SPATIO-TEMPORAL VARIATIONS IN LAND USE LAND COVER AND THEIR IMPACTS ON THE HYDROLOGY OF A RIVER BASIN

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JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

2024

DECLARATION AND RECOMMENDATION

Student's Declaration

This thesis is my original work and has not been presented for an award of a degree in any other university or institution. I also declare that all information, material, and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Dedication

I dedicate this dissertation to my lovely wife Gavin Akinyi Ogembo for the prayers, encouragement, and support during the research. The dedication also goes to my parents, Walter Obuya and Annah Aoko for their constant support and prayers that encouraged me to work hard in order to accomplish the best. To my daughters Flavian Favour and Jenifer Legacy. Also, to my siblings Christine, Mercy, Peter, Brian, Barack, Jael and my niece Saline.

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ABSTRACT

Changes in land use land cover (LULC) are consequences of anthropogenic activities on the surface of the land and they are linked to the hydrologic dynamics of a river basin. River Kuja basin has experienced rapid LULC changes over the past decades with alterations in the surface water. However, little is known about LULC changes in the basin that and how they impact on the surface water. The study aimed at investigating LULC changes and their impacts on the hydrology of the River Kuja basin. Specific objectives were: to determine LUCL changes in basin; to simulate changes in the basin hydrology; and to assess the perception of local communities of the impact of anthropogenic activities on the hydrology of the basin. The study adopted the systems theory, while the Driver-Pressure-State-Impact-Response model was used as a framework for analysis. The study used time series and cross-sectional survey design. Thirty years with four (4) decadal satellite images of 1990, 2000, 2010 and 2020 were downloaded and processed to determine land use land cover changes. Hydrological modelling through HEC-HMS model was used for rainfall-runoff simulation to determine the impact of LULC changes on the streamflow. Local communities' perceptions were investigated by administering questionnaires to a sample population size of 400 households. Remote sensing technology (Google Earth Engine (GEE) was used in analysing satellite images. Regression analysis was done for hydrological simulation between observed streamflow data and the HEC-HMS model parameters. Analysis of questionnaires was done using SPSS and Minitab softwares. Simple linear correlation matrix was used to show relationship between LULC changes and Kuja basin hydrology. Perceptions were analysed using percentages, while content analysis was used for qualitative data from key informants. Results have been presented using maps, figures, tables and graphs. The results show that there was an overall land use land cover change of 82% in the study area. Surface water resources reduced by 12.2%. The satellite images analysis gave an accuracy of 85%. The basin's anthropogenic activities had an indirect but significant effect on the hydrology (p-value = 0.037) as well as having a direct and significant influence on the land cover changes (p-value = 0.025). Negative correlation was found between water bodies (WaB) and agriculture (Agr -0.96), urban (Urb -0.84) bare land (BaL -0.98) and population (-0.91). Positive correlation was observed between the water bodies and forests (Fr 0.93), shrub land (ShL 0.49) and grass land (GrL 0.27). The hydrologic modelling regression analysis resulted in correlation coefficient value of 0.64 showing a positive moderate relation between hydrology of the basin and LULC change, and a coefficient of determination value of 0.41 showing that 41% of the change in hydrology is associated with the change in LULC. For objective three, 75.0% of the respondents acknowledged land use changes. 78.8% recognized variations in weather and hydrological patterns while 65.6% noted the change in River Kuja flow over the 30 years. Land degradation was also a major problem as reported by 95.0%. The results revealed that changes in land use land cover contributed to the declining surface water resources causing alteration in the hydrologic system of the basin. As such, there is a need for designing and enforcing catchment conservation and policy measures, building the capacity of locals on basin conservation; fostering flood awareness and warnings to communities, and constructing flood/inundation control structures in the flood prone areas.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Lands
CN	Curve Number
CRB	Colorado River Basin
CSPro	Census and Survey Processing System
DEM	Digital Elevation Model
DMS	Demand Management Strategy
DRSRS	Department of Resource Surveys and Remote Sensing
DSS	Data Storage System
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GCM	Global Climate Model
GIS	Geographic Information System
GUI	Graphical User Interface
HEC-GeoHMS	Hydrologic Engineering Centre – Geospatial Hydrologic Modelling System
HEC-HMS	Hydrologic Engineering Centre – Hydrologic Modelling System
HRB	Heihe River Basin
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
KenGen	Kenya Electricity Generating Company
KII	Key Informants' Interviews
Km	Kilometres
KMD	Kenya Meteorological Department
KMD	Kenya Meteorological Department
KNBS	Kenya National Bureau of Statistics
LULC	Land Use Land Cover
LVSWSB	Lake Victoria South Water Services Board
LVSWWDA	Lake Victoria South Water Works Development Agency

MDB	Murray–Darling Basin
MODIS	Moderate Resolution Imaging Spectroradiometer
MRB	Mara River Basin
MW	Mega Watts
NPP	Net Primary Productivity
NRCS	Natural Resources Conservation Service
NSE	Nash – Sutcliff Efficiency
O3	Ozone
R	Regression
SCS	Soil Conservation Service
SCS	Soil Conservation Service
SMA	Soil Moisture Accounting
SPSS	Statistical Package for the Social Sciences
STRM	Shuttle Radar Topography Mission
TR-55	Technical Release No. 55
UH	Unit Hydrograph
UN	United Nations
UNEP	United Nations Environmental Program
USACE	United States Army Corps of Engineers
USD	United States Dollars
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WEAP	Water Evaluation and Planning System
WRMA	Water Resources Management Authority
WRUA	Water Resources Users' Association

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Land use land cover (LULC) changes contribute to the alteration of global terrestrial environmental system and is considered to be the main factor affecting natural vegetation cover (Lin, Verburg, Chang & Chen, 2009). Escalating adverse changes on earth's surface have been attributed to both natural and anthropogenic factors (Aspinal & Hill, 2008). In recent decades, researchers have emphasized the need for inclusion of LULC discipline in climate change studies arguing that it is a major driver to climate change (IPCC 2011; Sleeter, Loveland, Domke, Herold, Wickman & Wood 2018). LULC changes alter the sustainability of various biophysical resources including water, soil, vegetation and agriculture. LULC changes include clearance of natural ground cover for other anthropogenic activities such as farming, human settlement, industrialization, urbanization among others. The impacts of these changes on the earth surface have attracted much research efforts in areas such as hydrological balance, water quality, global warming, droughts and flooding (Lambin, Rounsevell & Geist 2000), biodiversity loss and deforestation, as well as soil degradation (Dwivedi 2005). According to Su, Fu, Lu, Zeng and He (2011), land use land cover patterns in a given region is as a result of anthropogenic and socio-economic factors in time and space. The changes in these patterns have, thus, impacted on the natural resources, caused land related conflicts, and increased human vulnerability (Kagwanji, 2009; Bob 2010).

The performance of ecosystem services is directly linked to the type and intensity of LULC, and associated management practices in a given area. In other words, what defines land cover depends on land uses and the management practices which goes into the land use (Abellán, Sánchez-Fernández, Velasco & Millán, 2007). This explains therefore why changes in land use and land cover can alter the supply of ecosystem services and affect the well-being of both human and nature. Several factors, define land cover and they include anthropogenic activities (land use), geographical location, altitude and morphology (Gilma, Abell, & Williams, 2004). Any land use leads to a proportionate change in the land cover. With a constantly changing land use, leading to land cover changes of the same magnitude. The cumulative effects of changes in land use and land cover translates to changes in watershed functions, river basin morphology and the cascading system, water and air quality, waste generation, quality of the ecosystem, climate and human health in the long run (Rimal, Sharma, Kunwar, Keshtkar, Stork & Baral 2019).

Abella´n *et al*., (2007) argued that land cover cannot be understood in any dimension without delving into the concept of land use because land cover is a function of land use and so is the change in land use. Land use land cover change detection plays a critical role in planning and management of the existing natural resources to ensure sustainable development. It shows the dynamics of land use land cover change processes, drivers of these changes and their consequences.

Hydrology on a land surface shapes many important ecosystem functions along with the associated benefits and threats for humans. It is strongly correlated to land use planning and management (Garg, Nikam, Thakur, Aggarwal, & Gupta 2019). LULC change is therefore one of the elements that directly impacts on the watershed hydrological cycle (Brook, Argaw, Sulaiman & Abiye, 2011). Existing knowledge shows that anthropogenic activities cause LULC change and subsequently impose a huge impact on the hydrological processes and water resources in a river basin (Marie, Hosea, John & Gathenya, 2019). Garg, Nikam, Thakur, Aggarwal, Gupta and Srivastav, (2019) studied "*Human-induced land use land cover change and its impact on hydrology*," and established that the water supply and the hydrological cycle diminished as a result of LULC change that was worsened by an increasing population pressure and development along river basins (Babar, & Ramesh, 2015).

According to IPCC (2014), planning and managing water resources is critical since water resources are the most affected natural resource in LULC dynamics. According to Musau, Sang, Gathenya, and Luedeling. (2015), water resources directly influence socio-economic development. Consequently, its availability is threatened due to the rising population pressure that also causes changes on the land surface due to changes in land-use systems. This is in addition, to meeting the demands of a rising population, industrialization has also increased fifty-fold over the previous century, hence increased water demand (Aggarwal 2012).

Availability of water resources in different regions of the earth is dependent on human activities and the impacts of climatic change. Variability in rainfall and hydrological cycle affects the magnitude and timing of runoff and ecosystem patterns. At local levels, the spatial distribution and extent of climatic change defines the vulnerability of local communities to water stress and shifts in their livelihood (Green, Beaudreau, Lukin, & Crowde, 2021; IPCC, 2014).

Kenya is a country with diverse natural resource base including water, forests, fertile soils, minerals and electromagnetic radiation among others. Like many other developing countries, Kenya is depleting its natural resources at a faster rate than the natural rate of replacement (UNEP 2019; Lampert 2019). LULC changes in the country is posing threat to agricultural practices, water resources management and climate change interventions. Kenya is categorized as one of the water scarce countries. Furthermore, changes and variability of climatic conditions, population increase and land degradation threatens the per capita water availability in the near future (UNEP, 2015).

River Kuja basin found in Southwestern parts of Kenya serves as water catchment for several economic activities. Anthropogenic activities have altered the indigenous LULC systems in the basin. There are three sugar factories that rely on sugarcane production within the basin i.e. Sony Sugar, Sukari Industries and Kisii Sugar Factory. Several cash crops are also grown in the region including maize, tobacco, rice, coffee, tea, sorghum, millet and cassava. The basin also supports hydropower generation at Gogo Falls with a capacity of 2 MW and is connected to the national grid, operated by the National Hydropower Generation Company, KenGen. The dam constructed in 1956 has since been expanded to increase the capacity of hydropower generation to 12 MW, prevent frequent flash floods and allow a 25,000Ha irrigation for Orango, Okenge and Owiro farmers groups (WRMA & JICA 2014).

The increasing human activities within river Kuja basin have come with negative consequences as they have resulted in the destruction of the surrounding water ecosystems. For example, according to report by LVEMP (2010), development activities, discharge of nutrients and growth of population (about 3% in the Kenyan side) has caused changes in the nearby Lake Victoria ecosystem where River Kuja empties its water. Massive blooms of algae have developed, water borne diseases have increased in frequency and water hyacinth has choked important waterways and landings as well as water supply intakes. These impacts have exposed the lives of aquatic animals to higher risk of suffocation for lack of oxygen. The situation has further lowered the volume of fish in the rivers and Lake Victoria, hence lowering largely the fishing activity as an economic activity for the people.

The human economic activities have also, over the years, changed the beautiful landscape surrounding River Kuja. Many people have settled around the river for economic activities, some for agriculture and fishing while others just for the cool environmental surrounding of River Kuja basin. These activities have instigated population pressure, industrialization, over-grazing, deforestation, high congestion in small centres among other problems. The data from UNEP (1995), suggests this by submitting that the threat of water pollution is real and present in every region of the world, and can be attributed to an expanding population, rapidly developing technology, and increased industrial and food production. If there was no human influence, water quality would be determined by the weathering of bedrock minerals, by atmospheric processes of evapotranspiration and the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soils and by hydrological factors that lead to runoff. Anecdotal evidence suggests that the various activities in the Kuja river basin may have resulted into massive land use/cover changes, negatively impacted on the water resources and caused floods and soil loss due to sedimentation, however, limited studies have been done that can provide data and information to help in planning and management of the water resources of the Kuja river basin.

1.2 Statement of the Problem

Changes in land use land cover impact on the hydrology of an area. The LULC change is often a result of rapid growth of population within the river basins, which has been an issue of concern from the early 19th century. This growth creates pressure on natural resources resulting in uncontrolled and unplanned changes in LULC (Seto, Woodcock, Song, Huang, Lu & Kaufmann, 2002). The LULC changes are also caused by poor planning and management of agricultural practices, urban development, and natural resources such as range and forest lands, and water resources exploitation leading to loss in biodiversity, soil degradation and deforestation (Maitima, Olson, Mugatha, Mugisha & kaMutie. 2010; Kamwi, Chirwa, Manda, Graz, & Katsch, 2015). Furthermore, land use changes contribute to altered hydrology within the river basins. River basins have been subjected to diverse and intensified land use systems, with the key driver for land use land cover changes believed to be population increase in river basins and water catchments. Human beings have developed an increasing need for water for various technological advancements in agriculture, industrialization and domestic use to improve man's life. The increased need for water supply has resulted in the continuous movement of people to areas surrounded by large water bodies or urban centers for better services. The migration in search for water resources and the concomitant land use land cover changes has resulted in flooding, soil erosion, stream sedimentation and water scarcity. However, the assessment and quantification of water in the river basins remains limited owing to the fact that modelling of hydrological reactions is a factor of quality of data and model limitations (Bastola, 2011). How a basin discharge regime reacts to the changing land use land cover is a central question of interest to be integrated in a basin management.

This study addresses land use land cover changes and their impacts on the Kuja River basin in Kenya. The basin is undergoing several land use practice alterations in the natural environmental cover. The surface water resource in this basin serves for irrigated agriculture, sugarcane rain-fed agricultural production, hydro-power generation, rural and urban domestic water supply, livestock keeping, dams and other socio-economic activities. A number of studies have been carried out in River Kuja basin focusing mainly on the assessment of flooding risks (WRMA & JICA, 2014).

However, none or little emphasis has been put on the cause of the variations of streamflow resulting from land use land cover changes. Anecdotal evidence suggests that the various activities in the Kuja river basin may have resulted into massive land use/cover changes, negatively impacting on the water resources and causing floods and soil loss due to sedimentation. There is a strong need for a study that uses remote sensing and hydrological techniques and tools that can assess the effects of land use land cover changes on the hydrologic response of a watershed by using satellite images analysis, modelling the hydrologic response and assessing the perceptions of the local communities on the same. This study, therefore, seeks to investigate the LULC changes and their impacts on the hydrology of River Kuja basin to inform the design of appropriate interventions and measures for sustainable basin wide management.

1.3 Research Objectives

1.3.1 Overall Objective

The study aimed at investigating spatio-temporal variations in land use land cover and their impacts on the hydrology of River Kuja basin.

1.3.2 Specific Objectives

Specific objectives of this study were:

1. To determine land use and land cover changes in River Kuja basin for the period 1990 to 2020.
2. To simulate changes in River Kuja basin hydrology.
3. To assess the perception of local communities on the impact of anthropogenic activities to the hydrology of River Kuja basin between 1990 and 2020.

1.4 Research Questions

1 What are the changes in land use land cover within Kuja basin between 1990 and 2020?

2 How has the hydrologic discharge and water availability changed in the basin?

3 What is the perception of local communities on the impacts of anthropogenic activities to the hydrology of River Kuja Basin between 1990 and 2020?

1.5 Hypotheses

H_{01} There are no changes in land use land cover types in River Kuja basin between the period 1990 to 2020.

H_{02}: Hydrologic simulation of Kuja River will not show a change in water discharge over the time series period.

1.6 Justification of the Study

River basins have experienced alterations in rainfall patterns and general hydrology caused by land use land cover changes. Population increase has yielded much pressure on land use systems. This has negatively impacted on natural resources and agricultural activities. Analysis of LULC change and its impacts on hydrology of River Kuja provide information required for effective and sustainable river basin conservation and management. Kuja River basin is an important water resource basin in Western Kenya under the Lake Victoria South basin since it serves several large-scale cash crop productions like sugarcane. It is the source of water for key livelihood activities serving a population of over 2.2 million people thus any serious change in LULC will adversely affect these livelihoods. The river and its basin support a wide range of economic activities such as sugar factories, hydroelectric power generation station with a capacity of 2MW which is being upscaled, irrigation schemes, as well as urban and rural water supply systems. Any negative impact of LULC would therefore threaten the success of such economic activities in the basin. The area is well endowed with vegetation cover due to good rainfall distribution on the upper sub-catchments hence supporting a rich biodiversity of both fauna and flora (WRMA & JICA 2014). However, it is annually affected by flash floods, experiences water scarcity and loss of livelihoods by local communities. This study, therefore, was conducted to investigate land use land cover changes, their impacts on the hydrology of River Kuja basin and how it links to increased anthropogenic activities. The study generated important data and information that can facilitate informed water resource planning and management, and to design conservation and policy measures on water resources within the basin.

1.7 Significance of the Study

Land use land cover changes in a river basin have significant impacts on the basin's natural resources, environmental systems and socio-economic status of its residents. However, in assessing the impacts of land use land cover changes on the river flow, it is better to understand the hydrology and land use land cover patterns of the watershed. Understanding the watershed dynamics is important in analysis of natural resource base and also help in developing effective and relevant strategies for sustainable management of the area under study. This study presents data and information on the different land use changes and their impacts on the hydrology of the basin taking into consideration the perceptions of the people living in the basin. It is essential for researchers, local communities, water resource management authority, national environmental management authority and county governments among other stakeholders within the study area in designing conservation and policies measures on sustainable watershed and land cover management.

1.8 Scope of the Study

The study was conducted in Kuja basin which has an approximate area of 6,900 km^2. It is located in southwestern parts of Kenya. It is a sub basin to the larger Lake Victoria basin of East Africa. The study area was delineated using digital elevation model in an ArcGIS model. In terms of conceptual scope, the study covered land use land cover changes, hydrology of river Kuja and anthropogenic activities within the Kuja river basin. The land use/cover changes study covered a temporal extent of 30-years starting from 1990 to 2020 and the choice of the period was based on the Spatio-temporal change decadal timelines requirements; climate change detection period; and also, being the period under which three different sugar production factories took effect, Gold Mining improved, population growth rate increased, and climate change effects intensified – cases of drought and floods. The hydrological data used were the meteorological and streamflow data of the basin. Hydrologic Engineering Center –

Hydrologic Modelling System (HEC-HMS) model was used in rainfall-runoff simulation to determine the streamflow. The study also covered the anthropogenic activities which contributed to the land use land cover changes and hydrology of the basin.

1.9 Structure of the Thesis

The thesis is divided into different chapters in line with objectives of the study. Chapter one comprises of a brief background information on land use land cover, water situation in the study area, justification of the study, research objectives, research problems, research questions, research hypothesis, research scope, definition of key terms used in writing the thesis, and research outline. Chapter two presents literature review of the key concepts covered in this study. The literature is based on the specific objectives and have identified the research gap to be addressed by the study. Chapter three on methodology is divided into three parts namely; study area, research design and methods. It covers the source of data used and explains the step-by-step procedure taken to source the data and analyse it. Chapter four presents the results obtained from the satellite images analysis on land use land cover changes in the basin, the modelling results on river Kuja basin and the questionnaires survey outcome on socio-ecological factors of the river basin. The results are discussed based on the research objectives. Chapter five presents the discussion of the results. They are discussed and related to other research findings in order to draw scientific conclusions. Chapter six presents conclusions, recommendations and areas of future research. The thesis ends with references cited in the research and the relevant appendices are also attached.

1.8 Operational Definition of Key Terms

Classification: an abstract of representing the situation in the field using well-defined diagnostic criteria to order or arrange objects into groups or sets on the basis of their relationships.

Digital signature: a unique spectral response of each object on the earth's surface to the electromagnetic energy.

Driver: any natural or human-induced factor that causes a change in a system.

Ecosystem: a community of living organisms in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system.

GeoTIFF: GeoTIFF is a format extension for storing georeference and geocoding information and contain tags that provide projection information for that image as specified by the GeoTIFF standard.

Hydrodynamic: the motions and actions of water bodies as influenced by forces from within and without it.

Hydrological modelling: is the process of developing models which are fundamental for simulation of water resources for useful information.

Image classification: the process of extracting information classes from a multiband raster image by grouping all pixels in the image into one of the several land cover classes, or "themes" on the basis of their digital signature similarities.

Image resolution: description of the level of detail an image holds.

Kappa coefficient: an index of the agreement between two images ranging from 0 to +/-1 where 1 = full agreement (images are identical, no change), -1 = full disagreement (the images are opposite, complete transformation in a consistent manner), 0 – no correlation (change is random).

Land cover: the observed physical or biological material cover on the earth's surface including vegetation of various types such as papyrus or grassland, water or bare soil.

Land use: the expression of human influence and impact on various ecosystems for the welfare of human populations or the human activity that occurs on land such as agriculture or grazing.

Land Use Land Cover change: (Quantitative) changes in the areal extent (increases or decreases) of a given type of land use or land cover - changes caused on the earth by human anthropogenic activities.

Mixel: expresses the mixed nature of the contents of the smallest unit area or cell on an image whose size is determined by the aperture of the source or the receiving optics of the sensing system.

Overall accuracy: percentage of correctly classified points from the field visited set.

Photomorphic regions: image segments or areas with similar properties of size, shape, tone/colour, texture and pattern or areas of relatively uniform tone and texture on an image.

Pixel: smallest unit area or cell on the image whose size is determined by the aperture of the source or the receiving optics of the sensing system.

Population growth: is the average annual rate of change of population size during a specified period of a certain place.

Pressure: ways in which drivers are expressed physically, reflecting the inter-linkages between a human activity and the surrounding natural environment i.e. the actual consequences of a driver on a system to which the system reacts.

Producer's accuracy: measure of the error that a ground truth point is correctly mapped, and reflects the error of omission.

Resampling: digital process of changing the sample rate or dimensions of digital imagery by temporally or aerially analysing and sampling the original data.

Resolution: minimum distance between two adjacent features or the minimum size of a feature, which can be detected by a remote sensing system.

River basin: is an area of land over which surface water run-offs flows through streams, tributaries, and rivers into a lake, a sea or ocean.

Spatio-temporal: a variant that operates on the earth's surface and is a function of time.

Spatial resolution: a measure of the smallest area identifiable on an image as a discrete separate unit. In raster data, it is often expressed as the size of the raster cell.

User's accuracy: a measure of the error of commission for a category, and reflects the probability that a polygon or point on the map is correctly identified.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature reviewed in line with land use land cover changes and their impacts and effects on the hydrologic and hydrology of river basins. The sections are divided into land use/cover changes and detection, drivers of land use change, impacts of LULC changes on the hydrology in basins, research gap and conceptual framework.

2.2 Land Use Land Cover Changes

Land use primarily encompasses the economic and cultural uses including agriculture, residential, recreational, commercial, mining, industrial, social activities at a given place or on a given piece of land (Ramankutty, Katharina, Larissa, Claire, Mario & Loren, 2018). Land use in most cases is determined by ownership and as such public land use and private land uses are likely to be very different. However, there are instance where some public lands are used for private activities (Mattson, & Angermeier, 2007). A good example is riparian lands which are in most cases used by members of the community hosting the lands for their private use such as farming, production of bricks or planting of trees. Land use determines the land cover. Land cover on the other hand deals with the observable biophysical cover on the surface of land. It does not only refer to vegetation that covers the land but also the soils, groundwater, surface water and biodiversity (Moser, 1996). Some scholars insist that land cover should be limited to vegetation and man-made features on the earth's surface (Ramankutty *et al*., 2018). That definition thus cuts out places consisting of bare rock or naked earth surface and a description of the land as opposed to land cover. Within the same lenses, water surfaces are arguably not land covers. Fundamentally, land cover should mean something that covers the surface of land, whether it is natural or man-made and therefore all farm crops, forests, shrubs, infrastructure such as roads, rails, dams, residential or commercial premises, pavements, airports/strips, stadiums, swimming pools and the likes are land covers albeit artificial (Mattson, & Angermeier, 2007).

Factors considered while defining land cover depend on land uses and the management practices which goes into the land use (Abella´ n *et al*., 2007). This explains, therefore, why changes in land use and land cover can alter the supply of ecosystem services and affect the well-being of both human beings and nature. Several factors therefore define land cover namely anthropogenic activities (land use), geographical location, altitude and morphology (Gilma, Abell, & Williams, 2004). Any land use leads to a proportionate change in the land cover. With the constantly changing land use, land cover changes in the same magnitude. The cumulative effects of changes in land use and land cover translates to changes in the watershed function, river basin morphology and the cascading system, water and air quality, wastes generation, quality of the ecosystem, climate and human health in the long run (Rimal, Sharma, Kunwar, Keshtkar, Stork, Rijal & Baral, 2019). Abella´ n *et al*., (2007) emphasized that it is imperative to underscore the fact that land cover cannot be understood in any dimension without delving into the concept of land use because land cover is a function of land use and so is the change in land use.

According to Exum, Bird, Harrison and Perkins, (2005), impervious surface results into non-point source water pollution because it limits the capacity of soils to filter surface runoffs. In other words, where surface water runs on impervious surface, the retention time is extremely minimal because of the smooth and impermeable surface. Consequently, Ramankutty *et al.* (2018) concluded that all the pollutants which would otherwise be infiltrated by the loose soil surface, flow with the surface water downstream and thus changes the water quality. Additionally, impervious surfaces affect peak flow and volume which then accelerates erosion and thus affecting habitat or river basin and water quality. At the same time, impervious surfaces add the volume of storm water runoff which has the potential of carrying and transporting pollutants into water bodies downstream. The pollutant could range from toxic substances (from point sources discharges), dirt, oils from roads surface, and fertilizers. Since the surfaces are impervious, they could reduce the volume of ground water acquirers (Ramankutty *et al*., 2018).

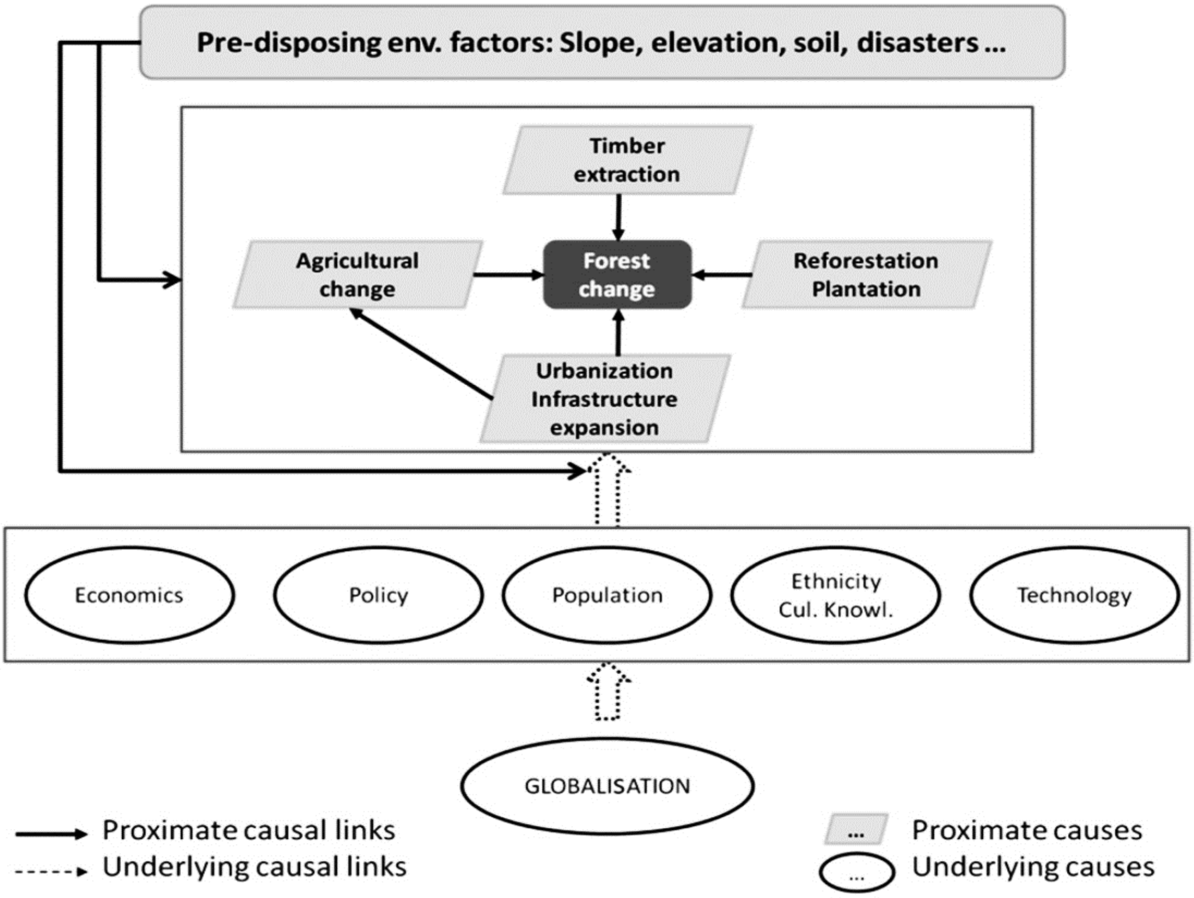


Figure 2. 1: Schematic diagram on Causes of LULC change

Source: Geist and Lambin, 2002

In agricultural uses, significant number of studies have explored the question of agricultural land use and its short term and long-term effects on land cover changes over time. According to Abell (2002), agricultural land uses such as growing of crops, tillage practices, and irrigation practices have direct impacts on the land cover. Linke, Pressey, Bailey and Norris (2007) argue that some plants and certain methods of irrigation can minimize the amount of water available for other uses through overuse. Matteson, & Angermeier, (2007) also observed that livestock farming, which rely on riparian zones as grazing lands, can induce changes in the landscape conditions through reduction of bank vegetation and increasing river water temperature, sedimentation and nutrients level in the water. Furthermore, land use which encourages usage of pesticide, fertilizers and herbicides can compromise water quality which flows into the rivers. Schenker (2000), adds that some agricultural land uses such as overgrazing, land conversion, intensive use of agricultural chemicals, and fertilization can encourage the growth of invasive plants such as water hyacinth which interferes with water transports, lower biodiversity and interfere with fishing practices in lakes as evidenced along the shores of L. Victoria (Westbrooks, 1998). Sutherst (2004) notes that there is a close association between some land use changes and the incidences of certain infectious diseases. Certain Vector-borne diseases has been closely linked to land use which leads to environmental change. A study by Patz, Daszak, Tabor, Aguirre and Epstein (2004) indicated that some agricultural land use practices such as fragmentation of forests into smaller parcels accelerates the “edge effect” thus promoting converting the forest state to other human activities. Impacts of land use/cover change have been identified and of concern are on biotic diversity (Sala and Chapin, 2000), human factors of biological systems (Praveen, 2017) and degradation of soil (Trimble & Crosson, 2000).

Transformation of terrestrial biosphere into anthropogenic biomes has resulted into different socio-ecological patterns. These transformations, being fostered by need to avail food, shelter, water and fibre, have degraded forests, waterways, croplands, pastures and plantations. As a result, there is increased energy production, high water consumption, heavy use of fertilizers hence massive loss in biodiversity (Foley, DeFries, Asner, Barford, Bonan, Carpenter, & Helkowski, 2005). A study by Kuemmerle (2009) concluded that the transformation of cropland to grassland in Romania was associated with demographic and socio-economic factors in Arges County in 1989. Rapid industrialization in eastern parts of China during 1990s was reported by Brown (1995) which escalated the conversion of arable land into constructed structures. In Zimbabwe Country within Shurugwi region in Midlands Province, Mark and Kudakwashe (2010) observed unusual increase in cropland. Vast forested lands were converted to agricultural activities to provide food, charcoal for fuel, logs for constructing houses and animals’ pens, and other uses. Communal built-up settlements increased around Davangere City in India, a region with several water bodies. The drivers were push for food security and shrub land for pastures (Begum, Narayana & Sl, 2010). Prakasam (2010) researched on land use changes in Kodaikanal Tamil Nadu. His study monitored the changes for a period of 40 years. He concluded that built-up and agricultural areas increased with direct decrease in forested areas and water bodies.

Land use and land cover change detection can be reliably achieved through the use of satellite data. Gudmann, Csikós, Szilassi and Mucsi, (2020) noted that there are various techniques through which LULC can be characterized but remote sensing presents the most reliable and extensive temporal and spatial resolution data. Remote sensing is presently the most accurate technology for examining different spectrally sensitive changes of the earth's surface. According to Dewidar (2004), the availability of large archived data sets, over the past decades, has initiated the evaluation and development of many digital change detection techniques and methods for detecting and analysing land use land changes. These methods and techniques have been reviewed and provided with excellent descriptions and comprehensive summaries (Haque & Basak 2017). The choice of the suitable method of change detection is very necessary in producing accurate results since digital change detection is heavily affected by temporal, spatial, spectral and thematic resolutions of remotely sensed data (Lu, Wang & Zhang, 2014). Different change detection methods lead to different change detection maps depending on the method used. There are seven different categories of change detection methods; algebra, transformation, classification, advanced models, geographic information system (GIS) approaches, visual analysis and other approaches (Bekalo, 2009). Table 2.1 summarizes the common change detection techniques or approaches and their examples.

The data acquired through GIS technology is imperative for sculpting other natural and cultural processes (Jensen, 2009). Integrating remote sensing images with adjustable resolutions with the use of diverse descriptive models, has been used to acquire past present and predict future land use and land cover patterns (Li, Wang, Jia, Wu & Xie, 2014). Satellite data in form of maps have been used over the years to assess LULC changes and the technology has been effective with regards to cost and time (Erener *et al*. 2012). From the operational point of view satellite images taken by remote sensing has been successful in monitoring LULC changes (Seto & Kaufmann 2005). The success is only based on comparing images of the same surface taken at different time. For any notable changes to be observed through satellite images, the timing should not be close. According to Alam, Bhat, and Maheen (2020), best results have been obtained by comparing images of the same land area taken at least a decade apart.

Table 2.1: Summary of Change Detection Techniques

Technique/Approach	Examples of Method
Algebra	• Image differencing • Image regression • Image rationing • Vegetation Index Differencing • Change Vector Analysis
Transformation	• Principal Component Analysis (PCA) • Tasselled Cap (KT) • Gramm-Schmidt (GS) • Chi-square
Classification	• Post-Classification Comparison • Spectral-Temporal Combined Analysis • Expectation-maximization (EM) detection • Unsupervised Change Detection • Hybrid Change Detection • Artificial Neural Networks (ANN)
Advanced Models	• Li-Strahler Reflectance Model Spectral Mixture Model • Biophysical Parameter Method
Visual Analysis	• Visual Interpretation
Other Change Detection techniques	• Measures of spatial dependence • Knowledge-based vision system • Area production method • Combination of three indicators: vegetation indices, landsurface temperature, and spatial structure • Change curves • Generalized linear models • Curve-theorem-based approach • Structure-based approach • Spatial statistics-based method

Source: Lu *et al*. (2014)

To improve the characterization and classification accuracy of land cover mapping, spectral indices are commonly used (Thakkar, Desai, Patel, & Potdar, 2015). Some studies (Hurni, Hett, Epprecht, Messerli & Heinimann, 2013; Han *et al*. 2015) have investigated the role played by landscape metrics in land use land cover analysis. Numerous other studies have, however, demonstrated a significant correlation between LULC and landscape, and subsequently, between LULC and landscape metrics and the associated changes as well (Southworth, Nagendra, & Tucker, 2002; Fichera, Modica, & Pollino, 2012; Gudman *et al*., 2017). These studies investigated not only the degree of relationship of certain LULC and landscape metrics, but also the effects of the scales and classifications on the landscape metrics themselves. According to Singh, Laari, Mustak, Srivastava and Szabó,*al.*, (2018) and Kumar, *et al.*, (2018), landscape metric parameters established through satellite imaging are commonly used to indicate biodiversity, water quality and land cover changes over time. They provide a set of spatial tools for analysing landscapes and their arrangement and properties of their morphological and topographical features. These metrics, can provide information about the LULC over a long period of time. Furthermore, the landscape metrics can provide quantitative values through which certain features can generally be described (Jiao, Liu, & Li, 2012). Because of these properties, landscape satellite images can provide additional information that improves LULC classification (Sertel, Topaloğlu, Şallı, Algan & Aksu, 2018).

Satellite images are generated through integrating Geographic Information System (GIS) and remote sensing technologies. According to Sundaram, Sowjanya, Amdavar, & Reddy (2018), GIS and remote sensing can help with mapping spatial location and real-world features and visualizing the spatial relationship among the features. For instance, GIS can help to visualize where some types of natural resources are and how human respond to their occurrence within their reach. This can help with raising a red alert if the occurrence of such natural resources or the human response to their occurrence is anything of an alarm for example sand harvesting.

2.3 Drivers of Land Use Land Cover Changes

Changes in LULC is a consequence of numerous factors interacting on the surface of the land. These factors either originate from anthropogenic activities or natural forces. Among the human activities, the size and growth of population plays a major role, but it is not the only triggering human cause of LULC changes (Zeitoun, Goulden, & Tickner, 2013). The effects of population growth can be magnified or weakened by institutional factors and national and regional policies, as well as processes of globalization, all of which shape economic opportunities (Stein, & Nix, 2002). Anthropogenic factors originate from human activities in a river basin. These activities could be driven by several factors including population pressure, urbanization, unemployment, or ignorance about the communal role of managing sustainable ecosystem (Stein, & Nix, 2002). In the arguments of Ding, Shan, and Zhao (2015), naturally, any ecosystem requires ecological security in order to function optimally. However, the ecological security could be compromised by anthropogenic processes which interfere with the integrity and health of the ecosystem. According to Zeitoun, Goulden, and Tickner, (2013), anthropogenic activities have the potential to alter energy source, cascading system, physical habitat, water quality and biotic relationships (Shen, Cao, Tang & Deng, 2017; Stein, & Nix, 2002).

Falcone, Carlisle and Weber (2010), identified, evaluated and qualified 33 potential anthropogenic factors which significantly affect ecological security of river basins. Vorosmarty *et al*. (2010) also selected 23 factors which were analysed as main threats to river basin. These factors are broadly categorized into three domains namely; urbanization, agricultural development and facility construction (Shen *et al.,* 2017). Shen *et al*., (2017) identified population growth, urbanized and industrial areas, secondary industrial output, large number of domestic animals, fertilizers, pesticides, reservoir storage, traffic land and mining and manufacturing activities as the major threat. Vörösmarty, *et al.,* (2020) also noted that these threats pose different level of risk to the river basin with agricultural area, population growth, mining and manufacturing posing the highest threat to the ecological security of the river. Urbanization encourages industrialization and the two combined contribute significantly to the alteration of land use. Urbanization has been seen as a huge threat because riparian lands along river basin are either grabbed or illegally used for construction of residential houses, industrial facilities or business premises (Ding, Shan, & Zhao, 2015). In the event industries are constructed in river basins, there are always very high chances of discharging of untreated or haphazardly treated industrial wastes into the water and thus compromising the water quality along the river and in the downstream end. A good example of a river which has suffered from urbanization and industrialization is the Songhua River of China. Construction of artificial facility in the Songhua River Basin (SRB), negatively impacted on the river regime, compromising its ecological security (Xue, Yun, Du & Zhang, 2012) and significantly affecting species and their distribution in the river's ecosystem.

Agricultural activities threaten river basin through clearing of forested or shrub covered land for farming activities. Consequently, more soil erosion occurs because the land surface remains bare. Additionally, keeping of large number of livestock on small pieces of land leads to overgrazing which also encourages soil erosion (Shen *et al*., 2017). Crop farming and livestock farming frequently uses fertilizers, herbicides and pesticides whose residues dissolve in rain water and are carried by surface runoffs that end into rivers (Xue *et al*., 2012). As a result, the quality of water is altered to the disadvantage of people or companies which may rely on the river water for their domestic and industrial use respectively. Notably, population growth partly accelerates agricultural land use. Heavy use of fertilizer has been a common practice in parts of many river basins because people have small pieces of land but since they want to maximize productivity of the land, they end up using a lot of fertilizer. Most of the anthropogenic activities are those associated with the exploitation of water resources and land use (Xue *et al*., 2012). The process of exploiting the water resources and land use within the water shed and river basin have caused significant changes in the ecosystems of most rivers across the world including River Nile, Songhua, Euphrates, Colorado and Rhine (Zeitoun, Goulden, & Tickner, 2013).

The impacts of growing number of people along the river basins has been an issue of concern from the early 19th century. Human beings all over the world have developed a high need for water for various technological advancements in agriculture, industrialization and the domestic use to improve man's life. The high demand for water supply has thence triggered the continuous movement of people from the arid and semi-arid areas to areas surrounded by large water bodies or to urban centers. Globally, the population in search of safe water has risen by 1.7 billion people between 1980 and 2010. (Shen & Chen, 2010). The increased number of people along the river basins brings with it both negative and positive consequences on the quality of water supply. For example, manufacturing and agricultural waste products like phosphorous are detrimental particularly to the organisms living in river waters and subsequently endangers human consumption safety.

Human settlements along river basins have witnessed human beings manipulating the natural hydrology to fulfil their irrigation, industrialization and domestic water needs. Over the years, the issue of river basin management and planning has taken the centre stage in various policy formulation and programs. Immense inquiries have been conducted at different times and in different places to understand that effective management and planning strategies of the water basins is of essence due to the surging population. The Murray–Darling Basin (MDB) in Australia and the Colorado River Basin (CRB) in the USA are among the major river basins that have over the years been selected in the quest for understanding how well water bodies can be managed to offer quality and safe water for industrial, technological, agricultural and domestic consumption both in developing and developed nations collectively (Gummer, Cash, Wrona & Prowse, 2000). The studies have suggested that water distribution policies should be based on regulations and marketplaces. Gummer *et. al.*, (2000) further proposed two other recommendations; public participation should be stressed by the channels between governance, organizations and local communities; and that scientific research should be integrated into river management to understand the interactions between man and nature. The effects of human activities along the areas adjacent to water bodies has been and still remains an issue of interrogation. The results of human water use for industrial, agricultural and domestic purposes accrue impacts that are felt by all living organism inside and around the water bodies.

The Intergovernmental Panel on Climatic Change (IPCC) has continuously conducted climatic assessments using two scenarios (A2 and B2) to aid in understanding the consequences of demography along the river basins. Individually, scenario A2 presupposes that the number of people and the fiscal changes are cognizant of the economically oriented world, but with a relative law rate of trade and economic indicators as compared to a scenario focused on globalization (Arnell & Liu, 2001). On the other side, scenario B2 is characterized by lower population, high economic growth and has relatively lower climatic change as compared to A2. In summary, the two IPCC scenario have been useful in assessing the changes in water availability and supply. These assessments have considered several issues ranging from the impacts of human activities and climate change on volume and variability of the river discharge, fluctuations in seasonal availability of water supply, to ultimately the altered extent of deposits in river basins (Arnell & Liu, 2001; Alcamo, Flörke & Märker, 2007). The studies conclude that besides climatic changes, continuous human actions, economic growth, technological and socio-cultural factors, impacts immensely on the quality of water existing in the river basins, hence may affect the future water availability.

Gummer (2000) reported that in the 21st world commission for the water availability, for improvement on the water related resources and giving more powers to the local governments, groups and citizens to take good action towards managing, planning the water use is recommended.

Kenya is considered one of the many African nations with challenges of freshwater management and planning (Wang, Cui & Lu, 2007). The country is surrounded by various water resources, for example rivers, lakes and oceans that cuts across a large geographical location per square unit in Kenya. Among the water bodies supplying water includes; Indian Ocean, Lake Victoria and rivers such as Kuja, Tana and Mara. These water bodies are pivotal as they provide water that favours economic, technological and domestic consumptions. The usefulness of these water sources is heralded from the fact that Kenya, being a developing country, has a high population which still depends on agrarian way of life. Therefore, high quality water resources are necessary for the agricultural activities. Some studies suggest that community wars and disagreements have led to water competition most particular during the dry spells when water supply is low compared to the number of people in need of water (Kilonzo, 2014). This situation has been evident, for example, in Nyangores catchment, one of the source tributaries of the Mara River in the larger Mara River Basin (Osoro, Mourad & Ribbe, 2018). The Kenyan government has tried to formulate policies on water use as in the case of River Mara, to reduce water use conflicts, and to balance the rate at which water is being supplied and the pressing needs of people in the lower Tana region (Omonge, Herrnegger, Gathuru, Fürst & Olang, 2020).

Past studies indicate that clustering of big squared farms, large scale extraction of land resources, exploitation of surface water for irrigation activities, farming of bare lands and the constant tilling are among the activities that contribute to severe land degradation (Aeschbacher, Linige, Weingartner, 2005). The sub-fields of agriculture such as horticultural activities are labour intensive and this most often attract many people to unplanned settlements along the water sources. Fishing activities along Lake Victoria also attracts a number of people along the lake regions of Kenya (Muriuki, Seabrook, McAlpine, Jacobson, Price & Baxter 2011). The increased population then leads to unrestrained growth within sub-watersheds that afterwards exerts pressure on environmental resources, enhances degradation and competition between and within species (Barrow, 2006), factors that can augment watersheds' vulnerability to climate change effects. The high population growth in relation to the geographical carrying capacity is unsafe since it poses pressure on the surrounding ecosystem species that results to the destruction of biodiversity (Oehl, Sieverding, Ineichen, Mäder, Boller & Wiemken, 2003).

River Kuja, a basin draining into Lake Victoria, runs from Kiabonyoru highlands in Nyamira County via Gusii land to Migori and Homabay Counties draining its water into Lake Victoria. River Kuja has enabled the generation and supply of 2 MW per unit of electricity by the Kenya Electricity Generating Company (KenGen) after the completion of Gogo Falls Dam in 1956. This dam has enabled increased supply of electricity to various counties such as Nyamira, Kisii, Migori and Homabay. The people from the larger southern Nyanza region have benefited much from the fresh water of River Gucha (Kuja) as many can engage in various economic activities. The communities along River Kuja, especially the Luos, have engaged in fishing activities from the river. Since the river passes through communities that have high affinity for agriculture, the people are applying modern use of irrigation to produce various crops in areas such as Lower Nyatike irrigation scheme.

The increasing human activities along the River Kuja has come with negative consequences resulting to the destructions of the surrounding water ecosystems. According to report by LVEMP, (2015), development activities, discharge of nutrients and growth of population (about 3% in the Kenyan side) has also caused changes in the Lake Victoria ecosystem where river Kuja empties its water. Massive blooms of algae have developed, water borne diseases have increased in frequency and water hyacinth has started choking important waterways and landings as well as water supply intakes. This state of water in Lake Victoria has, thus, put the lives of aquatic animals at a higher risk of suffocation for lack of oxygen. The situation has lowered the volume of fish in the lake, hence lowering largely the fishing activity as an economic activity of the people.

The anthropogenic activities have since 1993, changed the beautiful landscape surrounding River Kuja as many people have settled around the river for particular economic activities, some for agriculture and fishing while others just for the cool environment surrounding River Kuja basin. These activities have led to; industrialization, over-grazing, deforestation, high congestion in small centers among other problems. A study by Okungu & Opanga (1999) on the subject of pollution has confirmed that the human activities around River Kuja has contributed immensely to high level of land waste and water pollution that have thus, put the lives of many living organism in danger. The rate of pollution has been heightened by the waste products from the urban centers adjacent to the water basins. The many people living in the urban areas dump their waste products into River Kuja. These sources of pollution have lowered the quality of water in River Kuja making it unsafe for domestic consumption. The pollution triggers water bone disease infection mostly during dry season when people have to depend on the river water for home use. Many people drink the polluted water thereafter developing health complications.

Although rural populations have generally grown less fast relative to urban populations, the rural growth has been faster in many developing countries in Africa and Asia, and in most of the least developed countries than the developed countries. As was acknowledged by the Commission on Sustainable Development during its 14th conference (E/CN.17/2006/2), protecting and managing the natural resource base is an indispensable requirement for sustainable development. In situations where policies and initiatives for sustainable agricultural and rural development are not established, high rates of rural population growth could negatively impact on the use of land, water, air, energy and other resources (Bongaarts, 2009).

Population growth is often used as a surrogate for changes in land use but at lower scales, a set of complex drivers must equally be considered (Genet, 2020). Population growth implies increasing demand on food and thus more pressure on land resources to sustain the demand (Bongaarts, 2009). In developing countries, rapid population growth, poverty and the economic situation are the main driving forces to land use and land cover changes (Tendaupenyu, Magadza & Murwira, 2017). The effects of population growth occur mainly through the intensification of agricultural activities aimed at food production. Different population growth rates and different population densities produce different sets of land use changes depending on the place in question. The evidence is partly logical and historical. More people need more food and more residential land. This factor defines how land is used for agriculture and other purposes. Land use patterns over the last 6,000 years are associated with the expansion of the human population (Genet, 2020).

Bilsborrow and Geores's (2016) found a correlation between a country's population density and the percentage of agricultural land that is used for crop and livestock production. Boserup (2009) model indicates that population growth compels people to cultivate additional land hence clearance of forests or shrub lands or to farm their present land more intensely. Most of the changes in land use linked with population pressure are likely to be harmful not only for human beings but for the entire ecosystem in the long run. As population grows, the technology needed to sustain output is more expensive and requires more capital investment and human resource. Some of these technologies are the direct and on-site costs but there are also indirect and off-site costs that could be equal to or greater than the on-site implications. Such costs include salinization resulting from irrigation and contamination of common property resources like river from intensive fertilizer use induced by population pressure (Bongaarts, 2009).

Since the repercussion of population growth on land use also depend on other factors, case studies that articulately describe the relative role of these factors are necessary. Among these conditioning factors are markets for forestry and agricultural products, soil quality, land tenure systems, climate, and capital markets. Population growth is most likely to cause land degradation where land is held in private hands without rules governing its use, when production is mainly subsistence, and where the soil is unstable and rainfall light. Under these conditions, drastic population growth leads to soil degradation. Researchers suggest that many parts of Africa may suffer from the degradation although a few parts like northern Nigeria have shown that the farmers can adapt to the doubling of population (Mortimore, 2011). Rapid human population growth complicates the survival of other members of the fauna and flora. Greater species lose and higher attrition within some species has accompanied rapid human population growth. There are extensively variable opinions as to the stress that humans should ascribe to the welfare of other species which inhabit the river basins or which share ecosystems with human beings. It is obvious that the partialities for those plant and animal species are not presently being given attention in any market mechanism. However, the survival of several species of the flora and fauna is debated in the political process (Oehl *et al*., 2003).

It has been observed in West Africa that populations respond to multifaceted and interrelated ways that eventually affect land use and land cover patterns (Lambin *et al*., 2008). A good example is the progressive integration of West Africa into a global market economy which has added pressure to expand foreign investment in the mining and timber industries of the Guinean forest countries, resulting into increased rate of forest loss. This is a demonstration that land uses are partially defined by demands informed by need for merchandise for international trade. Structural adjustment innovations have stimulated agricultural specialization toward several cash crops, such as cotton and peanuts in the Sahelian countries. These crops have been substituted with a more diverse mix of local grains and tubers (FAO, 2011). Moreover, increasing household income of the growing population affects consumption patterns, for example, there has been increasing demand for processed food such as meat, and dairy from the wealthy urban populations. Consequently, land use and exploitation of natural resources has been intensified to meet the growing demand (Kleemann, Baysal, Bulley & Fürst, 2017).

Natural factors also drive significant changes in LULC. Climate change is reported to be the most dynamic natural factor which affects land cover at decadal time scales (Pongratz, Schwingshackl, Bultan, Obermeier, Havermann & Guo, 2021). The elements of climate change which induce LULC changes include recurrent and persistent drought conditions in Arid and Semi-Arid Lands (ASALSs) in many parts of the world including Sub-Saharan Africa (Mirzabaev, Wu, Evans, García-Oliva, Hussein, Iqbal & Weltz, 2019). Recent studies show that chronic and severe drought has directly changed the land cover by shrinking water bodies, desiccating soils, stressing the vegetation, and exposing bare soil and sandy substrate to intensive erosion. Indirectly, it has changed land use because people are not able to use the land for crop farming whether for commercial or subsistence purposes and neither for foraging by livestock hence people are subsequently forced to find alternative ways of securing their livelihoods, which in turn leads to a change in the land use and land cover (Mirzabaev *et al.*, 2019; Briassoulis, 2019). The threat of drought to agriculture in the Sahel forced farmers and pastoralists to migrate from the drought affected areas toward more humid stretches of land, or into the urban centers to search for alternative livelihood (Reij, Tappan, and Smale, 2009). The same authors asserted that the combined pressure of drought and population growth has stimulated investments in soil and water conservation, and in agricultural escalation in southern Niger and central Burkina Faso.

Climate change has led to torrential rainfall which has often caused devastating effects such as landslides, and flash floods. Flash floods on the other hand have caused huge changes on the land cover and land use. For example, reports indicate permanent displacement of people due to rise in Lake Victoria level or river draining their waters into the lake (International Federation of Red Cross and Red Crescent Societies, 2021). Consequently, even some agricultural activities along the rivers and the Lake Victoria basin are done amidst a lot of fear of floods.

2.4 Impacts of LULC Changes on the Hydrology within a River Basin

The hydrologic yield of a watershed is directly linked to the type and intensity of land use and land cover and associated management practices in a given area. The characteristics of hydrologic circulation are strongly correlated to land use planning and management (Garg *et al.*, 2019). Land Use/Land Cover (LULC) change is therefore one of the elements that directly impacts on the watershed hydrological cycle (Brook *et al*, 2011). Studies show that anthropogenic activities cause LULC change and subsequently impose a huge impact on the hydrological processes and water resources in a river basin (Marie *et al.*, 2019). Garg *et al.*, (2019) studied "*Human-induced land use land cover change and its impact on hydrology*," and established that the water supply and the hydrological cycle diminished as a result of LULC change that was worsened by an increasing population pressure and development along river basins (Babar, & Ramesh, 2015).

