops. It was noted that most of the respondents ploughed their farms twice (75.6%) and planted two seasons (69.9%).

Table 4. 19: Farming operations,

Duration	No times farms are ploughed	Cropping Seasons
Ones	1.90%	7.10%
Twice	75.60%	69.90%
Thrice	19.90%	15.40%
More than four	2.60%	7.70%

Source: Field Survey, 2024

#### **4.4.1.6 Population and land sub-division changes tremendously within the Koitobos river catchment.**

Trans-Nzoia county's population increased from 393,682 in 1989 to 990,341 in 2019, as reported in the Kenyan population census. Subdividing land that grandparents held in the 1990s to give to their children and grandkids is a terrible environmental consequence of a population boom. The County's population grew by 596,659 people between 1989 and 2019, a rise of 60.25 percent, or 1.37 percent each year on average. As discovered in a related study by Maja, M.M., and Ayano, S.F. (2021), such a shift frequently leads to the exhaustion and erosion of natural resources. Lots of land have been levelled to make way for homes and other various human endeavours. As a means of combating food insecurity, all arable land is turned into subsistence farms. More people mean more cattle, which means more competition for water, a resource that has always been in short supply. Few initiatives are underway to raise awareness and improve capacity for environmental management and conservation in the face of a rapidly expanding human population.

Destruction of farmland and other natural vegetation due to sprawling cities has an adverse effect

on ecosystems and habitat quality, hastening the deterioration of our planet. Because of the proliferation of informal settlements in the catchment area, this has also become much more pronounced.

Table 4.20 shows the Population and land sub-division changes within the Koitobos catchment area and predicts that in future trends.

Table 4. 20: Population and land sub-division in the Koitobos river catchment.

Statements	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Population pressure increases land use change and influence surface water in the catchment	45.8%	32.2%	15.3%	5.4%	1.3%
In future land sub-division within the catchment area is going to increase	67.9%	19.9%	7.2%	5.0%	0%

Source: Field Survey, 2024

The findings showed that population pressure increases land use, land cover changes and influence surface water in the Koitobos catchment with 78% (244) agreeing with the statement and about 20% of the population not understanding due to lack of knowledge and unawareness to development aspects within the area. On the projection of future scenario, 87.8% (274) of the population agree that land sub-division in the catchment was going to increase due to the escalating population in the area to meet their demands for space of built and food production. This will pose a negative impact on surface water acreage within the catchment as a result of riparian area encroachment.

## **4.5. Land use practices for Sustainable land and surface water management in Koitobos river catchment.**

### **4.5.1 Introduction**

The third objective sought to evaluate the land use practices adopted for sustainable land and surface water management in Koitobos river catchment, Trans Nzoia county, Kenya. The results were gathered mainly from the questionnaires, Key Informant Interviews (KII), and Focus Group Discussions (FGD) made by the researcher to persons who were either residents or have a stake working in the study area. Participants included Chairperson's and Executive Secretaries of the Water Resource Users at various sub-catchment levels (Farmers), members of the different social classes, such as village leaders, women, youth, traders, National government Officers such as Chiefs and Ast. Chiefs, and NGOs, accessible in the respective villages, and various extension workers (e.g. Agriculture, Forest, health, Water, Lands and Education) and others from NEMA, Kenya Meteorological Department, KWS, WRA, WRUA officials and Traders.

### **4.5.2. Proposed strategies and intervention**

Thematic analysis done on the FGD and interviews yielded certain important information on what could be done to address the negative implications of land use changes to surface water acreage.

#### **4.5.2.1. Sustainable Land Use Management**

A discussion with the experts on sustainable land use management measures within Koitobos catchment proposed strongly the implementation of land resource planning. One of them said that:

*“The systematic assessment of land use potential – is needed to help land users select, adapt and put SLM options (biological, agronomic and structural) into practice in an integrated way in a given farm or wider landscape with the aim of maintaining productivity and restoring degraded land” (FGD, 2021).*

The County Forest Officer suggested the use of agroforestry, which they defined as the deliberate integration of agriculture and forestry to generate productive and sustainable land use practices. These methods capitalize on the symbiotic relationship that can form when trees and shrubs are grown near other agricultural or livestock production systems.