River basins are characterized by certain features. These features include inputs, outputs, stores, morphological systems and cascading systems (Zhou, Pan, Binlin & Xin, 2020). The outputs are materials that are contained in the water as it moves from the source into the river. Inputs therefore include water and the sediments originating from weathering of underlying rocks, biological materials and dissolved substances from the atmosphere (atmospheric inputs), and decaying organic materials. All these materials form an open fluvial system which requires energy. The energy that drives the open fluvial system is derived from the atmospheric processes which carries and condenses moisture into the atmosphere which then falls back as precipitation over the watershed. The force of gravity then forces the water to flow downstream. The process thus represents an energy cycle (Newson, 1992). For the outputs, the water, the suspended material and dissolved materials flow downstream to the drainage basin outlet. The outlet in this sense represents the point at which the river discharges its content. It could therefore be a lake, a sea, or an ocean. In rare cases, river water may dry up without discharging its content into a lake, sea or ocean. A good example is River Okavango in Botswana which dries up before reaching the ocean (Bauer & Gumbricht, 2006). The drying up represents water loss by evaporation. There is much more to explore in the relationship between land use and water resources sustainability and identifying the dangers facing water availability in rivers (Ding, 2015).

Movement of water in a river basin contributes to soil erosion since the flow of water carries with its momentum. According to Garau, Torralba, & Pueyo-Ros, (2021), the momentum is directly dependent on the volume of flow and the velocity of the flow. Magnitude of soil erosion in the river basin is a function of land use and land cover (LULC). Where land use can cause reduction in the vegetative land cover, erosion is likely to be intensive as there is limited land surface features which can hold the soil (Teclaff, 2012). Consequently, the land use function translates into the volume of sediments likely to be carried, transported and deposited along the river basin. Subsequently, LULC becomes an essential factor of consideration while studying the cascading system of geomorphology.

Threats facing river basins in terms of their hydrologic yields are varied and often depend on whether the river is a national boundary, regional boundary, or just any other boundary between administrative units or a country, or county (Mekonnen, & Hoekstra, 2016). The threats can be categorized into two broad classes namely anthropogenic or natural threats. Anthropogenic threats originate from human activities within the river basin while natural threats occur due to occurrence of natural phenomena (Liu *et al*., 2018). One of the major natural threats facing river basins is Climate Change. Climate change can pose both direct and indirect threats to river basins with significant uncertainties. Among the notable characteristics of climate change include variation in temperature such as global warming, changes in precipitation, and evapotranspiration rate (Palmer, Reidy, Nilsson, Flörke, Alcamo, Lake, & Bond, 2008). When these changes occur, the cascading system and runoffs are affected. The changes however affect different basins differently, depending on the geography and climate of the watershed. The biophysical influence of the predictable changes in climate on river basins has been comprehensively studied for some regions but less for others (Liu *et al*., 2018). Limited research has been done on how such threats can impact on socioeconomics of many river basins including River Kuja basin.

Climatic change is believed to be the reason for extreme temperatures, extreme drought, and of unusually torrential rainfall in some parts of the world. Torrential rainfall mainly occurs due to changes in the temperature of the air and atmospheric stability. When air is warm, its ability to carry more moisture multiplies. Increasing air temperature – which could be caused by global warming- implies that the air mass can hold exponentially more moisture which then translates to torrential rainfall (Pittock, & Lankford, 2010). According to Schumacher, (2017), for one-degree Celsius increase in the temperature of the earth, the moisture content of the air increases by about 6%. Schumacher, (2017) also note that the increased prevalence of torrential rainfall is closely correlated with the increase in the moisture content of the Earth's atmosphere. Coupled with the melting of glaciers, the higher precipitation magnitude can cause more sedimentation in river flow and thus more erosion and deposition (Palmer *et al*., 2008). With increased sedimentation of a river, drops in dam reservoir capacity can easily occur thus lowering power production along rivers used for the same. The possible increase in water temperature due to global warming is expected to cause even greater impacts on downstream ecology in some regions (Palmer *et al*., 2008).

Torrential rainfall may be beneficial until such a time when the succeeding events are considered. Torrential rainfall causes loose soils or shallow set rocks to dismantle and flow as mass or just sink (Mao, Ping, Yin, & Qiu, 2018). Depending on the morphological system, the dismantled masses of soils and rocks can rapidly build up and gather velocity and momentum. In several parts of Kenya for example West Pokot, landslides have caused deaths of many people and property destruction. According to the Kenya Red Cross Society (Kenya Red Cross, 2020), at least 120 people reportedly died, including 72 people who lost their lives after a landslide buried their houses in West Pokot County in northwestern Kenya. In addition, infrastructure of undetermined value, including roads and bridges, were damaged, hampering effective humanitarian response efforts in affected areas.

Torrential rainfall has also been believed to be the cause of flash floods in many parts of Western Kenya and the coastal regions. River basins and low water crossings become the most susceptible to catastrophic events. Such catastrophic events have been witnessed in Western parts of Kenya where people have lost their lives, have been displaced and a lot of property including houses destroyed (International Federation of Red Cross and Red Crescent Societies, 2021). Majority of the victim are people living in riparian land along the rivers. In light of the possible impacts, basin managers should employ flexible river basin management methods, not only to protect the basins and their ecosystems but also to protect residents of the river basins from the outcomes of uncertainties associated with climate change.

Tufa, Abbulu, and Srinivasarao (2014) identified LULC changes and population pressure on natural resources as some of the most common problems in developing countries since their economic development mainly depends on agriculture. They reported, for instance, that over the past 40 years, Ethiopia has recorded increase in human activities leading to expansion of agricultural land, harvesting of timber, and urbanization (Tsegaye, 2010). Getu (2021) observed that increased deforestation in southeast Ethiopia resulted in varied changes in land use and corresponding land cover, thereby affecting the local watershed hydrological cycle leading to flood vulnerability of various sub watersheds within the region. According to Sun *et al.,* (2020) the changes in the natural vegetation and physical soil conditions are typically the prime cause of changes in the characteristics of rainfall-runoff of the local catchments, which consequently change the river cascading system (Beyene, Lettenmaier & Kabat, 2010; Biancamaria, Bates, Boone & Mognard, 2009). Several studies show that the changes in vegetation cover, i.e., deforestation, lead to an increase in water yield and sedimentation (Sun *et al*. 2020).

2.5 Hydrologic Modelling of a River Basin

Hydrologic modelling is fundamental for simulation of water resources for useful information in basins management. Recent studies have underscored the significance of online coupling strategies, representing feedbacks between floodplain inundation and vertical hydrology (Wen, Macdonald, Morrison, Hameed, Saintilan, & Ling, 2013). Regarding the modelling of river basins and large-scale wetlands, the current state-of-the-art technology is 1D channel/2D floodplain inundation models (Wen *et al*. 2013). Although simpler approaches (e.g. water balance) have been adopted to understand wetlands processes, hydrodynamic simulation of river basins and floodplain and flow divergences has been demonstrated as necessary for a more satisfactory exploration and predictability of characteristics such as flood storage and volume, flood peak magnitude and timing, and in multiple channels. Examples of river basins and wetlands with modelling applications in Africa include the Okavango Delta (Bauer *et al*., 2006), the Niger Inner Delta (Neal, Schumann & Bates, 2012), and Logone floodplains in Lake Chad basin (Férnandez, 2016). Global examples include the Macquarie Marshes in Australia (Wen *et al*. 2013) and the Pantanal wetlands in South America (Paz, Collischonn, Tucci & Padovani, 2011).

The responses of cascading systems greatly depend on the output flow from other parts of the river basin, therefore, floodplain inundation models are commonly forced with upstream flows (Wen *et al*. 2013) or integrated with rainfall-runoff models in an offline approach (Biancamaria *et al*., 2009). Although offline integration may be needed to model natural or anthropic influences on wetland inflows and river basins, the approach is limited for not allowing two-way feedbacks between floodplain hydrology and vertical hydrology. The interaction between vertical hydrological balance and flooded areas was studied by Paz *et al*. (2014), using a large scale 1D channel/2D in modelling of Pantanal wetlands. Their study demonstrated that the interactions are essential for the correct representation of wet and dry processes along the river basins, wetland and the channel-wetlands water exchange.

In semi-arid lands, specific model implementations has been demonstrated for hydrological and hydrodynamic processes. The model has sufficient practicality, including floodplain water percolation into un-saturated soil and related feedbacks (Jia, Wang & Zhu, 2020). It also has thorough representation of open water evaporation, given high evaporation rates (Jarihani, Larsen, Callow, McVicar & Johansen, 2015) and channel transmission losses. Additionally, specific runoff generation mechanisms may occur (e.g., occurrence of Hortonian process in contrast to tropical mostly dominant Dunnian process (Esteves & Lapetite, 2003; Mamadou, Gautier, Descroix, Noma, Moussa, Maiga & Vandervaere, 2015). The existence of ephemeral reaches and associated dry beds, and changes of endorheic basins into exoreic ones (and vice-versa) may alter the basin hydrological response (Mamadou *et al*., 2015).

HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) is preferred in studying river basin with dendritic watershed systems. Many scientists have applied HEC-HMS model in different hydrologic and hydrodynamic studies and proven its suitability in forecasting and simulation of streamflow (Sintayehu, 2015). In modelling the relationship between rainfall and runoff in a semi-arid area in Madina, Saudi Arabia, Norhan *et al*. (2016) applied HEC-HMS model and determined the hydrologic yield in Madina watershed. In the Upper Blue Nile River Basin, Sintayehu, (2015) used the model by employing exponential recession approach and Snyder unit hydrograph to simulate the surface water movements in the basin. Meiling, Lei, Thelma and (2016) used the HEC-HMS model in Northwestern China to model and simulate the rainfall-runoff relationship. In flash flood mitigation, Walega, (2013) reconstructed a flash flood event of short duration in Eastern regions of Algeria. The model has been applied in many basins surface water simulation across the world (Zare, Samani, & Mohammady, 2016; Chen *et al*., 2016). Different methods and models (Table 2.2) have produced satisfactory results in studying land uses and land cover changes, climate change factors, flood risk analysis, deforestation, future simulations and predictions, and tool development according to Deng, Zhang, Li, and Pan (2015).

Table 2. 2: Selected event-based HEC-HMS applications

Source	***Location***	***Study Area (km^2)***	***Runoff-Volume (Loss) Method***	***Direct- Runoff (Transform) Method***	***Baseflow Method***	***Routing Method***
(Chu & Steinman, 2009)	USA	192	SCS CN	Clark's UH	Recession	Multiple
(Oleyiblo & Li, 2010)	China	797	Initial Constant	SCS UH	Exp. Recession	Muskingum-Cunge
(De Silva, Weerakoon, & Herath, 2014)	Sri Lanka	2,230	Green and Ampt	Clark's UH	Recession	None
(Choudhari, Panigrahi, & Paul, 2014)	India	16	SCS CN	SCS UH	Exp. Recession	Muskingum
(Derdour, Bouanani, & Babahamed, 2018)	Algeria	1,957	SCS CN	SCS UH	None	Muskingum
(Zelelew & Melesse, 2018)	Algeria	55	SCS CN	Multiple	Constant Monthly	Muskingum
(Moraes, Santos, Calijuri, & Torres, 2018)	Brazil	1,276	SCS CN	SCS UH	None	Muskingum- Cunge
(Zema, Labate, Martino, & Zimbone, 2016)	Italy	795	Multiple	SCS UH	Constant Monthly	None
(Jin, Liang, Wang, & Tumula, 2015)	China	270	Multiple	Multiple	None	Muskingum
(Tassew, Belete, & Miegel, 2019)	Ethiopia	1,609	SCS CN	SCS UH	None	Muskingum
(Kaffas & Hrissanthou, 2014)	Greece	237	SCS CN	SCS UH	Recession	Muskingum- Cunge
(Fang, Yuan, Gao, Huang, & Guo, 2018)	China	2,631	SCS CN	SCS UH	Recession	Muskingum
(Adilah & Nuramirah, 2019)	Malaysia	1,630	SCS CN	Clark's UH	Recession	None
(Azam, Kim, & Maeng, 2017)	Korea	163	SCS CN	Multiple	Recession	Muskingum
(Koneti, Sunkara, & Roy, 2018)	Sri Lanka	300	SCS CN	SCS UH	Constant Monthly	Muskingum Cunge/Kinematic

Source: **Berkan 2020**

In most studies with continuous models, it is proven that Deficit and Constant and Soil Moisture Accounting (SMA) are the only loss methods while performing long term continuous simulations (De Silva, Weerakoon, & Herath, 2014). This is applicable both for small and large water resource basins (Halwatura & Najim, 2013). For the continuous simulations, short time steps are not preferred since they cause difficulties in computations for extended periods, rather, daily steps are so preferred in estimating the design flow (Boughton & Droop, 2003). Deficit and Constant model use less data compared to SMA method (Verdhen, Chahar & Sharma, 2013; Azmat, Choi, Kim & Liaqat, 2016; Gebre, 2015; Gumindoga, 2017; Halwatura & Najim, 2013). Simulation results are specific to locations and the methods applied may respond differently depending on a study area (USACE, 2000). The table below show the different research works with associated continuous model method applied (Table 2.3).

2.6 Research Gap

Several researches have been done on the subject of land cover and land use, river basin management and socio-ecological factors. The studies have focused on the implications of such factors on various river basins. Among the most researched river basins include Amazon, Nile, Yellow, Colorado, Euphrates, Mangli, Songhua, Pearl, Okavango, and Dong Nai rivers among others. The studies have comprehensively investigated the correlation between land use and land cover as well as changes in the watershed, river basin and the corresponding mouth basins. In the studies, weight has been given to human activities such as agriculture. Limited attention has been given to the influence of a combination of anthropogenic activities, hydrology, human population growth, government policies, and climate change. From the empirical review conducted, the LULC is a function of a combination of factors including international capital markets pressures, human population growth, government regulation and policies as well as climate change.

Table 2.3: Selected continuous HEC-HMS applications

Source	***Location***	***Study Area (km^2)***	***Runoff- Volume (Loss) Method***	***Direct- Runoff (Transform) Method***	***Baseflow Method***	***Routing Method***
(Chu & Steinman, 2009)	USA	192	SMA	Clark's UH	Recession	Multiple
(Fleming & Neary, 2004)	USA	22.83	SMA	Clark's UH	None	None
(Verdhen, Chahar, & Sharma, 2013)	India	350	Deficit and Constant	Clark's UH	Recession	Lag
(De Silva, Weerakoon, & Herath, 2014)	Sri Lanka	2,230	SMA	Clark's UH	Recession	None
(Azmat, Choi, Kim, & Liaqat, 2016)	Pakistan	33,867	Deficit and Constant	SCS UH	Constant Monthly	None
(Bhuiyan, McNairn, & Powers, 2017)	Canada	545	SMA	SCS UH	Recession	Muskingum
(Gebre, 2015)	Ethiopia	5,125	Deficit and Constant	Synder UH	Exp. Recession	None
(Gyawali & Watkins, 2013)	USA	5,273	SMA	None	None	None
(Gumindoga, Rwasoka, Nhapi, & Dube, 2017)	Zimbabwe	3600	Deficit and Constant	Synder UH	None	Muskingum
(Halwatura & Najim, 2013)	Sri Lanka	380	Deficit and Constant	Synder UH	Recession	None

Source: **Berkan 2020**

River Kuja, an important basin, has not been studied in terms of land use and land cover changes with their impacts on basin hydrology takin into consideration the peoples' perception. There is a need to investigate land use land cover changes and their impacts on the hydrology of River Kuja basin. Recent development indicates potential dangers along the river basin. Residents of Migori and Homa-Bay counties have been on record decrying of the bursting of the river bank during heavy rains (WRMA & JICA, 2014). They were on record noting that the recent flooding along the river has not been witnessed for decades (https://www.youtube.com/ watch?v=cJpUUQ1yH2w). Among the factors they highlighted as the cause of the flooding is the construction of Sukari Industries along the river.

The difficulty of actually delineating the factors affecting land use and land cover along River Kuja presents a challenge in developing data to determine past, present and future trends. Land use is generally a function of management decision, policies, laws, that may not always be possible to infer by examining the ground via household surveys only. No research studies have profiled the possible land use/land cover changes along River Kuja basin for the past three decades. Additionally, there has never been a hydrologic model for River Kuja which can be used to accurately predict long term possible cascading system of the river and the resulting effects on the river ecosystem. These are the focal issues for the research and the ultimate objective of the study.

2.7 Theoretical Framework

The study was anchored on "The Systems Theory" propounded by Von Bertalanffy in 1932 and adopted in 1937. A system is a whole with complex functions composed of several subsystems in a specific structure and form (Roth, 2019). Moreover, the whole function is not reducible to the isolated state of each subsystem. A system may also be viewed as a collection of components that are interdependent or "working together". In general usage a system is understood as a: 'complex whole', 'set of connected things or parts', an 'organized body of material or immaterial things' and 'group of objects related or interacting so as to form a unity'. A system may also be defined as a set of elements standing in interrelation among themselves and with the environment. It may also be seen as a set of interconnected subsystem /components/elements or parts, but each part may be seen as a system itself and the whole system may be regarded as but one part of a larger system. Systems often work to maintain a state of balance i.e. an equilibrium but this may be interrupted.

The system theory has been widely used in ecological research and fully integrated into other theories. Among them is the social–economic–natural complex ecosystem theory which suggests that evaluating the regional ecosystem requires a holistic view that considers the interactions among the elements of social, economic, and natural systems (Liu et al. 2007; Liu et al. 2015). The concept of system can be made very inclusive (examples - a society with a system of government, or an individual with a system of organs or tissues such as the immune system etc.). Every system has at least two elements, and these elements are interconnected/ interact.

The system theory was used in this research. The study looked at Kuja river basin as a system. The basin combines several components such land/soils, flora and fauna, infrastructure, water bodies, human activities among others. In this system, the components are interrelated and change in each component, for example, land use land cover was expected to directly or indirectly affect the state of other components. The systems theory treats the land use and land cover in a basin as material entities with characteristic properties which have particular ways of relating to one another and to the socio-economic forces that impinge on them. The possible forces driving land-use and land-cover changes in a river basin can be grouped into six categories: population; infrastructural development; technology; political economy; political structure; and attitudes and values (Turner and Meyer 1991; Stern et al. 1992). Changes in the land cover in the basin was expected to have impact on surface water resources thus indicating some imbalance in the River Kuja basin system like decline in surface hydrology.

2.8 Conceptual Framework

The study is based on the anthropogenic activities and their impacts on the land use land cover systems which contribute to underlying social driving forces of land use land cover changes. According to Waldo Tobler's first law of Geography, "everything is related to everything else, but near things are more related to each other than distant things (Miller, 2004). The interaction between human activities and the natural resources in a river basin are controlled in terms of spatial and temporal dimensions. Elements in space, which are closer to each other, interact more than those at a far distance to each other. This phenomenon on environmental interaction needs a robust analytical framework which is able to integrate the environmental, social and hydrologic sciences. The process involves describing and understanding the types of driving forces and the effects these forces exert on the environment. An overall framework known as Driver-Pressure-State-Impact-Response (DPSIR) was adopted. It is widely applied in studies such as this with relevant modifications (Millennium Ecosystem Assessment, 2005; Grünbühel, 2005; Zhang and Fujiwara, 2007; Arthurton, *et al.,*2008; Valkering, Tabara, Wallman and Offermans, 2009).

The D-P-S-I-R conceptual framework asserts that an environmental complex such as River Kuja basin has a spatial distribution of different natural resources and socio-economic activities originating from human activities and corelate to one another. In this study, the framework adopted is as in Figure 2.2. The independent variables were human population growth, land use and land cover change and climate change. The dependent variables were hydrology in surface water yield and state of lands. There is normally a third category of variable commonly referred to as intervening variable or moderating variable. Moderating variable do not originate from the research question or the objectives but has an influence on the relationship between the independent and the dependent variable. The moderating variable in this study is therefore government implementation of policies and legislation on land use along riparian lands. The study sought to establish how these factors can be used to influence the land use land cover changes and their impact on the hydrology of River Kuja basin. Literature review showed that the hydrodynamic characteristics of any river basin are a function of land use and land cover in the river basin, population growth and climate change.

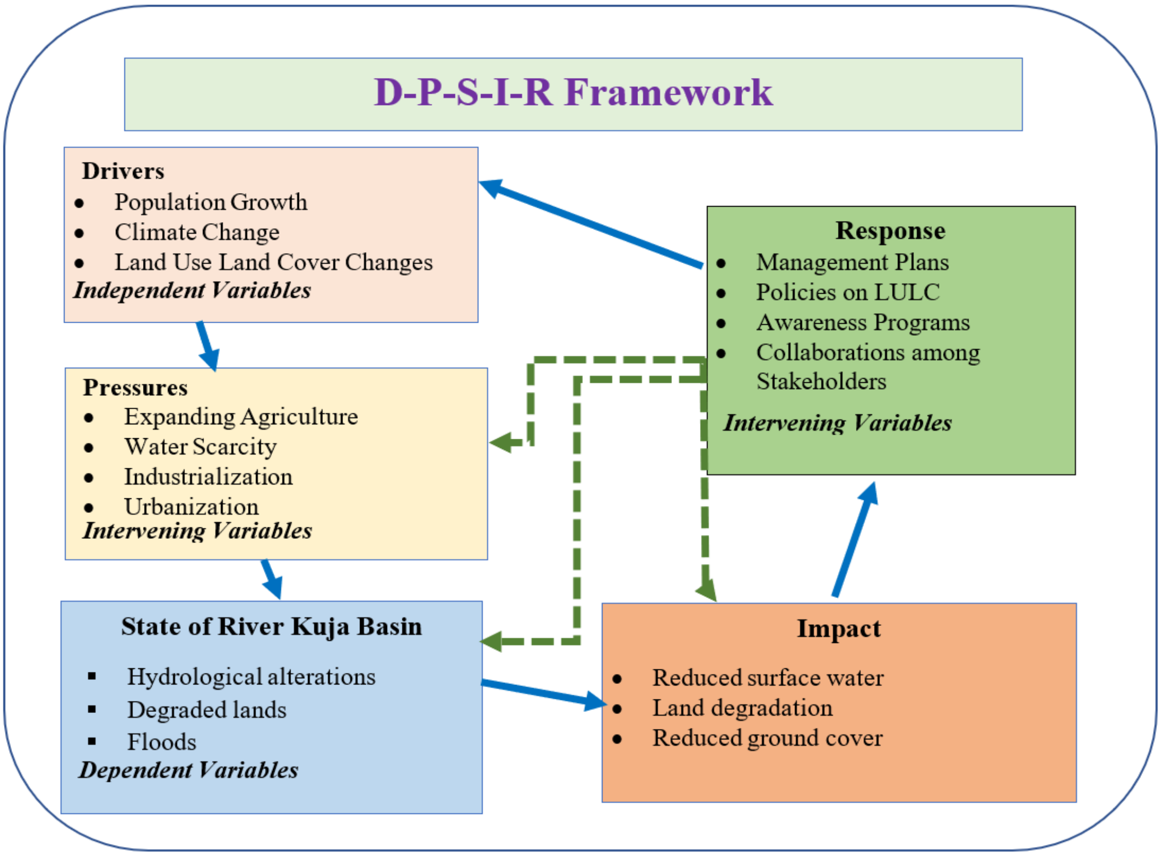


Figure 2. 2: Conceptual Framework

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

3.1.1 River Kuja basin

The Kuja river basin is an extensive basin spanning from Kiabonyoru highlands in Nyamira County downwards to Lake Victoria. It lies within coordinates 0.65ºS 43.97ºE (34.883110 -0.996036 Decimal Degrees) and has a total length of 147 km (Figure 3.1). The basin is averagely 2,000m above the sea level but rises to 3,000m above the sea level at its source in Nyamira.

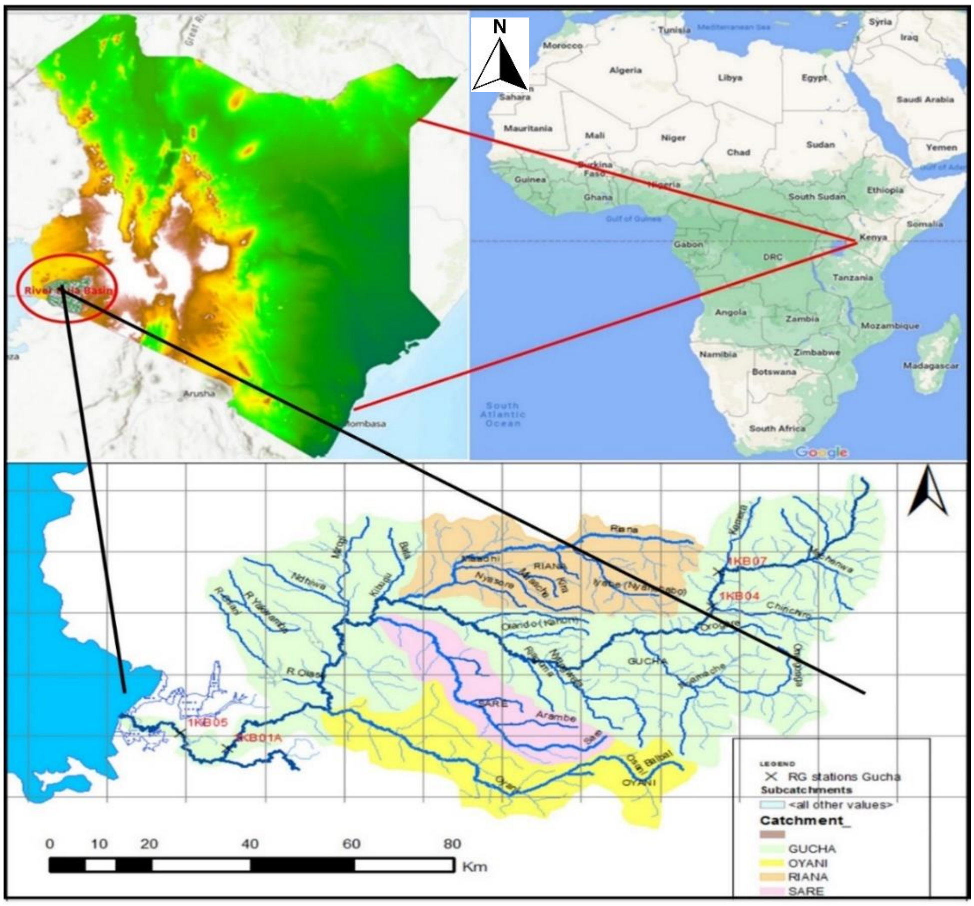


Figure 3.1: Location of River Kuja Basin (Source: Gucha-Migori basin IWRM Plan 2014)

The basin has an area of 6,900km^2 (2,664 sq. mi) with a population of approximately 2.2 million people (GoK, 2019). The river has an average discharge of 58 m^3 s^{-1} (2,048 cu ft s^{-1}). The river runs across the Gucha land where it is commonly known as Gucha river. Part of it is referred to as River Mogonga (a name symbolizing the deadly effects of this river when it floods). The part that passes through Luo communities is referred to as River Kuja. The River Kuja basin's delineation is as shown in Figure 3.2 below.

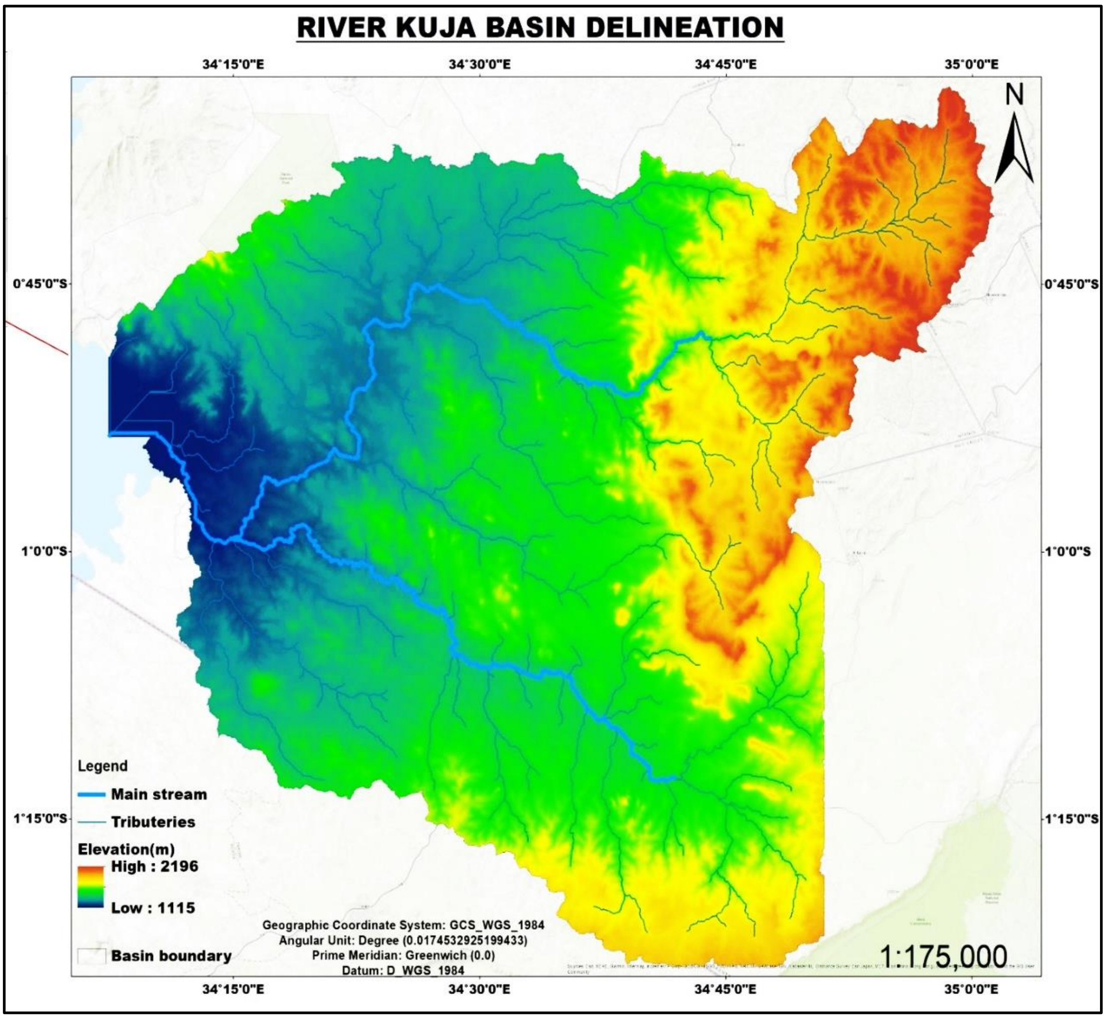


Figure 3.2: Map of Kuja-Migori River Basin Main Stream and Tributaries (Source: JICA 2014)

3.1.2 Hydrologic characteristics

The basin cuts across five counties in Kenya namely Nyamira, Kisii, Narok, Homabay and Migori counties. River Kuja drains into Lake Victoria downstream where it is joined by Migori River. The mean annual runoff near its outflow to Lake Victoria is estimated to be 1,884Mm^3/year. The basin is densely fed by small tributaries that drain into River Kuja (Figure 3.3). The tributaries include, River Gucha at the source, Sare, Oyani, Onyinjo, Mirogi, Riana, Nyamache, Mugonga and Chirichiro Rivers among others. There are over 800 springs and 8 major dams within the basin. There are three major River Gauging Stations within the basin; KB01A, KB04 and KB07.

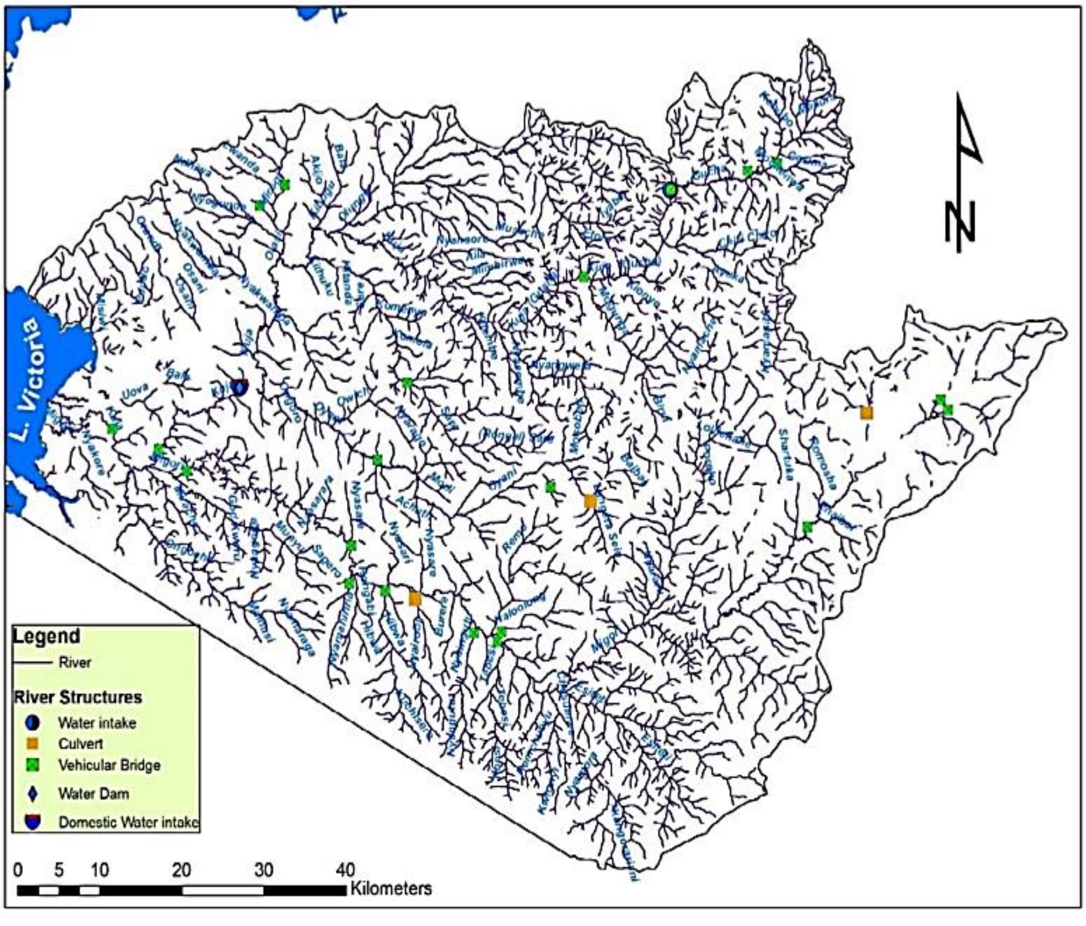


Figure 3.3: Map of Kuja-Migori River Basin hydrologic patterns (Source: Nyangaga 2010)

3.1.3 Climate

The basin experiences two rainy seasons with the highest rainfall being between March and October (Figure 3.4). The average annual rainfall is approximately 1200 mm. Temperatures range from 15°C to 20 °C within the highlands of Nyamira, and 21°C to 30°C in the lowlands towards Lake Victoria. The average temperature of the basin is 25 °C.

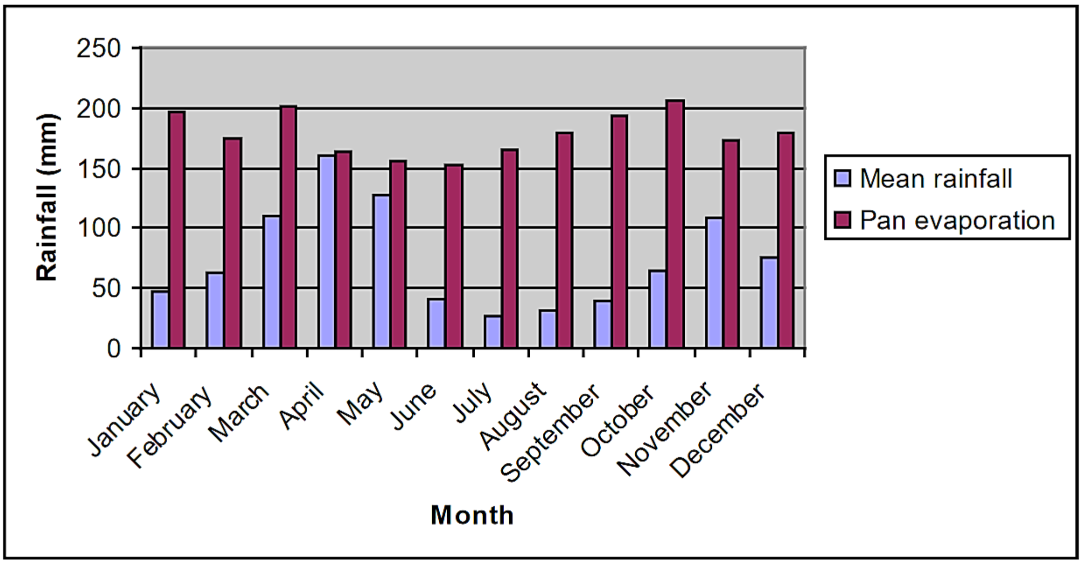


Figure 3.4: Mean Monthly Rainfall and Evaporation relationship in Kuja Basin (Source: Nyangaga, 2010)

3.1.4 Economic activities

The larger part of the population in this basin depends on subsistence agriculture. Some depend on businesses in some of the urban centers and towns while other rely on economic activities including fishing around the lake, animal husbandry, sand harvesting, brick making, handicraft, carpentry, stone curving, and small-scale businesses among others. There are several industrial factories within the basin which process agricultural products. These include Sony sugar processing company in Awendo, Sugar factory in Transmara and also in Ndhiwa, Tea Factory in Nyamira and another Tea Factory in Kisii county.

3.1.5 Topography and geology

The basin is well vegetated in the highlands of Nyamira and Kisii counties where the altitude is at 3,000m above the sea level. Vegetation cover depreciates downslope towards Lake Victoria due to increase in temperatures in the areas surrounding the lake. Sloping system of the basin is divided into three major categories i.e. upstream slope system of 25% to over 40% slope, midstream slope system of 10% to 20% slope and downstream slope system of 0% to 10% slope.

The geology of the area is majorly of old Bukoban rocks that are of Palaeozoic age in properties. This type of rock consists of acidic volcanics of quartzite and escarpments systems. In the sub catchments of Kisii, there is a thin belt of Kavirondian and Precambrian rock systems. Towards Lake Victoria is characterized by quarzitic belt circumscribed by a wide belt of basalt. There exist large soapstone belts within mid sub-basin areas of Kisii. The soapstone originates from the basalt through hydrothermal activities. The South Nyanza parts of the basin is characterized by porphyritic and non-porphyritic andesite and felsite rocks.

3.1.6 Soils

Kisii and Nyamira highlands consist of reddish fertile volcanic loamy soils while the downstream of South Nyanza region consists of greyish fertile alluvial soils. Most of the low-lying areas are characterized by black cotton, clay and sandy soils. Figure 3.5 shows the soil distribution of the basin with major river gauging stations.

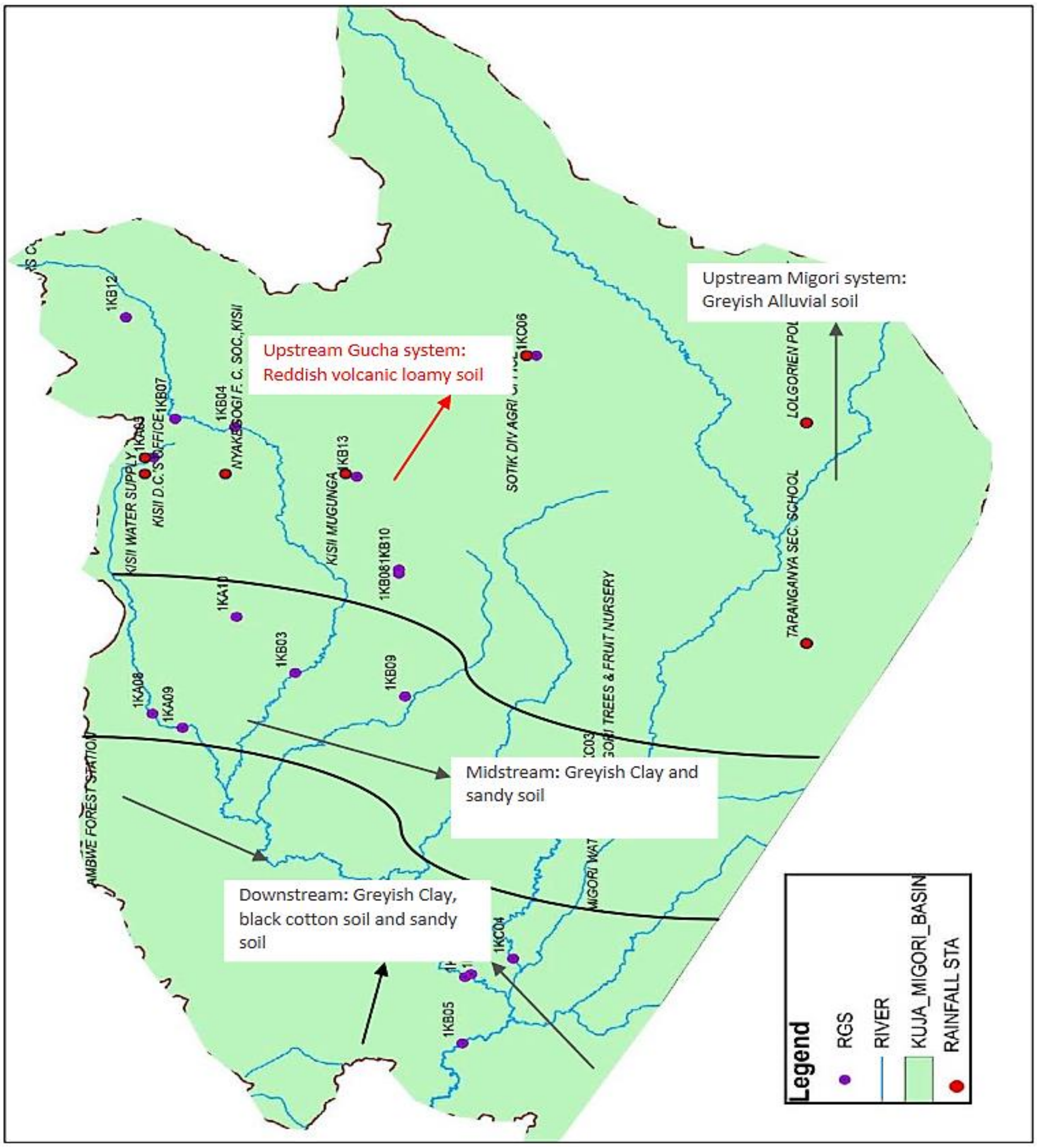


Figure 3.5: Soil Distribution Map (Soil texture) and River Gauging Stations (Source: JICA 2014)

3.2 Land Use Land Cover Changes

3.2.1 Study Design

The study used time series and cross-sectional survey design. It involved the use of remote sensing technology in analysing satellite images. Thirty-year decadal satellite Landsat images of 1990, 2000, 2010 and 2020 were downloaded and processed to 1G. Hardcopy images for use in reconnaissance and groundtruthing activities were processed, clipped to study area, enlarged and printed at the scale of 1:50,000 at the Department of Resource Surveys and Remote Sensing (DRSRS). Google Earth Engine (GEE) was used to process the satellite images by application of supervised image classification. There was a 12% cloud cover which was acceptable. The other data included in the process were Digital Elevation Model (DEM) of resolution 30m x 30m, field surveys data and basin shapefile. The study area was first delineated using DEM data and river shapefile. The images were captured over different times and compared while considering different temporal phenomena like water bodies, agriculture, forests, shrub land, urban areas and grassland. These data sources were considered adequate to cover the needs of the study since the objective was to measure broad categories of land cover/uses that influence the area covered by the basin. Since time series analysis requires a number of time steps to stabilize the change analysis process, more than two-time steps was required. This was because patterns of change in land and land use phenomena, though dynamic depending on the driving forces, often have slow progress and require such periods to detect major spatial and temporal changes.

3.2.2 Methodology

Methods employed to achieve the desired objective of land use land cover mapping for river Kuja entailed a couple of sequential steps; data acquisition, data processing, training data collection for supervised image classification, image classification, accuracy assessment and change detection. Thirty years with four (4) decadal satellite images of 1990, 2000, 2010 and 2020 were downloaded and pre-processed to 1G level as a *Geo*TIFF single band and eight (8) bit files. The images were sourced from *www/http/landsat.usgs.gov.* Full Scene digital Landsat Thematic Mapper (TM) and

Landsat Enhanced Thematic Mapper/ Plus (ETM+) satellite images were processed and used. Hardcopy images for use in reconnaissance and ground truthing activities were processed, clipped to study area, enlarged and printed at the scale of 1:50,000 at the Department of Resource Surveys and Remote Sensing (DRSRS). The year 1990 was chosen as the base year since it was the onset of large-scale sugarcane production in the basin and the study used decadal approach of 30 years until 2020. This is because patterns of change in land and land use phenomena, though dynamic depending on the driving forces, often have slow progress and require such periods to detect major spatial and temporal changes.

Reference data was collected from the field in order to understand and correlate the satellite image features with study area features. Using analogue image interpretation elements, hard copies of coloured images were applied to identify observable patterns of land cover features. The elements used include tone, colour, texture, association and pattern. The identified points were geo-referenced, described either retrospectively or instantaneously, and used as training features. The training sites were selected randomly based on observable features and information like government reports and vegetation maps were also collected during the field reconnaissance.

3.2.2.1 Data acquisition

Landsat data was selected and data was fetched through google earth engine application programming interface. The data can also be retrieved through Glovis and Earth explorer. Google Earth Engine (GEE) was preferred due to its ease of access and capabilities to leverage the platform for processing as it offers cloud computing functionalities in a free-to-use approach in the explorer web app. The preference was also based on the vastness of the study area. GEE has a parallel high-speed processing capability with Google computational machine algorithms and Application Programming Interfaces (APIs) which support the common coding languages. These modules easily enable the users to extract, analyse and present big spatial data in powerful and easier ways without applying specialized computer coding expertise. Landsat has evolved over time and there are a couple of sensors that have petabytes of data archived overtime. Landsat has numerous sensors ranging from Landsat 1 through to Landsat 9 that was launched by NASA in 2020. Table 3.1 shows the Landsat data used for this project. The respective datasets were acquired for the area of interest and made ready for processing.

Table 3. 1: Satellite Images downloaded for analysis

Data	Temporal resolution	Spatial Resolution	Source	Start year	End year	Where used in the project
Landsat 5	16 days	30m	USGS	1984	2013	1990
Landsat 7	16 days	30m	USGS	1999	-	2000, 2010
Landsat 8	16 days	30m	USGS	2014	2020	2020

3.2.2.2 Data Processing

Data processing was done by leveraging the power of Google Earth Engine (GEE) cloud computing resources. This was to enable the user to have access to powerful online tools in the research area. Algorithms were developed to do the following:

a. Cloud masking

River Kuja basin experiences moist conditions and rainfall during the rainy season. Given that the temporal resolution of Landsat instrument is relatively long (16 days) finding cloud free images was troublesome. Consequently, a cloud masking algorithm was applied on GEE to filter out images with clouds (Figure 3.6). However, the images obtained still had some cloud of about 23%, therefore, the process was repeated by stitching together images to create a cloud free image.

Figure 3. 6: Cloud Masking Algorithm for River Kuja Basin

b. Mosaicking

Mosaicking is a process of bringing together images of different scenes of the sensor to make one image. This process was done to generate one image for each epoch. (Figure 3.7).

Figure 3. 7: Mosaicking Process during satellite image preparation

c. Noise Removal

Remotely sensed data like other data tend to have components of errors. Therefore, the researcher sought to clean the images prior to their use. An algorithm was developed for pre-processing to address atmospheric and geometric corrections.

d. Band composite

At this stage the spectral bands were selected to aid in the identification of ground features. The principle behind this was that different objects would respond differently when illuminated by sunrays and therefore the spectral signature would vary across different wavelengths and detected differently by the sensor. The spectral bands were used to develop vegetation indices such as normalized difference vegetation index among others. The bands selected were the red, green blue, near infrared, and the shortwave infrared.

3.2.2.2 Land Use Land Cover Classes

The classes identified and used in the study are as shown in Table 3.2**.**

Table 3.2: Land use Land Cover classes used in River Kuja basin

No.	Land use/land cover	Description
1.	Built up Areas	Residential, industrial, commercial, recreational Areas, institutional, and road networks
2.	Forest	Area of land dominated by trees
3.	Cultivated areas/Agricultural Land	Both irrigated and rain fed arable land, cropland, farming and fallow fields
4.	Shrub land	Plant community characterized by vegetation dominated by shrubs, often including shrubs, herbs and geophytes
5.	Grass land	Area under continuous cover of grasses
6.	Water Bodies	Rivers and dams

3.2.2.3 Training Data Collection

Training data were collected to give information to a machine learning module, the spectral signature of a specific land cover type. This was done through image interpretation techniques as presented in section 3.2.2.5. Polygons for different classes were collected in readiness for classification exercise (Figure 3.8).

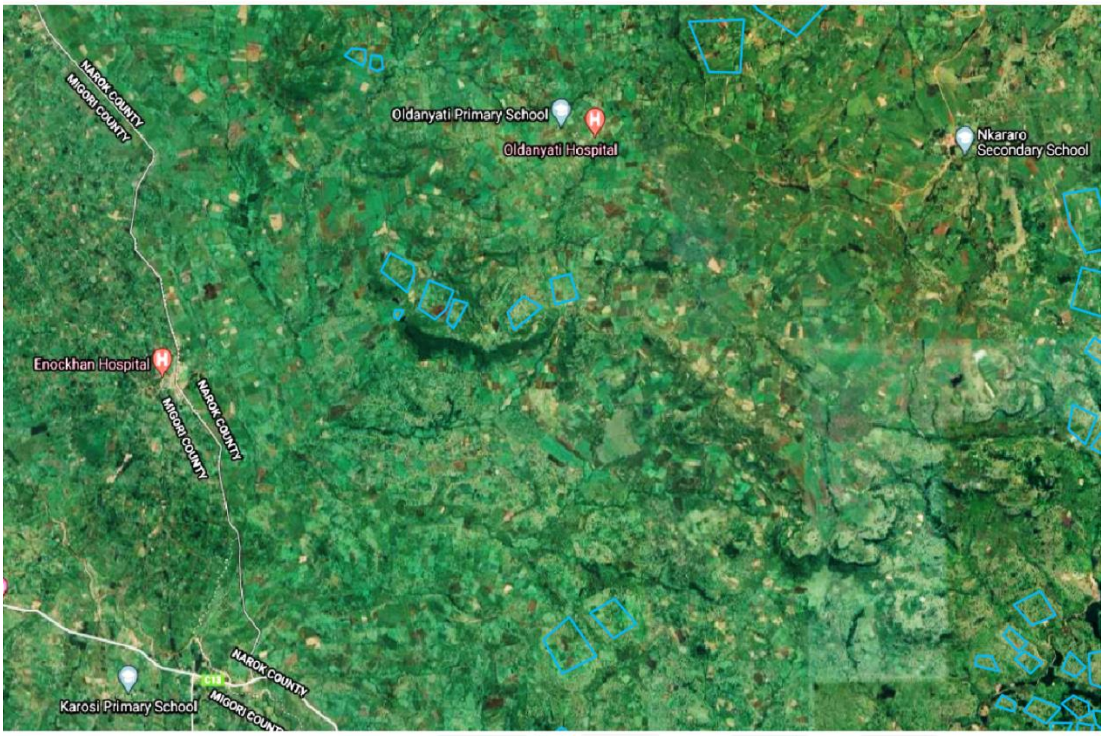


Figure 3. 8: Training data sites during the supervised classification process

3.2.2.5 Image classification

Image classification was done through the use of Random Forest and maximum likelihood algorithms. The training data was split into training, testing and validation sets using the ratio of 70, 20 and 10 respectively. A set of indices were also computed to help in differentiation between classes and reduce the probability of getting mixed classes, the indices calculated included: normalized vegetation index, normalized wetness index, normalized multiband drought index, modified soil-adjusted vegetation index, normalized difference snow index and enhanced vegetation index. The indices were added to the images as additional bands and were included during the classification process.

The classification made sure that the bands with the highest correlation plots were used to develop image composite that are then applied to collect the training datasets. Highly correlated bands, is interpreted as those having the same type of features, with minimal class to class confusion.

3.2.2.6 Accuracy assessment

This is a statistical test to evaluate the accuracy of a classification exercise, there are numerous modules for doing this, however, the most common and efficient method chosen for this exercise were the kappa coefficient, error matrix, producers and consumers accuracy assessment. The advantage of kappa coefficient error matrix is that it helps identify the type and nature of errors associated with classification process including their quantities. The following equations helped in computing the accuracy of the images' classification:

$$\boldsymbol{Producers\ Accuracy = \frac{Total\ number\ of\ correct\ pixels\ in\ a\ given\ category}{Total\ number\ of\ correct\ pixels\ in\ a\ reference\ data}} \quad \text{Equation 3.1}$$

$$User\ Accuracy = \frac{Total\ number\ of\ correct\ pixels\ in\ a\ given\ category}{\begin{array}{c}Total\ number\ of\ correct\ pixels\ ithat\ were\\ actually\ classified\ in\ that\ category\end{array}} \quad \text{Equation 3.2}$$

$$Overall\ Accuracy = \frac{Sum\ of\ diagonal\ metric}{Total\ number\ of\ pixels} \quad \text{Equation 3.3}$$

$$Kappa\ Index = \frac{Observed\ accuracy - Chance\ agreemet}{1 - Chance\ agreement} \quad \text{Equation 3.4}$$

3.3 Hydrologic Modelling of River Kuja Basin

3.3.1 Study Design

The hydrodynamic and hydrological modelling of Kuja basin was done using ArcGIS software and HEC-HMS model. The data used included Digital Elevation Model (DEM), rainfall data, river Kuja discharge, temperature, soil types, land use and land cover. The DEM was downloaded from Shuttle Radar Topography Mission (SRTM) and provided elevation and slopes forming tributaries that drain into River Kuja. It was of a spatial resolution of 30m by 30m. The basin was merged into five sub-basins out of the 67 sub-basins generated during ArcGIS Kuja basin shapefile processing. River discharge was obtained from Water Resources Authority for Muhuru Bay Station covering a period of thirty years. For the climate data, precipitation and temperature data used covered the period from 1990 to 2020. Stations used included Sotik, Sony Sugar, and Muhuru Bay weather stations. The data were processed using ArcGIS software, and extension HEC-GeoHMS was applied and exported to HEC-HMS for final results.