They also advocated for a practice known as "alley cropping," in which trees are planted alongside agricultural crops. The County Forest officer added that they support forest farming, which involves growing high-value crops under the shade of a carefully maintained forest. Interestingly, during my conversations with county officials, I was given advice on how to implement climate-smart agriculture, such as silvopasture, which combines tree-planting with feeds and animal production.

The county environment and water officer suggested the adoption of Sub catchment management plans (SCAMP) for the water resource users existing in the area will help provide guidelines to be followed in management the diminishing water resources by providing options for managing land and water resources within the catchment through proper land use practices.

The FGD also identified windbreaks, or the linear planting of trees and shrubs to improve and safeguard human and animal life as well as soil and water quality, as an effective approach.

The FIRM strategy was also proposed during the FGD meeting. The Forum for Integrated Resource Management (FIRM) is a community-led system that coordinates the efforts of Service Organizations (SOs), non-governmental organizations (NGOs), and funders to better meet local needs and take advantage of available resources. The FIRM method, in essence, takes on community-level issues in sustainable resource management and seeks ways to implement solutions that are both realistic and inclusive. Members of the community can get the help they need to create a management plan through FIRM in collaboration with WRUAs, and then they'll have the skills they need to continue working on the plan on their own. Major successes with FIRM have ensured its widespread application. Communities now feel more invested in their own development plans and the ability to prioritize development and gain support has been boosted. It has enabled the establishment of structures for tracking the progress of and responding to development as FIRM strategy has gained widespread support. This method aids in informing the inhabitants that they can practice climate-smart agriculture, pursue alternative means of subsistence, and refrain from constructing dwellings on steep slopes, riparian and other protected areas.

#### **4.5.2.2. Reforestation of Forest reserves and Management of Water resources**

Reforestation and sustainable management of existing water and forest resources at the stand and landscape scales were both identified as promising avenues for action during the FGD. Further, in line with the United Nations' (2017) mandate on reforestation, they suggested stepping up efforts to stop forest degradation and help to the international fight against climate change through SFM practices including integration of Agroforestry trees in the farming systems.

They also mentioned the strengthening of water resource users in the catchment to ensure sustainable management of available water resources and refrain from cultivating in protected areas for enhanced land and water management.

The FGD also found that there is a demand to better the economic, social, and environmental advantages of land, water and forests, particularly by boosting the living standards of land, water and forest-reliant communities. Also, improve scientific and technical cooperation and collaboration, and raise far more money from more places so that sustainable replanting may be put into action. Finally, they stressed the importance of increasing cooperation, coordination, coherence, and synergies on water, land and forest-related issues at all levels, including inside governmental institutions, across sectors, and among important stakeholders.

#### **4.5.2.3. Avoiding human settlement in designated protected and fragile environments.**

Discussions in the KII and FGD indicated that there has been steady increase in population within the study site for the past decades, this is attributed to increase in the numbers of the indigenous community in addition to those who migrated to the area through land purchase. This increase in population has led to more fragmentation of land into smaller units leading to others settling in encroached areas such as steep slopes and riparian areas. The FGD discussions brought out the need to have awareness creation within the communities on participatory approaches to sustainable land use and surface water management.

## **CHAPTER FIVE**

### **SUMMARY, CONCLUSION AND RECOMMENDATIONS**

#### **5.1 Introduction**

This chapter presents a summary of the study findings, the conclusions made thereafter and finally, several recommendations as put forward by the researcher. The overall objective of this study was to assess the implications of land use, land cover changes on the surface water acreage in the Koitobos river catchment between 1992 and 2022. Specifically, the study examined the extent of land use/land cover changes within the river catchment, assessed the variations in surface water acreage in the catchment, and evaluated Land use practices for sustainable surface water management. This chapter summarizes the major findings recorded and discussed in chapter four, conclusions from the findings, and recommendations, besides presenting suggestions for further study.