3.3.2 Methodology

3.3.2.1 Rainfall and Streamflow variability

The relationship in variability of rainfall and streamflow data was analysed using regression analysis approach. This is a quantitative expression of how dependent and independent variables relate in nature. Streamflow being a dependent variable was investigated by measuring its movement response to rainfall which was the independent variable. The analysis was used to determine the change in the amount of streamflow (dependent variable) with a unit change in rainfall (independent variable). The mathematical function below was used to calculate the regression model:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad i = 1,2,3, \dots , n$$ *Equation 3.5*

where:

y_i = the i^th^ dependent variable response observation

x_i = the i^th^ independent variable observation

β_0 = intercept

β_1 = slope

ε_i = the random error or residual for the i^th^ observation and

n = sample size.

3.3.2.2 Hydrologic Model Development

The study used HEC-GeoHMS 10.6 to process the hydrologic data. This is a geo-processing extension of AcrGIS 10.6. The basin's geospatial information like catchment boundary, sub-basins, elevations, streamflow paths and soil type were generated and processed using Arch Hydro tools. The main data sets processed included Digital Elevation Model (DEM) which provided topographical and geological features, land use data, meteorological data (River Kuja discharge, Rainfall and Temperature) and soil types. Processing of these data generated the parameters needed as input data into the HEC-HMS model for runoff simulation.

3.3.2.3 Terrain pre-processing

The DEM was used to delineate the basin and process all the streams in the study area. The shapefile of the boundary limit formed was used to clip other data parameters such as soil map and land use land cover activities. Terrain processing was achieved by application of Arc Hydro tools using DEM and stream files. It helped in carrying out run off estimation within the watershed. Sub-surface drainage such as culverts and flood control structures were not considered by "bare earth' DEM. These structures were accounted for by reconditioning the DEM. The automated process achieved this by artificially lowering the DEM alignment of sub surface structures (burning in to bare earth) resulting to a HydroDEM (Figure 3.9).

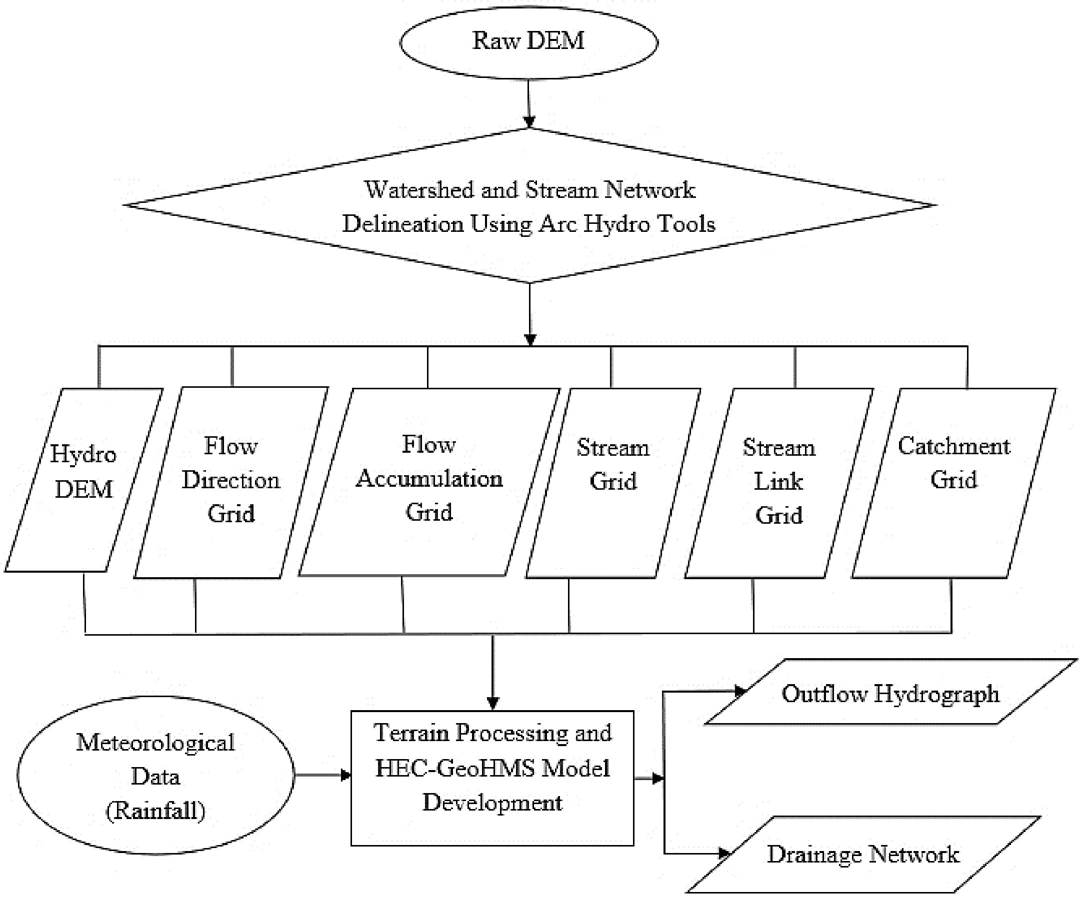


Figure 3.9: Schematic layout of the terrain processing in Arc Hydro

Terrain preprocessing was done to help develop a hydrological correct DEM and its derivatives i.e., the flow direction and the flow accumulation grids in the vector environment. The resultant was a correct drainage pattern that met the threshold for specific model consideration. This process was considered successful when the flow patterns met the expectation of the analysis.

3.3.2.4 Preparing HEC-HMS model inputs using HEC-GeoHMS

The terrain preprocessing techniques were sequentially done by first filling the sinks thereafter determining flow direction within the basin. Filling sinks happened in areas into which the basin water, after every precipitation, flew but did not exist as a surface flow such as localized ponding. They had to be filled in terrain preprocessing stage. The fill values are presented in Figure 3.10.

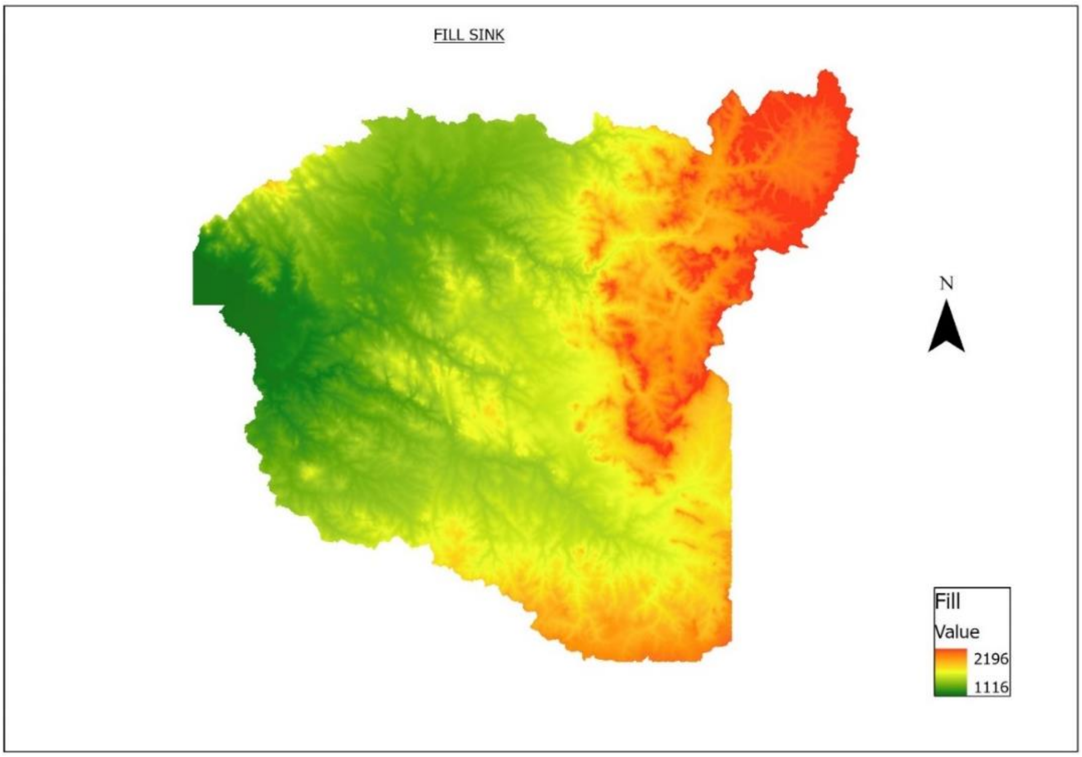


Figure 3.10: Illustration of Fill Sinks in the basin

Flow direction processing involved the direction of the steepest descent for each terrain cell to the next closest neighbouring cell. It showed the movement of water between the terrain cells. The flow direction in Arc Hydro was based on topography i.e. on the slope defined by the terrain only. When this function was called, numerical values were assigned to each grid cell based on the steepest descent direction (i.e. N, S, E, W, NE,). The outflow point, as well as all nearby high points, were recognized and marked on the map. All of the high points were connected by a watershed boundary line. Along the steepest descent path, the boundary line travelled perpendicular to each contour line.

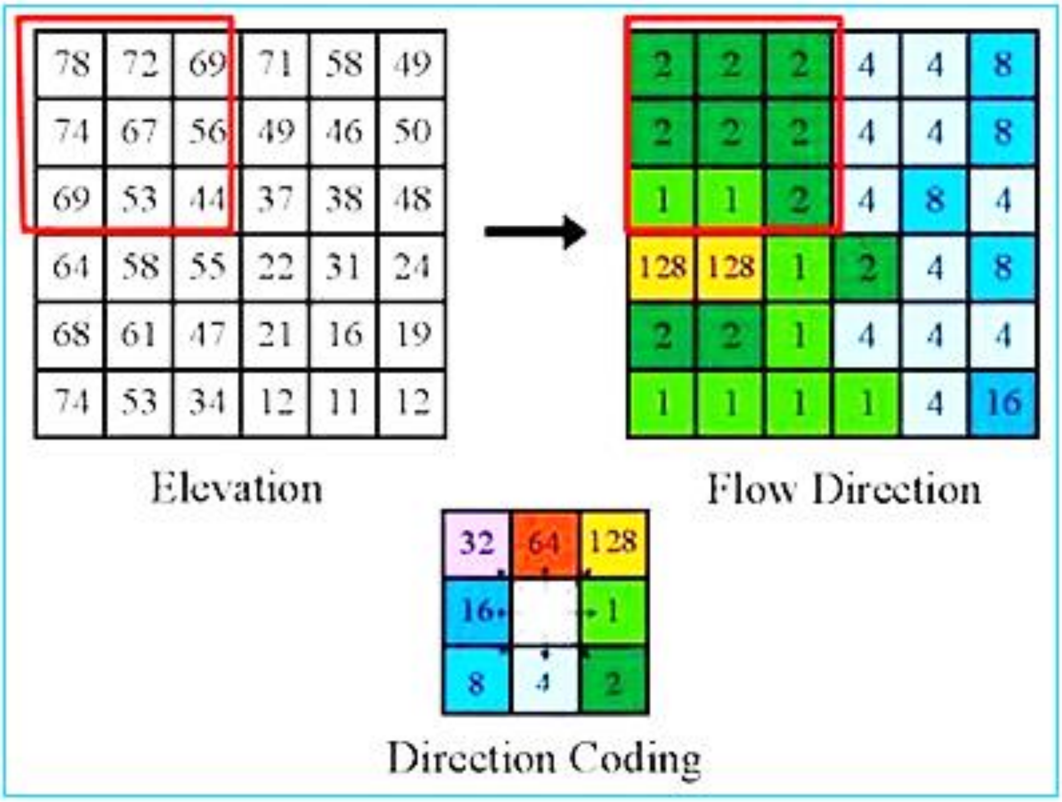


Figure 3.11: Flow direction illustration using D8 method

D8 method in ArcGIS software was used as shown in Figure 3.11. It specified 8 directions for every single cell. The resultant raster had values from 1, 2, 4 up to 128 as shown in the illustration in Figure 3.12. During the flow direction process, there was accumulation of surface water flow where the number of cells in the Hydro-DEM collected surface overflow from upstream of each cell. This created a grid with several upstream cells that drain through each Hydro DEM cell.

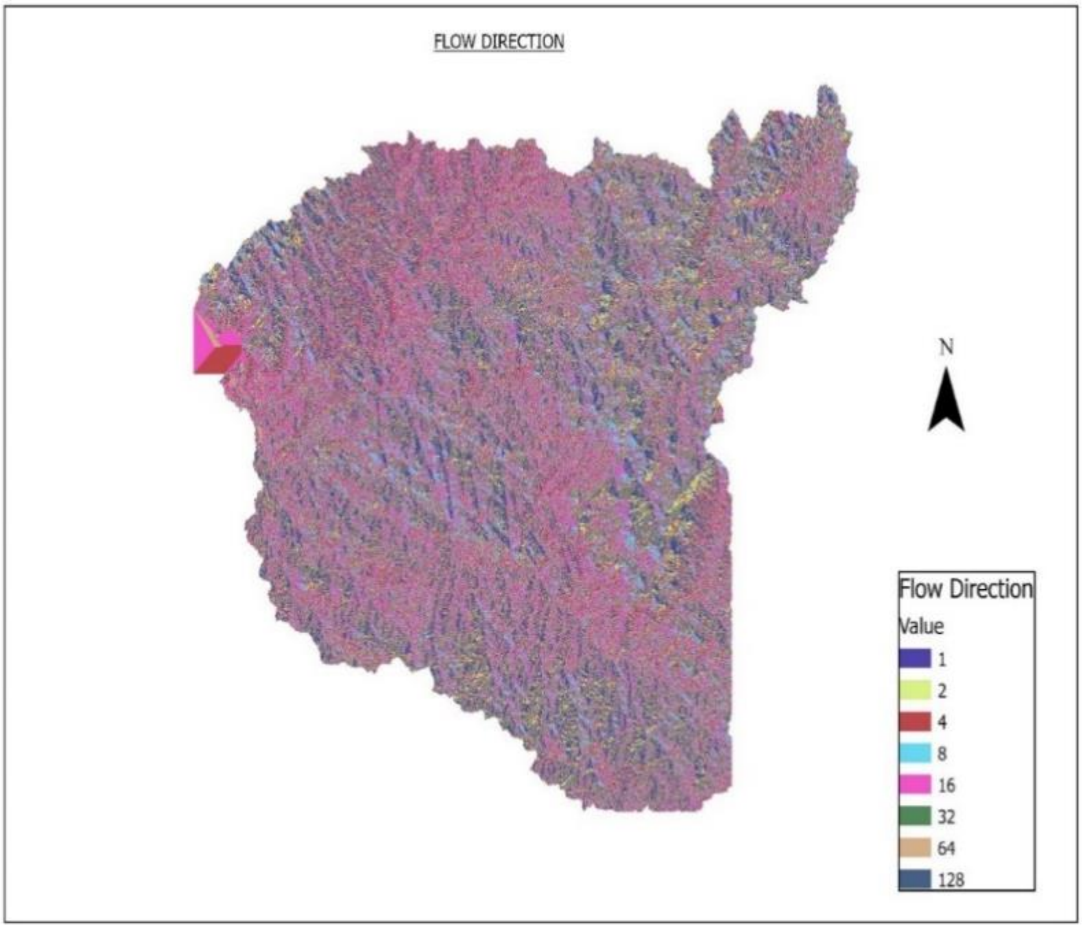


Figure 3.12: Flow Direction map of the basin

All cells having a flow accumulation greater than the user-defined threshold were classified as being part of the stream network. It recognized "stream" cells, which were defined as cells that drain more area than a user-specified threshold, which was 1% of the maximum flow accumulation. The threshold and drainage lines that resulted were utilized to optimize performance for subsequent operations. The stream grid was segmented in this step. A stream segment is a stretch of a stream that runs between two junctions. Between the confluences, it uniquely numbered stream segments (LINK). For the entire DEM to get processed, it was ensured that the "SINK Link Grid" and "SINK Watershed Grid" entries in the form were "null." The processes are as outlined in Figure 3.12, Figure 3.13 and Figure 3.14.

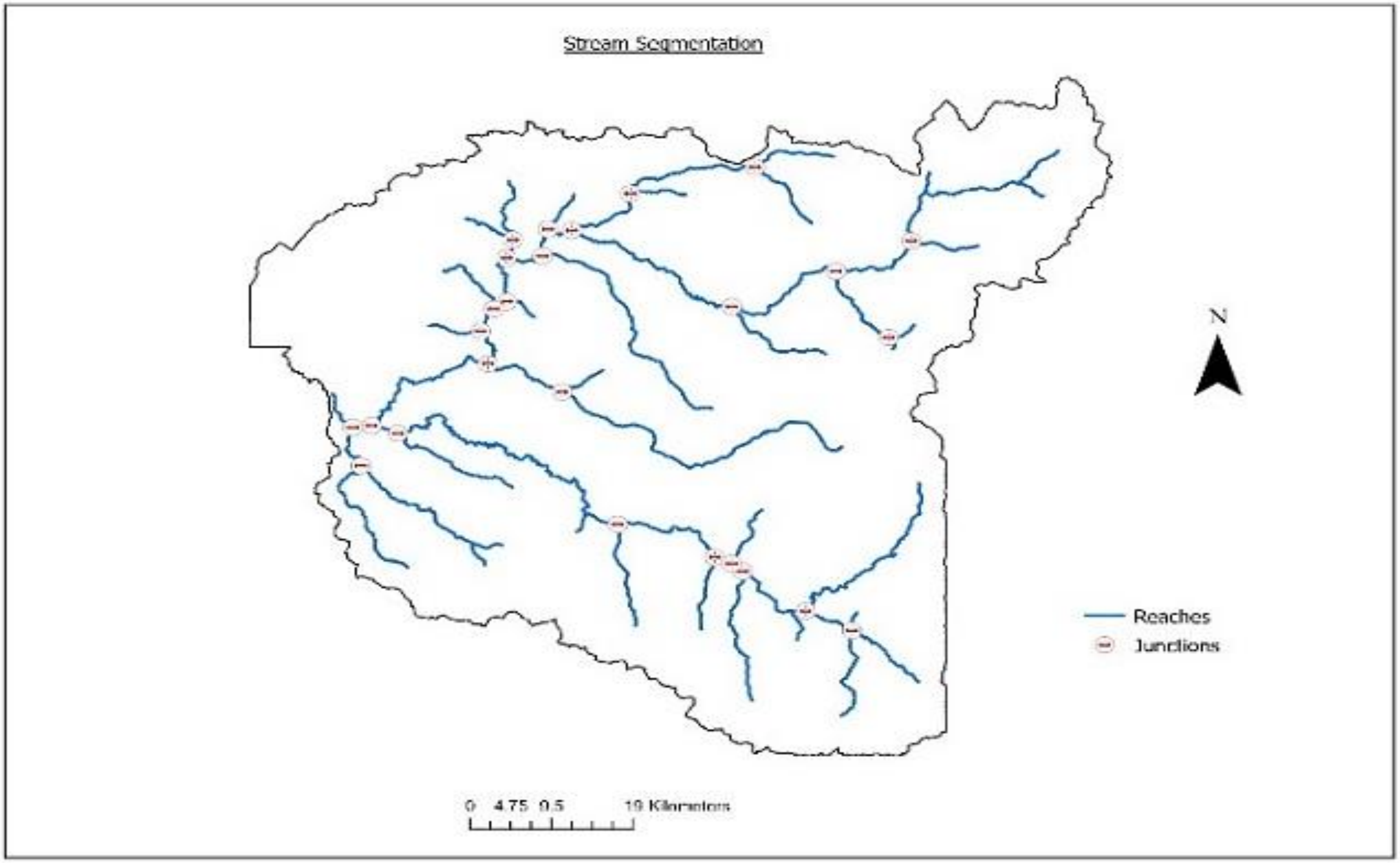


Figure 3.13: Stream Segmentation of River Kuja basin

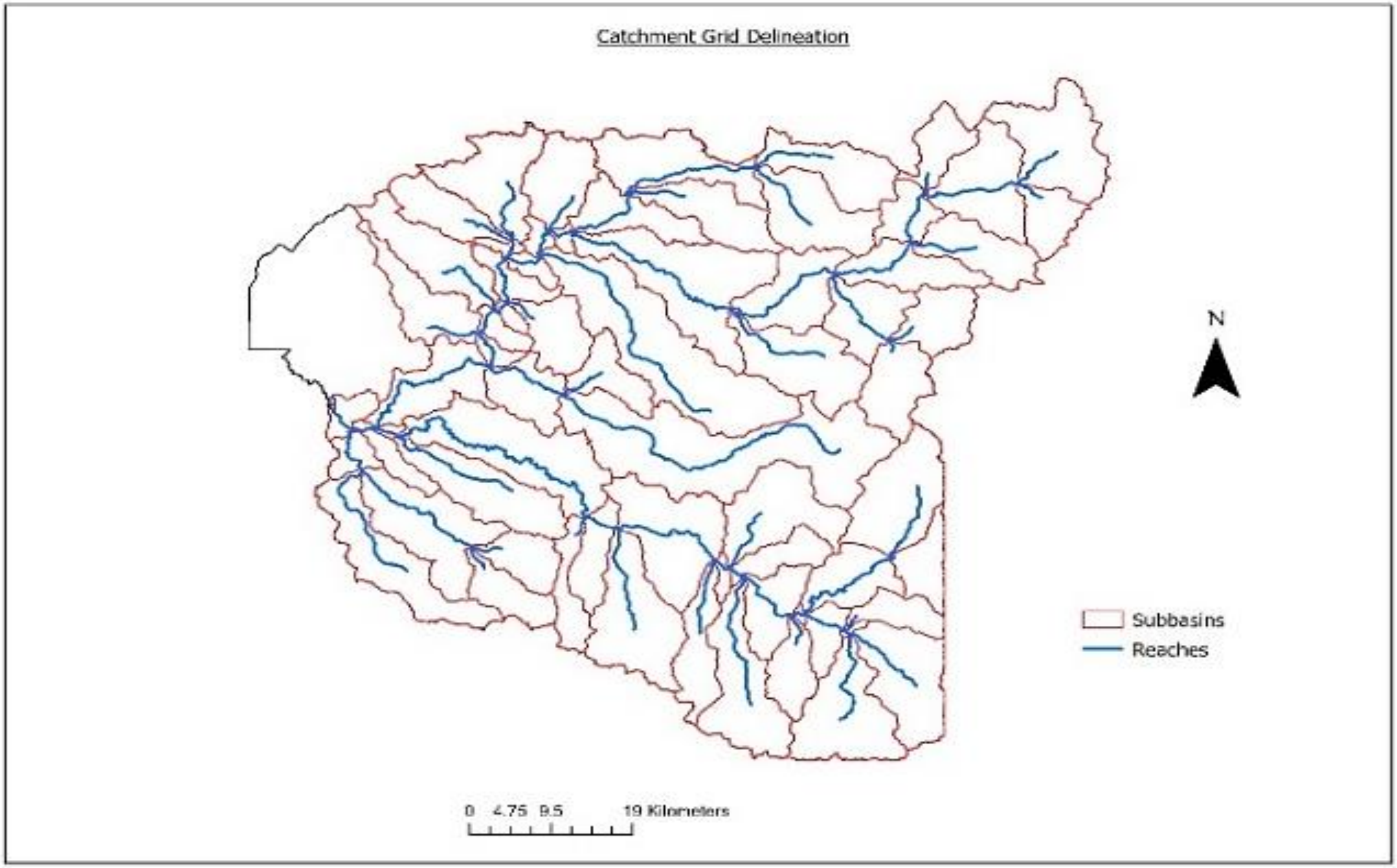


Figure 3.14: Grid Delineation of the basin

3.3.2.5 HEC-HMS modeling

The raster outputs and vector outputs from terrain preprocessing i.e. raster outputs (raw DEM, fill sink, flow direction, flow accumulation, stream network, stream link, catchment grid, slope grid) and vector outputs (catchment, drainage lines, adjoin catchment) were input data in the HEC-HMS project set up. The HEC-HMS project set up menu included tools for determining watershed outlets and delineating the HEC-HMS project's watershed. Multiple layers HMS models were created using the same spatial data. The "Break Point" and "Project Area" feature classes from terrain preprocessing outputs were used to manage these models. The entire project area included the run-off contributing area as well as the non-contributing region.

The river profile was processed using the HEC-HMS model. The river profile was mapped and exhibited a time of concentration of 5.35 hours. Hydrological characteristics of the River Kuja basin that were calculated during the processing included river slope, length, basin slope, longest flow path, basin centroid, centroid elevation and river profile. The river Kuja profile is shown in Figures 3.15 and Figure 3.16.

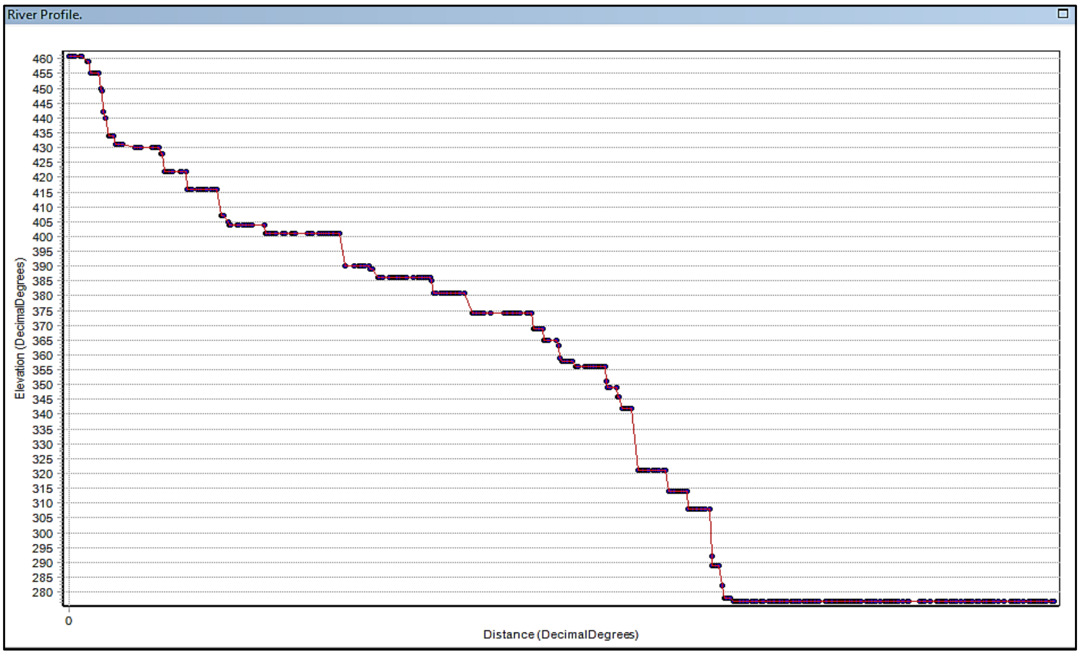


Figure 3.15: River Kuja Profile

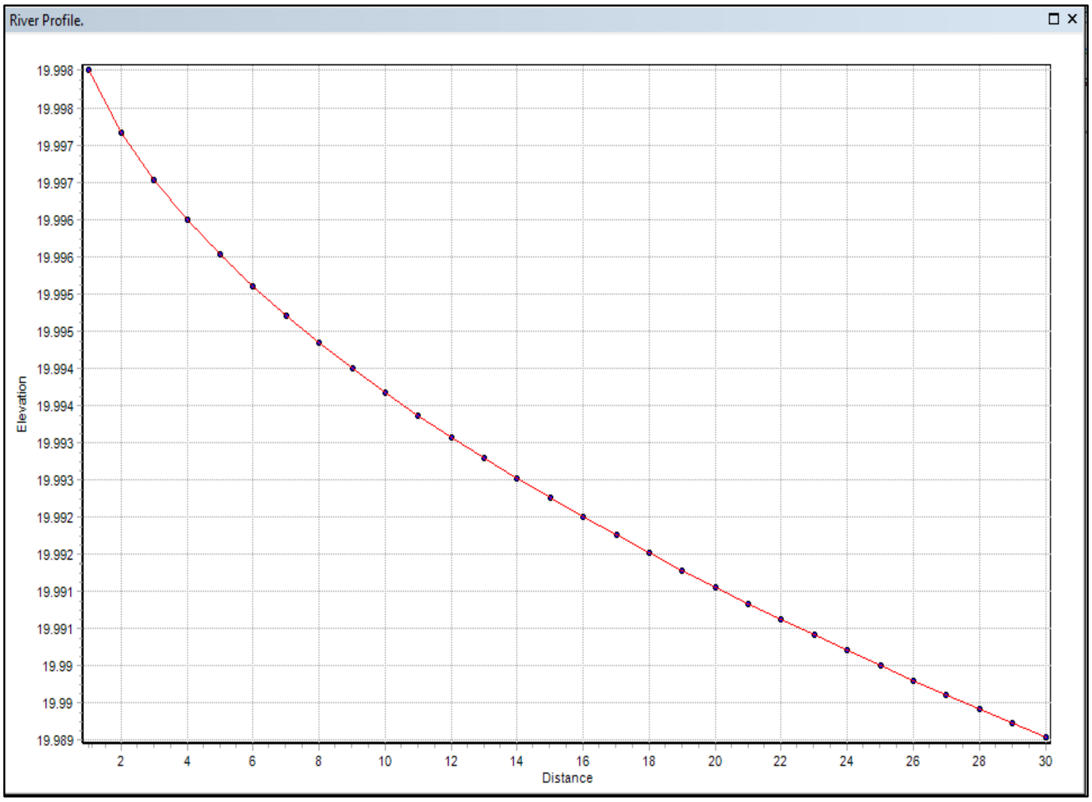


Figure 3.16: River Kuja profile in HEC-HMS model

a. Creating a New HMS project

A new HMS project is created before the hydrologic model is run to identify the Project Area and Break Point. The pour points depict the drainage line's outlets, whereas the project area depicts the complete project area, which includes both run-offs contributing and non-contributing areas. There were two feature classes as a result of this step: project point and project area, which were utilized to define a new project for the entire area of interest.

b. Basin Modelling

Basin modelling is done solely to generate the various sub basins and these enables the extraction of various basin parameters e.g. basin slope and river parameters e.g. river length. These parameters were later used in run off prediction in HMS. Before extracting these basin characteristics, basins with shared pour points were merged. This method avoids multi-routing during the routing process. The river profile is also examined to determine its functionality. It allows the display of the profile of the selected river reach and was used to split the river or watershed at a steep slope change. The basin was split into sub-basins and the extremely small sub-basins merged into five major ones (Figure 3.17 and Figure 3.18).

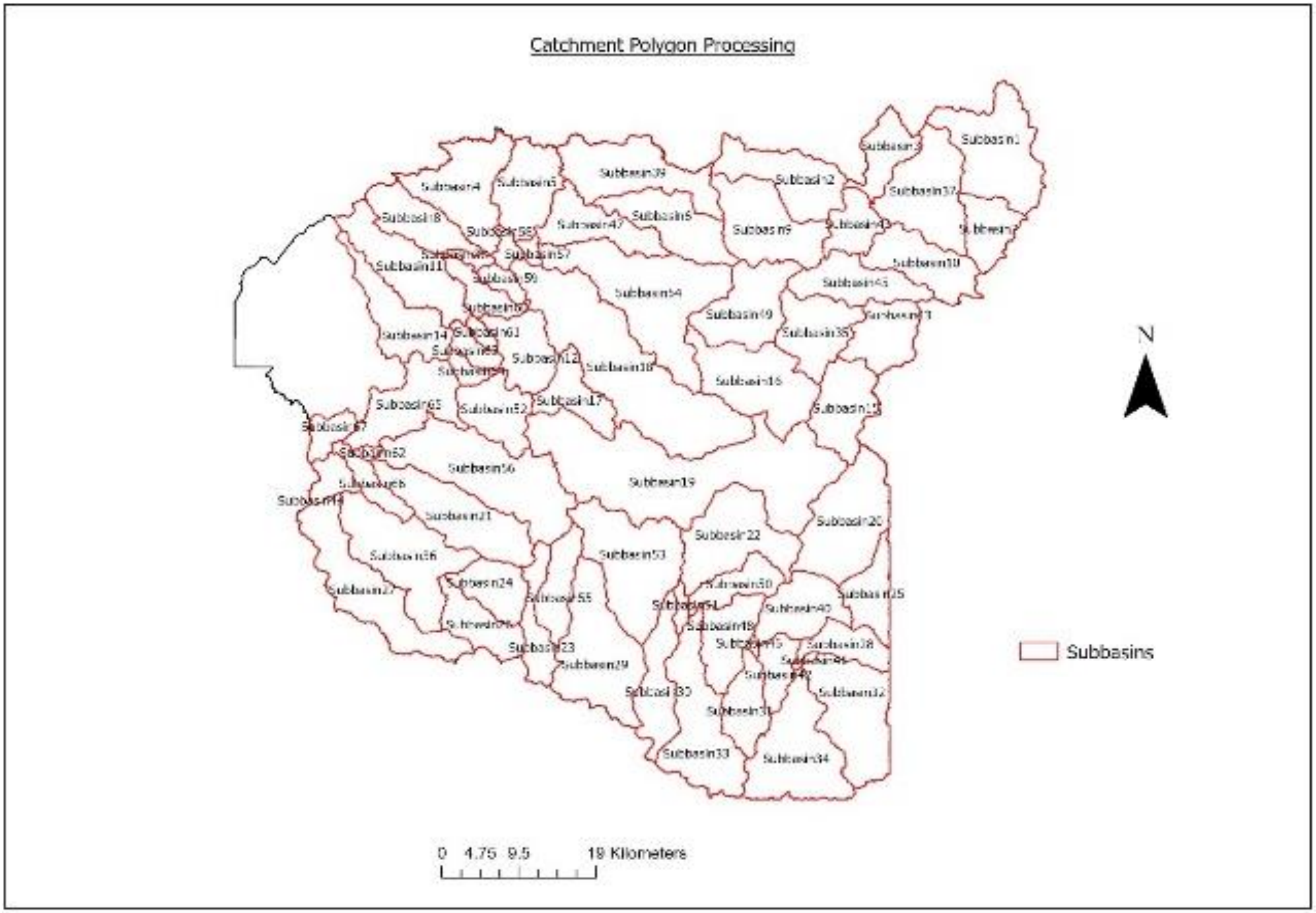


Figure 3.17: Catchment polygon processing

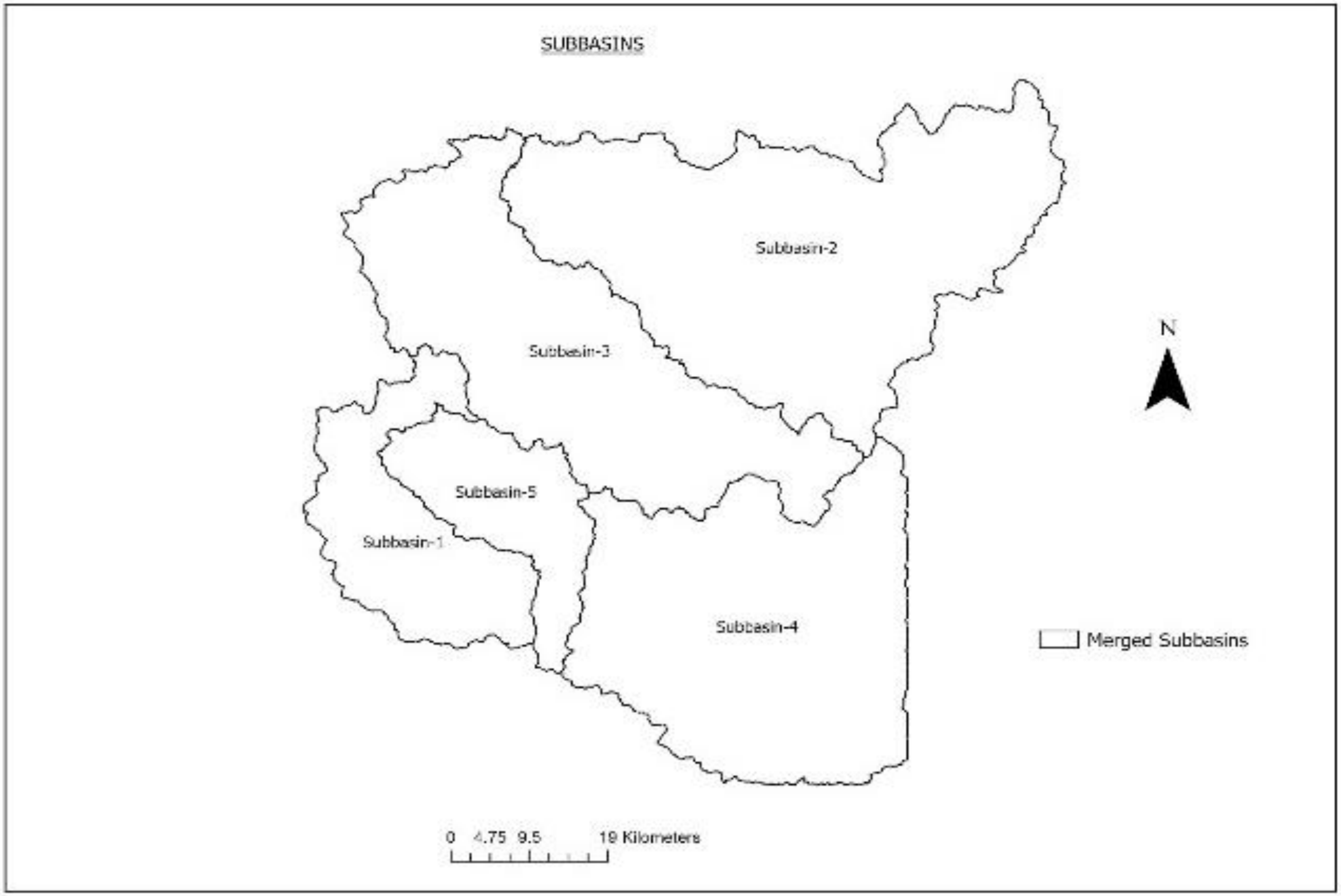


Figure 3.18: Merging of smaller sub-basins into five sub-basins

3.3.2.6 HMS Parameters

These are the parameters that were used in the HMS process. These parameters were acquired in sequential as follows:

1. **Routing**-Muskingum method

This is predefined arithmetical method for determining the channel route. In this method the X and K parameters were evaluated. Theoretically, K parameter is time of passing of a wave in reach length and X parameter is a constant co-efficient whose value varies between 0-0.5. These constants were varied based on each reach characteristics. The *Muskingum* routing method uses a conservation of mass approach to route an inflow hydrograph. The model was calibrated through trial and error after initial parameter estimates were made using GIS and observed data.

2. **Loss**-SCS Curve Number method

This method estimates the accumulated precipitation excess as a function of cumulative precipitation, soil cover, land use and moisture. In this modelling, the curve number (CN) is a key variable which is obtained from the look-up table of TR-55. The TR-55 table contains predefined values that are developed by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The SCS-CN model is unable to give more specific runoff information due to TR-55's limitations in describing complex urban areas and identifying land use/cover types. Moreover, because Kuja basin area consists of several soil types and land uses, a composite CN was therefore calculated. The composite CN was calculated by merging hydrological soil group data and land cover data.

3. **Transform**-SCS unit hydrograph method

This method was used to estimate direct run off. The basin lag time is parameter of SCS unit hydrograph Model which is 0.6 times the time concentration as suggested by Panigrahi *et al*.(2014).

4. **Base flow-**Exponential method

This method was used to represent watershed base flow and estimates initial base flow, recession constant and the threshold values

3.3.2.7 Calibration and validation of the model

The success of a hydrologic watershed model is determined by how effectively it is calibrated, which is determined by the hydrological model's technical capacity as well as the quality of the input. The HEC- HMS watershed model was calibrated for the event-based simulation. This aligns simulated run-off volumes, run-off peaks, and hydrograph timing with observed data. Using the HEC-HMS watershed (already calibrated and validated) the run off volumes for each sub basin were estimated and quantified in cubic meters.

3.3.2.8 Simulation of rainfall-run off process using HEC-HMS

HEC-HMS is a physically based and conceptually semi-distributed model designed to model a wide range of geographic areas, including run off volume calculation, direct run off calculation, and base flow modelling. Simulation was conducted using the rainfall data and resulting hydrographs presented as modelling findings.

3.3 Perception of Local Communities in River Kuja basin

3.4.1 Study Design

An exploratory survey was done in the study area to familiarize with the geographic features, local representatives, boundaries and River Kuja meanders. The survey design was cross-sectional. The impacts of human activities on land use/cover changes was determined by administering questionnaires and analysing the data using quantitative and qualitative methods. A questionnaire was designed and pretested on a small sample population of 30 households across the basin. The pre-test sample households were randomly selected among the respondents with similar characteristics to those that were targeted for the actual detailed survey. The resulting data from the pre-test exercise were analysed and the results used to strengthen the questionnaires by removing unnecessary questions, including more information and restructuring any question that appeared ambiguous to the respondents.

The actual field work was done in the month of March, April and May, 2022 to acquire the primary data. The information collected involved questionnaire administration and physical observations. The survey covered a total of 400 households (A sample questionnaire is attached under Annex 1). Key Informants Interviews (KII) were conducted to obtain views from stakeholders and different levels of leadership. These were essential for triangulating information for better understanding and quality data. The secondary data was obtained from literature reviews on studies conducted on the research topic. The sources included published books, articles, journals, reports, and existing maps. Techniques such as the use of SPSS software, Minitab software, and GIS and remote sensing tools were applied to validate ground observations. Primary and secondary data were applied to the data processing models and the conceptual framework.

3.4.2 Methodology

3.4.2.1 Human Population Data

The basin's population data was sourced from the population censuses conducted by the Kenya National Bureau of Statistics (KNBS) for the years 1999, 2009 and 2019. The data obtained included the human demographic parameters and sizes across the study area as per the administrative units. The 1999 and 2009 population census data were analysed based on Districts administrative boundaries while the 2019 census data was analysed based on County and Sub-county administrative units. The resulting data were tabulated in Excel 2016 worksheet for analysis and synthesis.

3.4.2.2 Sampling Design and Frame

The sampling frame was considered to be the population of people living in the entire basin. It was assumed that every household in the sampling frame was engaged in one or more forms of land use that affected the basin and were homogenously distributed for the purpose of this study. Using Yamane's Sample Size Formula on River Kuja basin's population of 2.2 million people, the formula determined a sample size of 400 households. The formula is applicable in determining survey sample size from high population numbers as was the case of Kuja basin.

$$N = \frac{N}{(1+N(e^2))} \qquad \textit{Equation 3.6}$$

where,

n = Sample Size being calculated

N = Population under study

e = *Margin error (in this case 0.05)*

Purposive sampling was applied in determining specific locations to be surveyed. Distance decay principle was used in selecting study locations according to the administrative boundaries. The sample households were randomly selected near River Kuja buffer area, an average buffer region of 36km from the river. Eight study locations were chosen and they included Borabu Constituency in Nyamira County, South Mugirango Constituency in Kisii County, Ndhiwa Constituency in Homabay County, Rongo Constituency in Migori County, Kadem Nyatike Constituency in Migori County, Gogo Nyatike Constituency in Migori County, Awendo Constituency in Migori County and Muhuru Bay Nyatike Constituency in Migori County. The sample size of 400 households was then distributed among the sites proportionately to their population density and proximity to River Kuja channel. The Equation 3.2 was used to calculate the distribution of sampled households across the units under survey and the results tabulated in Table 3.3.

$$n_i = N\left(\frac{h_i}{n}\right) \qquad \textit{Equation 3.7}$$

where,

N = the population size

h_i = the distance of the unit from the river (in km)

n = the overall sample size (400 households)

n_i = the sample size for the unit

Simple random sampling was used to select the 400 individual households with an assumption that all sampled households were engaged in existing land use practices. In each of the locations, a sample interval, which is a ratio of the required sample to the total population in that location was calculated as shown in Table 3.3. The calculation was based on Equation 3.3

$$i = \frac{N}{n}\left(k - \frac{N_i}{n_i}\right) \qquad \textit{Equation 3.8}$$

A random number between 1 and "i" was then generated, called the seed number, representing the unique identifier of the first population unit to be included in the sample. The sampling interval, "i", was summed with the random number between 1 and "i" and this was taken as the second unit in the sample. The process was continued until the end of the sampling frame was reached and the desired sample size achieved.

For instance, if the sampling interval was 4, all the numbers between 1 and 4 had equal chance of being selected as starting point of the transect.

Table 3.3: Sampled Household locations with Distance from River Kuja

Location (Constituency)	County	No. of HHs Interviewed	Average Distance from the River
Borabu	Nyamira	31	16.2 km
South Mugirango	Kisii	56	20.7 km
Ndhiwa	Homabay	38	13.1 km
Rongo	Migori	49	9.4 km
Kadem-Nyatike	Migori	57	28.6 km
Gogo-Nyatike	Migori	28	5.7 km
Awendo	Migori	78	35.7 km
Muhuru Bay-Nyatike	Migori	50	12.6 km
Total		**387**	

3.4.2.3 Anthropogenic Activities Survey

An initial ground survey and observations were conducted to familiarize with the sample locations, administrative boundaries and geographic features of interest. The exercise focused on households that were within 36km from the river. A pretest survey was done to specifically explore the targeted population sample of the basin. Questionnaires designed for the overall survey were pretested on a sample size of 30 households randomly selected across basin but not within the sampled locations. The pretest sample size was dictated by the minimum required household number of 30 households. This is the standard pretest population sample size by the statistical methods and softwares under normal conditions (Fabrigar, Wegener, MacCallum & Strahan, 1999). The data collected were analyzed and the results helped in improving and refining the questionnaires by correcting ambiguous questions, incorporating more information, and removing irrelevant sections.

3.4.2.4 Questionnaire Administration

The actual data collection after pretest sampling involved questionnaire administration and observations. The household surveys using questionnaires covered 400 households. Those who were surveyed during the pretest process were excluded from the main survey. The survey was aimed at providing perception and factual occurrences and information on the ecological changes and aspects in the basin (Piran, 2005). Independent verification of information generated by the questionnaires was carried out by involving key informants and participants observations. The findings were analysed and results presented and discussed. The resulting information was viewed as essential in generating a plan on how water resources in the basin should be sustainably utilized under the growing population in River Kuja basin.

Questionnaires were administered to the targeted respondents across the basin under study. The questionnaire is attached as Annex I. After arriving at a household, an amicable environment was created for a discussion with the available people. This was achieved by first giving a clear introduction and explaining the purpose of the research thereafter seeking consent from the respondent. The researcher administered the questionnaires in a language the respondent could easily understand and speak. Where there was a language barrier, the researcher engaged an interpreter or translator. Answers were recorded concurrently as the questionnaire administration was ongoing. The interaction continued throughout to ensure all questions were answered and the questionnaires duly filled before the researcher left.

For the households whose heads were literate and were willing to fill the questionnaires by themselves, the researcher allowed them to do so. After the respondent was done, the data provided were cross-checked and any further clarifications were sought in case some information filled was not clear to the researcher. At the end of the field survey, all the questionnaires were serialized, safely stacked together, and transported to the analysis centre awaiting processing and analysis.

3.4.2.5 Key Informants Interviews

Key informant interviews were carried out to triangulate the obtained information from the household interviews and gain an in-depth and detailed understanding of local people's perceptions on LULC changes in the basin, and the associated underlying causes perceived to have contributed to the changes. It involved sixteen people consisting of stakeholders such as government officials, community-based organizations, farmers, and community settlements. Highly prioritized respondents were selected from some regions. The selection criteria were based on their roles in the community and or government positions. Their interview was to collect information on the full historic accounts of anthropogenic activities of the basin (Appendix III). The questions were open-ended hence prompting explanations relevant to the field of research. The information gathered was triangulated by the primary and secondary data obtained from household surveys. This was relevant to authenticate other sources of information acquired in order to understand the hydrology of the basin.

3.4.2.6 Population Data Processing and Analysis

Population data was imported into the Excel 2016 worksheet and an analysis was conducted to determine the changes leading to growth. The population growth rate was calculated using the compound rate of growth method in order to determine population projections as shown in Equation 3.3 below;

$$R = \left[\left(\frac{P_n}{P_o}\right)^{\frac{1}{n}} - 1 \right] \times 100 \qquad \textit{Equation 3.9}$$

where,

R = Compounded rate of growth

P_n = Population in the current year

P_o = Population in the base year

n = Number of intermediary years.

After obtaining R, the result was then applied to Equation 4 to estimate the population size in any given year within the study period:

$$P_n = P_o\left(1 + \frac{R}{100}\right)^n \qquad \textit{Equation 3.10}$$

3.4.2.7 Peoples' Perception Data Processing and Analysis

The questionnaires were duly completed and serialized for ease of identification. During the process, some 13 questionnaires were excluded from data entry due to inadequate information provided by the respondents. Coding of the sheets from the first to the last assisted in linking the information from the data to ideas in all cases in the database. For the dichotomous responses of yes or no, values of either 1 or 0 were assigned whereas for ordinal and explanatory data of low, medium, or high, values of 1, 2, 3, onwards were assigned. The data were thereafter entered into Microsoft Office Excel 2016 worksheet and SPSS software.

The data was cleaned to achieve quality and be fit for use by managing errors for improved documentation and presentation. The cleaning process included checks such as, completeness, format, limit, duplicate, spelling, validity, reasonableness, and review of the data for outlier's identification. It further entailed excluding rows or characters that were not necessary in the analysis, deciding upon a single coding scheme then converting and replacing values and using logic to manually discover errors and replace or exclude characters.

3.4.2.8 Analysis of Population Growth and Water Resources Status in the Basin

The relationship between population growth and the hydrologic situation in the basin was determined using proportional odds and logistic regression models. The models were fitted to the selected parameters of exploratory variables (Brant, 1990, Thomson, 2009). To understand the relationship of the variables, a correlation analysis was conducted to determine the impact of exploratory variables such as population growth and land-use changes on the dependent variable water resources (hydrology) of the basin.

3.4.2.9 Ethical considerations

It is important to protect the dignity and safety of all research participants and respondents (Silverman, 2009). This study considered ethical issues that would arise due to respondents' confidentiality and secrecy. Several ethical considerations were put in place to ensure the study was conducted appropriately and that every interviewee was comfortable with all information they gave (Babbie & Mouton, 2001). The purpose of the research was explained to the respondents as well as their right to participate or refuse in the survey. All the respondents were then allowed to give verbal consent before they participated in the research. The interviewees had to be consenting adults. They were then allowed to participate willingly answering questions according to their understanding and context (NE, 2000; Neuman, 2000; Fritz 2008). They were also informed that any information they provided would remain confidential and only to be analysed for research purposes and not be discussed by any person. In this report, the identity of the participants is not included and pseudonyms were used to represent the participants. During the interviews, the researcher introduced himself and shared his background information as a native of River Kuja basin. This helped to win confidence and build trust hence enabling the participants to share their information freely.

At the end of the engagements, the researcher and the participants debriefed one another before reviewing the interview process and inquiring if everything was okay and the respondent still positive about every information given. This was to ensure that the respondent was not left harmed emotionally or traumatized whatsoever during the process. The information gathered from the sampled population was analysed by the researcher and the general conclusion drawn in line with the hydrology of River Kuja basin.

3.5 Impact of LULC Changes to the Hydrology of River Kuja Basin

The spatio-temporal changes in the basin, population change, the hydrological dynamics and perceptions from the household surveys were integrated and analysed. The proportional odds and logistic regression models were applied and fitted to the data for the selected parameters to investigate the relationships between the categorical outcomes and the explanatory variables according to Brant (1990), Agresti (2002) and Thompson (2009). In order to understand how the variables have related to each other over time, a correlation analysis was carried out to determine the nature of the relationship between the dependent variable (Kuja basin LULC and Hydrology) and the explanatory variables (land use practices, population and climate change). Land use was measured through its elemental indicators such as areas covered by agriculture, water surfaces, grasslands, bushes, built up area, shrub lands and forests. Five most frequent perception responses relating to the anthropogenic activities in the basin were chosen for the integrated analysis. They included change of land sizes over time, land use land cover changes, weather patterns, water issues and soil degradation. The entire study process is as shown in Figure 3.19 and Table 3.4.