#### **5.2 Summary of the Findings**

##### **5.2.1 Extent of land use, land cover changes within Koitobos River catchment**

The study findings revealed that different farming system were undertaken within Koitobos river catchment, among them being cultivation across the contour and along the contour while other farming practices identified were the traditional method of broadcasting, including manual and mechanized method and most of the respondents plough their farms twice and planted crops over the two seasons.

It was noted that while arable land had reduced, land prices had increased and therefore these had led to decrease in on farm yields. Generally, transport was a factor that was difficult to

access and access to extension support was very low. The study revealed that vegetation cover had reduced with the ratio of deforestation and afforestation not being directly proportional.

Fertile farmland has been lost due to the growth of urban built-up surfaces. The fact that the Koitobos River watershed is already spreading into riparian regions where irrigated agriculture is the dominant economic activity lends acceptance to this theory. The present trend of agricultural land parcel fragmentation proves beyond a reasonable doubt that it was no longer economically viable.

A combination of factors, including fast population growth, inadequate environmental control frameworks, and poor governance, has contributed to a decline in environmental quality in the area surrounding the Koitobos River and its basin. Locals' failure to strictly adhere to government restrictions governing land usage also contributes to the environmental damage. The main reasons for land degradation were changes in land cover and unsustainable land use practices. Some of these practices in the catchment were excessive removal of forests and plants, overgrazing cattle, and other similar activities.

### **5.2.2 Variations in surface water acreage in the Koitobos River catchment.**

The study findings revealed that the main source of water used by the residents within the catchment was from boreholes, rivers, springs, and wells while others harvested water in their farms through ditches and cut off drain systems. More so, irrigation practice, river water source, harvested water were used by residents in the Koitobos catchment.

Residents' population experienced drying of the water springs and reduced river volumes throughout the year attesting the effects of poor farming activities in the catchment as a contribution with an increased frequency in the flooding patterns due to the variations in rainfall

intensity. Majority of the residents within the catchment area had not established soil erosion control structures on the farms which resulted in to varied extent of surface runoff that contributes to change in surface water in the Koitobos river catchment due to high siltation.

Different environmental protection measures that included, building of gabions, planting Agroforestry trees along the riverbanks, constructing levees and other soil conservation structures had been taken up by few people within the area. Several springs had not been protected for better environmental measures in Koitobos river catchment for provision of quality water for the residents.

### **5.2.3 Land use practices for sustainable land and surface water management in the Koitobos River catchment.**

The study findings revealed that farming systems would improve through the application of sustainable agricultural land management practices while road networks and community social standards were highly deteriorating.

The residents of the study area had not been well sensitized on programs initiated along the catchment, it was also noted that projects in the catchment were run by the government, non-governmental organizations and faith-based organizations which were focusing on the well-being of the people.

It was realized that projections on population increase exerted pressure on land use/land cover changes thus influencing surface water acreage in the river catchment due to land sub-division which reflects to be changing tremendously, depicting that future pressure on the land resources anticipated to increase. It was also noted that increased unsustainable human and farming activities will impact on land cover changes in the Koitobos river catchment and the climatic

changes will influence food security negatively, which will in turn be a determining factor of land use, land cover changes in the area. Also, the study guided that the growth of towns and urban centers within Koitobos river catchment will influence the vegetation cover and human activities undertaken.

The analysis revealed substantial alterations in land use/land cover within the Koitobos River watershed area throughout the previous three decades. The area has experienced a decrease in forestland and shrubland, accompanied by a rise in cultivated land and artificial surfaces with deforestation being particularly noticeable inside the Koitobos watershed. The Koitobos river is experiencing significant siltation downstream, which is closely associated with the rise in soil erosion due to changes in land use and land cover. The main drivers for land use and land cover change (LUCC) in the study catchment were rapid population growth and GDP, along with macroeconomic activities concentrated in the western part of the river, such as manufacturing industries. Additionally, poor national policies have failed to effectively enforce a ban on the uncontrolled harvesting of forest resources. To address these issues, it is necessary to thoroughly evaluate and revise ineffective policies that promote noncompliance with legislation for the management of natural resources. For instance, any practices that promote or lead to soil erosion, such as cultivating riverbanks, should be revised. Local authorities should be granted the authority to actively participate in environmental protection and tree planting initiatives. Additionally, the government should have the ability to supply seedlings for these endeavours. The government should implement intentional initiatives to mitigate the ongoing impacts of climate variability, such as droughts and floods. These measures may involve promoting effective agricultural practices that preserve and safeguard soil against water erosion, discouraging cultivation along riverbanks, enhancing afforestation programs. The study findings

revealed that the primary factors contributing to changes in land use and land cover in this region were agricultural practices, population expansion, infrastructure development, climate change, and land tenure systems. Hence, there is a necessity to develop sustainable conservation methods and policy policies to safeguard the water resources in the region. Cheruto, et al, (2016) conducted studies in the Moiben and Chepkaitit rivers' watershed. Their analysis showed that the region had undergone gradual conversion to other land use and land cover (LULC) due to significant population pressure. From 1980 to 2020, there was a notable shift in land use and land cover (LULC) patterns. While the area of agricultural land was expanding, the extent of bush land, forest, and wetlands was decreasing. This suggests that deforestation was taking place in the region to make way for cultivation. In addition, the wetlands had been converted to accommodate agriculture because of the growing population in the surrounding area. The need to produce more food created pressure, leading to changes in land use and land cover (LULC).

### **5.3 Conclusions of the study**

Koitobos river catchment has experienced major land-use changes between 1992 and 2022. In the period of land use analysis for the study, the highest decline was in natural forest, with highest increase in cropland. The second most affected land use was the surface water resources (water bodies), which provides almost similar ecosystem services for the community livelihoods as most human activities are dependent on it. The land- use changes also led to increased land area under farming activities, especially due to food and financial motivations. Land use change tends to negatively affect natural forests and surface water resources because of the ever-increasing social, demographic, and economic demands of people in the catchment. These findings will be useful in management of water resources within Koitobos river catchment in

Trans Nzoia County, and aid in planning based on rainfall forecasts to avert water crisis scenarios in the county and resulted in the three main conclusions.

The study concluded based on the first objective, from the identified land use, land cover in the area, surface water bodies reduced drastically in the Koitobos river catchment due to reduced forest cover and increased agricultural land from the demanding population. Most of the surface water bodies noted to be drying up due to other land cover changes in the study area as the forest cover was decreasing consistently over the years (1992-2022). The agricultural land (farmlands) was increasing gradually over the years at the rate of 34 percent from 1995 to 2022, contributing to reduction of surface water acreage, forest cover and bare land. It can thus be concluded that most forests being cleared, and bare land reducing were inevitably converted to agricultural land and grasslands thus degrading the land and making it susceptible to environmental degradation in the Koitobos river catchment area of Trans Nzoia, Kenya.

Secondly, the study concluded based on the second objective, that Land use changes categorized by conversions in agriculture, forest and grassland affected surface water acreages in the Koitobos river catchment. The correlational analysis between Land use land cover changes and surface water acreage variations and further, from the FGDs and the Key Informants Interviews, showed a significant consensus to the positive link between land use land cover changes categorized by agricultural practices, human activities such as deforestation, increased population, urbanization, and surface water acreages in Koitobos river catchment in Trans Nzoia, Kenya.

Also, it came out that most of the inhabitants of Koitobos catchment area had experienced drying of the water springs and reduced surface water resources throughout the year resulting in poor

farming activities. It summed up that reduction in forest land cover and increase in Agricultural land cover within the catchment resulted in the reduction of water bodies and drying up of most water sources in the catchment.

Finally, the study concluded that farming systems should be improved through the application of sound and sustainable land management practices. These coupled with population increase exerted pressure on land use and land cover changes thus influencing degradation of the river catchment due to land sub-division which predicted future compression on the land resources.