3.6 Schematic Diagram of the Methodology

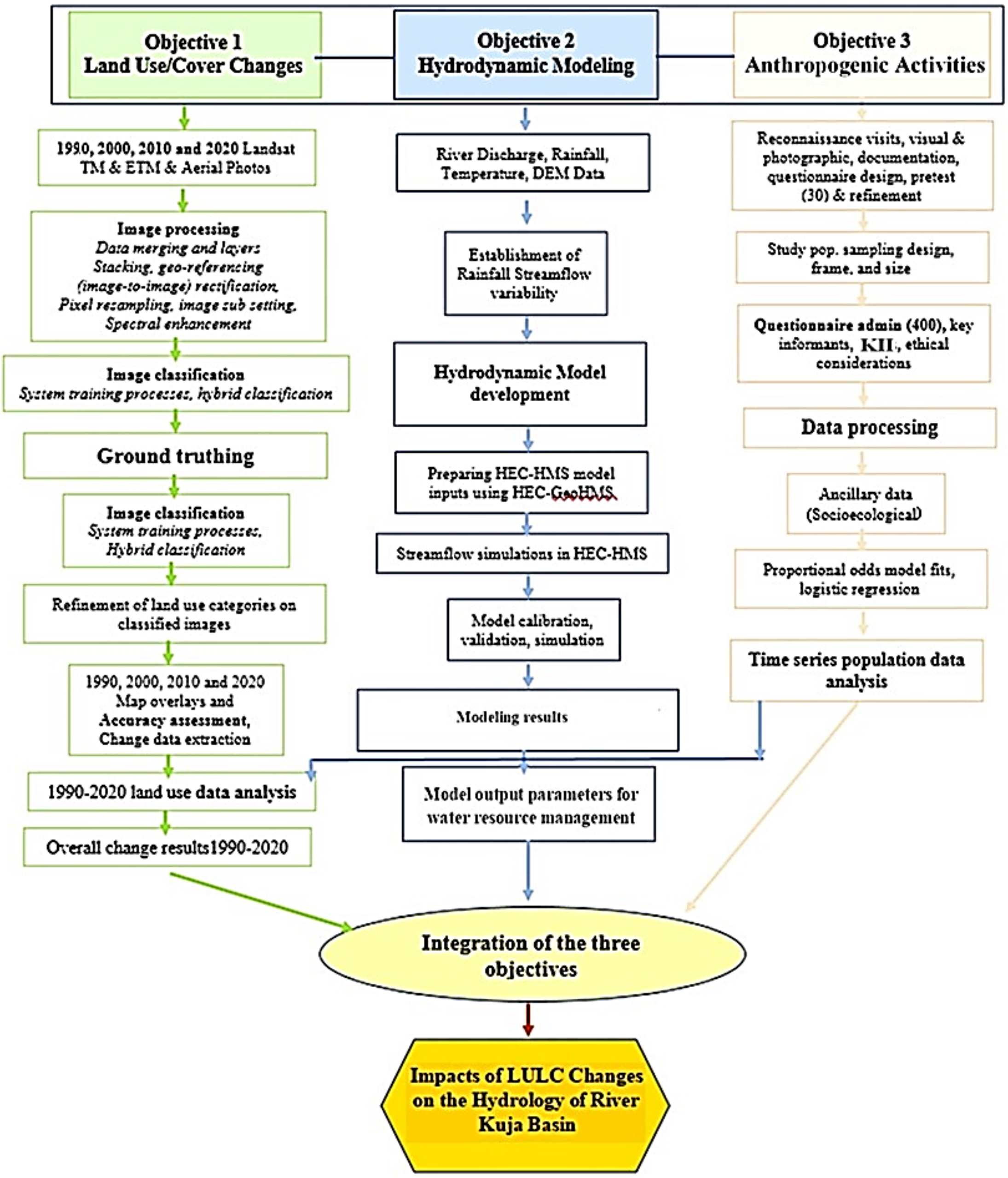


Figure 3.19: Summary of the Entire Study Process

Table 3.4: Summary of the entire study process

	Objective	Key Concept/Variables to be Measured	Data Collection Methods/Instruments	Data Analysis	Presentation
1	To determine land use and land cover changes in River Kuja basin for the period 1990 to 2020.	Land use/cover changes Change Detection - Percentage change using Satellite Images	Decadal satellite images for 1990, 2000, 2010, 2020 Seven land use classes	Satellite Image analysis using Google Earth Engine, GEE Land use Classes Analysis	Maps/Images with Land use/cover changes
2	To simulate changes in River Kuja basin hydrology	Basin surface hydrology	River Discharge at Gauging Stations Meteorological Data from KMD – Rainfall and Temperature Soil types	Modelling using HEC-HMS and HEC-GeoHMS Model	Model Simulation, Calibration, Validation, River Events Peak Discharges
3	To assess the perception of local communities on the impact of anthropogenic activities to the hydrology of River Kuja basin between 1990 and 2020.	Population growth Anthropogenic Activities	Administration of questionnaires to a population sample size of 400 households	Measure of Central Tendency and Spread. Inferential Statistics	Tables, Figures Graphical Presentations Discussion of Results

CHAPTER FOUR

4.0 RESULTS

4.1 Land Use Land Cover Change

4.1.1 Image Classification for Land Use Land Cover

The first objective of this study was to determine land use and land cover changes in River Kuja basin using satellite images for the period 1990 to 2020. Seven land use classes were used to define classes during the land cover land use mapping process as recommended and applied by (Chenghu & Jianghao 2018; Edward, 2015; Dominique & Amanda 2016). The classes applied are as presented in Table 4.1.

Table 4.1: Land use/land cover Class

No.	Land use/land cover Class	Description
1.	Water Bodies	Rivers, ponds, pans and dams
2.	Agricultural Land	Both irrigated and rain fed arable land, cropland, farming and fallow fields
3.	Built up Areas	Residential, industrial, commercial, recreational areas, institutional, and road networks
4.	Bare land	Land without any vegetation or structures
5.	Forest	Area of land dominated by trees
6.	Shrub land	Plant community characterized by vegetation dominated by shrubs, often including shrubs, herbs and geophytes
7.	Grass land	Area under continuous cover of grasses

As shown in Table 4.1, seven land use/cover classes were used in change detection process on the different satellite images acquired covering the entire Kuja River basin. The classes were first quantified in each time series step then each class, determined by the number of pixels, expressed as the surface area on the ground representing the spatial extent in kilometres.

4.1.2 Satellite images bands

Figure 4.1 presents the correlation plot for the various images acquired, that was used to decide on the image bands compositing. The bands were represented as: Water Bodies (B1) – Band 1; Agriculture (B2) – Band 2; Built up Area (B3) – Band 3; Bareland (B4) – Band 4; Forest (B5) – Band 5; Shrub land (B6) – Band 6; and Grass land (B7) – Band 7

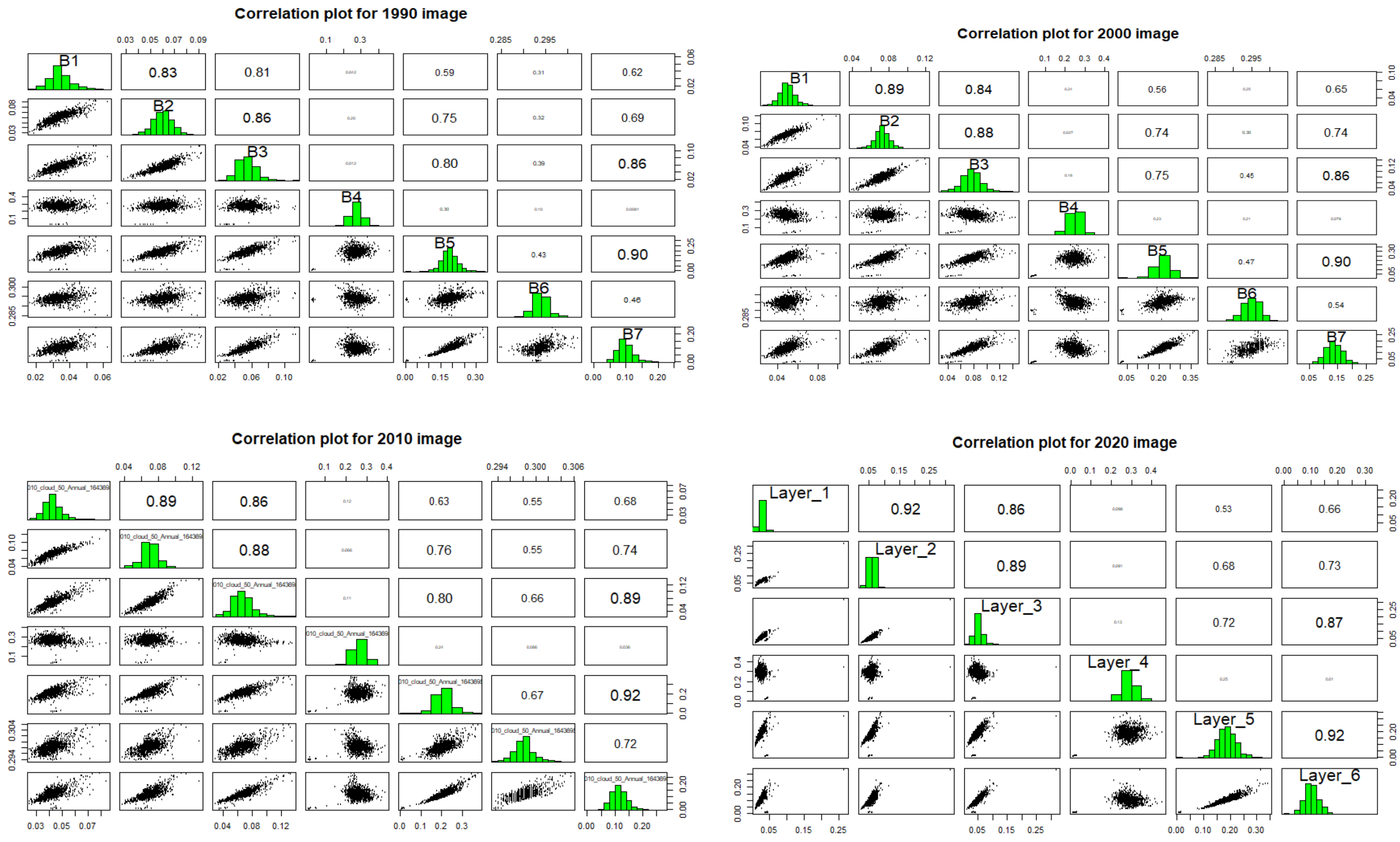


Figure 4.1: Correlation plots for the various images acquired in 1990, 2000, 2010 and 2020

4.1.3 The Correlation Plots for the satellite images

The results of land cover classification majorly followed the output of the major classes, represented by bands 1, 2, 3, 4, 5, and 6 in Figure 4.1. The correlation plots show that there was 2D measurements of changes in the satellite images with an accuracy of 86%. The bands that produced positive linear correlation index as shown in the scatterplots for band 1, 2 and 3. Negative linear correlations index were produced in the scatterplots for band 4 while band 5 and 6 had no correlation index in their scatterplots.

4.1.4 Land Cover Land Use Distribution in 1990

The baseline year for the decadal satellite images analysis process was 1990. The image for the year showed that agriculture and water occupied 11.4% with an area of 788 sq.km and 0.59% with an area of 41 sq.km respectively. Forests covered the greatest area of 27.31% of River Kuja basin followed by grassland and shrub land at 17.6% and 15.0% respectively (Table 4.2 and Figure 4.2). The high forest cover was attributed to the fact that some areas within the basin had not been opened for agriculture and urbanization hence remained under indigenous forest cover. The overall vegetative cover in the basin added up to 4,920.39sq.km. This translated to 71.31% of the total basin area. Built up Areas covered an area of 161sq.km which translates to 2.3% of the land. The Built-up Areas includes residential spaces, industrial spaces, commercial areas, road networks and road facilities. The overall Kappa accuracy analysis for the classification in 1990 was 82%. The matrix in Table 4.2 shows the land cover classes distribution of the basin with the level of both producers and users' accuracy.

Table 4. 2: Matrix table the Land Cover Classification Map for 1990

1990	Reference Data				Accuracy
	Class	**Area Covered (Km^2)**	**Percentage of Class**	**Producers Accuracy**	**User Accuracy**
Classified Area (Km^2)	Water	41	0.59%	0.96	0.77
	Agriculture	788	11.4%	0.87	0.83
	Built up Areas	161	2.3%	0.81	0.67
	Bare land	502	7.3%	0.79	0.75
	Forest	1886	27.31%	0.8	0.74
	Shrub land	1033	15.0%	0.87	0.82
	Grassland	1212	17.6%	0.77	0.83
	Others Unclassified	1277	18.5%		
	TOTAL	**6,900**	**100%**		
Accuracy	**Overall Accuracy = 85%**				
	Overall Kappa =82%				

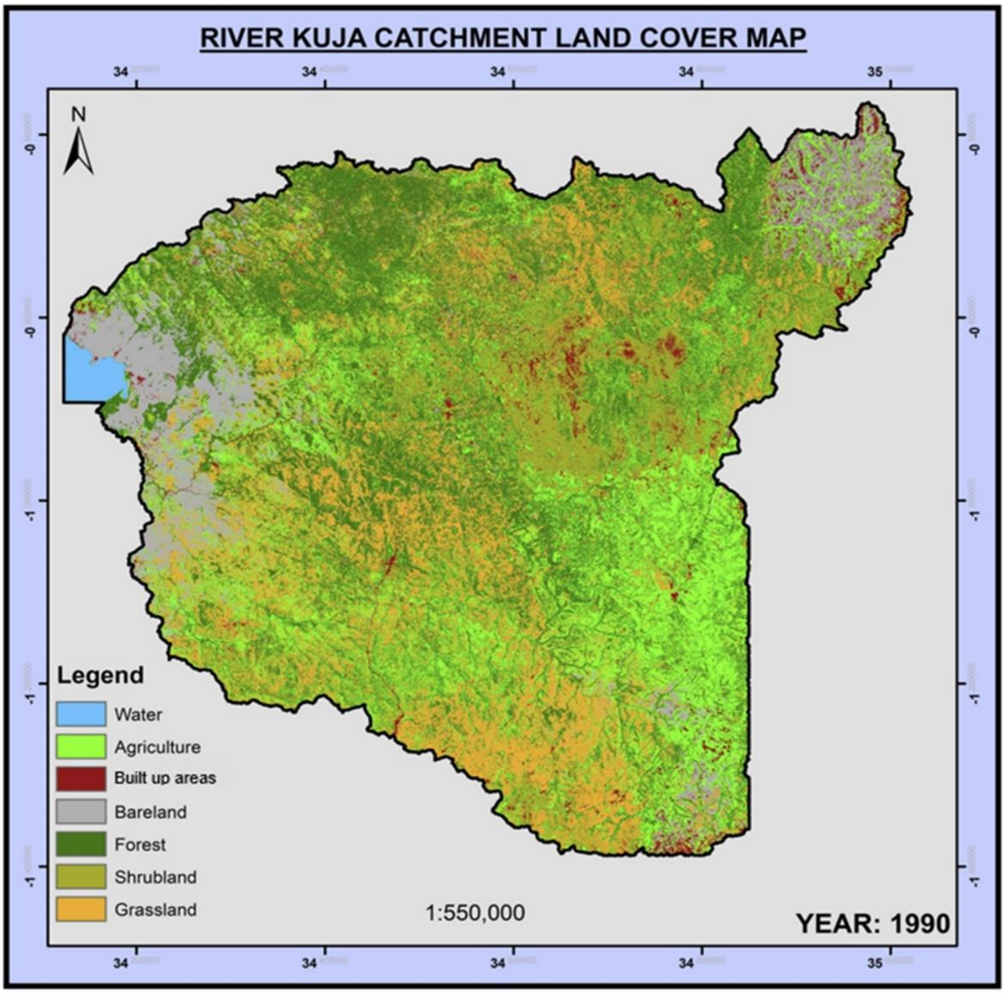


Figure 4.2: Land use Land Cover Image for the year 1990

4.1.5 Land Cover Land Use Distribution in 2000

The classes showed a spatial variability over the 10-year temporal time space. As shown in Table 4.3 and Figure 4.3, water bodies reduced their area of coverage from 41sq.km in 1990 to 40sq.km in 2000. The 1.0 sq.km variation in 10 years has potential for great impact on the hydrology of the basin. Agriculture increased from 788sq.km to 1973sq.km, hence more than double the area covered in a decade temporal space hence occupying 28.6% of the entire basin. Forests reduced from 27.31% in 1990 to 21.7% in 2000. Built up Areas increased with a margin of 12sq.km. The overall Kappa accuracy analysis for the classification in 2000 was 87%.

Table 4. 3: Matrix table for the Land Cover Classification Map for 2000

2000	**Reference Data**			**Accuracy**	
	Class	**Area Covered (Km^2)**	**Percentage of Class**	**Producers Accuracy**	**User Accuracy**
Classified Area (Km^2)	Water	40	0.58%	1	1
	Agriculture	1973	28.6%	0.97	0.93
	Built up Areas	173	2.5%	1	1
	Bare land	730	10.62%	0.93	0.81
	Forest	1500	21.7%	0.81	0.74
	Shrub land	718	10.4%	0.76	0.63
	Grassland	919	13.3%	0.73	0.82
	Others Unclassified	847	12.3%		
	TOTAL	**6,900**	**100%**		
Accuracy	**Overall Accuracy = 81%**				
	Overall Kappa =87%				

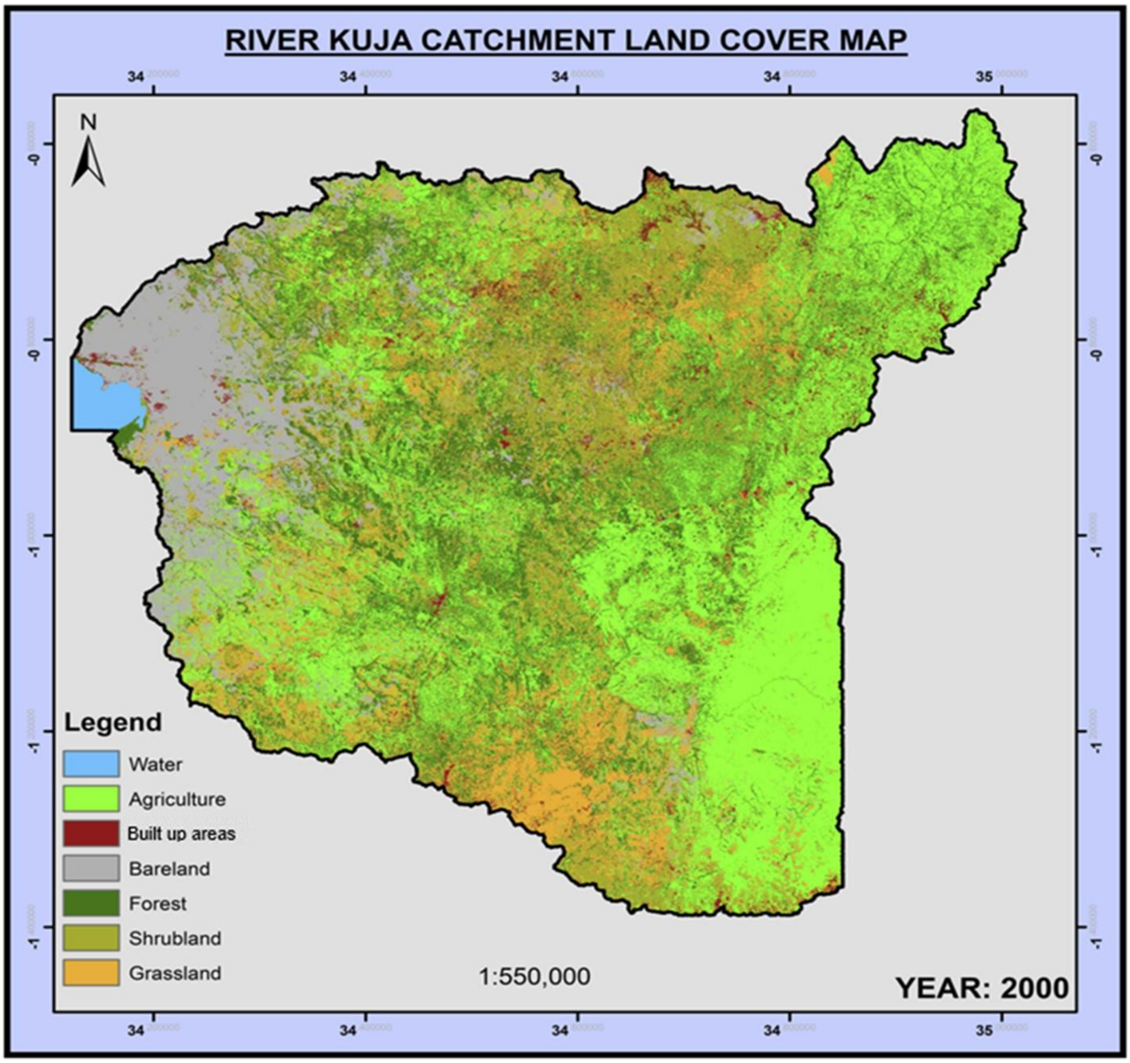


Figure 4.3: Land use Land Cover Image for the year 2000

4.1.6 Land Cover Land Use Distribution in 2010

The results show that, built up Areas increased from 2.5% in 2000 to 6.7% of the basin area in 2010. Forests reduced to 3.66% while Shrub land constantly declined from 15% in 1990, to 10.4% in 2000 and 3.2% in 2010. In addition, the results show that the water bodies in the basin were reducing in surface coverage. In the two decades, surface water reduced by 2sq.km. Bare land showed a mixed coverage over the period. The overall accuracy in the 2010 classification was 85% while overall Kappa accuracy analysis was at 82% as shown in Table 4.4 and Figure 4.4.

Table 4.4: **Matrix table for the Land Cover Classification Map for 2010**

2010	Reference Data			Accuracy	
	Class	**Area Covered (Km^2)**	**Percentage of Class**	**Producers Accuracy**	**User Accuracy**
	Water	39	0.56%	0.97	0.96
Classified Area (Km^2)	Agriculture	1863	27.0%	0.93	0.95
	Built up Areas	464	6.7%	0.76	0.72
	Bare land	700	10.1%	0.93	0.81
	Forest	1243	18.04%	0.98	0.98
	Shrub land	219	3.2%	0.83	0.93
	Grassland	1242	18.0%	0.93	0.78
	Others Unclassified	1130	16.4%		
	TOTAL	**6,900**	**100%**		
Accuracy	**Overall Accuracy = 85%**				
	Overall Kappa =82%				

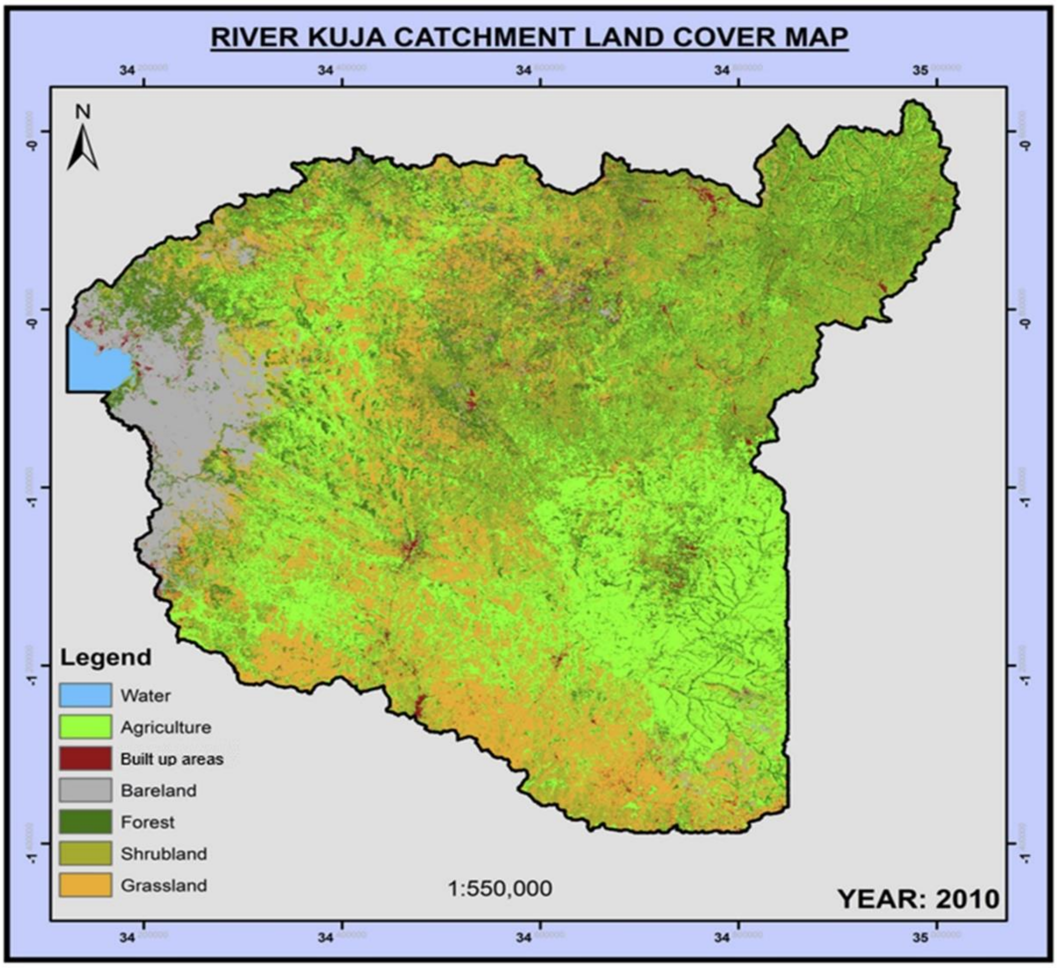


Figure 4.4: Land use Land Cover Image for the year 2010

4.1.7 Land Cover Land Use Distribution in 2020

In the last classification temporal space, water bodies reduced to 36sq.km while agriculture shot up to 2610sq.km occupying 37.8% of the River Kuja basin area. Built up Areas coverage increased to 521sq.km, 7.6% of the entire basin. Forests also reduced to 928sq.km translating to 13.44% of the basin coverage. The overall accuracy in the 2020 classification was 87% while overall Kappa accuracy analysis was at 88% as shown in Table 4.5 and Figure 4.5.

Table 4.5: Matrix table for the Land Cover Classification Map for 2020

2020	**Reference Data**				**Accuracy**
	Class	**Area Covered (Km^2)**	**Percentage of Class**	**Producers Accuracy**	**User Accuracy**
Classified Area (Km^2)	Water	36	0.52%	1	1
	Agriculture	2610	37.8%	0.94	0.96
	Built up Areas	521	7.6%	0.96	0.98
	Bare land	330	4.8%	0.81	0.91
	Forest	928	13.44%	0.80	0.78
	Shrub land	379	5.5%	0.89	0.82
	Grassland	1544	22.4%	0.67	0.72
	Others Unclassified	552	8.04%		
	TOTAL	**6,900**	**100%**		
Accuracy	**Overall Accuracy = 87%**				
	Overall Kappa =88%				

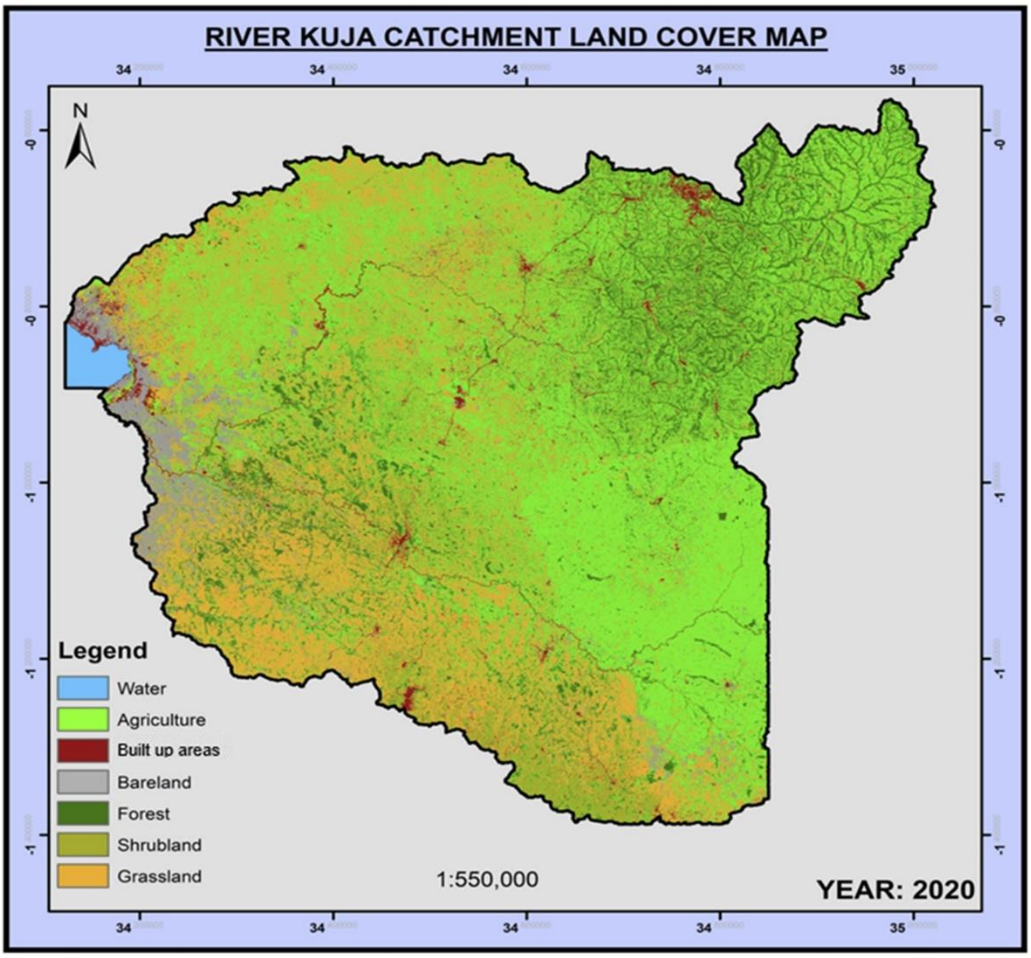


Figure 4. 5: Land use Image for the year 2020

4.1.8 Land Cover Classes and Distribution

Each land cover class was presented in a bar graph showing the trends in 1990, 2000, 2010 and 2020 (Figure 4.6). Surface water reduced; agriculture coverage increased; built up areas increased; bare land increased in the first decade but reduced in the last decade; forests reduced gradually; shrubland reduced in the first two decades but increased in the last decade; grassland reduced but increased in the last 2 decades while other land uses classes varied over the period under study (Figure 4.7 and Figure 4.8).

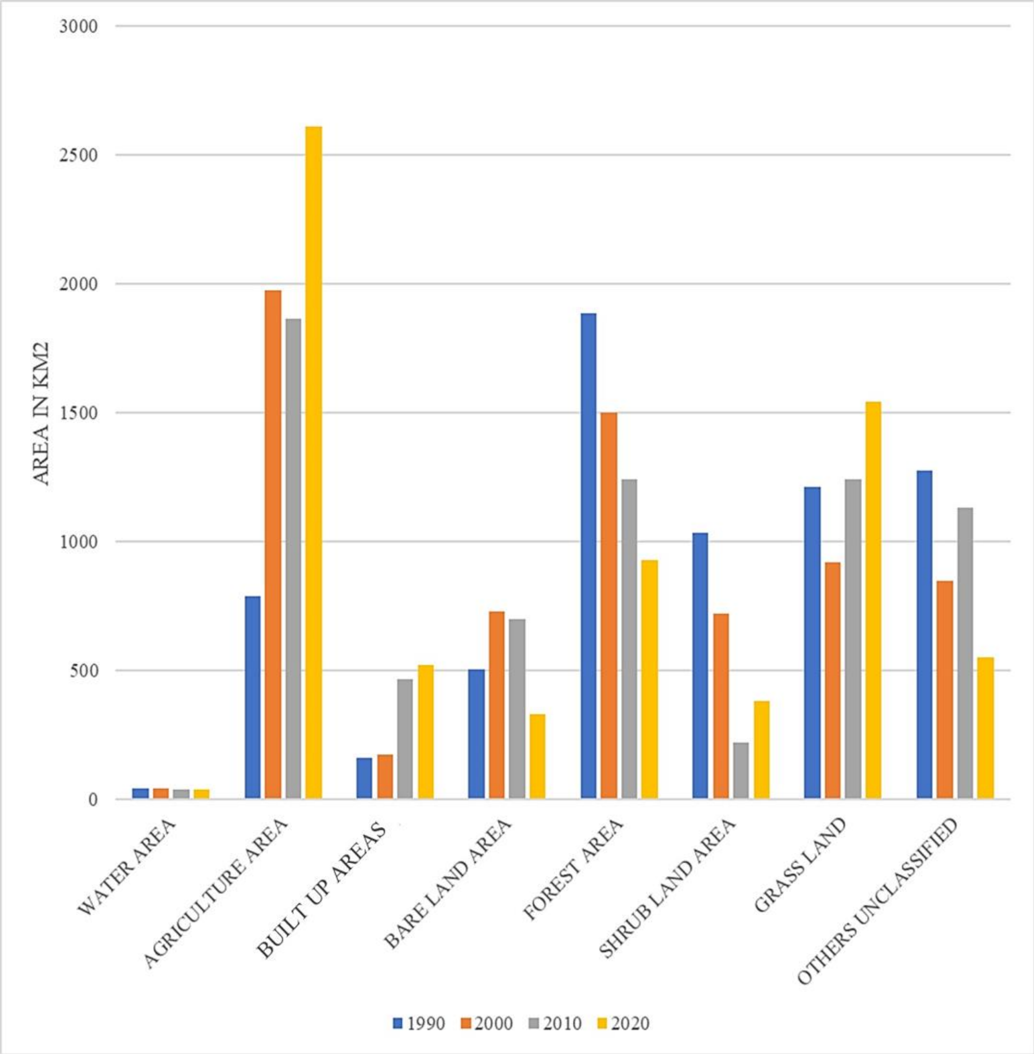


Figure 4.6: Comparison for land cover classes 1990 - 2020

4.1.9 Basin class distribution

Class Distribution indices: Water Bodies – 1; Agriculture – 2; Built up Areas – 3; Bare land – 4; Forest – 5; Shrub land – 6; Grass land – 7

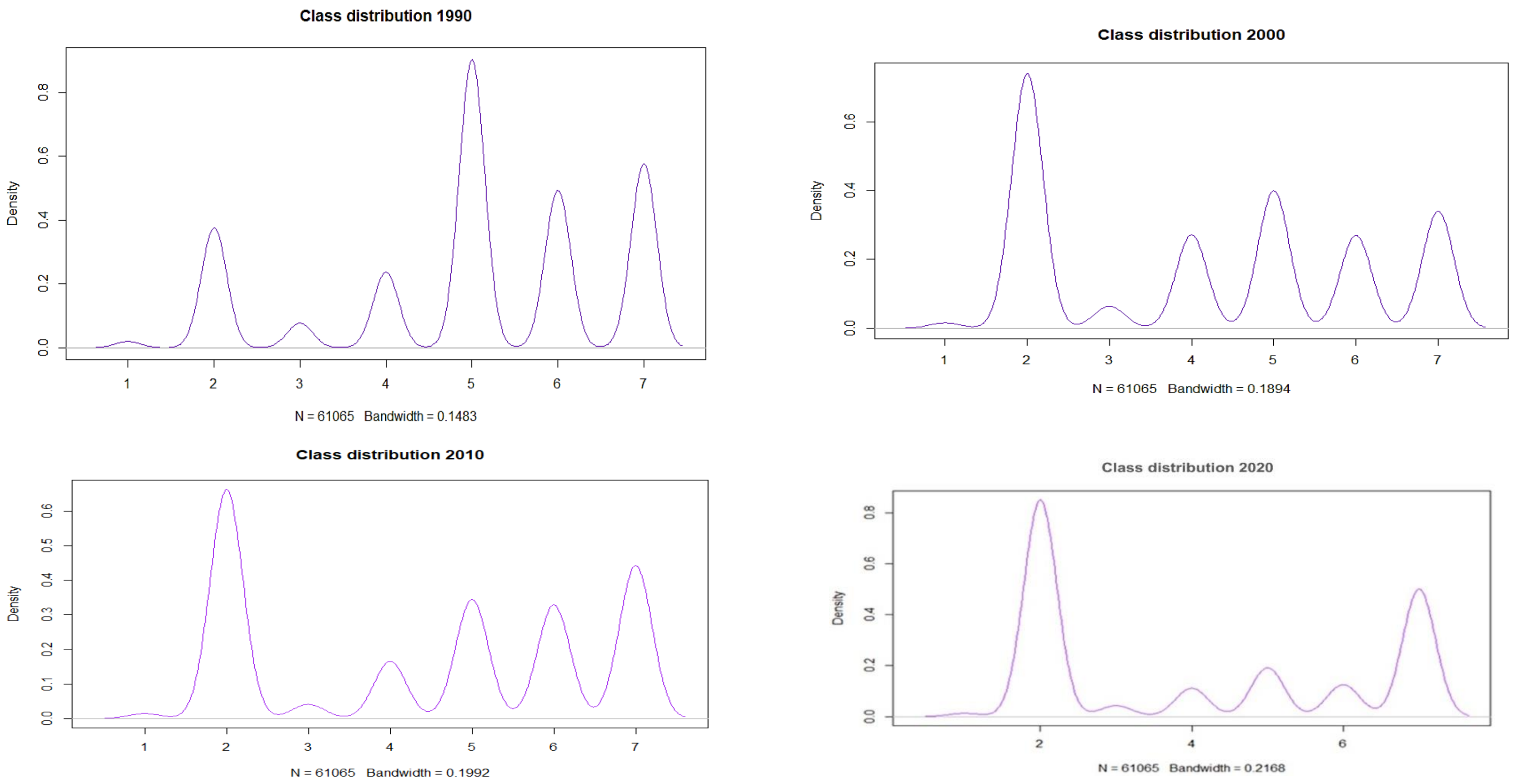


Figure 4.7: Class distribution for the year 1990, 2000, 2010, 2020

Figure 4. 8: Trends of Land Use Land Cover Classes

4.1.10 Change Detection Analysis

Change detection was undertaken to establish areas that have undergone any form of shifts across the study period, this is a pixel wise comparison of classes and was done to have an overview of stable areas and those areas that have undergone any form of shifts. Given the resolution of the satellite imagery and the size of the catchment pixel wise, analysis show significant shifts due to the number of activities that take place in a catchment. The following maps show the changes for different epochs (Figures 4.9, 4.10 and 4.11).

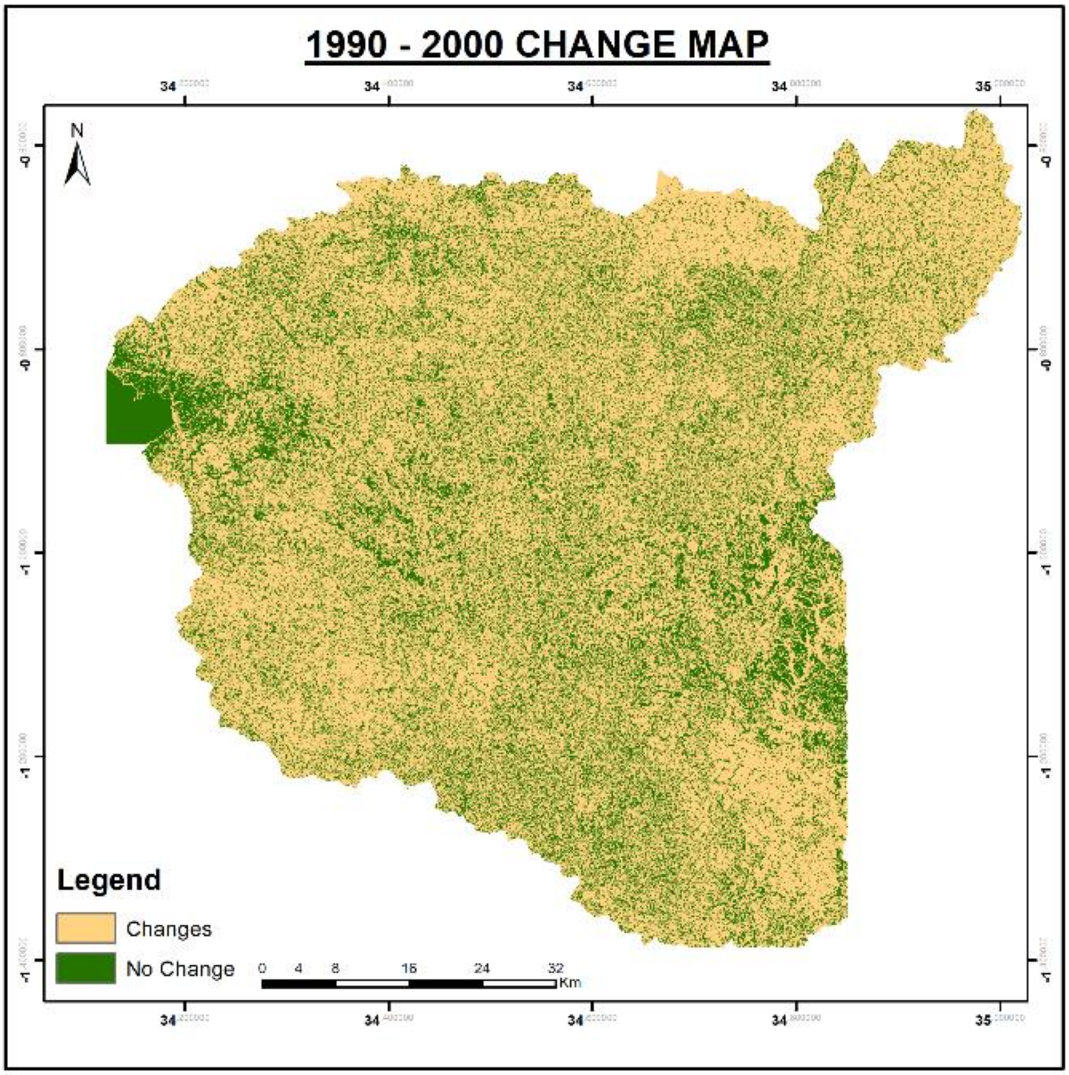


Figure 4.9: Decadal Change detection of the basin 1990-2000

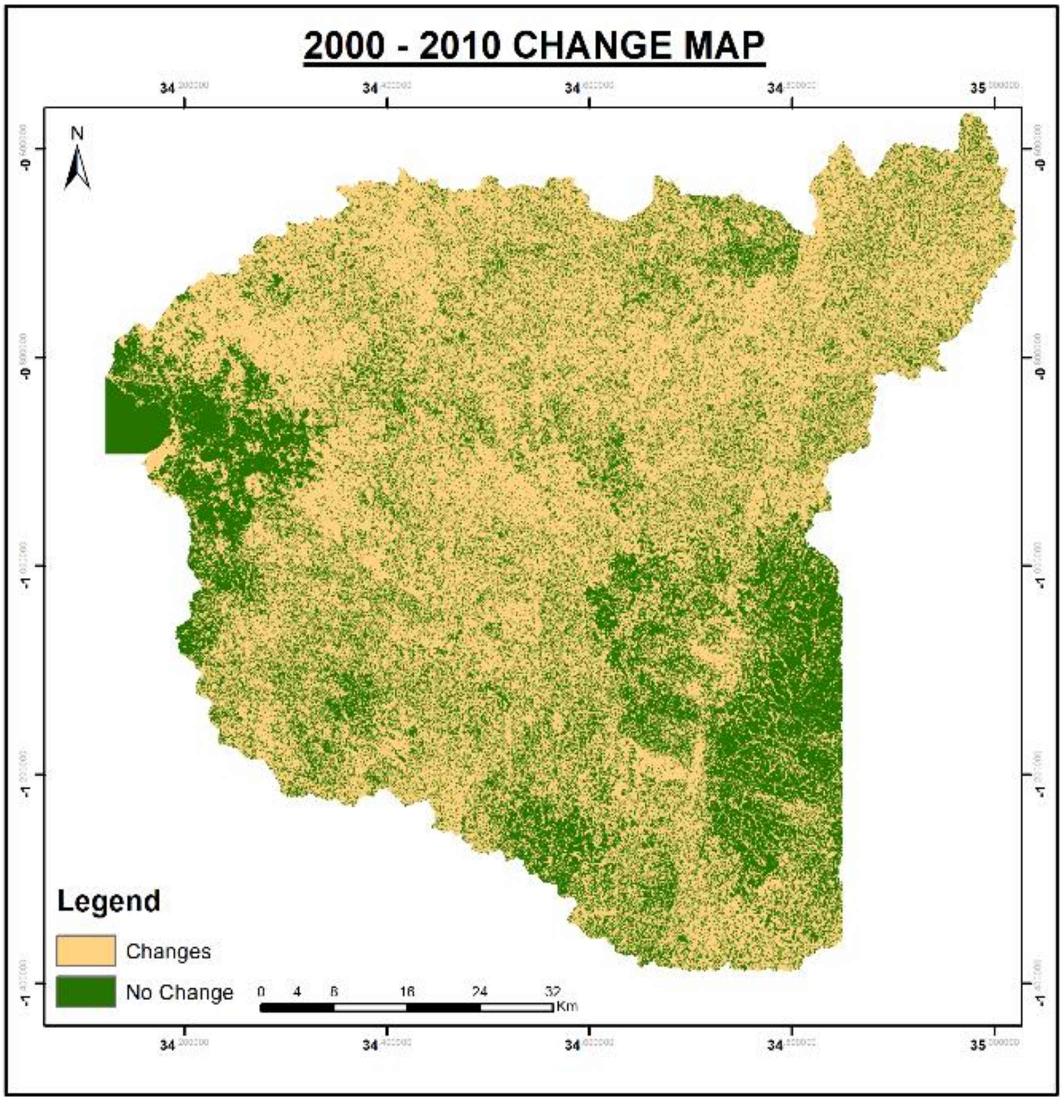


Figure 4.10: Decadal Change detection of the basin 2000-2010

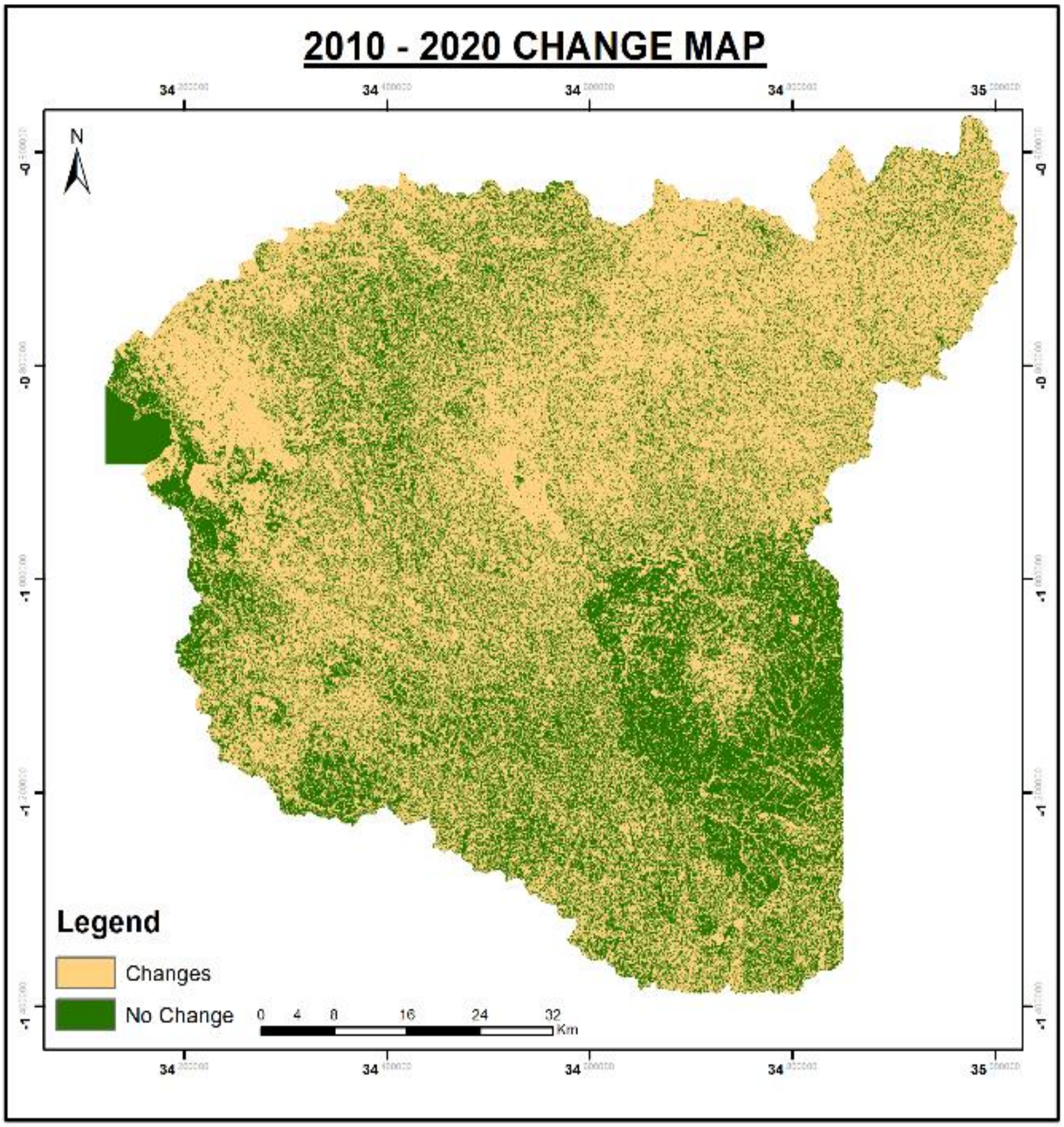


Figure 4.11: Decadal Change detection of the basin 2010-2020

Table 4.6: Overall Land Cover Land Use Change from 1990 to 2020

Class	Reference Data				Overall Change		
	1990 Area Covered (Km^2) Percentage of Class		2020 Area Covered (Km^2) Percentage of Class		Area Changed (Km^2)	Overall Percent Entire Basin	Percent Change per Class
Water	41	0.59%	36	0.52%	**-5**	**-0.07%**	**-12.2%**
Agriculture	788	11.4%	2610	37.8%	**1822**	**26.4%**	**231.2%**
Built up Areas	161	2.3%	521	7.6%	**360**	**4.4%**	**223.6%**
Bare land	502	7.3%	330	4.8%	**-172**	**-2.5%**	**-34.3%**
Forest	1886	27.31%	928	13.44%	**-958**	**-13.87%**	**-50.8%**
Shrub land	1033	15.0%	379	5.5%	**-654**	**-9.5%**	**-63.3%**
Grassland	1212	17.6%	1544	22.4%	**332**	**4.8%**	**27.4%**
Others Unclassified	1277	18.5%	552	8.04%	**-725**	**-10.46%**	**-56.7%**
TOTAL	**6,900**	**100%**	**6,900**	**100%**			

The results show that the land uses have changed over the decadal period in which the study was conducted (Table 4.6). The agricultural area expanded exponentially from 788sq.km to 2610sq.km while forests have reduced from 1886sq.km to 928sq.km between 1990 and 2020. This translates to an agricultural percentage increase of 231.2% and reduction of forests by 13.87% respectively. Surface water retention reduced from 41sq.km to 36sq.km (-12.2%) during the period under study. Built up areas generally increases towards 2020, however, due to high pixel confusion in 1990, the classification had a low accuracy, thus the high area for built up areas in 1990 (Figure 4.12). As the thick vegetation such as forest reduced, the grassland generally increased. Shrub land areas also experienced a reduction of 63.3% in land surface coverage. The satellite images analysis showed an average percentage accuracy of 85%. This was contributed to by different land use classes in which human activities influenced the conversion of one class to another over the three decadal period under study.

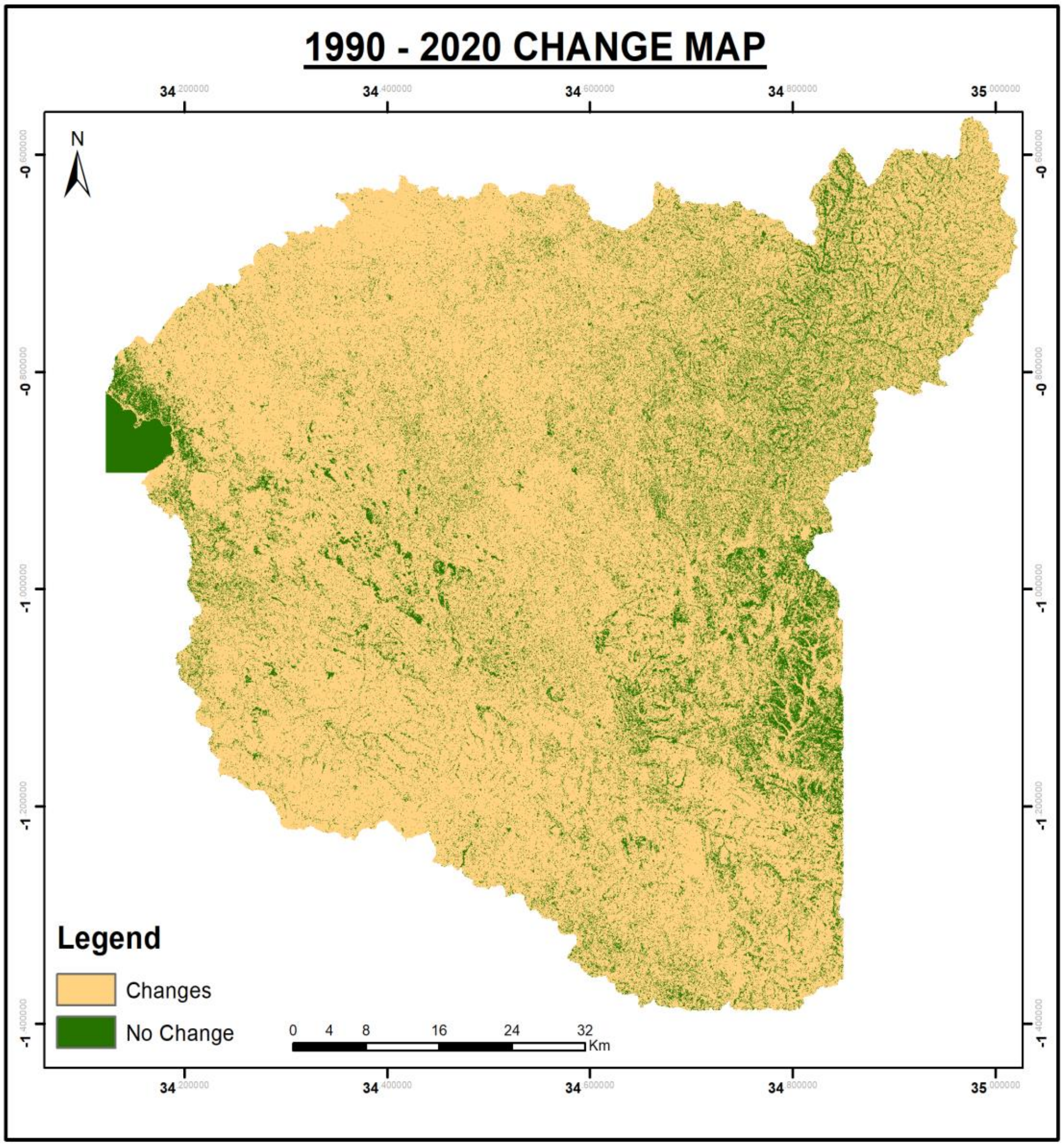


Figure 4.12: Overall Change detection of the basin from 1990-2020

4.2 Hydrologic Modelling

4.2.1 HEC-HMS model Output

The HEC-HMS model was run with the input parameters data estimated using the HEC-GeoHMS extension. Tools for assigning and calculating different river and watershed parameters were provided in the hydrologic menu. The tools assisted in determining key parameters such as channel routing coefficients, time of concentration and Soil Conservation Service (SCS) curve number (CN). Muskingum routing method was adopted in calculating the channel routing since it considers the amount of water stored by the river and also relates it to both the inflow and the outflow values. The resulting Muskingum equation was represented by equations 4.1 and 4.2:

$$S = K(xI + (1 - x)O) \quad \text{Equation 4.1}$$

$$O_2 = C_1 I_2 + C_3 I_1 \quad \text{Equation 4.2}$$

where;

S	=	for storage,
I	=	for inflow,
O	=	for outflow,
t	=	travel time, and
K and x	=	Muskingum parameters (constants).