The study determined that implementing sustainable soil and water management strategies, along with adopting sustainable agricultural land management techniques, will consistently restore the land and preserve biodiversity in the Koitobos river basin.

#### **5.4. Recommendations**

The recommendations were generated based on negative findings from the concluded study with the aim of soliciting viable interventions. The study recommends that: the impact of LULC changes to the river discharge is not impressive and thus, the study recommends that deforestation should be controlled by all. The locals, the environmentalists and the forest department should all take their initiatives. The laws that govern forest resources should be re-visited and thorough routine checks be done.

Forest management authorities should normalize disciplinary measures through penalties for the policy breakers and the authorities should ensure that reforestation be done in the government forest lands that have been degraded. The landowners living in the catchment and riparian areas of Koitobos river should be encouraged to plant more agroforestry trees species in their farms as good protectors of the soil.

Firstly, there is need for establishment of sustainable soil and water management measures to uphold biodiversity conservation. Secondly, restoration of forest cover and restraining the local communities from opening new areas for cultivation on critical slopes, particularly within the protected areas is critical.

And finally, recommended that all the proposed major developments in the Koitobos catchment which are likely to have environmental implications be subjected to Environmental Impact Assessment (EIA), in accordance with the provisions of Environmental Impact Assessment regulations of 2003. This proposal should be enforced by the National Environment Management Authority (NEMA) in conjunction with the local and county Authority.

The protection of fragile ecologies like the riparian vegetation and forests covers against encroachment by other human caused activities to be enforced by the laid down government policies. The land use suitability analysis is also imperative in protecting human life and property. Loss of life and property may arise due to disaster as occasioned by poor location of land uses such as the residential developments along the riparian reserves which are prone to occasional flooding disaster.

The study recommended that sustainable land Management practices should be adopted to mitigate the exceptional adverse climate impacts that increasingly threaten the resilience of communities, Agriculture, food, and nutritional security within the catchment.

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## APPENDICES

### APPENDIX I: RESEARCH INTRODUCTORY LETTER

Dear Respondent,

My Name is Bramwel Wotia Soita, a master's student at Masinde Muliro University of Science and Technology, pursuing a Master of Science in Climate Change Mitigation and Adaptation degree. As a requirement of the institution, I am supposed to conduct academic research to meet the requirement as a master's degree graduate. I am currently undertaking a research study on **'Land use, land cover changes, and implications on surface water acreage in the Koitobos river catchment, Trans-Nzoia County Kenya.'** Categorically, I seek to

- i. To assess the extent of land use, land cover changes in Koitobos River catchment of Trans Nzoia County Kenya.
- ii. To examine the variations in surface water acreage in Koitobos river catchment due to land use land cover changes of Trans Nzoia County Kenya.
- iii. To evaluate Land use, land cover change for the future in Koitobos River catchment.

You have been selected to participate in this study, and I am kindly requesting you to assist in providing the required information to the best of your knowledge by responding to the questionnaire attached. The information is strictly for academic purposes and personal information will be handled with utmost confidentiality. Your kind assistance will be highly appreciated.

Yours faithfully,



Wotia Soita Bramwel,

Master's student at Masinde Muliro University of Science and Technology.

## APPENDIX II: SURVEY QUESTIONNAIRE

1. Indicate your gender using a tick ✓  
Male ( ) Female ( )
2. What is your marital status?  
Married (Monogamous)[ ] Married (Polygamous)[ ] Divorced[ ] Separated[ ]  
Widow or Widower[ ] Bachelor/single [ ]
3. Indicate your age bracket.  
Below 25 years [ ] 25-35 years [ ] 36-45 years [ ] Above 45 years [ ]
4. What is the size of your household?  
No child [ ] Less than three children[ ] 3-5 children[ ] 6-10 children [ ]  
Over 11 children [ ]
5. What is your occupation?  
Farmer [ ] Businessperson [ ] Both [ ] Other (Specify).....
6. What is the size of land owned?  
Less than 1 acre [ ] 1-3 acre [ ] 4-7 acre[ ] 8-15 acre [ ] Over 16 acres [ ]
7. Have you ever sold land in the last 5 years?  
Yes [ ] No [ ]
8. What is the period you have resided in this place?  
Less than 1 year [ ] 1-5 years [ ] 6-15 years [ ] 15-30 years [ ] Over 31 years[ ]
9. What is the settlement pattern around your neighborhood?  
Clustered [ ] Sparse [ ] Linear (along the river channel)[ ] Other [ ]
10. Which level of education have you attained?  
Primary [ ] Secondary [ ] Tertiary [ ]
11. What is your estimated level of income per month?  
Dependent [ ] Less than Ksh. 3000 [ ] Ksh. 3,000-9,000[ ]  
Ksh. 10,000-29,000 [ ] Ksh. 30,000-49,000 [ ] Ksh. Over 50,000 [ ]