In the calculations x was assumed to have a value of 0.2 and K to be same value as the CN lag time.

$$C_1 = (0.5\Delta t - Kx)(K - Kx + 0.5\Delta t) \quad \textit{Equation 4.3}$$

$$C_2 = (0.5\Delta t + Kx)\,(K - Kx + 0.5\Delta t) \quad \textit{Equation 4.4}$$

$$C_3 = (K - Kx - 0.5\Delta t)(K - Kx + 0.5\Delta t) \quad \textit{Equation 4.5}$$

$$C_1 + C_2 + C_3 = 1 \quad \textit{Equation 4.6}$$

Where; *C1*, *C2* and *C3* are routing parameters obtained from the equations above. They all sum up to one as shown in equation 4.6.

The Soil Conservation Service (SCS) Curve Number (CN) method was used to measure land use as the indicator while determining surface runoff. CN values range from 0-100 where the value tends towards 100, there is a decreasing trend in infiltration capacity of the soil and vice versa. Factors taken into consideration while determining SCS CN included land cover types, antecedent runoff conditions, hydrological soil types and imperviousness of the soil. The runoff factor was expressed by the equation below (SCS, 1986):

$$Q = \frac{[P - I_a]2}{(P - I_a) + S} \quad \textit{Equation 4.7}$$

where,

Q = runoff measured in mm,

P = rainfall measured in mm,

S = potential maximum retention of the soil after runoff begins measured in mm,

I_a = initial abstraction measured in mm.

The I_a referred to all losses of water during precipitation before runoff begun. It varies depending on so many factors and in the case of River Kuja watershed, it was approximated using the equation below:

$I_a = 0.2S$ *Equation 4.8*

While eliminating Ia, an independent parameter, from the equations, S and P were allowed to produce an amount of surface runoff. This was achieved by substituting equation 3.8 into equation 4.7 and obtaining equation 4.9.

$Q = (P - 0.2S)/(P + 0.8S)$ *Equation 4.9*

In the equation 4.9, S was determined in relation to land use factors and soil conditions of Kuja basin through the CN and their relationship was given by equation 4.10:

$S = 1000CN$ *Equation 4.10*

As expressed by Wurbs and James (2001), the Soil Conservation Service unit hydrograph was used based on its simplicity of its two basic parameters, that is, lag time tL and watershed area A. The CN lag method function in HEC-GeoHMS was used to compute sub basins weighted time of concentration. The resultant lag time was in hours and represented time from the centre mass of excess hydrograph to the peak of the hydrograph.

$Q_p = 484AT_p$ *Equation 4.11*

$T_p = D2 + tL$ *Equation 4.12*

where,

Q_p = peak unit hydrograph measured in m^3 hr^{-1},
A = catchment area measured in m^2,
T_p = flow to peak; a function of lag time, tL (hrs) and rainfall duration, D
D = rainfall duration measured in hrs
tL = lag time measured in hrs.

4.2.2 Soil Data Mapping for River Kuja basin

The basin was characterized by different soil types as presented in Figure 4.13 below. The area was largely Clay soil followed by Clay Loam with the least being Sandy Clay. The Clay soil covered most parts of the upstream of the basin, that is the Kisii highlands while Sandy Clay Loam soils covered the downstream areas at the shores of Lake Victoria. The middle of the basin was characterized by Clay Loam and is the focal area for high production of sugarcane.

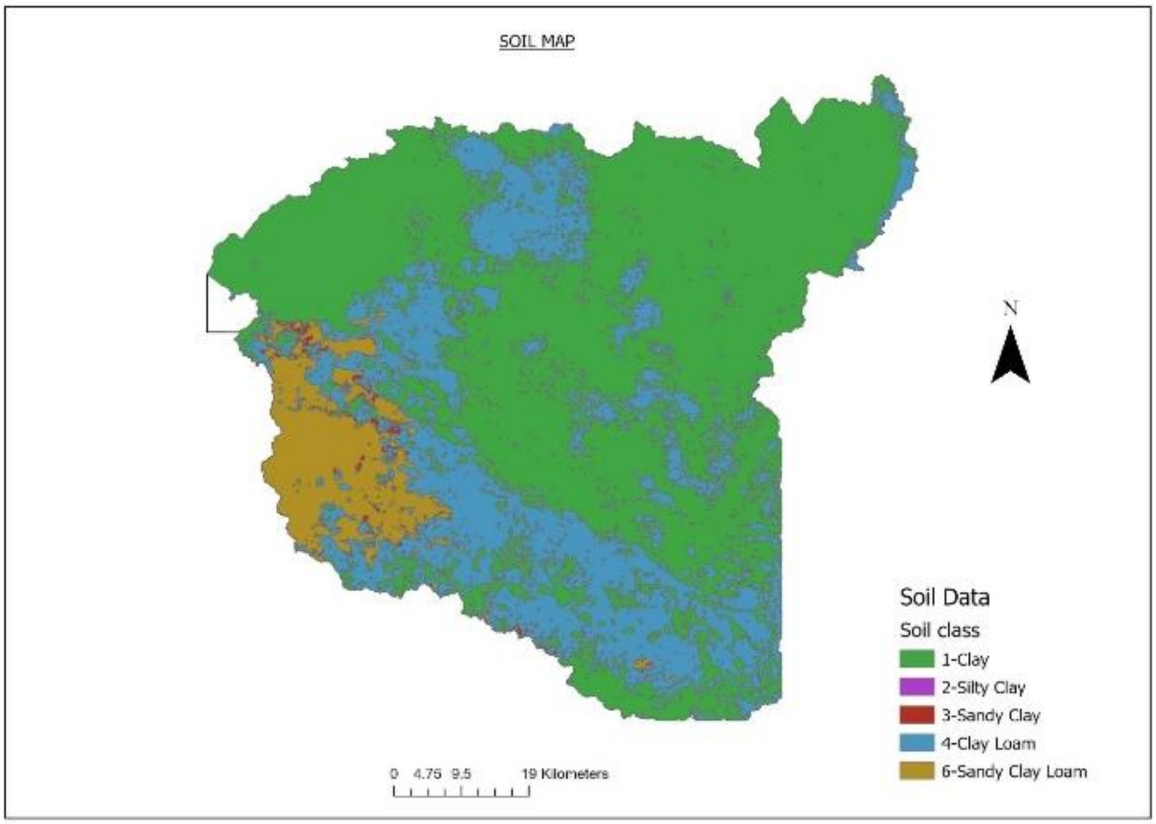


Figure 4.13: Soil Map of River Kuja basin

In terms of hydrological grouping of soils in River Kuja Basin, the basin has two major groups, C and D, as shown in Figure 4.14 below. The percentage coverage by hydrological soil group D is 91% while C only occupies 9%. Group A soil in terms of hydrological categorization has a low runoff potential, group B has moderately low runoff potential, group C has moderately high runoff potential, while group D exhibits high runoff potential according to Hydrology National Engineering Handbook (2007). The figure 4.15 and Figure 4.16 show the land cover and soil group map and extraction of composite curve numbers in reference to each sub-basin respectively.

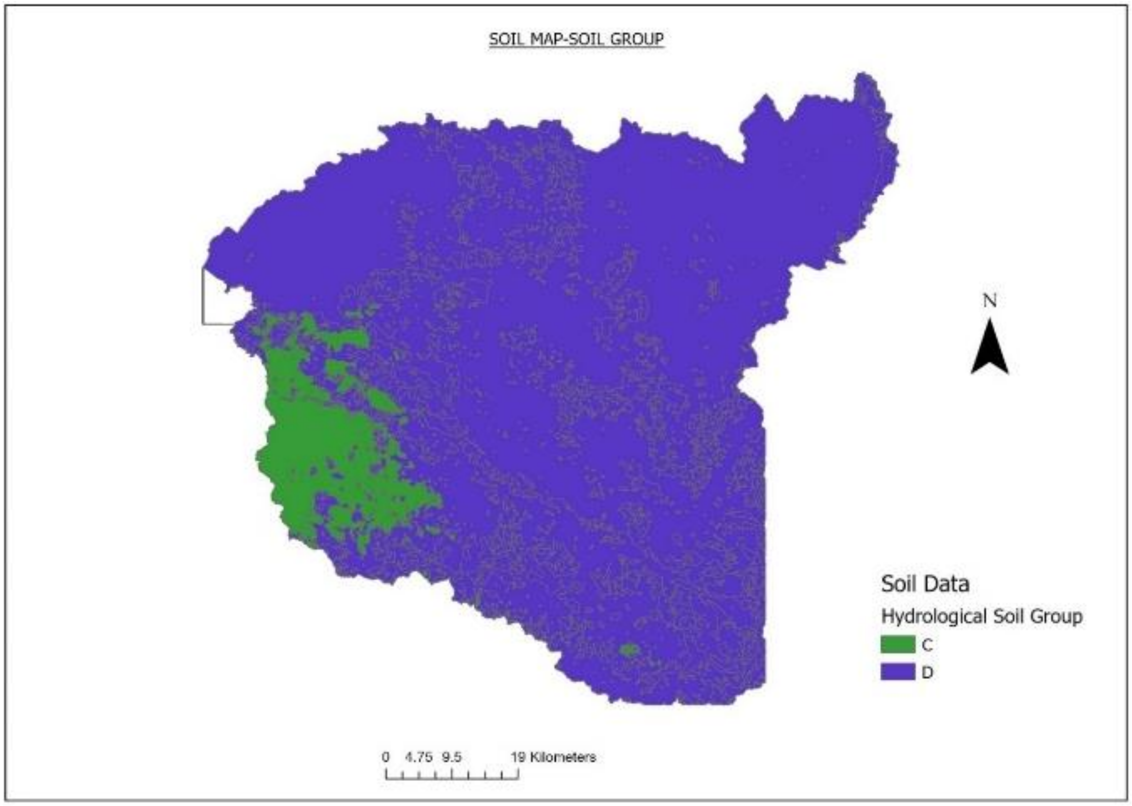


Figure 4.14: Categorization of soil cover into Hydrological soil Groups

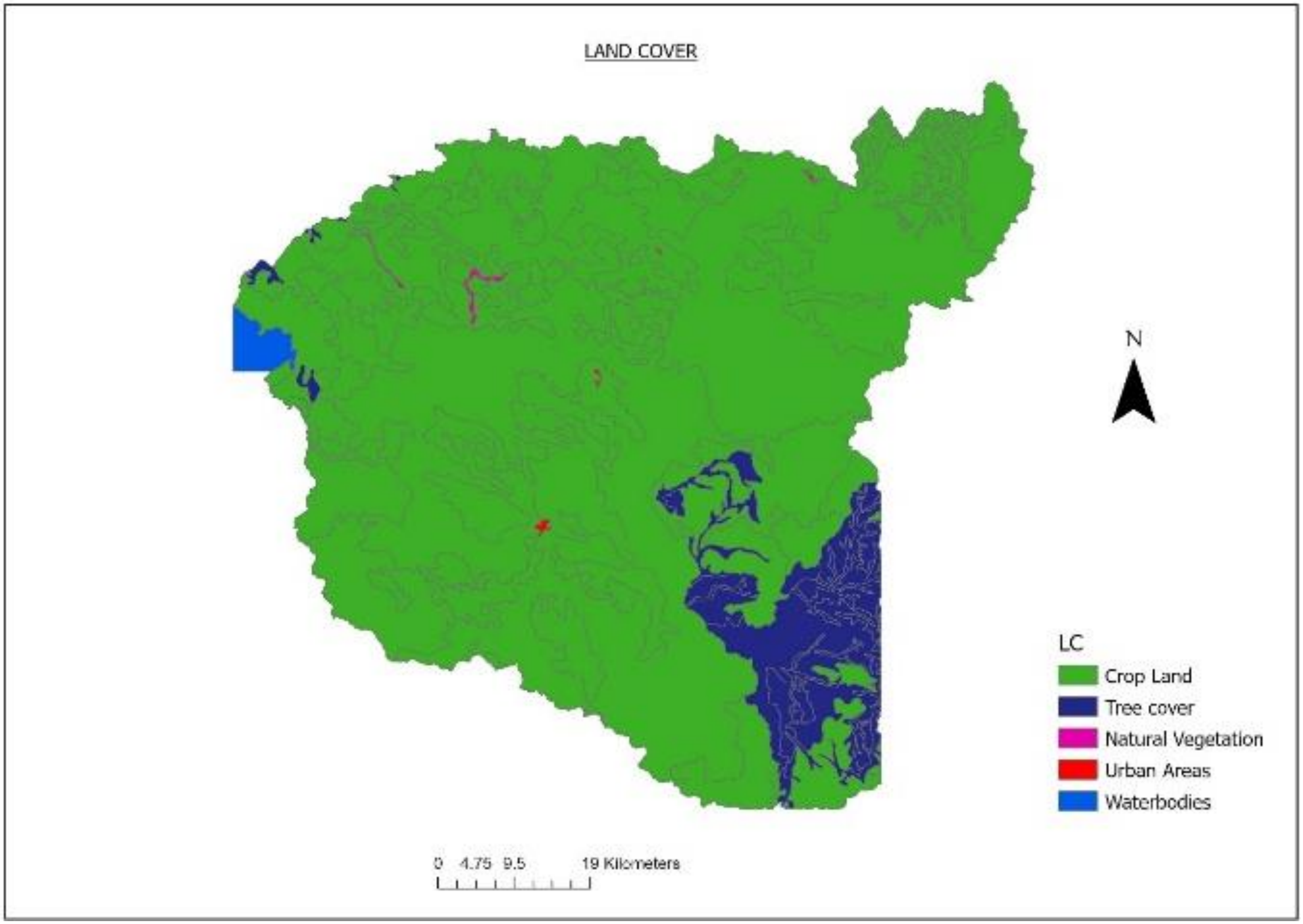


Figure 4.15: Land Cover and soil group map

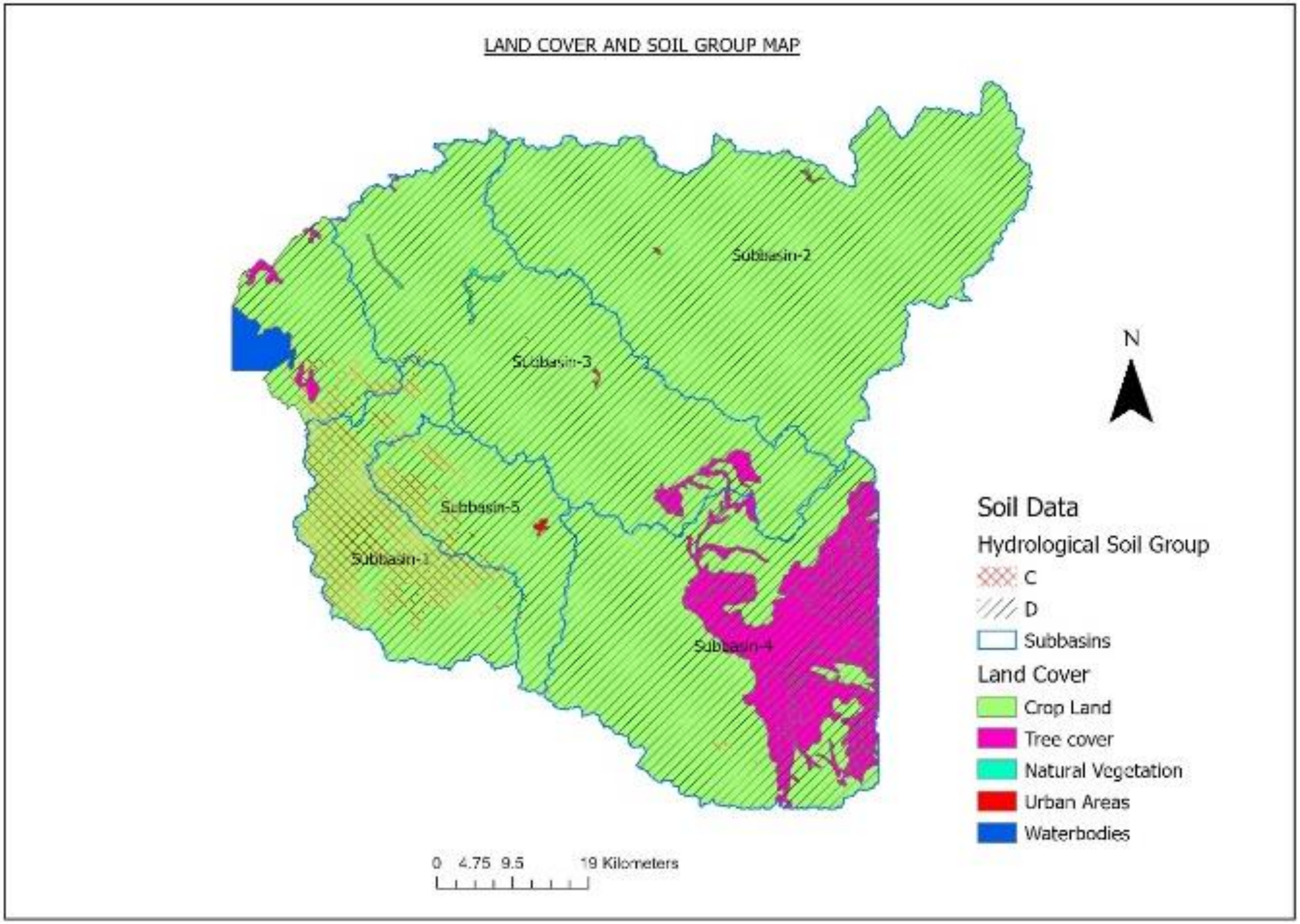


Figure 4.16: Extraction of composite curve numbers from each sub-basin.

4.2.3 Variation in Rainfall and Streamflow Results

The relationship between average daily rainfall and average daily river discharge at the River Kuja outlet was investigated by applying regression analysis method and the outcome presented. Simple linear regression method was used to test if daily rainfall could predict daily river flow. The fitted rainfall model was as shown in equation 4.13. The overall regression was statistically significant with the value of coefficient of determination represented by R^2 found to be 0.42 and the p-value at 0.008 which is a significant relationship. The result show that rainfall and streamflow related by 42% variation which is a moderately average relationship as shown in Figure 4.17.

$$y = 6.1419 + 1.2749x \qquad \textit{Equation 4.13}$$

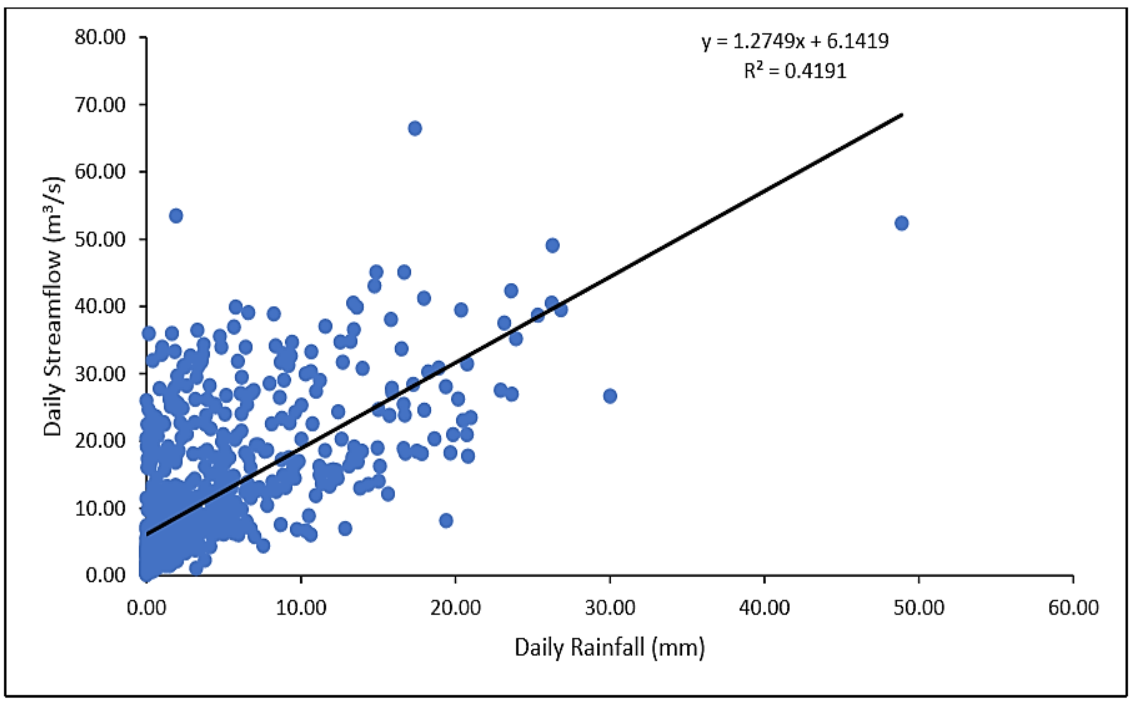
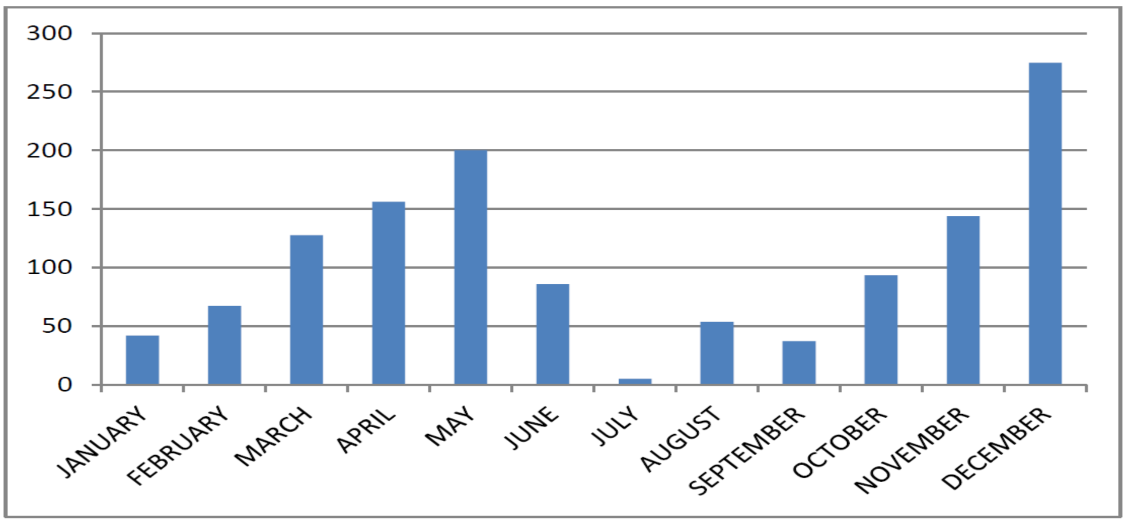
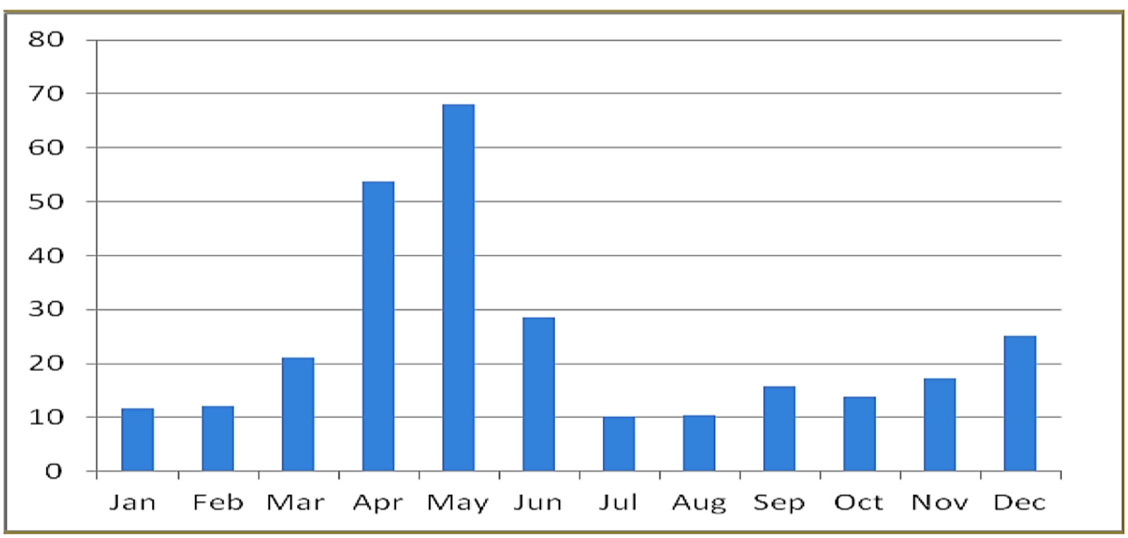


Figure 4.17: Regression Analysis Plot between the Daily Stream flows and Average Daily Rainfall Data

The relationship between average annual rainfall and the annual discharge at Muhuru bay station in Figure 4.18 showed a direct proportionality trend. The higher the rainfall the higher the river discharge and the lower the rainfall the lower the discharge. The correlation for the month of December has a deviation and this could be due to low rainfall in the upper catchments of River Kuja basin.



A



B

Figure 4.18: River Kuja basin (A) Average annual rainfall (B) Annual Discharge at the Muhuru Bay Station

4.2.4 Streamflow Simulation Using HEC-HMS

4.2.4.1 Simulation results

The initial values of the basin that were computed in the HEC-GeoHMS are as shown in Table 4.7. Simulations were done using the same values but the output hydrograph was not reasonable, with its simulated and observed streamflow values not close to each other. The disparities possibly emerged from merging the sub basins and using the average parameters in the simulation process. The initial and optimized values are presented in the table 4.7 showing their relationship.

Table 4.7: Initial Parameters Used in the HEC-HMS Model Simulation of Streamflow

Parameter Name	Initial Value	Optimized Value
Land Use Curve Number	67.10	35.00
Lag Time SCS	318.60 minutes	662.04
Muskingum X-value	0.20	0.17
Muskingum K-value	5.31 hours	26.77
Basin Reach	2.00	1.00
SCS CN - Curve Number Scale Factor	1.00	0.01

A ten-year period between the year 2000 to 2009 was chosen to run the model on a daily time step since the data obtained during the period has no gaps. The values obtained from calibration and validation processes were used in the simulation processes. Comparison hydrograph results of simulated and observed parameters are presented in Figure 4.19.

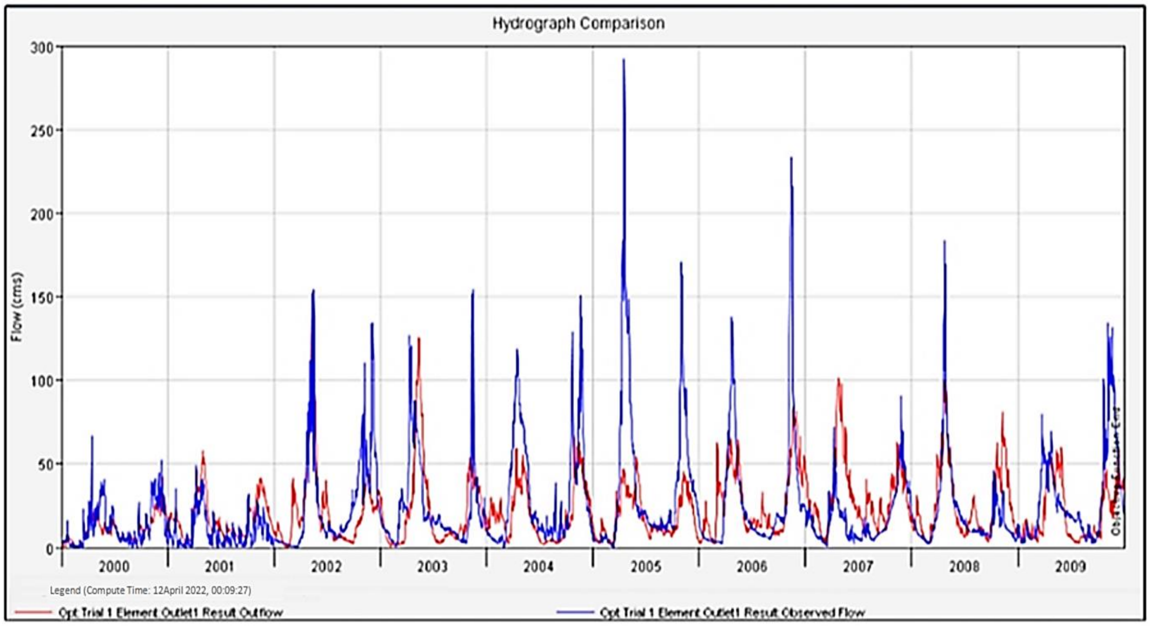
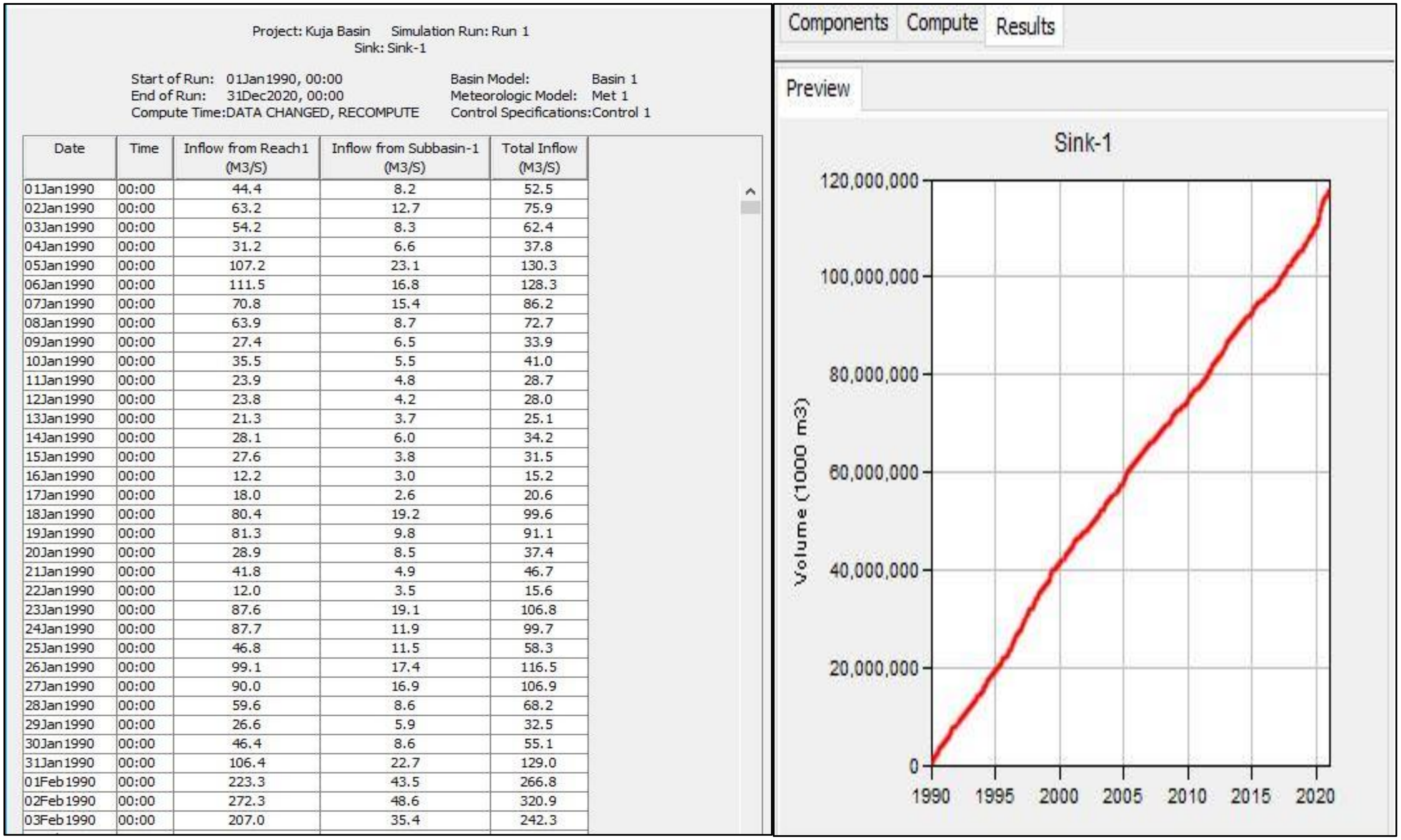


Figure 4.19: Hydrograph Comparison for Simulated and Observed parameters of the basin from 2000 to 2009

Results presented in the hydrographs (Figure 4.19) show that the values observed exceeded the values simulated by the model. The percentage difference between the observed and simulated values by the model was 8.2%. In terms of discharge volumes, observed volume was found to be 7060.45mm while the simulated discharge was 6524.28mm. However, this difference is considered small and reasonable as it is within the permissible limits of 10% for an accepted simulation comparison value. The model underestimated the low flows and peak flows as presented in figure 4.19. Integration of the tools with ArcGIS software enabled hydrologic processing and easy manipulation of various basin parameters. Figure 4.20 show the river flow within the basin reaches and sub-basins which contribute to the total inflow of River Kuja.



Project: Kuja Basin Simulation Run: Run 1
Sink: Sink-1

Start of Run: 01Jan1990, 00:00
End of Run: 31Dec2020, 00:00
Compute Time:DATA CHANGED, RECOMPUTE

Basin Model: Basin 1
Meteorologic Model: Met 1
Control Specifications:Control 1

Date	Time	Inflow from Reach1 (M3/S)	Inflow from Subbasin-1 (M3/S)	Total Inflow (M3/S)
01Jan1990	00:00	44.4	8.2	52.5
02Jan1990	00:00	63.2	12.7	75.9
03Jan1990	00:00	54.2	8.3	62.4
04Jan1990	00:00	31.2	6.6	37.8
05Jan1990	00:00	107.2	23.1	130.3
06Jan1990	00:00	111.5	16.8	128.3
07Jan1990	00:00	70.8	15.4	86.2
08Jan1990	00:00	63.9	8.7	72.7
09Jan1990	00:00	27.4	6.5	33.9
10Jan1990	00:00	35.5	5.5	41.0
11Jan1990	00:00	23.9	4.8	28.7
12Jan1990	00:00	23.8	4.2	28.0
13Jan1990	00:00	21.3	3.7	25.1
14Jan1990	00:00	28.1	6.0	34.2
15Jan1990	00:00	27.6	3.8	31.5
16Jan1990	00:00	12.2	3.0	15.2
17Jan1990	00:00	18.0	2.6	20.6
18Jan1990	00:00	80.4	19.2	99.6
19Jan1990	00:00	81.3	9.8	91.1
20Jan1990	00:00	28.9	8.5	37.4
21Jan1990	00:00	41.8	4.9	46.7
22Jan1990	00:00	12.0	3.5	15.6
23Jan1990	00:00	87.6	19.1	106.8
24Jan1990	00:00	87.7	11.9	99.7
25Jan1990	00:00	46.8	11.5	58.3
26Jan1990	00:00	99.1	17.4	116.5
27Jan1990	00:00	90.0	16.9	106.9
28Jan1990	00:00	59.6	8.6	68.2
29Jan1990	00:00	26.6	5.9	32.5
30Jan1990	00:00	46.4	8.6	55.1
31Jan1990	00:00	106.4	22.7	129.0
01Feb1990	00:00	223.3	43.5	266.8
02Feb1990	00:00	272.3	48.6	320.9
03Feb1990	00:00	207.0	35.4	242.3

Figure 4.20: Total Basin Inflow computation in the HEC-HMS model

4.2.4.2 Model calibration results

The initial parameters as shown in Table 4.7 were used in calibrating the model. The parameters yielded river flow results that were not acceptable as well as very low Nash–Sutcliffe model efficiency coefficient (NSE) value of -41. During the several calibration trials conducted, the best results showed an NSE value of 0.52, an acceptable value considering that the values should be within the standard ranges of 0 to 1. The results were similar to those reported in Pakistan, where Yassin, Fox, Laher and Ayas (2015) modelled hill torrents using the same model and obtained a calibration value of 0.54 which was considered acceptable. The errors realized during the calibration process could be due to filling in the missing values in the observed data. It could have also been a result of merging the small sub-basins into five major sub-basins and only using their averages. In conclusion, the calibration results were accepted because the values fell within the NSE scientific ranges. Figure 4.21, Figure 4.22 and Table 4.8 show the calibration results.

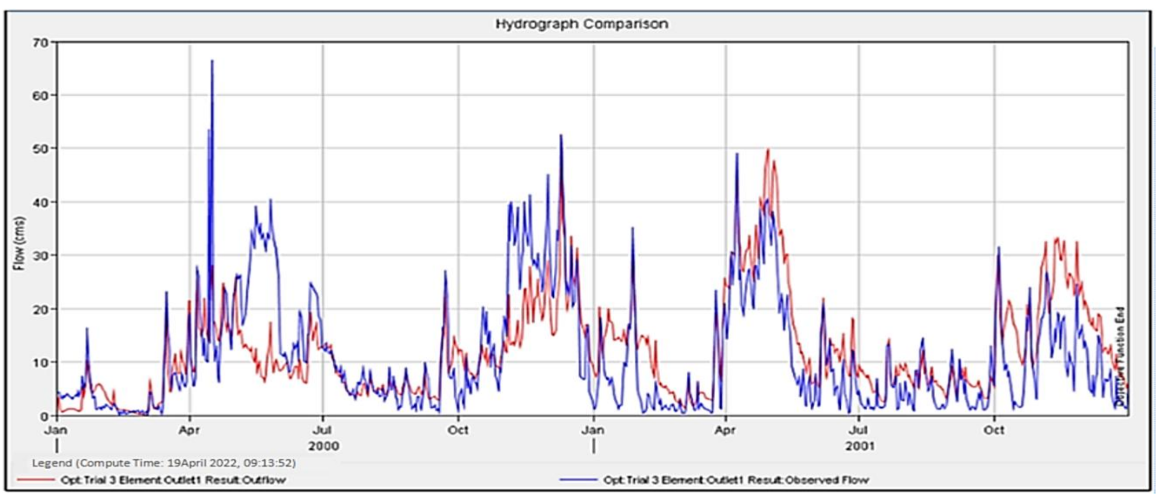


Figure 4.21: Model Calibration Hydrograph for the Period between 2000 and 2001

Table 4 8: Summary of the Objective Function Results for the Model Calibration

Volume Units: (●) MM ( ) 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	718.33	654.07	64.26	9.82
Peak Flow (M3/S)	52.6	66.5	-13.9	-20.9
Time of Peak	10Dec2000, 00:00	16Apr2000, 00:00		
Time of Center of Mass	16Feb2001, 23:29	19Dec2000, 07:01		

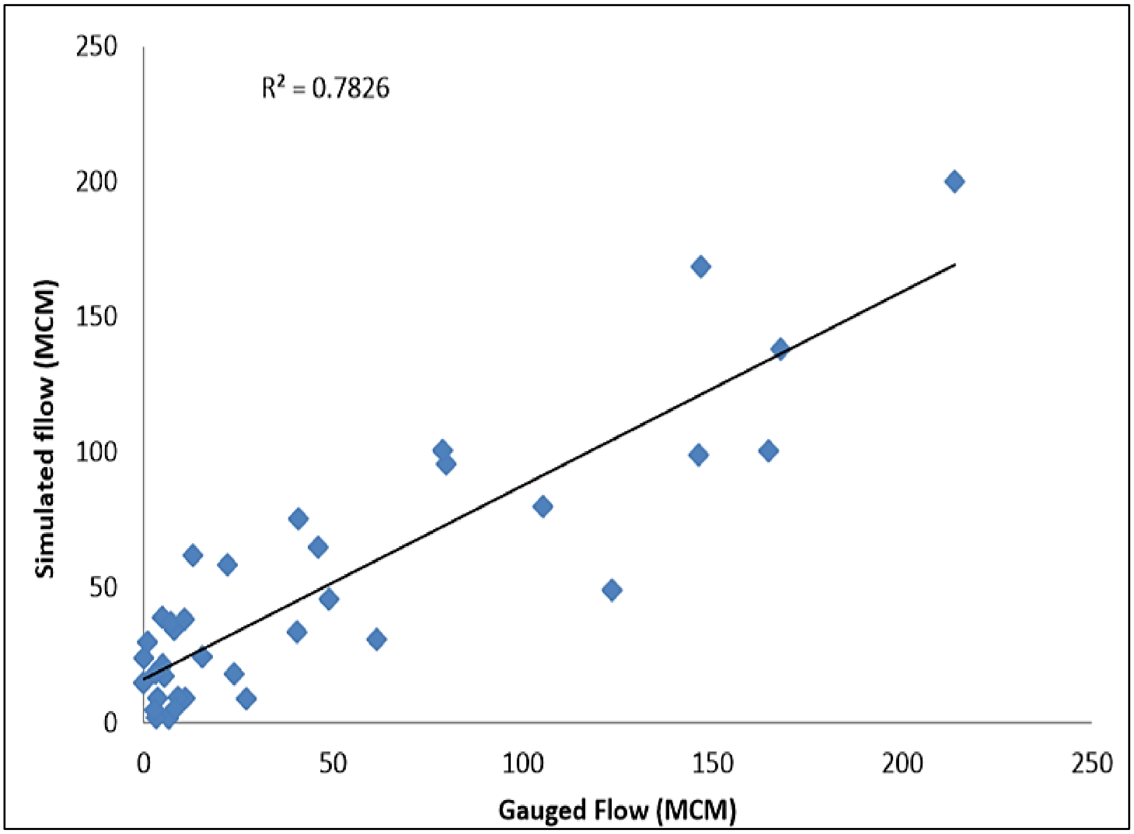


Figure 4.22: Simulated River Kuja flow

4.2.4.3 Model validation results

The validation of the model was done using data for the period January 1, 2002 to December 31, 2003, an outer period from the model calibration period. Optimized parameters in Table 4.7 were the baseline in carrying out simulations to achieve valid outcomes. The validation process produced NSE value of 0.32. The value was acceptable since it was within the NSE ranges of 0 to 1. The variation in the validation results was because rainfall data used during this research was not representing the entire basin but rather from only three gauging stations. Merging of sub-basins also contributed to the low NSE value. The results of the validation process are presented in Figure 4.23 and Table 4.9.

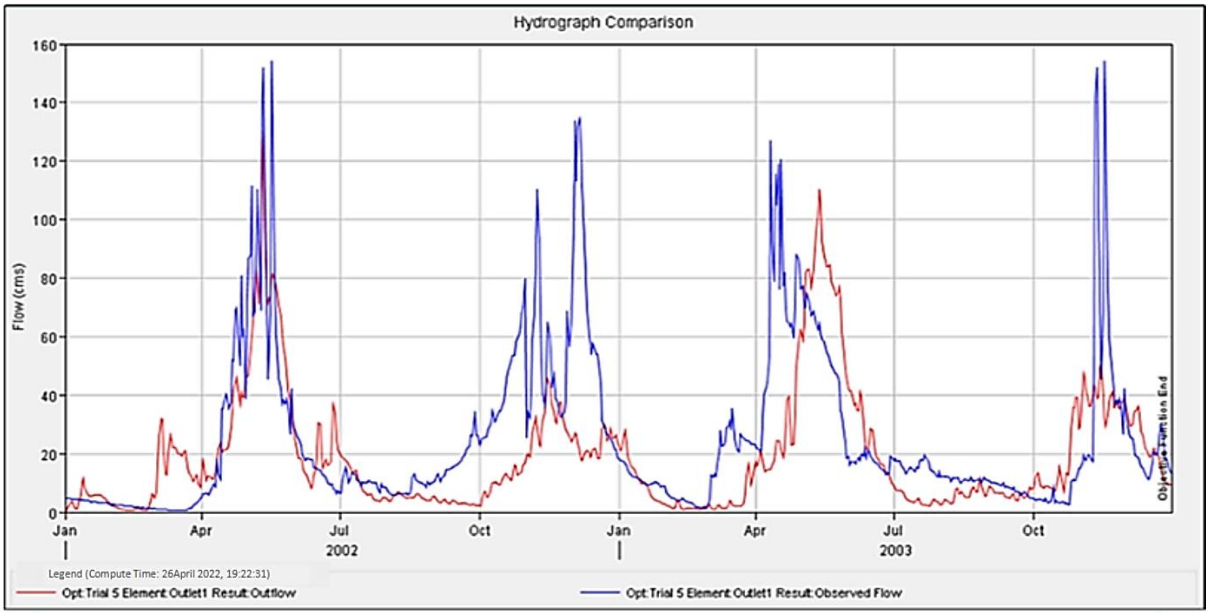


Figure 4. 23: Model Validation Hydrograph for the Period between 2002 and 2003

Table 4.9: Summary Results for the Model Validation

Volume Units: (•) MM ( ) 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	1127.91	1501.63	-373.72	-24.89
Peak Flow (M3/S)	84.5	154.3	-69.8	-45.3
Time of Peak	13May2003, 00:00	17Nov2003, 00:00		
Time of Center of Mass	20Jan2004, 09:30	03Feb2004, 22:01		

4.2.3 Hydrology of the Basin

Results show that the peak discharge was experienced in February 2020 (6^{th}) with a discharge rate of 2,481.6m^3/s with a volume of 33,629.21mm as shown in Figure 4.24. In addition, the rainfall patterns are showing an unprecedented trend since 2010 with high peak discharges thus causing floods along the river channel.

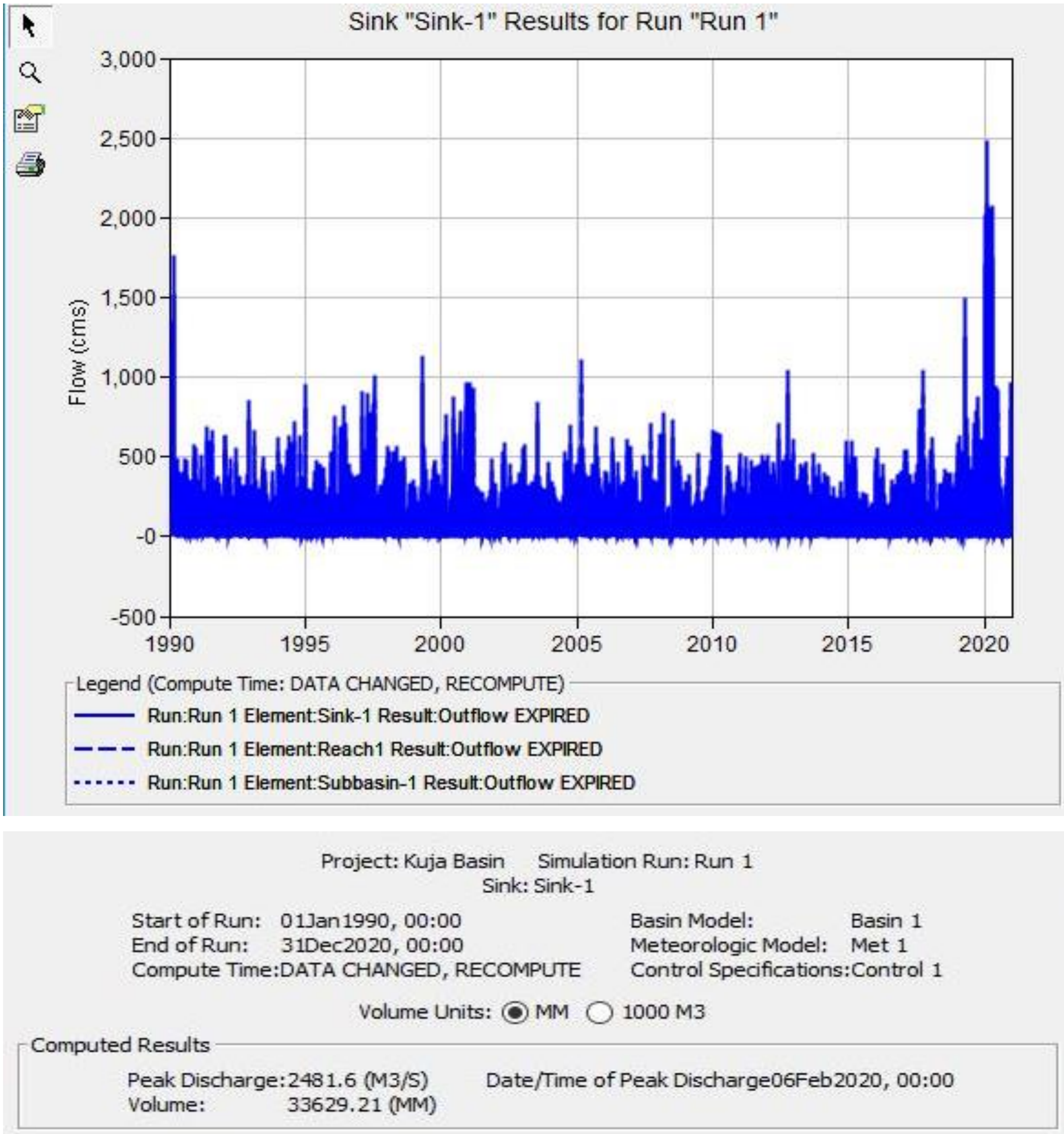


Figure 4. 24: River Kuja flow for the period 1990 to 2020.

4.3 Perception of local communities of River Kuja Basin

4.3.1 Characteristics of Human Population in the basin

4.3.1.1 Age and gender distribution of respondents

The results show that 56.1% of the respondents were male while 43.9% were female. 7% of the females interviewed in the households were the bread winners. The majority of the respondents were married (69%), 23% widows and widowers while 8% were single. A high number of respondents were 30years and above at 50.2%, followed by 20-30yrs at 38.2% and the least being 0-20years at 11.6% (Table 4.10).

Table 4.10: Respondent sex and age in Kuja basin

Respondent sex		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Male	217	56.1	56.1	56.1
	Female	170	43.9	43.9	100.0
	Total	387	100.0	100.0	
Age of the respondent					
Valid	0 to 20 years	45	11.6	11.6	11.6
	20 to 30 years	148	38.2	38.2	49.8
	30 years and above	194	50.2	50.2	100.0
	Total	387	100.0	100.0	

The study found out that 55.2% of the respondents were native of the Kuja River basin whereas 44.8% were immigrants from other regions as shown in Table 4.9. 23% of immigrants had stayed in the area for over 11years, while 9.3% had stayed for 6-10 years and 12% had stayed for the shortest period of 1-5 years.

Table 4.11: Period of immigration

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	214	55.3	55.3	55.3
	1-5	48	12.4	12.4	67.7
	6-10	36	9.3	9.3	77.0
	Above 11	89	23.0	23.0	100.0
	Total	**387**	**100.0**	**100.0**	

About 15.3% of the respondents had completely no formal education. The number of people who had attained primary education were about 74.4% in total. Secondary school education was attained by 7.1% while 3.2% reached post-secondary, middle level college and university levels (Figure 4.25).

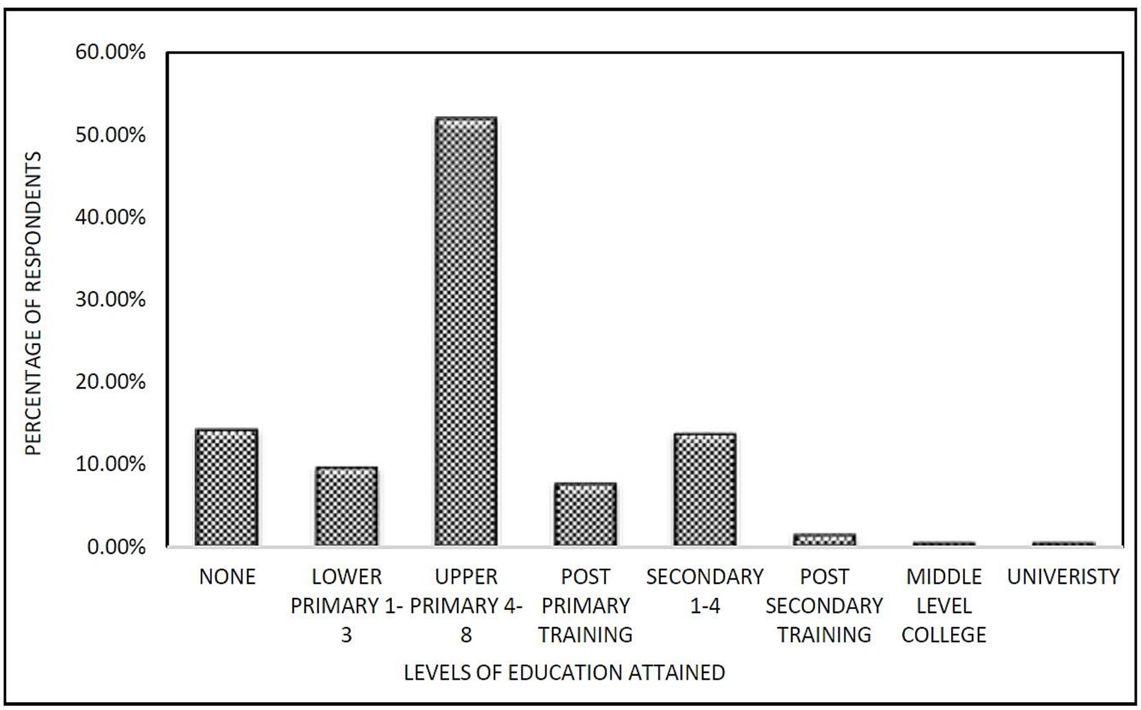


Figure 4.25: Education Attainment Levels of the respondents in River Kuja basin

4.3.1.2 Change in unit per parcel of Land owned

A total of 85.3% of the respondents acknowledged that there was change in the size of land owned while 14.7% reported no land size change over the period. A total of 60.8% of the respondents were of the view that there was a decrease in the size of land parcel where 10.4% reported that there was an increase in the size of land parcels as presented in Table 4.12 and Figure 4.26.