### SECTION B: STUDY VARIABLES

#### Assessing the extent of land use, land cover changes in Koitobos River catchment.

12. Do you have any livestock animals reared in your farm?  
Yes [ ] No [ ]

13. If yes, please indicate the specific number of animals in the table below.

Livestock	Number
Cows	
Sheep	
Goats	
Poultry	

14. How do you manage/rare the animals mentioned in 13 above and for how long?

Livestock management practices	Less than 3 months	3-6 months	6-12 months
Conventional system/free range			
Improved management/zero grazing			
Paddocking			

15. Which farming systems do you usually use in your farm?

Across the contour farming  Along the contour  Other, specify

16. Which methods of farming do you use in agricultural activities?

Manual Method  Mechanized method  Other

17. How many times do you plough your land before planting?

Once  Twice  Thrice  More than four times

18. How many cropping seasons do you practice in your farm?

One  Two  Three  More than four

19. Have you planted any trees in the last 5 years? Yes..., No....

20. If yes, which type of trees?

Long-term trees e.g. Eucalyptus, Cyprus, Grevillea, Elgon Teak and others

Short-term/Agroforestry trees e.g. Sesbania, Syzygium, Calliandra and others

21. Please indicate whether you use the following farming practices.

<b>Farming practices</b>	<b>Yes</b>	<b>No</b>
Clearing bush/grass (slash, burn, direct plough)		
Drainage		
Irrigation		
Grazing		
Fallowing		
Tree growing		
Fish farming		

22. Please indicate whether you use the following soil conservation structure.

Terracing                    1). Yes [ ]    2). No [ ]

Contour ploughing    1). Yes [ ]    2). No [ ]

Cover cropping        1). Yes [ ]    2). No [ ]

Others specify.....

23. Since you came/settled here, what has changed?

Land size (reduced/increased) explain.....

Land price (reduced/increased) explain.....

Vegetation (explain).....

Food harvest (increased/reduced) explain.....

Transport (easy/difficult) why? .....

Extension support (high/low). Explain .....

**Variations of surface water in Koitobos River catchment of Trans Nzoia County**

24. What is your source of water for domestic/household consumption?

Springs [ ] Boreholes [ ] River [ ] Well [ ] Others, Specify.....

25. Do you practice on-farm water harvesting?

Yes [ ]                    No [ ]

26. If yes, what are some of the on-farm waters harvesting techniques do you usually use?

List below

.....  
.....

27. Please indicate the extent to which you have either increased or reduced the following agricultural practices in the last two years.

Farming practices	Increased	Constant	Reduced
Clearing bush/grass (slash, burn, direct plough)			
Drainage			
Irrigation			
Grazing			
Fallowing			
Tree growing			
Fish farming			

28. Do you practice any micro-irrigation on your farm?

Yes  No

29. If yes, what is your source of water for irrigation?

Diverted water from the river  Harvested rainwater

Spring/well/boreholes  Other, specify.....