Table 4. 12: How the size of land parcels changing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Increasing	40	10.4	10.4	10.4
	Decreasing	235	60.8	60.8	71.2
	No change	49	12.7	12.7	84.0
	Not aware	62	16.0	16.0	100.0
	Total	**387**	**100.0**	**100.0**	

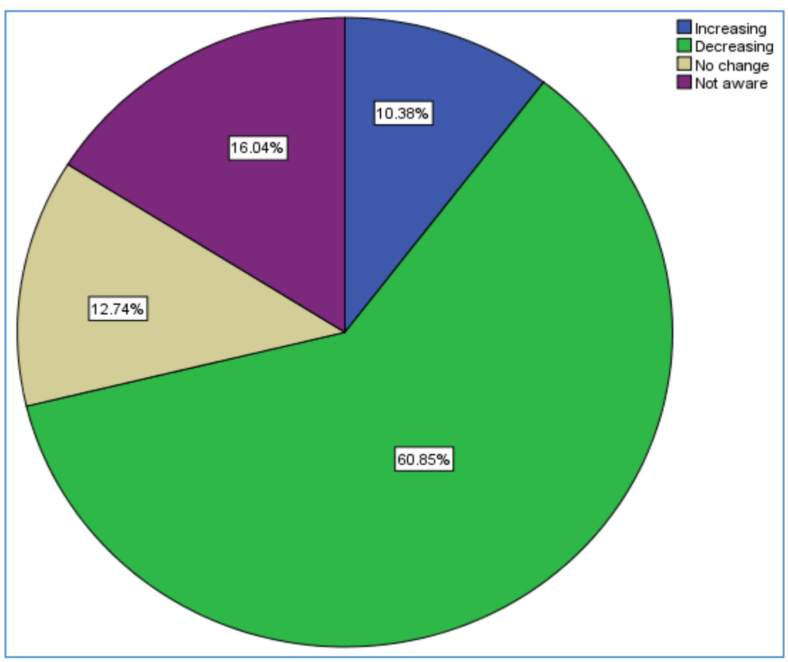


Figure 4.26: Change in unit area per parcel of lands

4.3.2 Human Population Growth

The human population growth rate per annum over the 30-year period from 1990 to 2020 was estimated at 1.52% as per Table 4.13 data. This was determined by the compounded growth rate formula as below:

$$R = \left[\left(\frac{P_n}{P_o}\right)^{\frac{1}{n}} - 1\right] \times 100 \qquad \textit{Equation 4.14}$$

where;

R = Compounded rate of growth

P_n = Population in the current year

P_o = Population in the base year

n = Number of intermediary years.

Therefore;

Population Growth Rate $= ((2{,}215{,}764/1{,}408{,}887)^{1/30} - 1) \times 100 = 1.52\%$

Growth Rate $= 1.52\%$

Table 4.13: Population Data for Kuja River basin

County	Year 1989	Year1999	Year 2009	Year 2019
Migori	487,556	714,897	779,878	916,436
Kisii	391,067	414,601	437,665	453,281
Homabay	180,432	217,887	227,998	335,868
Nyamira	198,776	215,951	227,697	253,282
Narok	151,056	170,591	176,497	256,897
Total	**1,408,887**	**1,733,927**	**1,849,735**	**2,215,764**

Source: Kenya National Census 1989, 1999, 2009, 2019

The decadal population growth rate between the year 1989 and 1999 was 2.10% as calculated using the compound growth rate formula:

Population Growth Rate $= ((1{,}733{,}927/1{,}408{,}887)^{1/10} - 1) \times 100 = 2.10\%$

Growth Rate for the years 1989-1999 = 2.10%

For the years 1999 to 2009, the decadal population growth rate was 0.65% as calculated using the compound growth rate formula:

$$Population\ Growth\ Rate = ((1{,}849{,}735/1{,}733{,}927)^{1/10} - 1) \times 100 = 0.65\%$$

Growth Rate for the years 1999-2009 = 0.65%

For the years 2009 to 2019, the decadal population growth rate was 1.82% as calculated using the compound growth rate formula:

$$Population\ Growth\ Rate = ((2{,}215{,}764/1{,}849{,}735)^{1/10} - 1) \times 100 = 1.82\%$$

Growth Rate for the years 1999-2009 = 1.82%

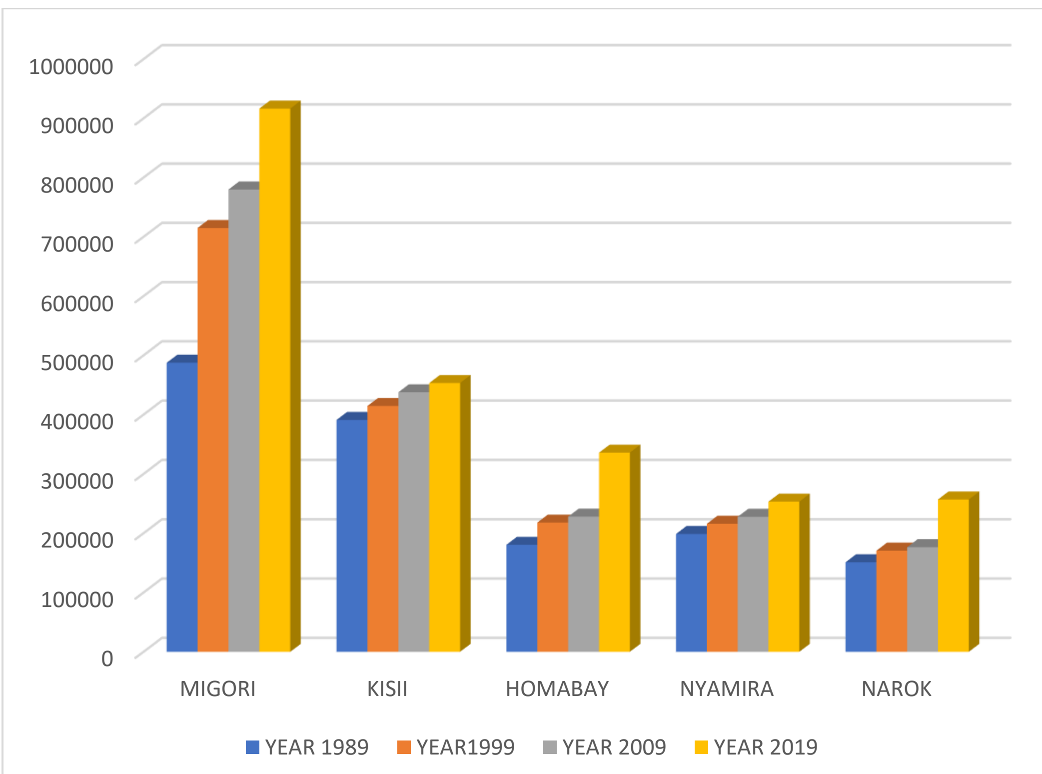


Figure 4.27: Population Trends within the portions of Counties under River Kuja basin

Generally, the human population in the basin increased from 1,408,887 in 1989 to 2,215,764 in 2019 giving a difference of 806,877 which translates to a 57.3% increase with a compounded growth rate of 1.52% (Figure 4.27). The part of the basin that falls within Migori County contributed a greater population size than within other counties. Narok County is the least covered by the basin hence the small population size (Figure 4.28). Migori County had a sharp population rise between 1989 and 1999 which was attributed to the Sony Sugar Factory economic development. The sugar factory attracted immigration to the region and economic development. Homabay and Narok Counties registered sharp increases between 2009 and 2019. However, a comparison with the national growth rate shows a lower increase for the basin as shown in Figures 4.28 and 4.29.

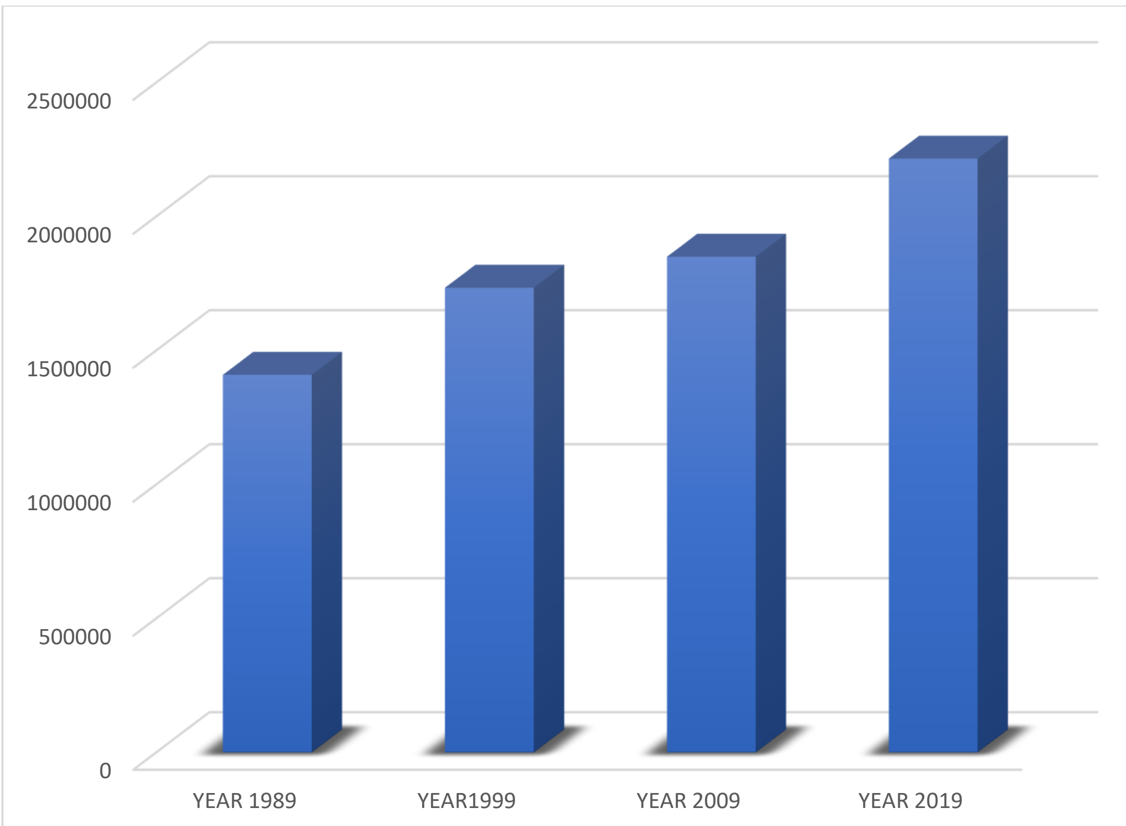


Figure 4.28: Population increase in Kuja basin from 1989 to 2019

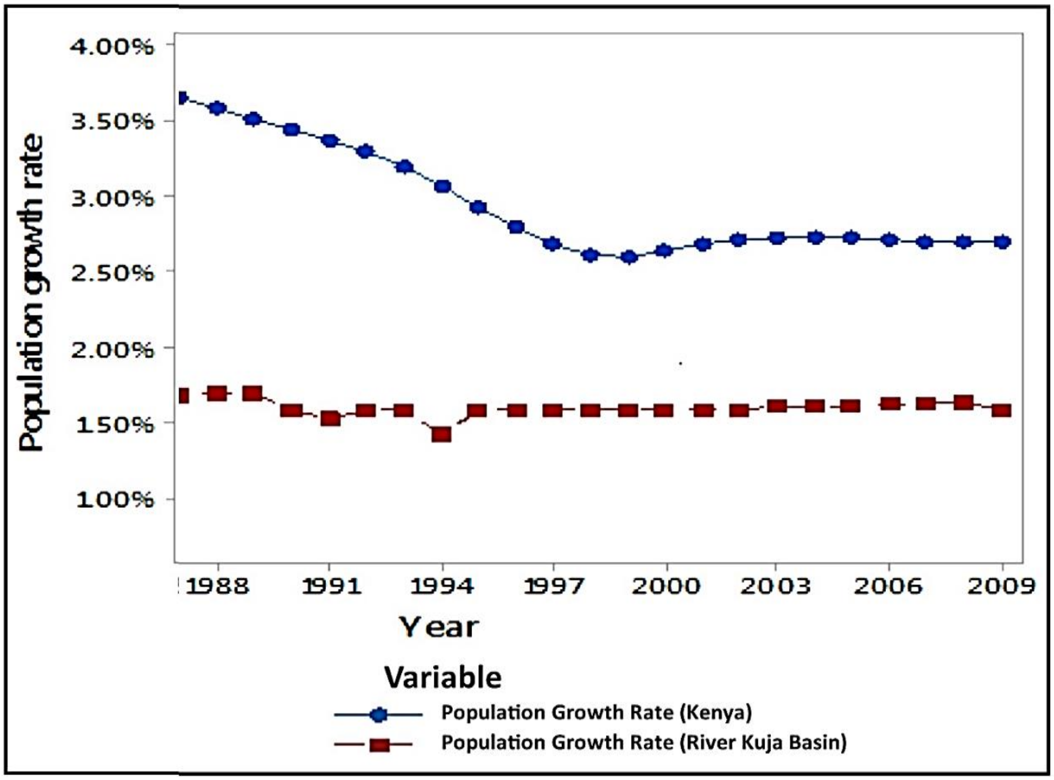


Figure 4.29: Population Growth Rates of the Study Area as Compared to Mean National Growth Rates (Source: KNBS 1989, 1999 and 2009)

4.3.3 Household Interaction with River Kuja and the Basin

4.3.3.1 Changes in land use and land cover

75% of the respondents reported that there was change in land use and cover over the years while 25% of the respondents were of the contrary opinion as shown in Table 4.14 and Figure 4.30.

Table 4.14: Changes in land use and land cover

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not aware	13	3.3	3.3	3.3
	Yes	290	75.0	75.0	78.3
	No	84	21.7	21.7	100.0
	Total	**387**	**100.0**	**100.0**	

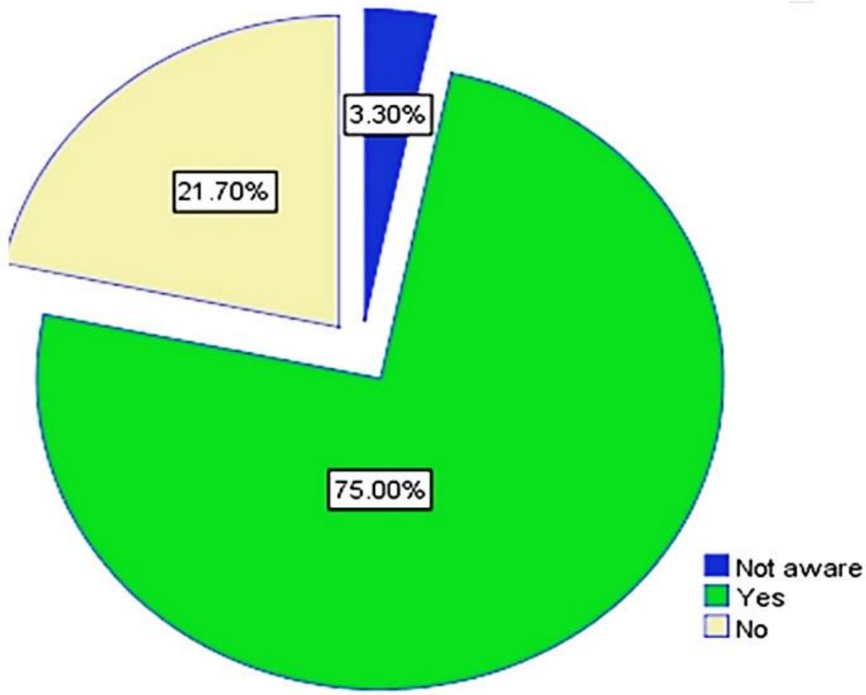


Figure 4.30: Changes in Land Use Land Cover of Kuja basin

Among the various changes in land use and land cover, the major factor was conversion of natural forest to cropland as reported by 25% of the respondents. Conversion of wetlands to cropland was the least reported by 10% of respondents. The results can be explained by introduction of sugarcane production in the area. This seems to have been adopted by large population in the area hence made the natural forest cover be cleared for sugarcane growing as shown in figure 4.31.

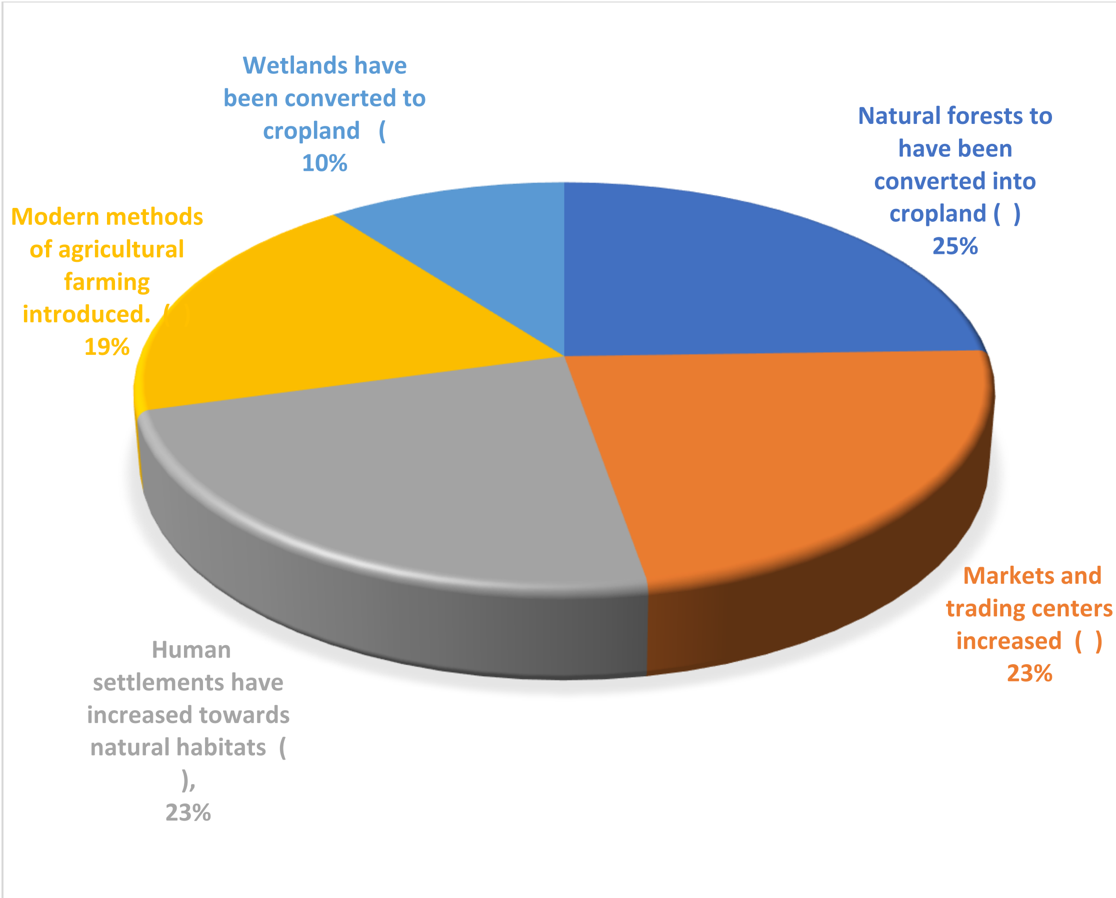


Figure 4.31: Nature of change of land use/cover

4.3.3.2 Weather patterns

The results of inquiry into change in weather patterns as shown in Figure 4.32, indicate that 78.8% of the respondents were of the view that there was variation in weather conditions for which rain, temperature and windstorm increased over the years whereas the fires reduced over the years.

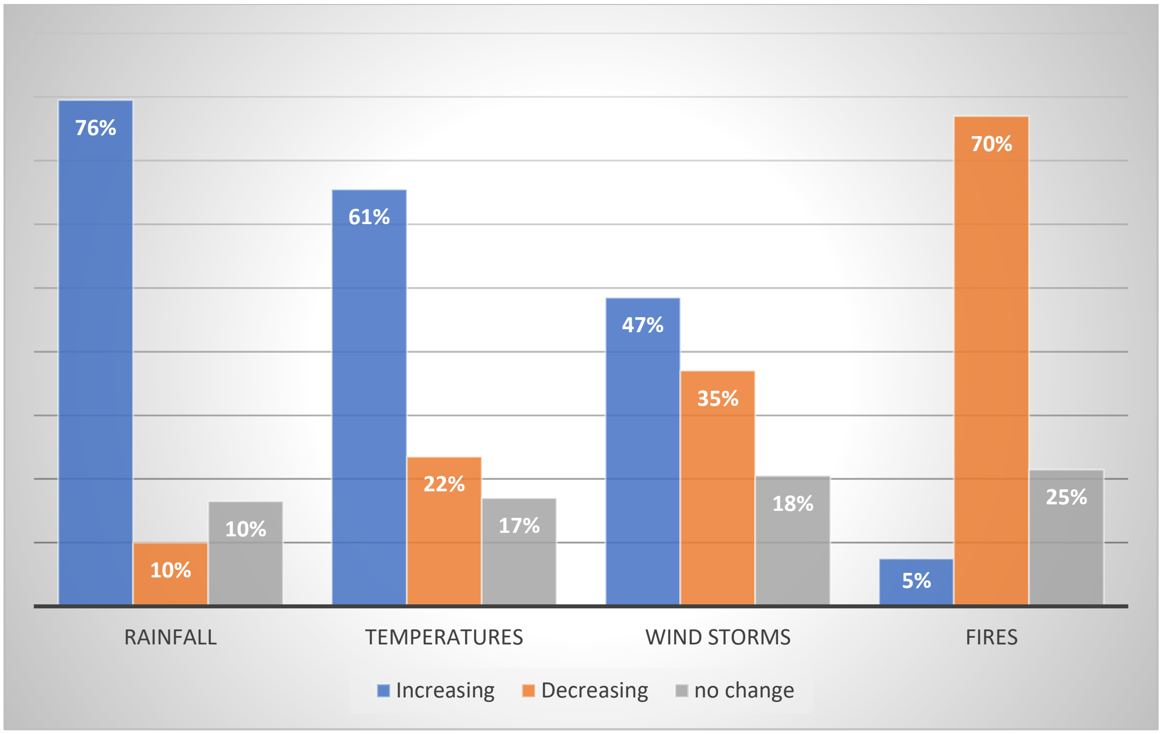


Figure 4.32: Change in weather patterns in the basin – households' perception.

4.3.3.3 Water resource issues

Results of the study as presented in figure 4.33 show that the majority (20%) of the respondents reported flooding as the main problem faced. Human –human conflict was reported by the least number of respondents at 8%. The problem associated with water resources and widely reported is flooding which destroys properties and cause loss of life in the lower end of River Kuja.

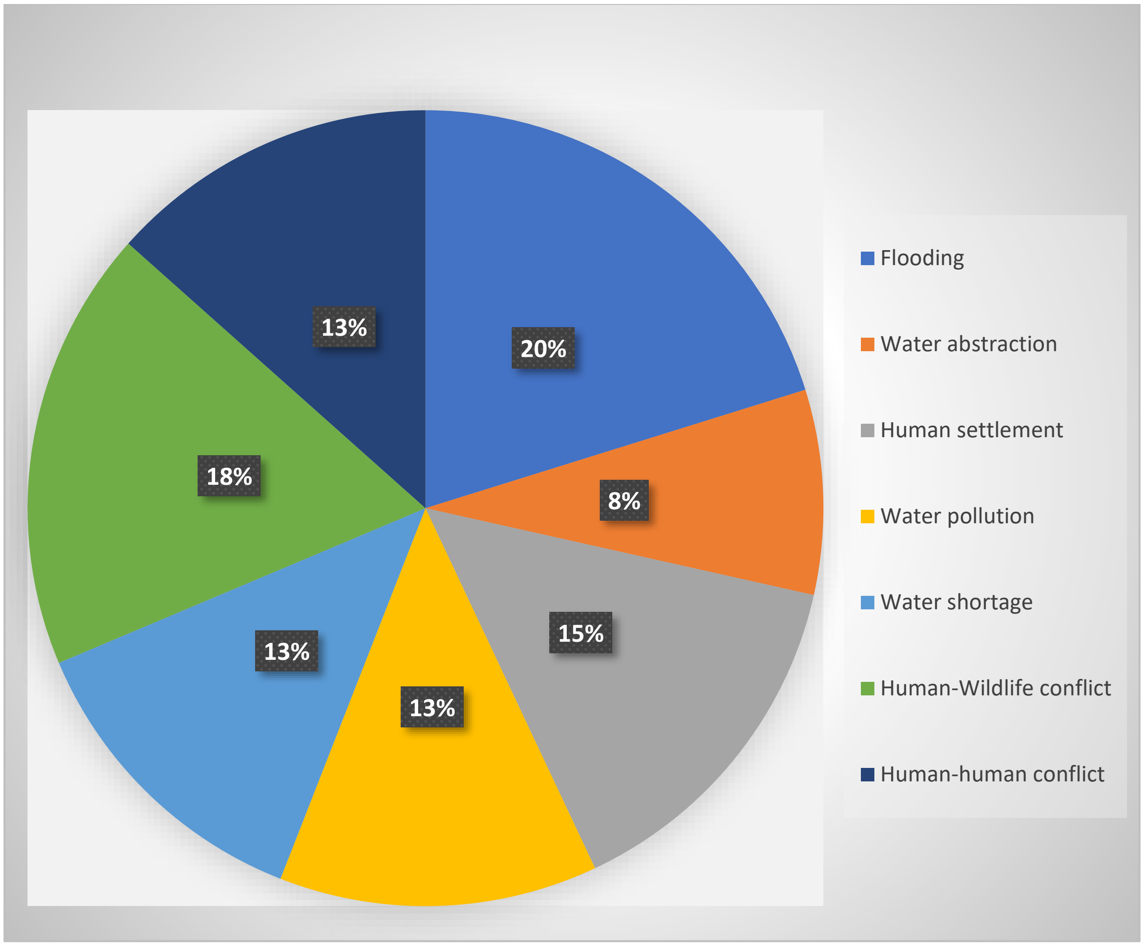


Figure 4.33: Water Resource issues in Kuja basin

The respondents identified various activities that have led to water abstraction in river Kuja Migori. Domestic use appears to be the main reason for water abstraction as reported by 39% and could be linked to the increased population in the basin. Industrial use was the least as stated by 12% of respondents as shown in figure 4.34.

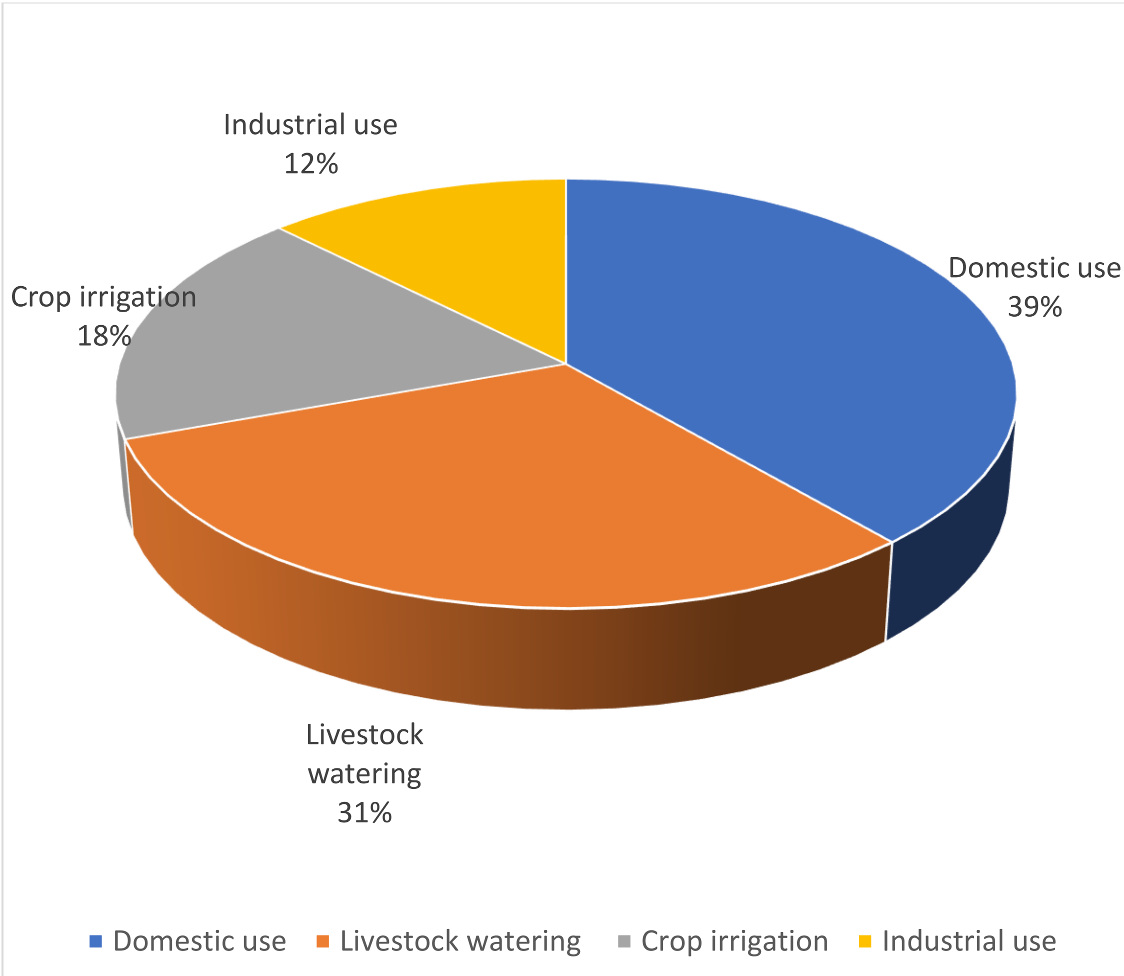


Figure 4.34: Nature of water abstraction

4.3.3.4 Change in river flow

65.6% of the respondents stated that they have noted changes in the flow of river Kuja Migori over the years as compared to 34.4% of those who did not see any change. From the responses on the trends of the river flow, it is evident in that the highest change in flow was noted within <10 years ago at 53% and the lowest being 20-30 years ago at 15%. The change in trend seen in river flow is attributed to high rate of conversion of forest cover to agricultural production which has resulted in increased surface runoff (Figure 4.35).

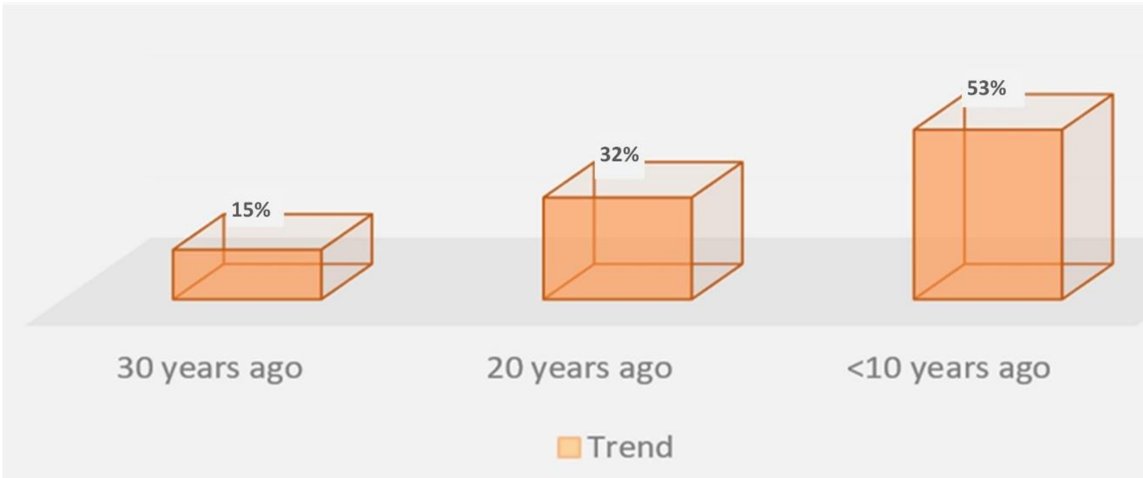


Figure 4.35: Change in River Kuja flow

4.3.3.5 Land degradation

The study found out that land degradation has been observed as reported by 95.8% of the respondents. The most affected activity was reported as rain-fed-crop by 63% of respondents, while the least affected activity was stated as shrub-land by 1% of the respondents as shown in figure 4.36.

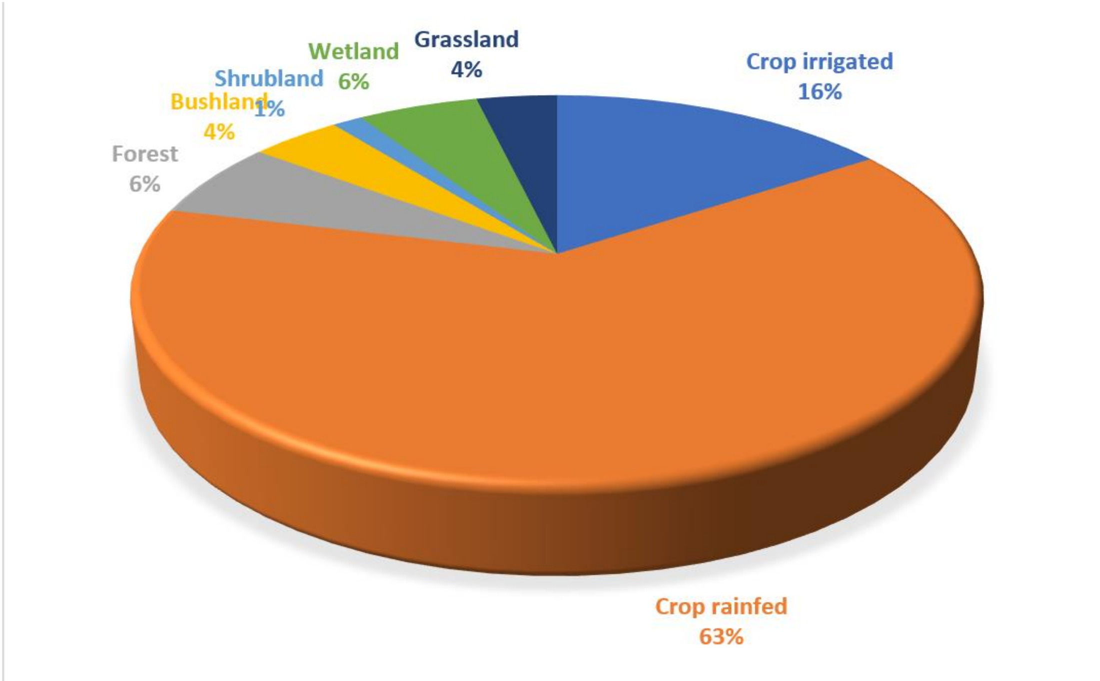


Figure 4.36: Effects of land degradation on human activities in the basin

4.3.3.6 Soil degradation

The views from respondents presented in Figure 4.37 show that soil erosion is a key challenge in the area as reported by 43% of the study respondents, followed by gully formation and soil fertility decline as reported by 27% and 24% of the respondents respectively.

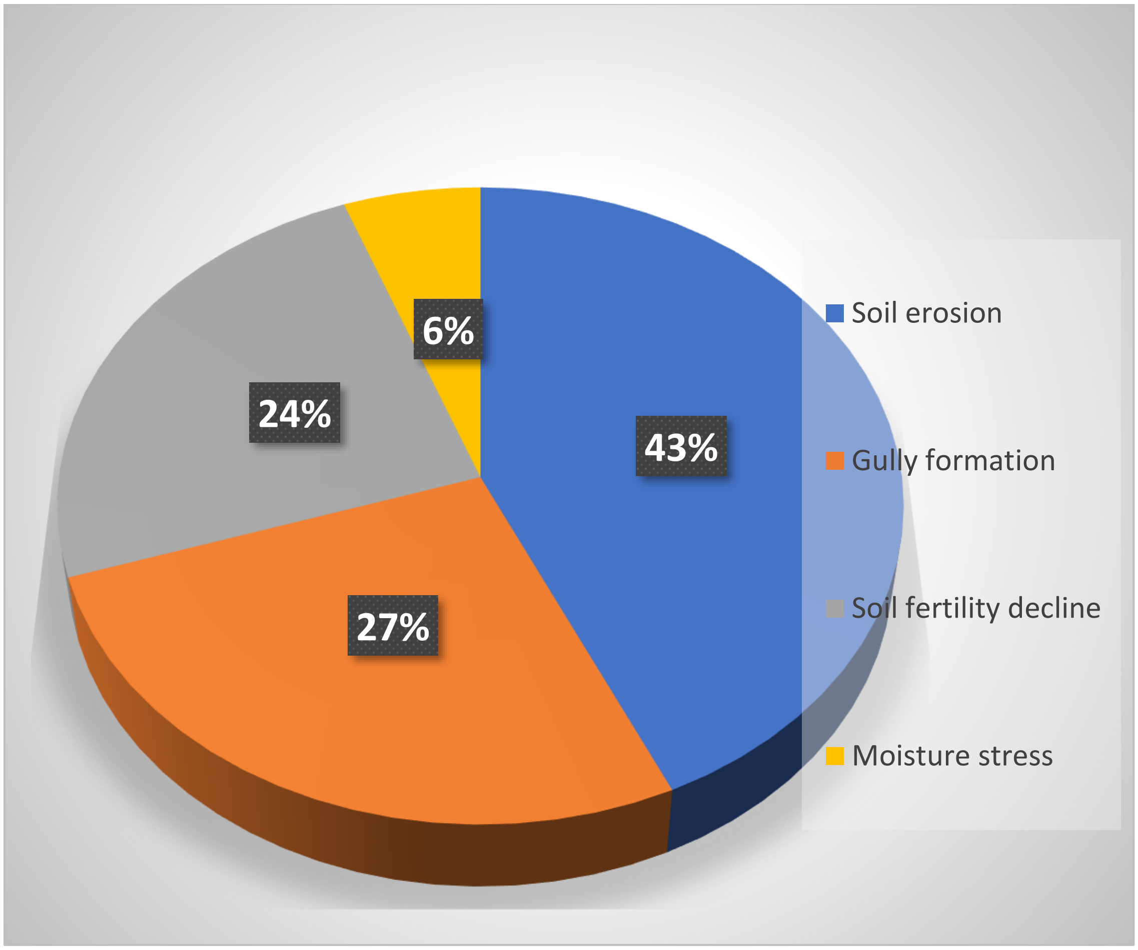


Figure 4.37: Soil degradation in the basin

4.3.4 Land and water management

In terms of land and water management practices (Figure 4.38) along river Kuja Migori, conservation farming reported by 48% and tree planting reported by 46 % of the respondents were the first and second preferred methods.

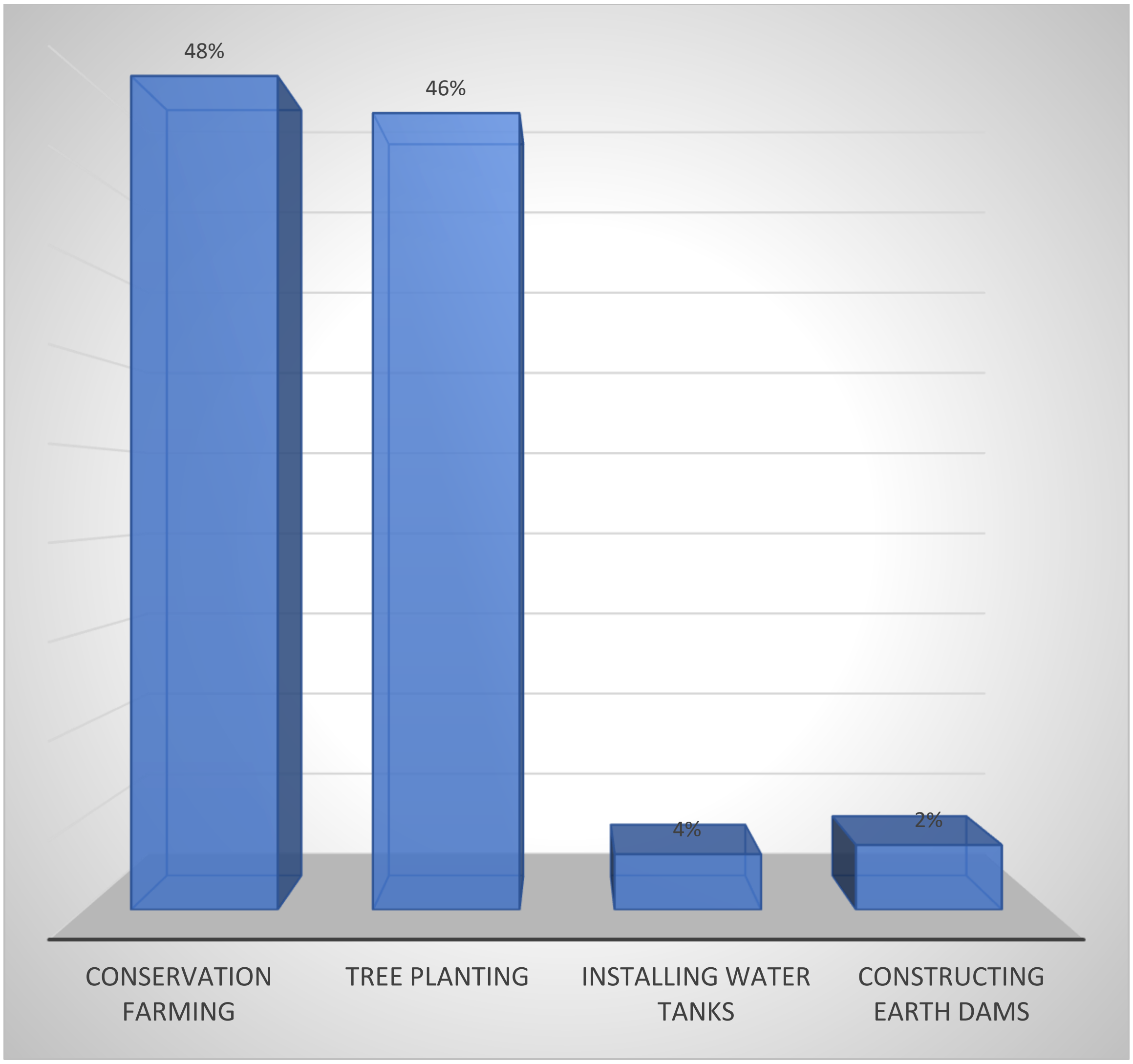


Figure 4.38: Land and water management approaches

4.3.5 Key Informants Interview Results

The key informants in Kuja Basin included those purposively selected from Water Resource Authority (WRA), Kenya Forest Service (KFS), Ministry of Agriculture (MOA), National Environmental & Management Authority (NEMA), Kenya Meteorological Department (KMD), Local Area Administrations, Community Based Organizations (CBOs), Fisheries Department, and County Water Department. The results of the Key Informants Interview showed that different organizations have been putting efforts to manage the natural resources in River Kuja basin. According to their perception, the key informants reported that poverty is a major problem in the region and many households make use of available natural resources without considering the long-term effects of their over-exploitation. As stated by the Key Informant 01, "the area under Migori County has had environmental degradation challenges and the county is limited in implementing environmental degradation management and mitigation measures."

Every key informant stated their role in relation to the basin's natural resources management and conservation. They all mentioned that the public residents had little knowledge on resources depletion in the basin. Twelve out of the thirteen informants asserted that water resources had deteriorated and suspected the fact that sugarcane production and human population increase were the major drivers. One of them observed that "our Authority has always tried to enforce the policies regarding water resources management but for its success, all the relevant stakeholders in this basin must work together for a successful basin-based management effort."

The increasing population, pressure on cooking fuel like firewood and charcoal, human settlements, gold mining and agricultural expansion were perceived as the main causes of LULC in the study area. According to the key informants, these proximate drivers were triggered by high poverty levels, population growth, unreliable rainfall lack of law enforcement by government, poor access to an alternative-energy supply, and high cost of agricultural input. They asserted that the rapid increase of the population in the study area was largely due to high fertility rates, early marriages, high birth rates, reduced mortality, polygamy, immigration, and illiteracy. Another key concern was the varying rainfall pattern in the basin. They revealed that there was a high conversion of forest cover to agricultural land, to meet the demands of the growing family size at each household level. Failure of institutions to deliver their responsibilities and law enforcement led to high deforestation and agricultural land expansion.

4.4 Analysis of Impact of LULC Changes to the Hydrology of River Kuja Basin

The spatio-temporal variations and hydrological variables that were measured showed corresponding results with the perceptions of the people living in the basin. The surface area covered by water bodies reduced by 12.2% for the period between 1990 and 2020. The agricultural area expanded by 231.2% while forests reduced 50.8%. As the thick vegetation such as forest reduced, the grassland generally increased. Shrub land areas also experienced a reduction of 63.3% in land surface coverage. The hydrological modelling results show that the peak discharge was experienced in February 2020 (6^{th}) at a discharge rate of 2,481.6m^3/s with a volume of 33,629.21mm. The survey results showed that water availability in the basin is declining. Land degradation is getting severe. River Kuja average annual discharge increased from 31.9782 m^3/s in 1990 to 48.3772 m^3/s in 2020. Table 4.16 shows the changes in independent and dependent variables over the study period. The human population in the basin increased, average annual River Kuja discharge increased, while surface water bodies reduced. Higher differences were recorded between 2010 and 2020 as shown in Table 4.16 and Figure 4.39.

Table 4.15: Independent and dependent variables

	Independent Factors							Dependent Variables	
Year	**Agriculture (Km^2)**	**Built up Areas (Km^2)**	**Bare Land (Km^2)**	**Forest (Km^2)**	**Shrub Land (Km^2)**	**Grass Land (Km^2)**	**Basin Population Dynamics (No. of People, KNBS)**	**Average Annual River Kuja Discharge (m^3/s)**	**Land Surface Hydrology - Water Bodies (Km^2)**
1990	788	161	502	1886	1033	1212	1,408,887	31.9782	41
2000	1973	173	730	1500	718	919	1,733,927	36.4867	40
2010	1863	464	700	1243	219	1242	1,849,735	38.7689	39
2020	2610	521	330	928	379	1544	2,215,764	48.3772	36

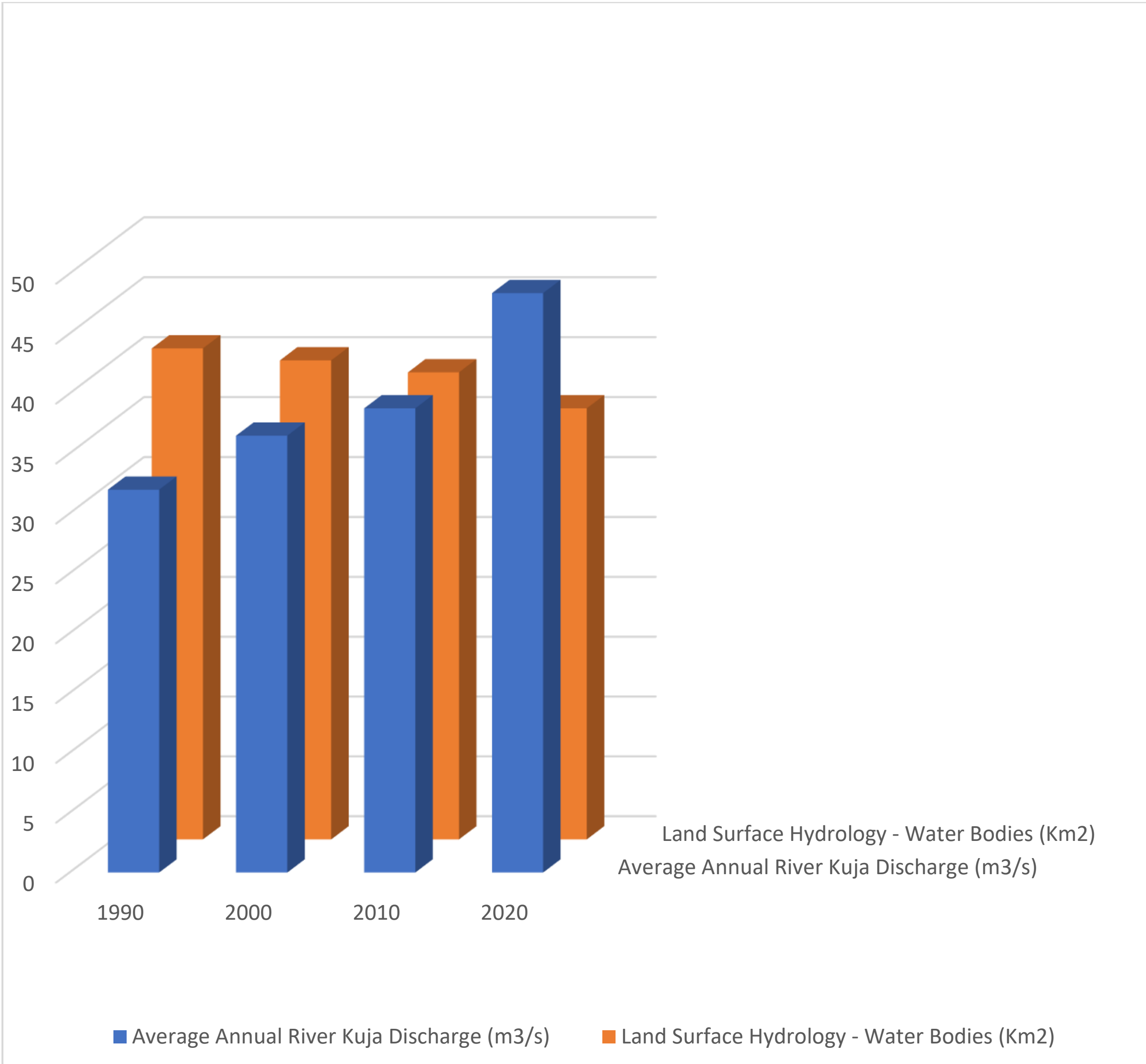


Figure 4. 39: Land Surface Hydrology vs Average Annual Discharge of River Kuja

A simple linear correlation matrix in Table 4.17 shows how the variables relate to one another. The dependent factor was surface water bodies while independent variables included agriculture, built up areas, bare land, forests, shrub land, grass lands, human population and river Kuja discharge. In the table, negative correlation was found between water bodies (WaB) and agriculture (Agr -0.96), built up areas (Urb -0.84) bare land (BaL -0.98), population (-0.91) and average annual river Kuja discharge (AADg -0.67). Positive correlation was noted between the water bodies and forests (Fr 0.93), shrub land (ShL 0.49) and grass land (GrL 0.27).

Table 4. 16: Simple linear correlation matrix for the variables

	WaB (y)	Agr (x1)	Urb (x2)	BaL (x3)	Fr (x4)	ShL (x5)	GrL (x6)	Population (x7)	AADg (x8)
WaB (y)	1.00								
Agr (x1)	-0.96	1.00							
Urb (x2)	-0.84	0.32	1.00						
BaL (x3)	-0.98	0.11	0.08	1.00					
Fr (x4)	0.93	-0.39	-0.19	-0.33	1.00				
ShL (x5)	0.49	-0.17	-0.05	0.01	-0.53	1.00			
GrL (x6)	0.27	0.41	0.31	-0.29	-0.44	-0.03	1.00		
Population (x7)	-0.91	0.89	0.99	0.72	-0.86	-0.41	0.29	1.00	
AADg (x8)	-0.01	-0.91	0.22	0.91	0.57	0.13	0.37	0.79	1.00

Key: WaB = Water Bodies, Agr = Agriculture, Urb = Built up areas, BaL = Bare Land, Fr = Forests, ShL = Shrub Land, GrL = Grass Land, AADg = Average Annual Discharge

Note: The numeric values in the table represent the extent to which each variable is correlated to the surface area covered by Water Bodies (WaB) which is the dependent variable.

The proportional odds and logistic regression model were applied and fitted to the data to investigate the relationships between the integrated results as shown in Table 4.18 and Figure 4.39.

Table 4.17: Binary Logistic Regression analysis for the integration of the study variables

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	822	947.63	0.001
Pearson	822	878.84	0.083
Hosmer-Lemeshow	8	32.20	0.000

Measures of Association

Pairs	Number	Percent	Summary Measures	Value
Concordant	139781	78.2	Somers' D	0.57
Discordant	38511	21.5	Goodman-Kruskal Gamma	0.57
Ties	523	0.3	Kendall's Tau-a	0.28
Total	178815	100.0		

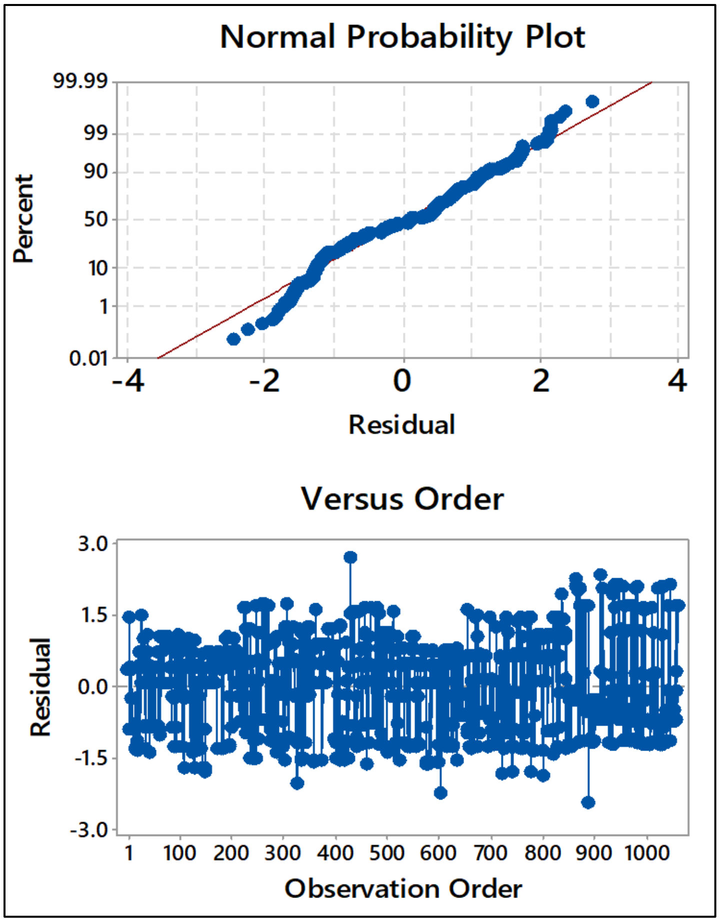


Figure 4.40: Association between the response variable and predicted probabilities of the basin

The binary regression analysis produced the most appropriate model which best predicts the surface water bodies alterations in the basin and the model is established in Equation 4.15

$$Y = a+b_1(Agr)+b_2(Urb)+b_3(BaL)+b_4(Fr)+b_5(ShL)+b_6(GrL)+b_7(Pop)+b_8(AADg)$$

………(Equation 4.15)

The average annual River Kuja discharge was removed from the model since the analysis indicated that it was not a direct predictor of the changes in the basin's surface hydrology. The resultant model is an shown in Equation 4.16.

$$Y = a+b_1(Agr)+b_2(Urb)+b_3(BaL)+b_4(Fr)+b_5(ShL)+b_6(GrL)+b_7(Pop)$$

………...(Equation 4.16)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Land Use Land Cover Change

The land use land cover changes between 1990 and 2020 was impacted by human activities. The findings have demonstrated that the entire basin experienced overall land use land cover change over the study period. The agricultural area expanded exponentially from 788sq.km to 2610sq.km. This translates to an increase of 231.2%. The high increase of agricultural practices is likely as a result of increasing sugarcane production in the basin as an economic activity. There are three sugar factories that rely on sugarcane production i.e. Sony Sugar, Sukari Industries and Kisii Sugar Factory. Sony sugar factory also called South Nyanza Sugar Factory is located in Awendo Town in Migori County Kenya. It was established in 1979 and currently produces over 60,000 metric tons on sugar with a Kenyan market share of 10.14%. Sukari Industries also called Ndhiwa Sugar Factory is located in Ndhiwa Constituency Homabay County, Kenya and started in 2015. The factory produces over 45,000 metric tons of sugar with a market share of 7.12%. There is also a sugar factory in South Mugirango constituency called Kisii Sugar Factory. It was established in 2016 and estimated to produce 500 metric tons on sugar per day. Besides sugarcane production in Kuja basin, several cash crops are also grown in the region (Ogoye, 2014). They include maize, tobacco, rice, coffee, tea, sorghum, millet and cassava. Previous studies suggest that riparian communities within the Kuja basin are poor, with a poverty level of about 66% (Odada, Ochola & Olago, 2009). They fully rely on subsistence farming which contributes to the physical and chemical land degradation. In this type of farming, farmers abandon some over cultivated and infertile lands as they search for more fertile lands (Kogo, Kumar & Koech, 2020). The abandoned land masses are left bare and exposed to soil erosion.