30. Since you settled in this place and until now, have there been any existing wells and springs that dried up?

Yes  No  I don't Know

31. Does the river close to you have water throughout the year?

Yes  No  I do not know

32. Have you ever experienced any flooding?

Yes  No  I do not know

33. If yes above, when did you first experience flooding?

1-10 years ago  11-20 years ago  21-30 years ago  Over 31 years ago

34. If yes, above, how many times in the last ten years have you experienced flooding?

Once  Twice  Thrice  Four times  More than Five times

35. If yes above, is the frequency of flooding increasing or decreasing?

Increasing  no change  decreasing

36. Do you have any soil erosion control structures on your farms?

Yes  No

37. If yes, above, which one? You can select more than one.

Terraces [ ] Trash lines [ ] Grass strips [ ] Cut-off drains [ ] Trenches [ ]

Contour planting [ ] Cover cropping [ ] Allaying cropping [ ] Gabions [ ]

38. To which extent do you usually use the above-mentioned soil conservational structures?

Very great extent [ ] great extent [ ] moderate extent [ ] low extent [ ] no extent

39. Which environmental protection measures do you use to prevent flooding?

Building Gabions [ ] Planting trees along the riverbanks [ ]

Constructing levees [ ] Construction of other soil and water conservation structures [ ]

40. Do you have spring/well protection measures?

Yes [ ] No [ ] I do not know [ ]

**Land use land cover change evaluations for the future within Koitobos River catchment**

41. In your own view, what is your response towards the future development of this place based on the following, respond by selecting one option and giving a brief explanation why?

Farming systems (improving, no change, deteriorating).....

.....

Road Networks (improving, no change, deteriorating) .....

.....

Social Status/standards of living (improving, no change, deteriorating) .....

.....

42. Are there any programs/projects initiated along the catchment?

Yes [ ] No [ ] I do not know [ ]

43. If yes above, which institution is involved/runs the project/program?

Government [ ] Non-Governmental Organization [ ]

Faith-based organization [ ] Others, specify.....

44. In your own view, give your response to the following statement, “population is expected to increase and the pull to settle and the push to be food secure will influence land cover and cause tremendous changes to the future of Koitobos River catchment.”

Strongly Agree [ ]    Agree [ ]    Neutral [ ]    Disagree [ ]    Strongly Disagree [ ]

45. In your own view, give your response to the following statement “Land sub-division in the future within the catchment area is going to be high.”

Strongly Agree [ ]    Agree [ ]    Neutral [ ]    Disagree [ ]    Strongly Disagree [ ]

46. In your own view, state the extent to which the following statements influence land cover land changes in the future within Koitobos River catchment.

Statements	Great extent	Moderate extent	Low extent	No extent at all
Human activities will influence land cover land change within the river catchment				
Climatic changes will influence food security, which will in turn influence land cover land changes within the river catchment				
The growth of towns and urban centers will influence the vegetation cover and human activities within Koitobos River catchment				

47. In your own opinion, what do you think should be done to shape the future of land cover changes within the Koitobos River catchment? Briefly explain.....

**ADDITIONAL QUESTIONS ON DEPENDENT VARIABLE**

48. In your own observation, how do you rate surface water run-off experienced in the last rainy season? 1 [ ]    2. [ ]    3[ ]    4 [ ]    5 [ ]

49. How has been the river flow rate trend in the last five years?

Increasing [ ]    constant [ ]    decreasing [ ]

*Thank for your time.*

### APPENDIX III: INTERVIEW SCHEDULE FOR COMMUNITY MEMBERS

**Instructions:** *For Researcher- after brief introductions and sharing the purpose of the study with respondents, the researcher should start the interview session. Interview questions should be shared with the respondents.*

- i. In your own understanding, give a history of the extent to which land has been used and how land cover changes have affected the surface water acreage within the Koitobos River catchment.
- ii. Give your comments and views on surface water variations in Koitobos river catchment.
- iii. What sustainable management measures do we require for sustainable land and water management in Koitobos River catchment?

#### **APPENDIX IV: FOCUS GROUP DISCUSSION SCHEDULE**


**Instructions:** For Researcher- after brief introductions and sharing the purpose of the study with respondents, the researcher should outline the roles/expectation of each member and start the discussion session. Allow members to story tell and discuss based on the following topics.

- i. Assessing the land use and land cover changes activities in Koitobos River catchment
- ii. The variations on surface water acreage in Koitobos river catchment.
- iii. Through Land use and land cover change, how can we sustainably manage land and surface water resources in the Koitobos River catchment

**APPENDIX VIII: NACOSTI PERMIT**

THIS IS TO CERTIFY THAT:  
**MR. BRAMWEL WOTIA SOITA**  
**of MASINDE MULIRO UNIVERSITY OF**  
**SCIENCE AND TECHNOLOGY, 2721-30200**  
**KITALE, has been permitted to conduct**  
**research in Transzoia County**  
**on the topic: LAND USE AND LAND**  
**COVER CHANGE INFLUENCE ON WATER**  
**DISCHARGE IN THE KOITOBOS RIVER**  
**CATCHMENT, TRANS-NZOIA COUNTY**  
**KENYA**  
**for the period ending:**  
**22nd May, 2019**

**Permit No : NACOSTI/P/18/69643/22356**  
**Date Of Issue : 25th May, 2018**  
**Fee Recieved :Ksh 1000**



*[Handwritten Signature]*  
**Director General**  
**National Commission for Science,**  
**Technology & Innovation**

## APPENDIX IX: NACOSTI AUTHORIZATION



### NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone: +254-20-2213471,  
2241349, 3310571, 2219420  
Fax: +254-20-318245, 318249  
Email: dg@nacosti.go.ke  
Website: www.nacosti.go.ke  
When replying please quote

NACOSTI, Upper Kabete  
Off Waiyaki Way  
P.O. Box 30623-00100  
NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/69643/22356**

Date: **25<sup>th</sup> May, 2018**

Bramwel Wotia Soita  
Masinde Muliro University of Science  
And Technology  
P.O. Box 190-50100  
**KAKAMEGA.**

#### **RE: RESEARCH AUTHORIZATION**

Following your application for authority to carry out research on "*Land use and land cover change influence on water discharge in the Koitobos River Catchment, Trans-Nzoia County Kenya,*" I am pleased to inform you that you have been authorized to undertake research in **Trans Nzoia County** for the period ending **22<sup>nd</sup> May, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Trans Nzoia County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

**GODFREY P. KALERWA MSc., MBA, MKIM  
FOR: DIRECTOR-GENERAL/CEO**

Copy to:

The County Commissioner  
Trans Nzoia County.

The County Director of Education  
Trans Nzoia County.

*National Commission for Science, Technology and Innovation is ISO9001:2008 Certified*

## APPENDIX X: UNIVERSITY AUTHORIZATION

Tel: 056-30871/31561  
Fax: 056-30153  
Email: [cdmha2004@yahoo.com](mailto:cdmha2004@yahoo.com)  
Website: <http://www.mmust.ac.ke>



P.O Box 190  
Kakamega - 50100  
Kenya

### MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY

#### SCHOOL OF DISASTER MANAGEMENT AND HUMANITARIAN ASSISTANCE

Department of Disaster Preparedness and Engineering Management

**Our Ref:** MMU/COR: 542018

**Date:** 11<sup>th</sup> April, 2018

#### TO WHOM IT MAY CONCERN

Dear Sir/Madam,

**RE: PERMISSION TO CONDUCT A RESEARCH FOR BRAMWEL WOTIA SOITA  
CCA/G/03/14**

The above subject refers.

The bearer of this letter is a bonifide student at the School of Disaster Management and Humanitarian Assistance (SDMHA) of Masinde Muliro University of Science and Technology (MMUST). He is pursuing an MSc. Degree in Climate Change Adaptation and Sustainable Development.

He is therefore conducting a research entitled "*Land use and land cover change influence on water discharge in the Koitobos River Catchment, Trans-Nzoia County - Kenya*" as a requirement for award of the Masters Degree.

All data acquired will be acknowledged in the study findings

Any assistance accorded to him will be highly appreciated

  
Dr E. N. Masibayi  
Chairman, Department of Disaster Preparedness and Eng. Management