Forests reduced from 1886sq.km to 928sq.km between 1990 and 2020. This translates to a reduction of forests by 50.6%. The economy of River Kuja basin is based on agriculture, gold mining, charcoal production, and fishing for those living near Lake Victoria (UNEP, 2012). Human settlements due to immigration into the basin, pressure for cooking fuel which leads to cutting down of trees for firewood and charcoal, and climatic variations are suggested to have contributed to the conversion of forested lands to agriculture (Oeba, Otor, Kung'u & Muchiri, 2012). It is estimated that about 80% of deforested areas in developing counties are converted to agricultural activities (Ngaira & Omwayi, 2012).

Climate variations and changes are the possible cause of the prolonged dry seasons in the basin. The climate issues are also suggested to be the cause of widespread massive flooding due to unprecedented heavy rainfall that make flood water to quickly run downstream hence reducing surface retention. At the shores of Lake Victoria, the lake water levels have occasionally experienced rise and fall with a resultant recession (Swenson, & Wahr, 2009, Vanderkelen, Van Lipzig & Thiery, 2018). More forests, shrub and bare lands were converted to cultivated agriculture and infrastructure development. This exposed the soil surface and reduced indigenous land cover hence resulting to hydrological alterations. Recharge of water resources like rivers, springs, tributaries, natural ponds, natural dams etc. was affected. During precipitation, excess surface runoff accumulates and flow downstream from tributaries into the river and finally into the lake without reduced resistance. Many water resources are therefore exposed to increased evaporation with low ground water recharge thus the plausible cause of reduced water bodies' capacity in the basin.

Built up areas increased by 223.6% towards 2020, however, due to high pixel confusion in 1990, the classification had a low accuracy, thus the high area for built up areas in 1990. It is plausible to argue that as a result of increase in sugar production companies, market centers expanded, more roads were constructed and consequently boosting the general economy of the region resulting into natives improving their homes and opening more businesses. The construction and expansion of more roads enhanced mobility of goods and services leading to trading activities across the southern parts of Kenya hence expanding the towns and centers. In addition, more schools, hospitals and social amenities may have been constructed for the increasing population. Furthermore, with the enactment of the Constitution of Kenyan 2010, devolution brought into being county governments that have also contributed to several infrastructural developments within the basin (Muoria, Wilkister & George., 2019). The increase in built up areas can also be attributed to the idea that larger Lake Victoria basin experienced rapid population growth over the three decades hence more demand for built up area for human settlement (Githui, 2007).

The population in the basin rose from 1,469,849 in 1999 to 2,615,764 in 2019 according to Kenyan population census. The 20 years change in population from 1999 to 2019 was 1,175,915. This change resulted into natural resources depletion and degradation like the surface water, soil fertility, forests, etc. By the year 2020, the basin had a population density of 321 persons per square kilometre compared to 1990 when it was 204 persons per square kilometre. The increase of 117 people per unit area of land could have led to heightened land use dynamics like clearing of bushes for settlements and agriculture, constructing structures on the land surface, overusing water resources for domestic and livestock needs, among others.

Population growth often has a direct impact on river basin water resources and River Kuja basin is not an exception. The environmental effect of rapid population increase is devastating, for example, land that was owned by grandparents in 1990s has been unceasingly subdivided to their children and grandchildren. Subdivision of land and its fragmentation has led to water resources being drained, bushes cleared to create space for agricultural activities and human settlement. Clearing of bushes has also reduced availability of wood as source of cooking fuel (Kihima, 2017). The high rate of population growth caused built up areas sprawl in several rural areas in the basin which slowly grew into administrative and trading centers (Rakama, Obiri & Mugalavai, 2017). Natural forests and wetlands were substantially converted to cropland in order to attain food security for the increasing population. This high population then leads to unrestrained growth within sub-watersheds that afterwards exerts pressure on environmental resources, enhances degradation and competition between and within species (Barrow, 2006), factors that can augment watersheds’ vulnerability to climate change effects.

The ecosystem carrying capacity is unsafe since population growth poses pressure on the species in a river basin hence threatening biodiversity (Oehl *et al*., 2003). The higher the population the more livestock rearing hence competition on water resources. In some regions in the basin, ground water drilling and supply is the only option for water availability. With the increasing population, there is insignificant capacity building on environmental conservation measures. The results of this study are similar to those reported in other studies- increasing human population in a small area adds pressure on the utilization of natural resources like agricultural land and water leading to ecosystem degradation (Cohen, 1999; AFIDEP and PAI, 2012; Benedick, 2000; Ben-Edigbe, 2009; Liverman and Cuesta, 2008).

The study shows that the grassland areas increased by 27.4% while shrub land reduced by 63.3% and bare land reduced by 34.3%. The increase in percentage land cover by grass land and corresponding reduction in shrub and bare land could be due to agricultural dynamics and human settlement purposes. Mining and quarrying especially gold mining in Migori County could have led to consequential impact on bare land as it causes outstripping of natural vegetative cover leading to degraded bare lands. The mining methods used in these areas involve underground excavations and open cast methods which results into land degradation processes. The growth of plants in such exposed bare lands is usually affected by the acidic ground conditions, therefore making the mining areas bare for so many years as also reported by (Ogola, Mitullah & Omulo, 2002).

The satellite image analysis showed an overall percentage land use land cover change of 82%. Whenever imageries used in LULC classification register an overall accuracy of over 80%, they are considered acceptable (Turan, 2010). On the other hand, the average Kappa coefficient value for the satellite images classification was found to be 0.83 which is above the minimum requirement of 0.62 according to the rating criteria for Kappa co-efficient statistics (Landis, 1977). This shows that the classification process using satellite images had a strong agreement with the reference data from the ground therefore proving a high reliability of the research findings. The accuracies achieved were within the recommended range for satellite imagery analysis therefore acceptable and comparable to those of other similar studies like Maxa and Bolstad (2009), Congalton and Green (1999), Lu *et al.* (2004), Ozdogan and Woodcock. (2006), Maheu-Giroux and de Blois (2005), and Beekhuizen and Keith (2010). With these accuracy levels in mind, it is clear that the rapid human population growth and the land use land cover change in River Kuja basin, when combined with the demands for human use, constitute unrelenting negative driving forces of environmental change in the basin (Ogello, Obiero & Munguti, 2013).

5.2 Hydrologic Modelling of River Kuja basin

The modelling process involved calibration, simulation and validation of the model using basin's rainfall data and river Kuja discharge. The simulation results presented in the hydrographs showed that the values observed exceeded the values simulated by the model by 8.2%. The daily hydrograph in the simulation process agreed with the observed river flow data during the calibration process though the peak flows were under predicted in the model. The SCS curve number loss and unit hydrograph methods used, Muskingum routing method, and constant monthly baseflow method were useful in best fit hydrological processing of infiltration losses and surface water runoff prediction. The statistical analysis of the coefficient of determination, R^2, and the Nash-Sutcliff Efficiency, NSE, showed that the basin was well performing for the entire calibration period. This also applied to the validation process with similar under prediction in very low flows and peak flows. As also observed by Yilma & Moges, (2007) under prediction during the peak flows and low flows is a common modelling challenge.

In terms of discharge volumes, observed volume was found to be 7060.45mm while the simulated discharge was 6524.28mm. However, this difference is considered small and reasonable as it is within the permissible limits of 10% for an accepted simulation comparison value. The calibration result gave confidence and was similar to those reported in Pakistan, where Yassin *et al.* (2015) modelled hill torrents using the same model and obtained a calibration value of 0.54 which was considered acceptable. The errors realized during the calibration process could have been due to filling in the missing values in the observed data. It could have also been as a result of merging the small sub-basins into five major sub-basins and only using their averages.

The model simulated the daily stream flow at the outlet of the basin but with slight variations in peak and low flows which is a common issue with hydrological models (Zhang and Savenije, 2005). In hydrological modelling, the basin's land use practices, rainfall intensity and duration contribute to the quantity of runoff generated at the basin's outlet. The findings suggest that River Kuja basin has experienced a lot of land use change over the modelling period. As explained earlier, this could be due to large scale sugarcane production for the sugar processing industries. These land use changes lead to imperviousness of the land surface hence the increased discharge volume at the basin's outlet. On the other hand, the increased rainfall intensity in the basin could have also caused peak discharge as shown in the generated hydrographs (Figure 4.24). The rainfall patterns also changed in the basin with prolonged rainfall events. This directly translates to high runoff accumulation hence the flooding events at the basin outlet. Peak discharge was experienced on 6th February 2020 with a discharge rate of 2,481.6m^3/s with a volume of 33,629.21mm.

The results further indicate that the rainfall patterns were showing an unpredictable trend since 2010 with high peak discharges causing floods along the river channel. The river discharge trend shows an increasing trend from 1990 to 2020. The increase is relatively minimal but has overally affected the river flow volume at the basin's outlet thus plausible cause of floods during peak storms. This increasing surface water flow could be attributed to factors such as climate change and land use changes where forests and land cover are destroyed by human activities. Therefore, the simulations in this study agree with other studies which also show that change in land use alters hydrological impact in a catchment hence the change in streamflow and/or water yield (e.g Lin *et al*., 2009; Mekonnen and Hoekstra, 2016; Marhaento, Booij, & Hoekstra, 2018; and Puno, Puno, Cern, 2019).

The results showed that most of the peak discharges were obtained off the usual rainy seasons. The heavy rains upstream from the Kisii highlands are likely to be the possible cause of massive runoff downstream which eroded the soils leading to heavy sedimentation within the river channel. Recent development indicates potential dangers along the river basin. Residents of Migori and Homa-Bay counties have expressed concerns over the bursting of the river bank during heavy rains (WRMA & JICA, 2014). They seem to suggest that the recent frequent flooding events along the river has not been witnessed for decades (https://www.youtube.com/watch?v=cJpUUQ1yH2w). Sedimentation causes the shallowness of River Kuja downstream hence water overflows the natural channel forming floods in the buffer region. The study suggests that alterations in climatic and weather patterns, anthropogenic activities, population growth and infrastructural development are some of the key factors contributing to increasing floods in the basin. Several properties, lives, crops and livestock are damaged due to flash floods during rainy seasons as also asserted by Dennedy-Frank (2018), Adhikari, Shrestha, Singh, Upadhaya & Stapp (2016), Agarwal, Green, Grove, Evans & Schweik. (2000), Aid (2010) and Delphine (2016).

5.3 Perception of local communities in River Kuja basin

The ordinal logistic regression analysis method explained the relationship between the locational benefits with respect to the demographic factors within River Kuja basin. The response variables were categorical hence the benefits derived from the basin versus the demographic factors like location, gender, age, education, migration issues and available resources indicated that there were a lot of benefits derived in Nyamira area (P-value = 0.001, Odds ratio = 2.46) and Kanga area (P-value = 0.001, Odds ratio = 2.38) more than the nine sampled research areas. The area with least benefits derived was Makalda (P-value = 0.045, Odds ratio = 0.53). The P- values for Kanga and Nyamira locations, as shown, were less than the significance level of 0.05 therefore implying that that there was a statistical significance in the association between these two locations and the benefits while the rest of the locations had p-values of more than 0.05 indicating an insignificant relationship.

In the study, the education level of the population had a significant association with the land use factors of p-value of 0.01. About 59% of the respondents had basic education up to primary level while the rest had attained secondary education and other higher levels. The influence of demographic factors on the land use change was significant with p-value of 0.000, which is below the confidence level of 0.005. Farming activities, employment and business issues were the lead cause of immigration into the basin. The indigenous inhabitants practiced the traditional cultural and economic activities while 79% of the immigrants practiced farming and business activities. It is plausible to argue that the installation of sugar industries in the basin starting with the first one, Sony Sugar Company, in 1979 opened the basin into large scale sugarcane production.

In terms of change in weather patterns, 78.8% of the respondents were of the view that there was a variation in weather conditions for which rain, temperature and windstorm increased over the years whereas the fires reduced over the years. The logistic regression analysis gave a significant p-value of 0.001 of Log-Likelihood weather pattern parameters change with a Chi-Square goodness of fit test of 147.021. This indicate that the basin experienced weather patterns alterations where rainfall and temperature increased according to 76% and 64% of the respondents respectively. This could have been the reason for the cases of floods during rainy seasons, and severe drought during dry seasons.

There was a 5% size of the sampled respondents in the survey who were not well fitted in the regression analysis since there was a high delta Chi-Square (χ^2) which resulted into a high Person Residual. This number of respondents represented by the delta are assumed to be new immigrants or those who had poor knowledge of the basin's factors that were being investigated or simply unreliable responses. Being that the large number of the respondents (50.2%) were aged thirty (30) years and above, the information provided are considered accurate since the study investigated issues in the basin for the past 30 years. The immigrants were 44.8% while the natives were 55.2% of the respondents surveyed. About 70% of the immigrants settled in the basin during the period under study suggesting that there were new activities in the basin which attracted immigrants.

Water resource problems analysis results showed that majority (20%) of the respondents reported flooding as the main problem faced, 18% identified human-wildlife problems, human settlement problems at 15%, human-human conflict, water shortages and water pollution at 13% each, and water abstraction problems reported by the least number of respondents at 8%. The problem associated with water resources and widely reported is flooding which destroys properties and cause loss of life in the lower end of River Kuja. The measure of association relating the water issues in the basin against the basin parameters and demographic factors produced a negative coefficient of determinant factor of -1.376 with a p-value of 0.411. This implies that the basin factors affected water resources status negatively over the study period. Land use changes are suspected to have reduced natural ground cover hence exposing water resource to degradation and intense evapotranspiration.

Results show that soil erosion is prominent as reported by 43% of respondents thus a key possible cause of land degradation among other factors. This has likely been occasioned by the increased land clearance for agricultural activities as also reported by other studies (Wino & Ryan, 2007; Benedick, 2000; and MEMR, 2012). As already alluded to, the basin is a hub for sugarcane production. Over the last three decades, four sugar factories were established in the region. To meet the growing sugar cane demand, many subsistence farmers changed to large scale sugarcane farming necessitating clearance of land not just for farms but also for increased road networks, urbanization and settling immigrants. Coupling these factors with the steady population increase, soil erosion intensified which in turn increased siltation in River Kuja and its tributaries. During heavy storms, runoff easily flows with little vegetative resistance and upon reaching highly silted rivers, flash floods are generated in the basin.

The changes in the river were acknowledged by 65.6% of the survey respondents with its severity being experienced in the recent 10 years compared to 20-30 years ago. According to key informants, flash floods have been a disaster in the basin claiming human and livestock lives, destroying farmlands and properties, and disrupting transport networks. This has also been reported by WRMA & JICA (2014). The lower regions of the river comprise of Rongo, Ndhiwa and Nyatike constituencies. Flood plains hot spots in Nyatike constituency include Nyora, Kabuto, Kimai, Sere, Aeko, Aneko among others which suffer from riverine floods (WRMA & JICA 2014). During wet seasons, these areas experience flood inundation period of one to two months. The inundation takes a long time because the lower parts of the basin has black cotton soil with high rate of water retention.

The key informant in Kuja Basin were drawn from Water Resource Authority (WRA), Kenya Forest Service (KFS), Ministry of Agriculture (MOA), National Environmental & Management Authority (NEMA), and Kenya Meteorological Department (KMD). The results from interviews conducted focused on the environmental and hydrologic changes within the basin. It was noted that there had been population increase in the basin which in turn fostered anthropogenic activities. The basin suffers severe flash floods and river outbursts during rainstorms. The land surface has been exposed to degradation by factors such as; deforestation for cultivation, urbanization, human settlement, prolonged droughts and soil erosion. As stated by the Key Informant 01, "the area under Migori County has had environmental degradation challenges and the county is limited in implementing environmental degradation management and mitigation measures". An anonymous key informant suggested that the public needs capacity building and awareness on sustainable land management techniques. Consequently, the basin's water resources are gradually declining with several natural springs, ponds, streams and dams drying up during dry seasons.

The human population in the basin increased from 1,408,887 in 1989 to 2,215,764 in 2019 translating to 57.3% increase with a compounded growth rate of 1.52%. This population growth rate was, however, below the national growth rate of 2.9% during the same study period (KNBS, 2020). Nevertheless, double population growth is an estimated growth by the Malthusian generalized proposition of about 25 years like in this study area (Haupt & Kane, 2004). This translates to an increase of 107 persons per square kilometres over the study period. The increasing human population requires additional resources both now and, in the future, (National Academy of Sciences, 2015; NCPD, 2013). The population growth exhibits an upward rate therefore high competition on use of natural resources (KNBS, 2010). Key issues affecting the basin and arising out of anthropogenic factors include increased flooding during rainy seasons, land degradation and water resource problems both in domestic and agricultural use. To fight food insecurity, most available land was converted to agriculture. Clustering of big squared farms, large scale extraction of land resources, exploitation of surface water for irrigation activities, farming of bare lands and the constant tilling are among the activities in Kuja basin and other parts of Kenya that put the land into exploitation and degradation (Aeschbacher *et al*., 2005). The sub-fields of agriculture such as sugarcane production activities require labour intensive and this most often attract many people to unplanned settlements along the water sources. Fishing activities along Lake Victoria also attracts sundry number of people along the lake regions of Kenya, hence increasing population (Muriuki and Muchiri., 2011).

The study has shown possible alteration in rainfall patterns and distribution and change in temperature in the area, suggesting change in climate. Coupled with the alterations in major climatic elements, human activities like deforestation, expansion of agricultural land, urbanization and gold mining appears to be causing long term effects on land use and the hydrological processes such as runoff, infiltration, evapotranspiration and precipitation.

5.4 Discussion on the Impact of LULC Changes to the Hydrology of River Kuja Basin

The results presented in this study show that 82% of different land use and land cover changed as were driven by several anthropogenic activities. The changes in LULC altered the hydrology of River Kuja basin. Hydrologic modelling showed that the river discharge increased towards the year 2020 while analysis of LULC changes indicating that surface water reduced in the basin. The correlation matrix that involved both the dependent and independent variables gave a negative correlation between water bodies and agriculture (-0.96), built up areas (-0.84) bare land (-0.98), population (-0.91) and average annual river Kuja discharge (-0.67). Positive correlation was noted between the water bodies and forests (0.93), shrub land (0.49) and grass land (0.27). Agriculture increased by 231.2% over the study period and is suspected to have contributed to clearing of natural vegetation like forests and ground cover. There are three sugar factories that rely on sugarcane production within the basin i.e. Sony Sugar, Sukari Industries and Kisii Sugar Factory. The rise of the three factories motivated the people to convert land use to sugarcane production for economic purposes. Several cash crops are also grown in the region including maize, tobacco, rice, coffee, tea, sorghum, millet and cassava (WRMA & JICA 2014). This was ascertained by 75% of survey respondents who acknowledge conversion of natural forest to cropland as the major factor that contributed to hydrological alteration in the basin.

The built-up areas development had a correlation of -0.84 with water bodies. Spatio-temporal variations analysis by use of satellite images showed a built-up area sprawl of 223.6%. The use of land space for residential and commercial purposes driven by development and increasing human population exerted pressure on the natural ecosystems in the basin (Stefan, 2021). Angel (2015) estimated that the annual increase in built-up areas in developing countries was around 3.6% between 1990 and 2010. River Kuja basin experienced an average of 7.45% built up areas development, twice the estimated percentage growth in Africa. The space converted to structures has a direct effect on other land use land cover practices. In the process of urbanization, immigration into River Kuja basin has increased the demand for water in the region, resulting in reduction of waterbodies. There is a possibility that surface water retention points in a catchment are converted to other land uses like built up areas and agricultural activities as reported by Oroda, Anyango, Situma & Branthomme (2016).

Population increase gave a strong correlation of -0.91. This implied that the population increase of 117 persons per sq.km had a great impact on the depletion of surface water resources in the basin. The impacts of growing number of people along river Kuja basin has been an issue of concern since people manipulate the natural hydrology in the watershed to fulfil their irrigation, industrialization and domestic water needs. The increased number of people along the basin brings with it both negative and positive consequences on the quality and availability of water. The analysis has shown a strong negative correlation suggesting that the high population growth rate directly contributed to the alterations in the basins hydrology. Tufa, Abbulu and Srinivasarao (2014) identified LULC changes and population pressure on natural resources as some of the most common problems in developing countries since their economic development mainly depends on agriculture.

The annual average hydrologic yield of River Kuja produced a gradual increasing discharge at the outlet in Muhuru Bay station as shown in Figure 4.39. While conducting survey, 65.6% of the respondents stated that they had noted changes in the flow of river Kuja Migori over the years as compared to 34.4% of those who did not see any change. From the responses on the trends of the river flow, it is evident in that the highest change in flow was noted within <10 years ago at 53% and the lowest being 20-30 years ago at 15%. The change in trend seen in river flow is attributed to high rate of conversion of forest cover to agricultural production which has resulted in increased surface runoff. The introduction of sugarcane production in the area which attracted the increasing population to clear the natural land cover for large scale sugarcane growing. Mass land was increasingly being left open hence escalating surface runoff and reducing rainwater infiltration. The depletion of surface water sources was also observed by the communities in River Kuja basin. The results agree with findings from remotely sensed satellite images analysis that the areas occupied by water bodies decreased by 12.2%. According to Bronstertet and Saha (2002), IPCC (2007) and Gibbard, Caldeira, Bala, Phillips and Wickett (2005), changes in LULC substantially affect the climate of any landscape which adversely affects water resources such as wetlands and water. The findings of impacts of LULC changes on water resources are in line with Gessesse and Bewket (2014) and Gessesse (2018) who reported that changing LULC that took in Central Highlands of Ethiopia had impacts on water resource availability and agricultural land productivity.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Land Use Land Cover Change

In this study, the land use land cover change for River Kuja basin over the three decadal period was analysed. The results showed an overall spatio-temporal change of 85% over the basin. The agricultural area expanded exponentially from 788sq.km to 2610sq.km while forests have reduced from 1886sq.km to 928sq.km between 1990 and 2020. This translates to an agricultural percentage increase of 26.4% and reduction of forests by 13.87% respectively. Surface water retention reduced from 41sq.km to 36sq.km during the period under study. Built up areas generally increases towards 2020, however, due to high pixel confusion in 1990, the classification had a low accuracy, thus the high area for built up areas in 1990. As the thick vegetation such as forest reduced, the grassland areas increased. Shrub land areas have also experienced a great reduction in percent. Water resources reduced by 5sq.km which has a negative impact on the increasing human population and ecosystem at large. The satellite image analysis on the land use land cover changes had an overall percentage accuracy of 85%. The basin experienced land use land cover changes with natural ground cover being converted to both agricultural and infrastructural developments. In this study, the analysis of land use land cover using remote sensing and GIS approach provided useful information on the dynamics and patterns of land use. This is essential for planners and decision makers to help manage Kuja river basin for sustainable natural resources utilization.

6.2 Hydrologic Modelling of Kuja Basin

Hydrologic modelling of River Kuja basin using HEC-HMS model produced successful results. The hydrology of the basin was altered where towards the year 2020, there was an increase in discharge with unpredictable rainfall patterns. The regression analysis focusing on the relationship between rainfall and streamflow resulted in correlation coefficient value of 0.64 and coefficient of determinant value of 0.41. The relationship was moderate and acceptable. Different land use practices have significantly altered the hydrology of the basin. With the precipitation variations expressed in the modelling parameters, probability of floods is expected to be higher in future due to the increasing rainfall intensity and increasing surface runoff. Overall River Kuja annual runoff discharge increased gradually. It was concluded that changes in the basin's land cover and the climatic variations resulted into high river flow events hence the flash floods along the River Kuja buffer regions.

6.3 Perception of local communities of River Kuja Basin

River Kuja basin's population data from the Kenya Bureau of Statistics for the period between the years 1990 to 2020 showed an increasing population trend. The human population in the basin increased from 1,408,887 in 1989 to 2,215,764 in 2019 translating to 57.3% increase with a compounded growth rate of 1.52%. In a survey of 400 households, 75.0% acknowledged land use changes while 78.8% recognized variations in weather and hydrological patterns. 65.6% noted the change in River Kuja flow over the 30 years. Land degradation was a major problem at 95.0% of the respondents. According to the survey results, the basin's anthropogenic activities had an indirect but significant (p-value = 0.037) effect on the hydrology as well as having direct and significant (p-value = 0.025) influence on the land cover changes. The study reveals that the anthropogenic activities in the basin stimulated land degradation and water resources depletion in the basin. It is further concluded that the population growth, per see, seem to have a direct influence on the changes in land cover through the anthropogenic activities whose magnitude expands in space and time in response to the growing population size. As such, there is a need to design conservation and policy measures to conserve the water resources within the basin.

6.4 Research Contribution to Scientific Advancements

This study provides important insights on land use land cover changes in a river basin and its implications on the land surface hydrology and rural livelihoods. It demonstrates the importance of integrating the application of Google Earth Engine as a remote sensing tool, hydrological modelling of surface water and actual household survey. The approach is rarely used despite the advantages it gives in assessing the impacts of land use land cover changes on the hydrology of a river basin. Evidence from the study findings confirms the important role of land use planning and management in achieving sustainable natural ground cover and rural livelihoods sustainability. This is to act as shocks towards the impacts of land use land cover changes. In this regard, the natural resources agencies such as water, agriculture, land and forests to focus on the development and implementation of policies and regulations that balances the social, economic and environmental demands of River Kuja basin. The study has sufficient evidence that infers that remote sensing technologies, hydrologic studies and indigenous knowledge and perceptions can lead to water resource management and human livelihoods sustainability.

6.5 Recommendations

The study recommends the following;

1. It is important to create awareness and build capacity of the communities in the basin on sustainable land use planning and management of water resources with much emphasis on bare land restoration, bush land and forests conservation, regulation of agricultural expansion among others. This is to help reduce the natural land cover conversion to other human land uses.
2. The National Water Resource Management Authorities, Ministry of Water and Irrigation, County Water Departments and relevant Non-Governmental Organizations to help in fostering flood awareness and warnings to communities and construct flood/inundation control structures in the highly affected areas in the lower parts of Rive Kuja channel like in Ndhiwa, Kadem and Aneko.
3. Some of the key institutions in the basin such as Lake Basin Development Authority, National Environmental Management Authority, Ministry of Water, Lake Victoria South Water Works Development Agency and Lake Victoria Economic Block to generate joint interventions on projects that will improve water availability to the people in the basin through drilling boreholes, constructing water dams and water pans,

and harnessing rainwater. This will provide water to the growing population that live in areas with reducing natural surface water within River Kuja basin.

4. The Hydrologic Modelling showed an increasing trend in River Kuja discharge which could lead to extreme floods in the near future. The Department of Disaster Management and the Counties to set in place mechanisms regarding unexpected flood incidents in the basin and prepare for emergency support since the river discharge is gradually increasing due to several factors/drivers discussed in the study.
5. While reproductive health is a human right, the National Council for population Development, the County Governments of Kisii, Nyamira, Homabay and Migori and local non-governmental organizations should empower local community institutions such as village community workers, with sufficient knowledge and resources to encourage the local communities to balance such rights with development. This should be aimed at creating an environment suitable for a successful transition from current family sizes to smaller and ecologically sensitive families to reduce population growth rates in the study area.
6. Training and support on sustainable agricultural systems that increase crop produce through technological adoptions like improved drought resistant crop varieties, expanded aquaponics, organic farming, soil conservation techniques and ecosystem protection.
7. Upgrading and installation of more hydropower plants along the River Kuja channel with flood control base dams to help regulate the river flow and increase basin revenue. The modelling peak discharges shown in the study which may result to adverse floods in the basin will be controlled by the dams.
8. The Kenya Forestry Services and NEMA should sensitize communities on tree planting programs for improved afforestation. The law discouraging deforestation be strengthened with strict implementation strategies.
9. Human-Animal conflict management should be taken into consideration by Kenya Wildlife Services since some aquatic wild animals live or follow River Kuja channel from Lake Victoria which have claimed lives and destroyed crops along the banks of the river as reported by the survey results and key informants.

6.5 Areas for Further Research

Further research in the basin should be conducted to:

1. Investigate the water quality of River Kuja in regards to the increasing sugar companies as key drivers.
2. Hydrogeological assessment of the ground water status and its contribution to the declining surface water availability including mitigation measures
3. Effects of Sedimentation on river Kuja discharge and biodiversity
4. Quantitative study on water demand and supply status in the basin
5. Climate change effects on the human livelihood in the basin with future climatic projections and scenarios
6. Impacts of Sugarcane production on the human population and the indigenous crop productions systems in the basin
7. Water usage, human conflicts and policies on water management

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RESULTS ANNEXES

Annex I: Questionnaire on Population Growth, Land Use Land Cover Changes, and Hydrology of River Kuja Basin, Kenya

Questionnaire on Population Growth, Land Use Land Cover Changes, and Hydrology of River Kuja Basin, Kenya

Introduction

The aim of this questionnaire is to assess the anthropogenic factors causing land use and land cover changes in the study area and how this land use land cover changes have impacted on land and water resources in River Kuja Basin. The findings will contribute to designing suitable planning and management measures to conserve the natural resources through sustainable land use practices in the basin.

Any assistance towards gathering this data will be highly appreciated.

Instructions: Tick as appropriate

Name of Enumerator ……………………………………… Date of Survey…………………

Section I Personal details

1.0 Name/code of respondent (optional) ______________________________

1.1 Village / Sub-location / Location / Division_________________________

1.2 **Sex** Male ( ) Female ( ) **Age** <20 ( ), 20-30( ), >30( )

1.3 **Education Level:** Primary ( ), Secondary ( ), Tertiary ( ) Informal Education ()

1.4 **Residential Status**: Indigenous () Immigrant ()

1.5 If immigrant, how long have you lived in the area? ______________________

1.6 If immigrant, what was your reason for moving in the area?

Business ( ), Farming ( ), Work ( ), other ( ) specify________________

____

____

Section II Knowledge of benefits derived by Locals from River Kuja Basin

2.0 Do you derive any benefit from River Kuja Basin? **Yes ( )** **No ( )**

2.1 What benefits do you derive from the Basin? Rank in order of importance (5=highest value, 4=very high value, 3=high value, 2=low, 1=very low)

Value	**Rank**
I. Fuel wood production	
II. Fodder production	
III. Farming activities	
IV. Dry season grazing land	
V. Pole and timber harvesting	
VI. Any Other (specify)	

2.2 Are there any restrictions prohibiting locals from deriving benefits from the catchment? **Yes ( )** **No ( )**

2.3 Name those restrictions

I. Fee restrictions ( )
II. Permit restrictions ( )
III. Seasonal ban ( )
IV. Total government ban ( )
V. Cultural restrictions ( )
VI. Other ( ) ____

2.4 Are there any problems you face from deriving the benefits from the catchment mentioned above? **Yes ( )** **No ( )**

2.5 Name the Problems

I. Poaching ( )

II. Human-Wildlife conflict ( )

III. Human-human conflict ( )

IV. Over exploitation of resource ( )

V. Others specify ____

Section III Land use change, their drivers and impact

3.0 Are there any changes in unit per parcel of land owned by households? **Yes ( ) No ( )**

3.1 If yes, how is the size of land parcels changing among different households?

A. Increasing ( )

B. Decreasing ( )

C. No change ( )

D. Not aware ( )

3.2 Have you noticed any change in land use and land cover in your locality. **Yes ( ) No ( )**

3.3 What are the major land use changes that have occurred on Kuja basin since the 1990s in your locality? (Provide qualitative description; +, - & No change)?

What major shift in land use occurred?

	<10 years		10-20 years ago		20-30 years ago	
	Area	Quality	Area	Quality	Area	Quality
Cropland – rainfed						
Cropland – irrigated						
Grassland land –private						
Grassland –communal						
Forest land						
Bushland						
Shrubland						

Wetland						
Bareland						

3.3 Please mention the nature of changes.

I. Natural forests to have been converted into cropland ( )

II. Markets and trading centers increased ( )

III. Human settlements have increased towards natural habitats ( ),

IV. Modern methods of agricultural farming introduced. ( )

V. Wetlands have been converted to cropland ( )

3.4 . What are the cause of the above-mentioned changes? Please list the causes from the most critical to least important cause. **Highest score 5 and lowest 1**

Cause	**Rank**
I. Livestock grazing	
II. Agricultural activities	
III. Fuel wood collection,	
IV. Charcoal production	
V. Tree felling for timber and poles	
VI. Bush fires	
VII. Other	

Section IV Climate change related issues

4.0 Have you noticed any change in weather patterns? **Yes ( ) No ( )**
(specify period)

4.1 Please tick the period which changes were observed

Period	Yes	No
30 years ago		
20 year ago		
< 10 years ago		

4.2 How has the weather patterns changed over time?

Weather	Increasing	Decreasing
Rainfall		
Temperatures		
Wind Storms		
Fires		
Others (mention)		

4.3 Has this weather patterns posed any problems to the livelihood of inhabitants within the catchment? **Yes ( )** **No ( )**

4.4 What has been the nature of the threats

I. Flooding ( )
II. Water shortages ( )
III. Forage shortages ( )
IV. Migrating from lowlands to highlands ( )………………….
V. Other Specify ( )

4.5 How do you cope with this changes mentioned?

Section V Land and Water related issues

5.0. What are the major problems associated with water resources in your locality?

I. Flooding ( )
II. Water abstraction ( )
III. Human settlement ( )
IV. Water pollution ( )
V. Water shortage ( )
VI. Human-Wildlife conflict ( )
VII. Human-human conflict ( )
VIII. Other specify____

5.1 Are there any activities involving water abstraction from the Basin? **Yes ( )** **N0 ( )**

5.2 If Yes, Name the activities____

I. Domestic use ( )

II. Livestock watering ( )

III. Crop irrigation ( )

IV. Industrial use ( )

V. Other ( ) Specify____

5.3 Have you noticed changes in the trend of the river flows within River Kuja Basin between 1990 and 2020? **Yes ( )** **No ( )**

5.4 What has been the trend within the different periods below?

Period	Increasing	Decreasing	No Change	Not Aware
30 years ago				
20 year ago				
< 10 years ago				

5.5 Is land degradation a problem in your locality? **Yes ( )** **No ( )**

5.6 What type of land cover is vulnerable to land degradation (in order of vulnerability score of 5 (most vulnerable) - 1 (list vulnerable) score)?

I. Crop irrigated ( )

II. Crop rainfed ( )

III. Forest ( )

IV. Bushland ( )

V. Shrubland ( )

VI. Wetland ( )

VII. Grassland ( )

VIII. Others specify_______________________

Provide reason for above response_______________________________________

5.7 What type of Soil degradation is prominent in your area in order of severity 5 most severe, 1-Least severe?

I. Soil erosion ( )

II. Gully formation ( )

III. Soil fertility decline ( )

IV. Moisture stress ( )

V. Others, specify ( )

5.8 How do you evaluate trend of land degradation over?

	Now/2021	10 year	20 years	Next 30years?
Severity of land degradation **1**				
Extent of land degradation **2**				
Signs of land degradation **3**				

1 1: light; 2: moderate; 3: severe; 4: very severe

2 1: absent; 2: present on vulnerable land units; 3: widespread everywhere

3: 1: soil erosion; 2: gully formation; 3: vegetation degradation; 4: soil fertility degradation; 5: water stress; 6: others (specify)

5.9. What land and water management practices are present in your locality and which ones are your preferences 5 to 1(most to least preferred)?

I. Conservation farming ( )
II. Tree planting ( )
III. Installing water tanks ( )
IV. Constructing earth dams ( )
V. Other Specify ( )________________________________

5.10 Are there organizations working towards management of various land and water based resources in your locality? **Yes ( ), No ( )**

5.11 What initiatives are being done to protect the Basin by different organizations? (name them under categories provided)

I. By Government institutions________________________
II. By Local community ________________________
III. By community based organizations ________________________
IV. By County Government ________________________
V. By Non Governmental organizations ________________________

5.12 How do you evaluate the efforts made?

I. Excellent ( )

II. Very good ( )

III. Good ( )

IV. Poor ( )

V. Very Poor ( )

5.13 What's not achieved so far and what could have been done differently?__________
____
____

5.14 What are the most priority issues in your locality that needs intervention and please suggest ways to address it?

I. Land degradation ( )

II. Flood control ( )

III. Water scarcity ( )

IV. Forage shortage ( )

V. Resource use conflict ( )

VI. Food shortage ( )

VII. Poverty ( )

VIII. Other ( )____

Section VI Institutional issues

6.0 What are the major factors that affect your decision related to land use or Management in order of importance (+explain)?

Factors	**Causes**
Natural factors	
Demographic factors	
Institutional factors, laws	
Political factors, policies	
Economic Factors, Policies	
Socio-Cultural factors	

6.1 Describe new practices & regulations that influence land management in your locality at different points in time and their impact.

Period	**Regulation /Practices**
Last 10 years	
Between 10 and 20 years ago	
Between 20 and 30 years ago	
Other	

6.2 . What are the major changes in land use (area + quality) and management you noted in communal properties over the last 30 years and the institutional changes that go along with these

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

Section VII Miscellaneous

6.3 Do you have additional issues to forward pertaining points discussed?

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

6.4 . Would you like to make any comments, observations or recommendations that would be helpful to addressing the land use issues and water resources management?

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

Annex II: Key Informants Interview Protocol for River Kuja Basin Study

1. What is your current position in the community or in your current employment and your employer?
2. What role does your organization or agency play in the management of water resources in the Kuja River Basin area?
3. What are the challenges that face the area in terms of land use, water resource use and the entire river basin ecosystem?
4. In decision-making process about river basin, what are the influencing factors?
5. What do you think the public or residents know about the resource depletability of the river basin ecosystem resources?
6. How does the public view Kuja river basin area?
7. What environmental changes in the basin have occurred over the years?
8. What relationship exists between human activities and the declining water resources in Kuja river basin?
9. Who are the key stakeholders in decision-making about the use of water resources?
10. Which of these stakeholders exert the most influence?
11. What role can the public play in the design of sustainable water resource management measures?
12. How does the public influence regulatory decision-making in the area?
13. How effective is current water resource management policy if it exists or regulation?
14. What can be done to improve current or future water resource utilization controls?
15. Explain, in your own opinion, the link between population growth and the land use changes in Kuja river basin?
16. What are the effects of sugarcane production in the basin's water resources?
17. Any suggestions on mitigating the changes in the land use/cover and population growth?
18. Anything you would like to add that we have not covered?

Thank you for your time!

Annex III: List of Key Informants

NO.	NAME	MINISTRY/ORGANIZATION	CONTACT
1.	Patrick Oyamo	Agriculture	[redacted]
2.	Sharon Awuor	Fisheries	[redacted]
3.	Kennedy Abura	County - Environment	[redacted]
4.	James Marwa	Sony Sugar Weather Station	[redacted]
5.	Anna Akoko	Community Leader	[redacted]
6.	Collins Makori	WRMA	[redacted]
7.	Maurice Ouma	Chief - Kabuoch	[redacted]
8.	Silfanus Ajwaka	Community Oldest	[redacted]
9.	James Nyadiang'a	Ass. Chief - Kadem	[redacted]
10.	Jared Makawa	KFS	[redacted]
11.	Paul Kurgat	Extension Officer	[redacted]
12.	Mary Shituma	CBO Director	[redacted]

Annex IV: Table for Finding a Base Sample Sizeb According to Watson, (2001)

+/- 5% Margin of Errorc

	Sample Size				
	Variability				
Population	**50%**	40%	30%	20%	10% [d]
100 [e]	**81**	79	63	50	37
125	**96**	93	72	56	40
150	**110**	107	80	60	42
175	**122**	119	87	64	44
200	**134**	130	93	67	45
225	**144**	140	98	70	46
250	**154**	149	102	72	47
275	**163**	158	106	74	48
300	**172**	165	109	76	49
325	**180**	173	113	77	50
350	**187**	180	115	79	50
375	**194**	186	118	80	51
400	**201**	192	120	81	51
425	**207**	197	122	82	51
450	**212**	203	124	83	52
500	**222**	212	128	84	52
600	**240**	228	134	87	53
700	**255**	242	138	88	54
800	**267**	252	142	90	54
900	**277**	262	144	91	55
1,000	**286**	269	147	92	55
2,000	**333**	311	158	96	57
3,000	**353**	328	163	98	57
4,000	**364**	338	165	99	58
5,000	**370**	343	166	99	58
6,000	**375**	347	167	100	58
7,000	**378**	350	168	100	58
8,000	**381**	353	168	100	58
9,000	**383**	354	169	100	58
10,000	**385**	**356**	**169**	**100**	**58**
15,000	**390**	**360**	**170**	**101**	**58**
20,000	**392**	362	171	101	58
25,000	**394**	363	171	101	58
50,000	**397**	366	172	101	58
100,000	**398**	367	or172	101	58

Qualifications for a, b, c, d and e are presented in items a, b, c, d, and e below;

Qualifications

a) This table **assumes a 95% confidence level,** identifying a risk of 1 in 20 that actual error is larger than the margin of error (greater than 5%).

b) Base sample size should be **increased** to take into consideration potential nonresponse.

c) A **five per cent margin of error** indicates willingness to accept an estimate within +/- 5 of the given value.

d) When the estimated population with the smaller attribute or concept is less than 10 percent, the sample may need to be increased.

e) The assumption of normal population is poor for 5% precision levels when the population is 100 or less. The entire population should be sampled, or a lesser precision accepted.

Annex V: Regression Analysis Results for the Questionnaires Data

STATISTICAL ANALYSIS OF THE SOCIO-ECOLOGICAL FACTORS OF RIVER KUJA BASIN

Ordinal Logistic Regression: Dbenefits versus Location, Gender, ...

Link Function: Logit

Response Information

Variable	Value	Count
Dbenefits	None	164
	very low	81
	low	291
	high value	263
	very high value	203
	highest value	58
	Total	1060

Factor Information

Factor	Levels	Values
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira, Obera, Ombo, Waganjo
Gender	2	Female, Male
Age	3	0 to 20 years, 20 to 30 years, 30 years and above
Edu	4	Informal education, Primary, Secondary, Tertiary
Rstatus	2	Immigrant, Indigeneous
Ireasons	5	Business, Education, Farming, Others, Work
Resources	5	Farming, Fodder, Fwood, Grazing, Timber

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-1.01506	0.414729	-2.45	0.014			
Const(2)	-0.429830	0.413019	-1.04	0.298			
Const(3)	1.01222	0.413542	2.45	0.014			
Const(4)	2.26551	0.417581	5.43	0.000			
Const(5)	4.12157	0.435699	9.46	0.000			
Location							
Kadem	0.140915	0.235722	0.60	0.550	1.15	0.73	1.83

Kanga	0.865207	0.265828	3.25	0.001	2.38	1.41	4.00
Kisii	-0.427273	0.310086	-1.38	0.168	0.65	0.36	1.20
Makalda	-0.626431	0.312384	-2.01	0.045	0.53	0.29	0.99
Migori	-0.355343	0.242419	-1.47	0.143	0.70	0.44	1.13
Muhuru	-0.451131	0.246177	-1.83	0.067	0.64	0.39	1.03
Ndhiwa	-0.273891	0.316567	-0.87	0.387	0.76	0.41	1.41
Nyamira	0.902186	0.282085	3.20	0.001	2.46	1.42	4.28
Obera	0.385902	0.451040	0.86	0.392	1.47	0.61	3.56
Ombo	-0.483568	0.334077	-1.45	0.148	0.62	0.32	1.19
Waganjo	-0.496697	0.522867	-0.95	0.342	0.61	0.22	1.70
Gender							
Male	0.0079327	0.115015	0.07	0.945	1.01	0.80	1.26
Age							
20 to 30 years	-0.699203	0.202196	-3.46	0.001	0.50	0.33	0.74
30 years and above	-0.598618	0.207768	-2.88	0.004	0.55	0.37	0.83
Edu							
Primary	0.112410	0.221880	0.51	0.612	1.12	0.72	1.73
Secondary	0.658273	0.220898	2.98	0.003	1.93	1.25	2.98
Tertiary	0.599434	0.235730	2.54	0.011	1.82	1.15	2.89
Rstatus							
Indigeneous	-0.436735	0.165456	-2.64	0.008	0.65	0.47	0.89
Ireasons							
Education	-0.0818201	0.388516	-0.21	0.833	0.92	0.43	1.97
Farming	-1.02909	0.264064	-3.90	0.000	0.36	0.21	0.60
Others	-0.656299	0.270474	-2.43	0.015	0.52	0.31	0.88
Work	-1.40687	0.262847	-5.35	0.000	0.24	0.15	0.41
Resources							
Fodder	0.411000	0.174501	2.36	0.019	1.51	1.07	2.12
Fwood	-0.418497	0.174642	-2.40	0.017	0.66	0.47	0.93
Grazing	0.236428	0.174194	1.36	0.175	1.27	0.90	1.78
Timber	1.17854	0.178064	6.62	0.000	3.25	2.29	4.61

Tests for terms with more than 1 degree of freedom

Term	**Chi-Square**	**DF**	**P**
Location	68.6595	11	0.000
Age	12.0708	2	0.002
Edu	19.8940	3	0.000

Ireasons	41.3833	4	0.000
Resources	84.8992	4	0.000

Log-Likelihood = -1637.789
Test that all slopes are zero: G = 246.737, DF = 26, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	4475.57	4144	0.000
Deviance	2901.94	4144	1.000

Measures of Association: (Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	302232	67.8	Somers' D	0.36
Discordant	141566	31.8	Goodman-Kruskal Gamma	0.36
Ties	2062	0.5	Kendall's Tau-a	0.29
Total	445860	100.0		

Binary Logistic Regression: Brestrict versus Location, Gender, Age, Edu, Rstatus, ...

Link function: Logit

Categorical predictor coding	(1, 0)
Rows used	1060

Response Information

Variable	Value	Count
Brestrict	Yes	150 (Event)
	No	910
	Total	1060

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	26	269.049	10.3481	269.05	0.000
Location	11	26.063	2.3694	26.06	0.006
Gender	1	0.472	0.4721	0.47	0.492
Age	2	3.327	1.6633	3.33	0.190
Edu	3	5.338	1.7793	5.34	0.149
Rstatus	1	0.007	0.0068	0.01	0.934
Ireasons	4	3.116	0.7791	3.12	0.539

Resources	4	237.785	59.4463	237.79	0.000
Error	1033	595.262	0.5762		
Total	1059	864.312			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
31.13%	28.12%	649.26

Regression Equation

P(Yes) = exp(Y')/(1 + exp(Y'))

Y' = -0.458 + 0.0 Location_Gogo - 0.112 Location_Kadem + 1.120 Location_Kanga
- 0.949 Location_Kisii - 0.647 Location_Makalda - 0.452 Location_Migori
+ 0.152 Location_Muhuru - 0.209 Location_Ndhiwa - 0.573 Location_Nyamira
- 0.732 Location_Obera - 0.676 Location_Ombo - 0.192 Location_Waganjo
+ 0.0 Gender_Female - 0.147 Gender_Male + 0.0 Age_0 to 20 years
+ 0.620 Age_20 to 30 years + 0.705 Age_30 years and above
+ 0.0 Edu_Informal education - 0.414 Edu_Primary - 0.618 Edu_Secondary
- 0.014 Edu_Tertiary + 0.0 Rstatus_Immigrant - 0.026 Rstatus_Indigeneous
+ 0.0 Ireasons_Business + 0.397 Ireasons_Education - 0.509 Ireasons_Farming
- 0.183 Ireasons_Others - 0.035 Ireasons_Work + 0.0 Resources_Crestrict
- 4.262 Resources_Frestrict - 4.262 Resources_Prestrict
- 0.280 Resources_SBrestrict - 3.130 Resources_TGBrestrict

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	1033	595.26	1.000
Pearson	1033	852.40	1.000
Hosmer-Lemeshow	8	17.87	0.022

Measures of Association

Pairs	Number	Percent	Summary Measures	Value
Concordant	118758	87.0	Somers' D	0.74
Discordant	17381	12.7	Goodman-Kruskal Gamma	0.74
Ties	361	0.3	Kendall's Tau-a	0.18
Total	136500	100.0		

Association is between the response variable and predicted probabilities

Binary Logistic Regression: Pbenefits versus Location, Gender, Age, Edu, Rstatus, Ireasons, ...

Link function	Logit
Categorical predictor coding	(1, 0)
Rows used	848

Response Information

Variable	Value	Count
Pbenefits	Yes	202 (Event)
	No	646
	Total	848

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	25	167.740	6.7096	167.74	0.000
Location	11	30.608	2.7826	30.61	0.001
Gender	1	0.007	0.0072	0.01	0.932
Age	2	0.436	0.2178	0.44	0.804
Edu	3	5.850	1.9498	5.85	0.119
Rstatus	1	1.454	1.4538	1.45	0.228
Ireasons	4	5.200	1.3000	5.20	0.267
Resources	3	132.638	44.2126	132.64	0.000
Error	822	763.373	0.9287		
Total	847	931.112			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
18.01%	15.33%	815.37

Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
Gender			
Male	Female	0.9841	(0.6804, 1.4234)
Age			
20 to 30 years	0 to 20 years	1.1866	(0.6323, 2.2271)
30 years and above	0 to 20 years	1.2421	(0.6488, 2.3779)
30 years and above	20 to 30 years	1.0467	(0.6723, 1.6297)
Edu			
Primary	Informal education	0.7220	(0.3699, 1.4092)

Secondary	Informal education	0.5327	(0.2737, 1.0368)
Tertiary	Informal education	0.9123	(0.4504, 1.8478)
Secondary	Primary	0.7378	(0.4589, 1.1862)
Tertiary	Primary	1.2635	(0.7483, 2.1336)
Tertiary	Secondary	1.7127	(1.0183, 2.8804)
Rstatus			
Indigeneous	Immigrant	0.7139	(0.4121, 1.2368)
Ireasons			
Education	Business	1.6837	(0.5001, 5.6684)
Farming	Business	1.2852	(0.5565, 2.9679)
Others	Business	2.3614	(0.9991, 5.5814)
Work	Business	1.5647	(0.6899, 3.5488)
Farming	Education	0.7633	(0.2585, 2.2540)
Others	Education	1.4025	(0.4734, 4.1548)
Work	Education	0.9293	(0.3177, 2.7184)
Others	Farming	1.8374	(0.9521, 3.5456)
Work	Farming	1.2175	(0.6328, 2.3425)
Work	Others	0.6626	(0.3453, 1.2715)
Resources			
HWconflict	HHconflict	3.2937	(2.1405, 5.0684)
OEresource	HHconflict	0.6527	(0.4009, 1.0625)
Poaching	HHconflict	0.1459	(0.0710, 0.2996)
OEresource	HWconflict	0.1982	(0.1247, 0.3148)
Poaching	HWconflict	0.0443	(0.0219, 0.0897)
Poaching	OEresource	0.2235	(0.1070, 0.4672)

Odds ratio for level A relative to level B

Regression Equation

P(Yes) = exp(Y')/(1 + exp(Y'))

Y' = -1.681 + 0.0 Location_Gogo + 0.214 Location_Kadem + 1.252 Location_Kanga + 0.209 Location_Kisii - 0.550 Location_Makalda + 0.017 Location_Migori + 0.683 Location_Muhuru + 0.318 Location_Ndhiwa - 0.135 Location_Nyamira - 1.66 Location_Obera - 0.630 Location_Ombo - 0.169 Location_Waganjo + 0.0 Gender_Female - 0.016 Gender_Male + 0.0 Age_0 to 20 years + 0.171 Age_20 to 30 years + 0.217 Age_30 years and above + 0.0 Edu_Informal education - 0.326 Edu_Primary - 0.630 Edu_Secondary - 0.092 Edu_Tertiary + 0.0 Rstatus_Immigrant - 0.337 Rstatus_Indigeneous + 0.0 Ireasons_Business + 0.521 Ireasons_Education + 0.251 Ireasons_Farming + 0.859 Ireasons_Others + 0.448 Ireasons_Work + 0.0 Resources_HHconflict

+ 1.192 Resources_HWconflict - 0.427 Resources_OEresource
- 1.925 Resources_Poaching

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	822	763.37	0.929
Pearson	822	830.04	0.415
Hosmer-Lemeshow	8	12.16	0.144

Measures of Association

Pairs	Number	Percent	Summary Measures	Value
Concordant	102355	78.4	Somers' D	0.57
Discordant	27720	21.2	Goodman-Kruskal Gamma	0.57
Ties	417	0.3	Kendall's Tau-a	0.21
Total	130492	100.0		

Association is between the response variable and predicted probabilities

Nominal Logistic Regression: Lchange2 versus Area-Change, Quality-Change

Response Information

Variable	Value	Count
Lchange2	Not aware	916 (Reference Event)
	No change	729
	Increasing	594
	Decreasing	3481
	Total	5720

Factor Information

Factor	Levels	Values
Area-Change	4	Not aware, No change, Increase, Decrease
Quality-Change	4	Not aware, No change, Increase, Decrease

* NOTE * 5720 cases were used
* NOTE * 4 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Logit 1: (No change/Not aware)							
Constant	-5.30301	0.495989	-10.69	0.000			

Area-Change							
No change	1.67143E+12	239046	6992087.36	0.000	*	*	*
Increase	27.1780	17877.6	0.00	0.999	6.35709E+11	0.00	*
Decrease	1.60003	1.02686	1.56	0.119	4.95	0.66	37.06
Quality-Change							
No change	6.22243	0.539561	11.53	0.000	503.93	175.02	1450.92
Increase	6.40187	0.512848	12.48	0.000	602.97	220.68	1647.54
Decrease	6.76295	0.508795	13.29	0.000	865.19	319.17	2345.31
Logit 2: (Increasing/Not aware)							
Constant	-0.537800	0.0616274	-8.73	0.000			
Area-Change							
No change	2.31429E+12	169031	13691499.00	0.000	*	*	*
Increase	0.0455483	29016.7	0.00	1.000	1.05	0.00	*
Decrease	-20.0883	12783.8	-0.00	0.999	0.00	0.00	*
Quality-Change							
No change	-0.209312	0.322722	-0.65	0.517	0.81	0.43	1.53
Increase	0.155248	0.192690	0.81	0.420	1.17	0.80	1.70
Decrease	0.424972	0.161601	2.63	0.009	1.53	1.11	2.10
Logit 3: (Decreasing/Not aware)							
Constant	0.288894	0.0494802	5.84 0.000				
Area-Change							
No change	2.35714E+12	239046	9860636.03	0.000	*	*	*
Increase	23.2613	17877.6	0.00	0.999	1.26542E+10	0.00	*
Decrease	2.98250	0.721319	4.13	0.000	19.74	4.80	81.15
Quality-Change							

No change	1.87395	0.196000	9.56	0.000	6.51	4.44	9.56
Increase	2.15572	0.130882	16.47	0.000	8.63	6.68	11.16
Decrease	2.33159	0.117202	19.89	0.000	10.29	8.18	12.95

Tests for terms with more than 1 degree of freedom

Term	**Chi-Square**	**DF**	**P**
Logit 1: (No change/Not aware)			
Area-Change	4.88893E+13	3	0.000
Quality-Change	1.77436E+02	3	0.000
Logit 2: (Increasing/Not aware)			
Area-Change	1.87457E+14	3	0.000
Quality-Change	7.91004E+00	3	0.048
Logit 3: (Decreasing/Not aware)			
Area-Change	9.72321E+13	3	0.000
Quality-Change	6.18587E+02	3	0.000

Log-Likelihood = -6089.497

Test that all slopes are zero: G = 328.556, DF = 18, P-Value = 0.000

Goodness-of-Fit Tests

Method	**Chi-Square**	**DF**	**P**
Pearson	2.71111E+13	21	0.000
Deviance	1.65145E+03	21	0.000

Binary Logistic Regression: Nchange versus Location, Gender, Age, Edu, Rstatus, Ireasons, ...

Link function: Logit

Categorical predictor coding	(1, 0)
Rows used	1059
Rows unused	1

Response Information

Variable	**Value**	**Count**
Nchange	Yes	563 (Event)
	No	496
	Total	1059

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	26	233.60	8.9848	233.60	0.000
Location	11	52.18	4.7432	52.18	0.000
Gender	1	2.00	1.9970	2.00	0.158
Age	2	2.05	1.0266	2.05	0.358
Edu	3	16.53	5.5089	16.53	0.001
Rstatus	1	0.13	0.1336	0.13	0.715
Ireasons	4	39.02	9.7543	39.02	0.000
LUC-Nature	4	93.37	23.3437	93.37	0.000
Error	1032	1230.24	1.1921		
Total	1058	1463.84			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
15.96%	14.18%	1284.24

Coefficients

Term	Coef	SE Coef	VIF
Constant	0.077	0.502	
Location			
Kadem	0.804	0.292	2.64
Kanga	0.288	0.322	2.42
Kisii	0.598	0.381	1.72
Makalda	0.350	0.391	1.68
Migori	0.169	0.299	2.55
Muhuru	0.786	0.306	2.40
Ndhiwa	1.653	0.440	1.42
Nyamira	-0.665	0.353	1.90
Obera	1.448	0.613	1.23
Ombo	0.615	0.422	1.45
Waganjo	0.460	0.639	1.27
Gender			
Male	-0.203	0.144	1.07
Age			
20 to 30 years	0.347	0.244	2.94
30 years and above	0.242	0.249	3.26
Edu			
Primary	0.513	0.270	3.47
Secondary	0.321	0.266	3.27

Tertiary	-0.279	0.285	3.06
Rstatus			
Indigeneous	0.077	0.212	2.34
Ireasons			
Education	-0.969	0.466	1.84
Farming	0.478	0.324	2.93
Others	-0.827	0.331	5.71
Work	0.299	0.321	3.08
LUC-Nature			
MFintroduced	-0.578	0.214	1.62
MTincrease	-0.184	0.214	1.60
NFcropland	0.142	0.217	1.58
Wcropland	-1.726	0.229	1.58

Odds Ratios for Categorical Predictors

Level A	**Level B**	**Odds Ratio**	**95% CI**
LUC-Nature			
	HShabittat	0.5609	(0.3688, 0.8530)
MFintroduced			
MTincrease	HShabittat	0.8323	(0.5467, 1.2669)
NFcropland	HShabittat	1.1522	(0.7524, 1.7645)
Wcropland	HShabittat	0.1780	(0.1137, 0.2787)
MTincrease	MFintroduced	1.4838	(0.9789, 2.2490)
NFcropland	MFintroduced	2.0543	(1.3461, 3.1352)
Wcropland	MFintroduced	0.3174	(0.2044, 0.4927)
NFcropland	MTincrease	1.3845	(0.9065, 2.1145)
Wcropland	MTincrease	0.2139	(0.1372, 0.3335)
Wcropland	NFcropland	0.1545	(0.0983, 0.2428)

Odds ratio for level A relative to level B

Regression Equation

P(Yes) = exp(Y')/(1 + exp(Y'))

Y' = 0.077 + 0.0 Location_Gogo + 0.804 Location_Kadem + 0.288 Location_Kanga + 0.598 Location_Kisii + 0.350 Location_Makalda + 0.169 Location_Migori + 0.786 Location_Muhuru + 1.653 Location_Ndhiwa - 0.665 Location_Nyamira + 1.448 Location_Obera + 0.615 Location_Ombo + 0.460 Location_Waganjo + 0.0 Gender_Female - 0.203 Gender_Male + 0.0 Age_0 to 20 years + 0.347 Age_20 to 30 years + 0.242 Age_30 years and above + 0.0 Edu_Informal education + 0.513 Edu_Primary

+ 0.321 Edu_Secondary - 0.279 Edu_Tertiary + 0.0 Rstatus_Immigrant
+ 0.077 Rstatus_Indigeneous + 0.0 Ireasons_Business
- 0.969 Ireasons_Education + 0.478 Ireasons_Farming - 0.827 Ireasons_Others
+ 0.299 Ireasons_Work + 0.0 LUC-Nature_HShabittat - 0.578 LUC-Nature_MFintroduced - 0.184 LUC-Nature_MTincrease + 0.142 LUC-Nature_NFcropland - 1.726 LUC-Nature_Wcropland

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	1032	1230.24	0.000
Pearson	1032	1059.82	0.267
Hosmer-Lemeshow	8	33.09	0.000

Measures of Association

Pairs	Number	Percent	Summary Measures	Value
Concordant	212623	76.1	Somers' D	0.53
Discordant	65846	23.6	Goodman-Kruskal Gamma	0.53
Ties	779	0.3	Kendall's Tau-a	0.26
Total	279248	100.0		

Association is between the response variable and predicted probabilities

Ordinal Logistic Regression: Nchange versus Location, Gender, ...

Link Function: Logit

Factor Information

Factor	Levels	Values
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira, Obera, Ombo, Waganjo
Gender	2	Female, Male
Age	3	0 to 20 years, 20 to 30 years, 30 years and above
Edu	4	Informal education, Primary, Secondary, Tertiary
Rstatus	2	Immigrant, Indigeneous
Ireasons	5	Business, Education, Farming, Others, Work

LUC-Causes	6	Agric, Bfires, Cprod, Glives, Tpoles, Wood

* NOTE * 1271 cases were used

* NOTE * 1 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-3.60168	0.397630	-9.06	0.000			
Const(2)	-1.47623	0.386086	-3.82	0.000			
Const(3)	-0.266824	0.383855	-0.70	0.487			
Const(4)	0.858989	0.383573	2.24	0.025			
Const(5)	2.56187	0.394721	6.49	0.000			
Location							
Kadem	-0.198123	0.218431	-0.91	0.364	0.82	0.53	1.26
Kanga	-0.223421	0.243587	-0.92	0.359	0.80	0.50	1.29
Kisii	0.847994	0.292224	2.90	0.004	2.33	1.32	4.14
Makalda	-0.0106783	0.288358	-0.04	0.970	0.99	0.56	1.74
Migori	0.146627	0.224916	0.65	0.514	1.16	0.75	1.80
Muhuru	-0.0501465	0.227845	-0.22	0.826	0.95	0.61	1.49
Ndhiwa	-0.364093	0.292424	-1.25	0.213	0.69	0.39	1.23
Nyamira	-0.832393	0.259655	-3.21	0.001	0.44	0.26	0.72
Obera	0.554934	0.421426	1.32	0.188	1.74	0.76	3.98
Ombo	-0.0240352	0.308473	-0.08	0.938	0.98	0.53	1.79
Waganjo	0.208837	0.485248	0.43	0.667	1.23	0.48	3.19
Gender							
Male	0.135656	0.106162	1.28	0.201	1.15	0.93	1.41
Age							
20 to 30 years	-0.553416	0.186306	-2.97	0.003	0.57	0.40	0.83
30 years and above	-0.670216	0.191648	-3.50	0.000	0.51	0.35	0.74
Edu							
Primary	-0.185959	0.204150	-0.91	0.362	0.83	0.56	1.24
Secondary	0.0126386	0.202201	0.06	0.950	1.01	0.68	1.51
Tertiary	0.136455	0.216254	0.63	0.528	1.15	0.75	1.75

Rstatus							
Indigeneous	0.114964	0.152283	0.75	0.450	1.12	0.83	1.51
Ireasons							
Education	0.0850897	0.359296	0.24	0.813	1.09	0.54	2.20
Farming	-0.443105	0.239836	-1.85	0.065	0.64	0.40	1.03
Others	-0.559055	0.245927	-2.27	0.023	0.57	0.35	0.93
Work	- 0.0518174	0.237126	-0.22	0.827	0.95	0.60	1.51
LUC-Causes							
Bfires	4.50486	0.215477	20.91	0.000	90.46	59.30	137.99
Cprod	1.80970	0.181640	9.96	0.000	6.11	4.28	8.72
Glives	0.659650	0.175009	3.77	0.000	1.93	1.37	2.73
Tpoles	2.30454	0.185692	12.41	0.000	10.02	6.96	14.42
Wood	1.92843	0.182387	10.57	0.000	6.88	4.81	9.83

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
Location	40.620	11	0.000
Age	12.415	2	0.002
Edu	4.734	3	0.192
Ireasons	12.092	4	0.017
LUC-Causes	491.956	5	0.000

Log-Likelihood = -1872.010
Test that all slopes are zero: G = 611.519, DF = 27, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	9262.92	4978	0.000
Deviance	3353.55	4978	1.000

Measures of Association:(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	Value
Concordant	493932	75.5	Somers' D	0.51
Discordant	157716	24.1	Goodman-Kruskal Gamma	0.52
Ties	2431	0.4	Kendall's Tau-a	0.42

Total	654079	100.0

Nominal Logistic Regression: Wpartterns versus Location, Gender, ...

Response Information

Variable	Value	Count
Wpartterns	Not aware	142 (Reference Event)
	Decreasing	295
	Increasing	411
	Total	848

Factor Information

Factor	Levels	Values
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira, Obera, Ombo, Waganjo
Gender	2	Female, Male
Parameters	4	Cfires, Crain, Cstorm, Ctemp

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Logit 1: (Decreasing/Not aware)							
Constant	0.885218	0.378670	2.34	0.019			
Gender							
Male	-0.107736	0.229147	-0.47	0.638	0.90	0.57	1.41
Parameters							
Crain	-1.73169	0.355693	-4.87	0.000	0.18	0.09	0.36
Cstorm	-0.370393	0.301234	-1.23	0.219	0.69	0.38	1.25
Ctemp	-0.903059	0.310671	-2.91	0.004	0.41	0.22	0.75
Logit 2: (Increasing/Not aware)							

Constant	-2.06398	0.469293	-4.40	0.000			
Gender							
Male	0.0711895	0.221023	0.32	0.74	1.07	0.70	1.66
Parameters							
Crain	2.91539	0.394707	7.39	0.000	18.46	8.51	40.00
Cstorm	2.49072	0.396579	6.28	0.000	12.07	5.55	26.26
Ctemp	2.65984	0.393511	6.76	0.000	14.29	6.61	30.91

Tests for terms with more than 1 degree of freedom

Term	**Chi-Square**	**DF**	**P**
Logit 1: (Decreasing/Not aware)			
Location	27.2851	11	0.004
Parameters	26.3830	3	0.000
Logit 2: (Increasing/Not aware)			
Location	19.0911	11	0.059
Parameters	59.0314	3	0.000

Log-Likelihood = -628.083
Test that all slopes are zero: G = 469.706, DF = 30, P-Value = 0.000

Goodness-of-Fit Tests

Method	**Chi-Square**	**DF**	**P**
Pearson	147.021	160	0.761
Deviance	167.847	160	0.320

Binary Logistic Regression: Nthreats versus Location, Gender, Age, Edu, Rstatus, ...

Link function	Logit
Categorical predictor coding	(1, 0)
Rows used	848

Response Information

Variable	Value	Count
Nthreats	No	429 (Event)
	Yes	419
	Total	848

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	25	134.77	5.391	134.77	0.000
Location	11	24.52	2.229	24.52	0.011
Gender	1	1.11	1.111	1.11	0.292
Age	2	5.23	2.615	5.23	0.073
Edu	3	10.72	3.573	10.72	0.013
Rstatus	1	7.22	7.220	7.22	0.007
Ireasons	4	13.74	3.436	13.74	0.008
Problem	3	65.27	21.758	65.27	0.000
Error	822	1040.69	1.266		
Total	847	1175.46			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
11.47%	9.34%	1092.69

Regression Equation

P(No) = exp(Y')/(1 + exp(Y'))

Y' = -0.045 + 0.0 Location_Gogo - 0.581 Location_Kadem - 0.261 Location_Kanga
- 1.219 Location_Kisii - 0.625 Location_Makalda - 0.006 Location_Migori
- 0.706 Location_Muhuru - 0.178 Location_Ndhiwa - 0.611 Location_Nyamir
- 1.345 Location_Obera - 1.308 Location_Ombo + 0.156 Location_Waganj
+ 0.0 Gender_Female - 0.164 Gender_Male + 0.0 Age_0 to 20 years
+ 0.239 Age_20 to 30 years - 0.184 Age_30 years and above
+ 0.0 Edu_Informal education + 0.030 Edu_Primar - 0.272 Edu_Secondary
+ 0.449 Edu_Tertiary + 0.0 Rstatus_Immigrant - 0.606 Rstatus_Indigeneous
+ 0.0 Ireasons_Business + 0.125 Ireasons_Education - 0.599 Ireasons_Farming
+ 0.207 Ireasons_Others - 0.530 Ireasons_Work + 0.0 Problem_Flooding
+ 1.563 Problem_Fshortage + 1.283 Problem_Mlowhigh
+ 1.262 Problem_Wshortage

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	822	1040.69	0.000

Pearson	822	845.88	0.274
Hosmer-Lemeshow	8	2.30	0.971

Observed and Expected Frequencies for Hosmer-Lemeshow Test

Group	Event Probability Range	Nthreats = No		Nthreats = Yes	
		Observed	Expected	Observed	Expected
1	(0.000, 0.216)	11	13.3	73	70.7
2	(0.216, 0.318)	22	22.8	63	62.2
3	(0.318, 0.400)	33	31.3	53	54.7
4	(0.400, 0.465)	40	36.4	44	47.6
5	(0.465, 0.520)	44	42.0	41	43.0
6	(0.520, 0.580)	47	46.5	37	37.5
7	(0.580, 0.640)	49	52.1	36	32.9
8	(0.640, 0.686)	55	56.7	30	28.3
9	(0.686, 0.743)	62	60.8	23	24.2
10	(0.743, 0.859)	66	67.2	19	17.8

Measures of Association

Pairs	Number	Percent	Summary Measures	Value
Concordant	128847	71.7	Somers' D	0.44
Discordant	50289	28.0	Goodman-Kruskal Gamma	0.44
Ties	615	0.3	Kendall's Tau-a	0.22
Total	179751	100.0		

Association is between the response variable and predicted probabilities

Binary Logistic Regression: Awater versus Activity, Location, Gender, Age, Edu, Rstatus, ...

Link function	Logit
Categorical predictor coding	1, 0)
Rows used	848

Response Information

Variable	Value	Count
Awater	Yes	393 (Event)
	No	455
	Total	848

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	25	223.42	8.9366	223.42	0.000
Activity	3	143.77	47.9248	143.77	0.000
Location	11	55.27	5.0247	55.27	0.000
Gender	1	1.40	1.3998	1.40	0.237
Age	2	1.78	0.8894	1.78	0.411
Edu	3	3.01	1.0033	3.01	0.390
Rstatus	1	8.97	8.9671	8.97	0.003
Ireasons	4	18.05	4.5133	18.05	0.001
Error	822	947.63	1.1528		
Total	847	1171.04			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
19.08%	16.94%	999.63

Coefficients

Term	Coef	SE Coef	VIF
Constant	-1.376	0.581	
Activity			
Duse	1.835	0.228	1.50
Iuse	-0.569	0.230	1.43
Lwatering	1.099	0.215	1.51
Location			
Kadem	0.969	0.338	2.73
Kanga	0.615	0.374	2.46
Kisii	-0.976	0.494	1.49
Makalda	0.821	0.440	1.77
Migori	0.536	0.346	2.63
Muhuru	0.747	0.350	2.54
Ndhiwa	1.175	0.457	1.61
Nyamira	-0.883	0.428	1.74
Obera	0.288	0.645	1.24
Ombo	1.000	0.479	1.49
Waganjo	-0.093	0.770	1.24
Gender			
Male	-0.195	0.165	1.07
Age			
20 to 30 years	0.233	0.287	3.11

30 years and above	0.383	0.295	3.48
Edu			
Primary	0.081	0.315	3.67
Secondary	0.137	0.311	3.38
Tertiary	-0.253	0.333	3.08
Rstatus			
Indigeneous	0.720	0.244	2.36
Ireasons			
Education	-0.805	0.559	1.68
Farming	-0.150	0.363	3.16
Others	-0.874	0.377	5.69
Work	0.259	0.362	3.12

Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
Activity			
Duse	Cirrigation	6.2658	(4.0064, 9.7993)
Iuse	Cirrigation	0.5661	(0.3610, 0.8878)
Lwatering	Cirrigation	3.0007	(1.9685, 4.5741)
Iuse	Duse	0.0904	(0.0562, 0.1451)
Lwatering	Duse	0.4789	(0.3105, 0.7386)
Lwatering	Iuse	5.3006	(3.3858, 8.2983)
Gender			
Male	Female	0.8232	(0.5962, 1.1366)
Age			
20 to 30 years	0 to 20 years	1.2619	(0.7189, 2.2152)
30 years and above	10 to 20 years	1.4671	(0.8229, 2.6153)
30 years and above	20 to 30 years	1.1625	(0.7860, 1.7195)
Edu			
Primary	Informal education	1.0846	(0.5853, 2.0099)
Secondary	Informal education	1.1468	(0.6236, 2.1089)
Tertiary	Informal education	0.7765	(0.4041, 1.4921)
Secondary	Primary	1.0573	(0.6978, 1.6019)
Tertiary	Primary	0.7159	(0.4482, 1.1435)
Tertiary	Secondary	0.6771	(0.4263, 1.0756)
Rstatus			
Indigeneous	Immigrant	2.0545	(1.2724, 3.3173)

Odds ratio for level A relative to level B

Regression Equation

P(Yes) = exp(Y')/(1 + exp(Y'))

Y' = -1.376 + 0.0 Activity_Cirrigation + 1.835 Activity_Duse - 0.569 Activity_Iuse + 1.099 Activity_Lwatering + 0.0 Location_Gogo + 0.969 Location_Kadem + 0.615 Location_Kanga - 0.976 Location_Kisii + 0.821 Location_Makalda + 0.536 Location_Migori + 0.747 Location_Muhuru + 1.175 Location_Ndhiwa - 0.883 Location_Nyamira + 0.288 Location_Obera + 1.000 Location_Ombo - 0.093 Location_Waganjo + 0.0 Gender_Female - 0.195 Gender_Male + 0.0 Age_0 to 20 years + 0.233 Age_20 to 30 years + 0.383 Age_30 years and above + 0.0 Edu_Informal education + 0.081 Edu_Primary + 0.137 Edu_Secondary - 0.253 Edu_Tertiary + 0.0 Rstatus_Immigrant + 0.720 Rstatus_Indigeneous + 0.0 Ireasons_Business - 0.805 Ireasons_Education - 0.150 Ireasons_Farming - 0.874 Ireasons_Others + 0.259 Ireasons_Work

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	822	947.63	0.001
Pearson	822	878.84	0.083
Hosmer-Lemeshow	8	32.20	0.000

Observed and Expected Frequencies for Hosmer-Lemeshow Test

Group	Event Probability Range	Awater = Yes		Awater = No	
		Observed	Expected	Observed	Expected
1	(0.000, 0.141)	15	7.7	69	76.3
2	(0.141, 0.229)	20	15.9	65	69.1
3	(0.229, 0.286)	23	21.8	62	63.2
4	(0.286, 0.358)	26	27.3	59	57.7
5	(0.358, 0.439)	21	33.7	64	51.3
6	(0.439, 0.544)	33	41.1	52	43.9
7	(0.544, 0.639)	50	50.7	35	34.3
8	(0.639, 0.722)	52	57.0	32	27.0
9	(0.722, 0.803)	71	65.2	14	19.8
10	(0.803, 0.942)	82	72.6	3	12.4

Measures of Association

Pairs	Number	Percent	Summary Measures	Value

Concordant	139781	78.2	Somers' D	0.57
Discordant	38511	21.5	Goodman-Kruskal Gamma	0.57
Ties	523	0.3	Kendall's Tau-a	0.28
Total	178815	100.0		

Association is between the response variable and predicted probabilities

Ordinal Logistic Regression: Dland versus Cover, Location, ...

Link Function: Logit

Response Information

Variable	Value	Count
Dland	highest value	218
	very high value	156
	high value	288
	low	498
	very low	324
	Total	1484

Factor Information

Factor	Levels	Values
Cover	7	Forest, Icrop, Lbush, Lgrass, Lshrub, Lwet, Rcrop
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira, Obera, Ombo, Waganjo
Gender	2	Female, Male
Age	3	0 to 20 years, 20 to 30 years, 30 years and above
Edu	4	Informal education, Primary, Secondary, Tertiary
Rstatus	2	Immigrant, Indigeneous
Ireasons	5	Business, Education, Farming, Others, Work

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-2.71655	0.369254	-7.36	0.000			
Const(2)	-1.73608	0.362960	-4.78	0.000			
Const(3)	-0.608884	0.360165	-1.69	0.091			

Const(4)	1.05918	0.361281	2.93	0.003			
Cover							
Icrop	-0.463343	0.175020	-2.65	0.008	0.63	0.45	0.89
Lbush	-0.248630	0.174371	-1.43	0.154	0.78	0.55	1.10
Lgrass	-0.934886	0.177220	-5.28	0.000	0.39	0.28	0.56
Lshrub	-0.584323	0.175481	-3.33	0.001	0.56	0.40	0.79
Lwet	-1.01763	0.177725	-5.73	0.000	0.36	0.26	0.51
Rcrop	2.58728	0.195053	13.26	0.000	13.29	9.07	19.48
Gender							
Male	-0.0127387	0.0992273	-0.13	0.898	0.99	0.81	1.20
Age							
20 to 30 years	0.244217	0.172766	1.41	0.157	1.28	0.91	1.79
30 years and above	0.247844	0.177769	1.39	0.163	1.28	0.90	1.82
Edu							
Primary	0.194649	0.191594	1.02	0.310	1.21	0.83	1.77
Secondary	0.0004136	0.189831	0.00	0.998	1.00	0.69	1.45
Tertiary	0.130373	0.202679	0.64	0.520	1.14	0.77	1.69
Rstatus							
Indigeneous	0.175337	0.142471	1.23	0.218	1.19	0.90	1.58
Ireasons							
Education	0.487017	0.333001	1.46	0.144	1.63	0.85	3.13
Farming	0.162839	0.224482	0.73	0.468	1.18	0.76	1.83
Others	0.236272	0.229792	1.03	0.304	1.27	0.81	1.99
Work	0.437646	0.221971	1.97	0.049	1.55	1.00	2.39

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
Cover	399.627	6	0.000
Location	10.472	11	0.488
Age	2.232	2	0.328
Edu	2.753	3	0.431
Ireasons	5.434	4	0.246

Log-Likelihood = -2058.256
Test that all slopes are zero: G = 440.558, DF = 28, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	6083.93	4644	0.000
Deviance	3660.04	4644	1.000

Measures of Association:(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	Value
Concordant	579977	68.5	Somers' D	0.38
Discordant	261789	30.9	Goodman-Kruskal Gamma	0.38
Ties	5470	0.6	Kendall's Tau-a	0.29
Total	847236	100.0		

Ordinal Logistic Regression: Dland2 versus Dland-Type, Location, ...

Link Function: Logit

Response Information

Variable	Value	Count
Dland2	Most severe	350
	High severe	126
	Severe	127
	Moderate severe	154
	Least severe	91
	Total	848

Factor Information

Factor	Levels	Values
Dland-Type	4	Terosion, Tfertility, Tgully, Tmoisture
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira, Obera, Ombo, Waganjo
Gender	2	Female, Male
Age	3	0 to 20 years, 20 to 30 years, 30 years and above

Edu	4	Informal education, Primary, Secondary, Tertiary
Rstatus	2	Immigrant, Indigeneous
Ireasons	5	Business, Education, Farming, Others, Work

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI	
						Lower	Upper
Const(1)	0.560467	0.488325	1.15	0.251			
Const(2)	1.37888	0.490525	2.81	0.005			
Const(3)	2.28354	0.494358	4.62	0.000			
Const(4)	3.81326	0.505617	7.54	0.000			
Dland-Type							
Tfertility	-1.45721	0.198420	-7.34	0.000	0.23	0.16	0.34
Tgully	-1.05242	0.199132	-5.29	0.000	0.35	0.24	0.52
Tmoisture	-3.14942	0.212842	-14.80	0.000	0.04	0.03	0.07
Location							
Kadem	0.223345	0.275617	0.81	0.418	1.25	0.73	2.15
Kanga	0.904622	0.316850	2.86	0.004	2.47	1.33	4.60
Kisii	0.452411	0.364608	1.24	0.215	1.57	0.77	3.21
Makalda	-0.252749	0.363672	-0.69	0.487	0.78	0.38	1.58
Migori	0.221678	0.283199	0.78	0.434	1.25	0.72	2.17
Muhuru	0.422099	0.291884	1.45	0.148	1.53	0.86	2.70
Ndhiwa	-0.140926	0.369109	-0.38	0.703	0.87	0.42	1.79
Nyamira	0.252188	0.327738	0.77	0.442	1.29	0.68	2.45
Obera	0.564069	0.548256	1.03	0.304	1.76	0.60	5.15
Ombo	0.379559	0.401297	0.95	0.344	1.46	0.67	3.21
Waganjo	-0.168641	0.612821	-0.28	0.783	0.84	0.25	2.81
Gender							
Male	0.205638	0.136420	1.51	0.132	1.23	0.94	1.60
Age							
20 to 30 years	-0.0973787	0.234918	-0.41	0.678	0.91	0.57	1.44
30 years and above	0.384482	0.243147	1.58	0.114	1.47	0.91	2.37
Edu							
Primary	0.466179	0.263597	1.77	0.077	1.59	0.95	2.67
Secondary	0.412181	0.260984	1.58	0.114	1.51	0.91	2.52
Tertiary	-0.186765	0.275817	-0.68	0.498	0.83	0.48	1.42

Rstatus							
Indigeneous	0.204227	0.197524	1.03	0.301	1.23	0.83	1.81
Ireasons							
Education	-0.734846	0.458274	-1.60	0.109	0.48	0.20	1.18
Farming	-0.375748	0.321504	-1.17	0.243	0.69	0.37	1.29
Others	-0.861591	0.327710	-2.63	0.009	0.42	0.22	0.80
Work	-0.270937	0.317470	-0.85	0.393	0.76	0.41	1.42

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
Dland-Type	234.544	3	0.000
Location	17.602	11	0.091
Age	8.775	2	0.012
Edu	14.585	3	0.002
Ireasons	10.300	4	0.036

Log-Likelihood = -1093.033

Test that all slopes are zero: G = 327.781, DF = 25, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	2942.80	2643	0.000
Deviance	1922.40	2643	1.000

Measures of Association: (Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	Value
Concordant	200234	75.2	Somers' D	0.51
Discordant	65176	24.5	Goodman-Kruskal Gamma	0.51
Ties	891	0.3	Kendall's Tau-a	0.38
Total	266301	100.0		

Ordinal Logistic Regression: Severity versus Dserve-Time, Location, ...

Link Function: Logit

Response Information

Variable	Value	Count
Severity	Very severe	220
	Severe	172
	Moderate severe	174
	Light	282
	Total	848

Factor Information

Factor	Levels	Values
Dserve-Time	4	Dsevere10, Dsevere20, Dsevere30, DsevereN
Location	12	Gogo, Kadem, Kanga, Kisii, Makalda, Migori, Muhuru, Ndhiwa, Nyamira,Obera, Ombo, Waganjo
Gender	2	Female, Male
Age	3	0 to 20 years, 20 to 30 years, 30 years and above
Edu	4	Informal education, Primary, Secondary, Tertiary
Rstatus	2	Immigrant, Indigeneous
Ireasons	5	Business, Education, Farming, Others, Work

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-2.82522	0.489445	-5.77	0.000			
Const(2)	-1.74813	0.483449	-3.62	0.000			
Const(3)	-0.639941	0.480617	-1.33	0.183			
Dserve-Time							
Dsevere20	-0.878270	0.181205	-4.85	0.000	0.42	0.29	0.59
Dsevere30	-1.60997	0.190939	-8.43	0.000	0.20	0.14	0.29
DsevereN	0.576317	0.180783	3.19	0.001	1.78	1.25	2.54
Locatio							
Kadem	1.30920	0.287349	4.56	0.000	3.70	2.11	6.50
Kanga	0.716648	0.315572	2.27	0.023	2.05	1.10	3.80
Kisii	1.26099	0.369582	3.41	0.001	3.53	1.71	7.28
Makalda	0.353490	0.384764	0.92	0.358	1.42	0.67	3.03
Migori	0.846256	0.293180	2.89	0.004	2.33	1.31	4.14
Muhuru	0.460811	0.295225	1.56	0.119	1.59	0.89	2.83
Ndhiwa	1.43029	0.380052	3.76	0.000	4.18	1.98	8.80
Nyamira	1.12311	0.334182	3.36	0.001	3.07	1.60	5.92
Obera	1.22200	0.542745	2.25	0.024	3.39	1.17	9.83

Ombo	0.0840421	0.397021	0.21	0.832	1.09	0.50	2.37
Waganjo	-0.306007	0.627066	-0.49	0.626	0.74	0.22	2.52
Gender							
Male	0.204066	0.135565	1.51	0.132	1.23	0.94	1.60
Age							
20 to 30 years	0.0043602	0.233359	0.02	0.985	1.00	0.64	1.59
30 years and above	0.569439	0.240613	2.37	0.018	1.77	1.10	2.83
Edu							
Primary	0.875302	0.261646	3.35	0.001	2.40	1.44	4.01
Secondary	0.706982	0.258948	2.73	0.006	2.03	1.22	3.37
Tertiary	-0.282472	0.278413	-1.01	0.310	0.75	0.44	1.30
Rstatu							
Indigeneous	0.460738	0.195217	2.36	0.018	1.59	1.08	2.32
Ireasons							
Education	-0.0810190	0.452781	-0.18	0.858	0.92	0.38	2.24
Farming	0.355956	0.302968	1.17	0.240	1.43	0.79	2.59
Others	-0.301282	0.312004	-0.97	0.334	0.74	0.40	1.36
Work	0.535132	0.300186	1.78	0.075	1.71	0.95	3.08

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
Dserve-Time	142.841	3	0.000
Location	42.571	11	0.000
Age	13.225	2	0.001
Edu	41.657	3	0.000
Ireasons	15.905	4	0.003

Log-Likelihood = -1029.533
Test that all slopes are zero: G = 255.538, DF = 25, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	2318.40	1976	0.000
Deviance	1869.77	1976	0.956

Measures of Association:(Between the Response Variable and Predicted Probabilities)

Pairs	**Number**	**Percent**	**Summary Measures**	**Value**
Concordant	192243	72.4	Somers' D	0.45
Discordant	72540	27.3	Goodman-Kruskal Gamma	0.45
Ties	877	0.3	Kendall's Tau-a	0.33
Total	265660	100.0		

Annex VI: Drivers of Land Use/Cover Change in River Kuja Basin

The major drivers included population increase, sugarcane production, gold mining, infrastructural developments and climate change.

a. Population increase

Population growth has a direct impact on River Kuja basin water resources. By the year 2020, the basin had a population density of 321 persons per square kilometer compared to 1990 when it was 204 persons per square kilometer. The increase of 117 people per unit area of land heightened land use dynamics. The survey results of this study demonstrate that the basin experienced hydrological alterations and changes in the land use systems over the thirty years study period. Key issues affecting the basin included increased flooding during rainy seasons, land degradation (both physical and chemical) and general water shortage for both domestic and agricultural use. Both the natural forests and wetlands were converted to cropland in order to attain food security towards the increasing population.

b. Sugarcane Production

In the basin, three sugar factories were constructed and many communities converted idle lands into agricultural production of sugarcane. This contributed to the highest increase in the agricultural coverage over the entire basin.

Figure 4. 41: Sugarcane farming in Kuja basin (Source: www.sonysugar.co.ke)

c. Infrastructure

There has been an improved infrastructure in the region. The good road network systems and several social amenities have attracted investment. Many small centres have expanded to towns with accessible roads. This has resulted into rural urban migration and resettlements.

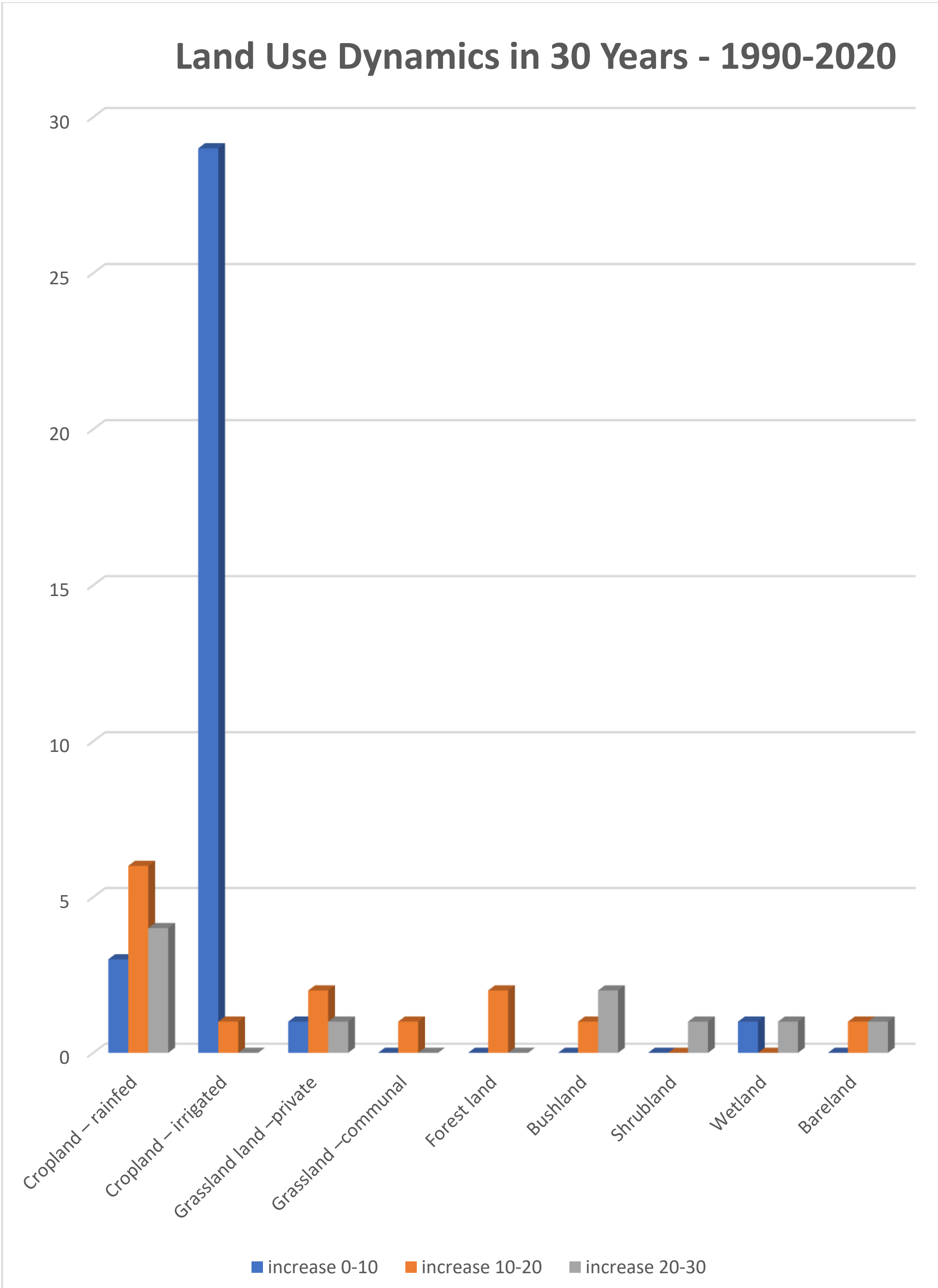
Figure 4. 42: Aerial Photo of Peri-urban areas of Kisii town (Source: www.kisii.go.ke)

d. Gold Mining

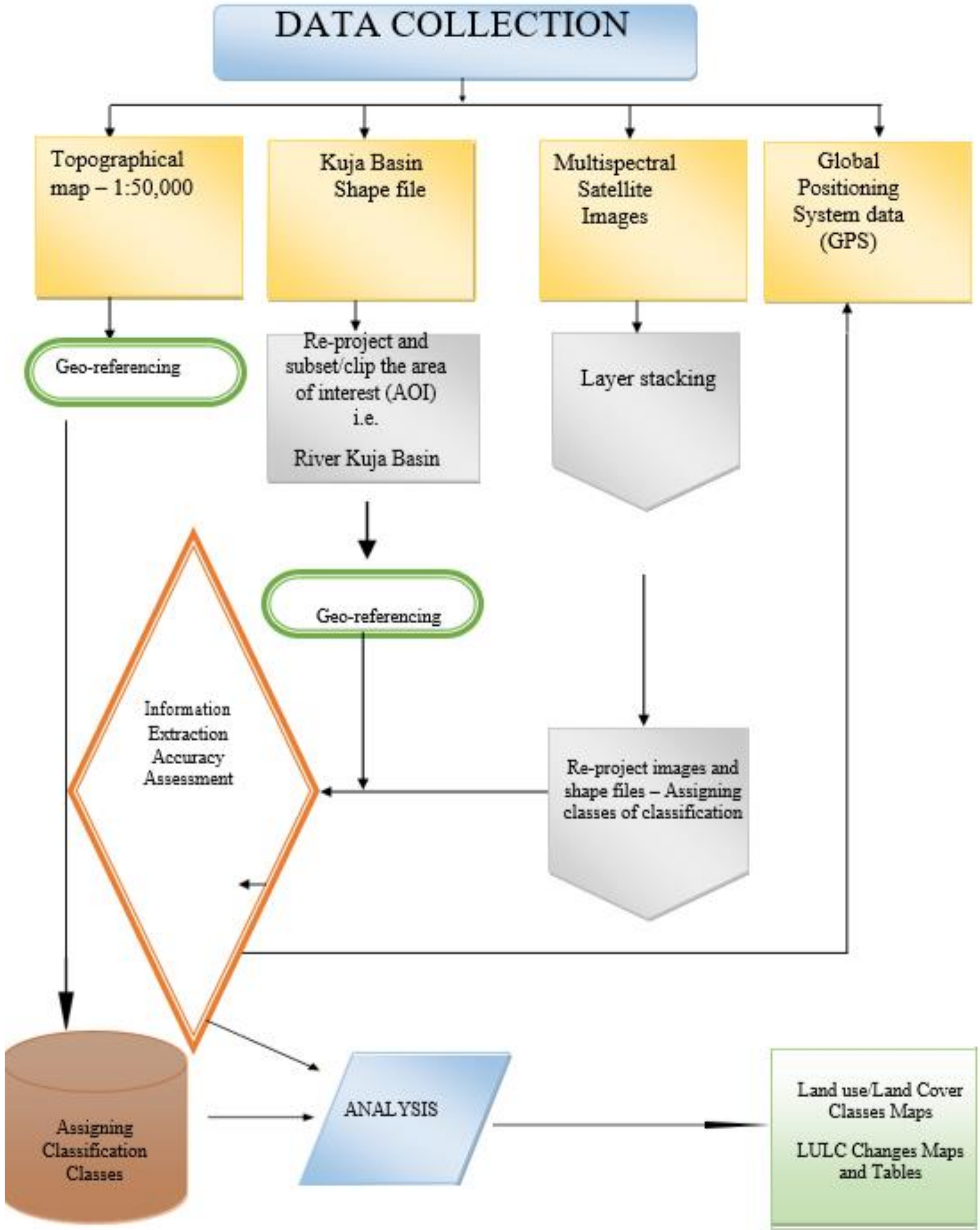
Figure 4. 43: Photo of a sample Gold mining area in Macalda Migori County

Annex VII: Land use Parameters

Land use	increase 0-10	decrease 0-10	not change 0-10	increase 0-10	decrease 0-10	not change 0-10	increase 10-20	decrease 10-20	not change 10-20	increase 10-20	decrease 10-20	not change 10-20
Cropland – rainfed	3	4	205	127	6	78	6	2	204	121	6	85
Cropland – irrigated	29	49	134	49	29	134	1	3	208	25	39	148
Grassland land – private	1	2	208	60	66	86	2	4	206	51	60	101
Grassland – communal	0	4	208	38	85	89	1	4	207	49	68	95
Forest land	0	4	208	18	111	83	2	4	206	29	96	87
Bushland	0	4	208	35	99	78	1	6	205	31	93	88
Shrubland	0	4	207	39	97	76	0	6	206	26	96	90
Wetland	1	3	208	42	90	80	0	5	207	40	83	89
Bareland	0	5	207	26	112	74	1	5	206	22	101	89


Land Use Dynamics in 30 Years - 1990-2020
30
25
20
15
10
5
0
Cropland – rainfed
Cropland – irrigated
Grassland land –private
Grassland –communal
Forest land
Bushland
Shrubland
Wetland
Bareland
increase 0-10
increase 10-20
increase 20-30

Annex VIII: Land Use Land Cover Change Analysis Approach



Annex IX: Population of the Basin Based on 2019 Census – Raw Data

MIGORI SUB COUNTIES

AWENDO	117290
KURIA EAST	96872
KURIA WEST	208513
NYATIKE	176162
RONGO	124587
SUNA EAST	122674
SUNA WEST	128890
URIRI	141448
TOTAL	**1116436**

KISII

SUB COUNTIES	POPULATION
ETAGO	83787
GUCHA	83740
GUCHA SOUTH	83623
SAMETA	66997
KISII SOUTH	135134
TOTAL	**453281**

HOMABAY

SUB COUNTIES	POPULATION
NDHIWA	218136
RANGWE	117732
TOTAL	**335868**

NYAMIRA

SUB COUNTIES	POPULATION
MANGA	94209
NYAMIRA	159073
TOTAL	**253282**

NAROK

SUB COUNTIES	POPULATION
TRANSMARA EAST	111183
TRANSMARA WEST	245714
TOTAL	**356897**

Annex X: Population of the Basin Based on 2009 Census – Raw Data

MIGORI SUB COUNTIES

AWENDO	35286
KURIA EAST	81833
KURIA WEST	174253
NYATIKE	52997
RONGO	325211
SUNA EAST	36906
SUNA WEST	38776
URIRI	42554
TOTAL	**787816**

KISII

SUB COUNTIES	**POPULATION**
ETAGO	232639
GUCHA	390803
GUCHA SOUTH	159049
SAMETA	186021
KISII SOUTH	114615
TOTAL	**1542814**

HOMABAY

SUB COUNTIES	**POPULATION**
NDHIWA	238108
RANGWE	128512
TOTAL	**366620**

NYAMIRA

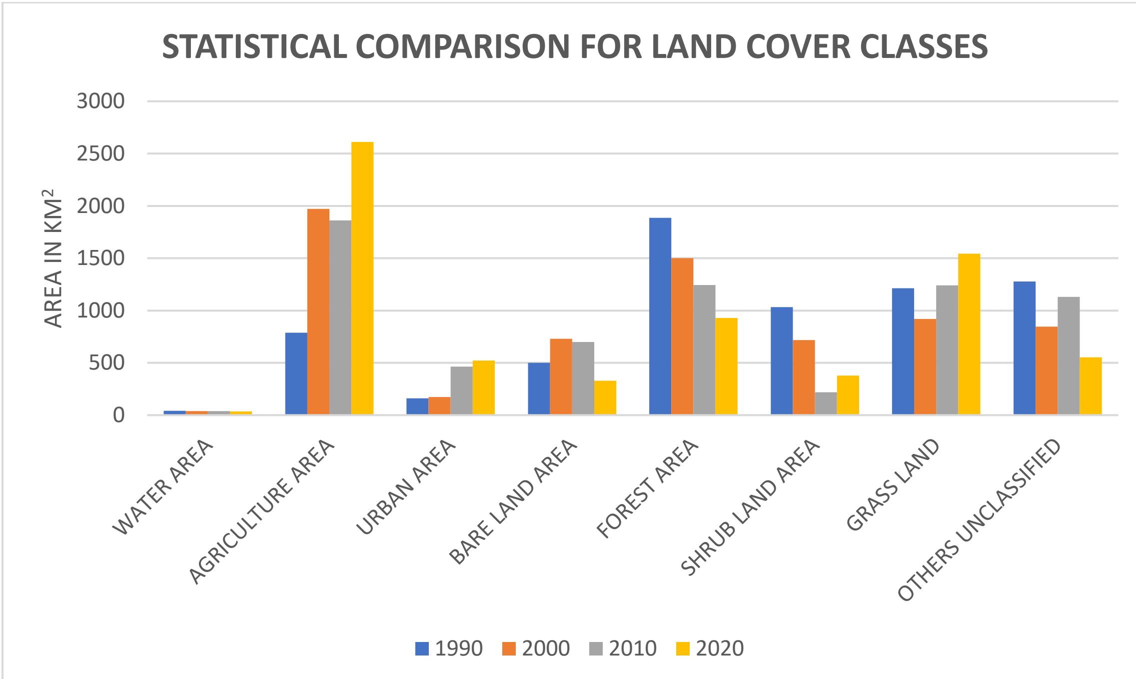
SUB COUNTIES	**POPULATION**
MANGA	87859
NYAMIRA	325690
TOTAL	**413549**

NAROK

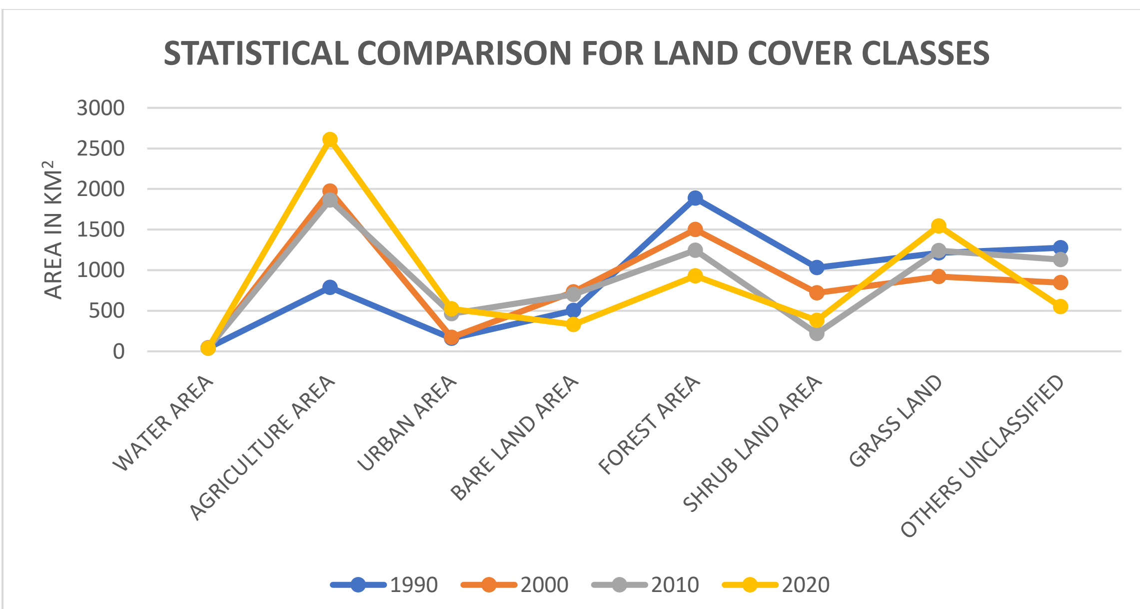
SUB COUNTIES	**POPULATION**
TRANSMARA EAST	85524
TRANSMARA WEST	189008
TOTAL	**274532**

Annex XI: Statistical Comparison of Land Cover Classes

BAR GRAPH

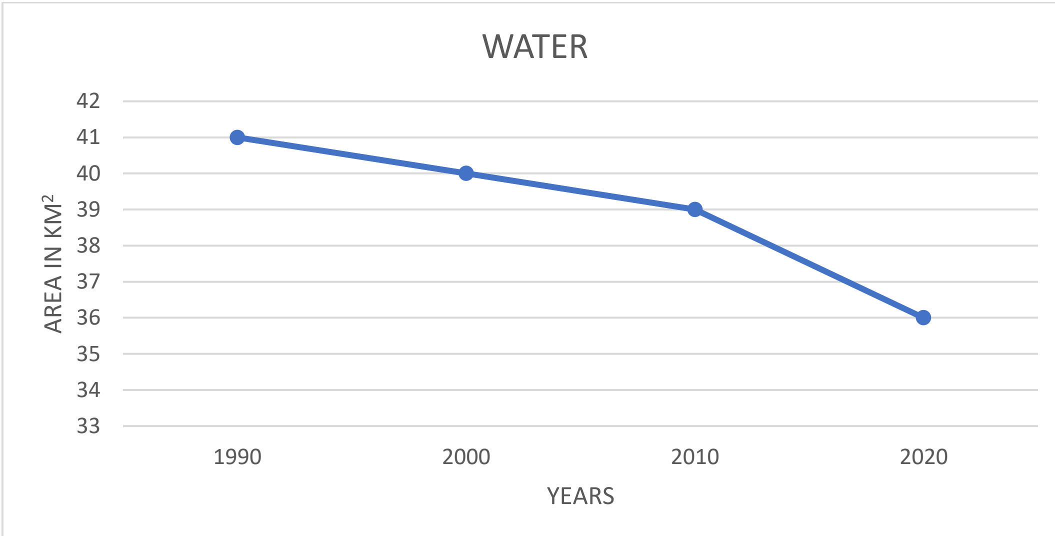


LINE GRAPH

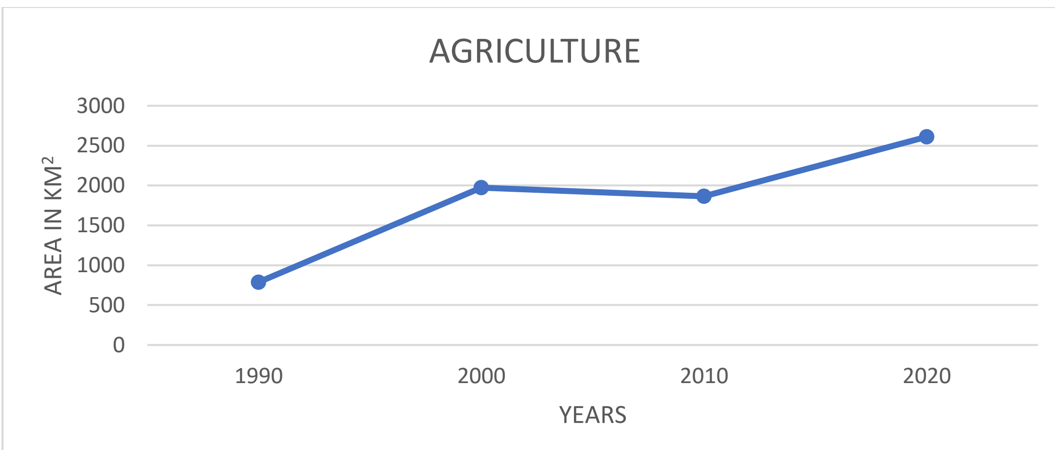


Annex XII: The Trends of Each Land Cover Classes

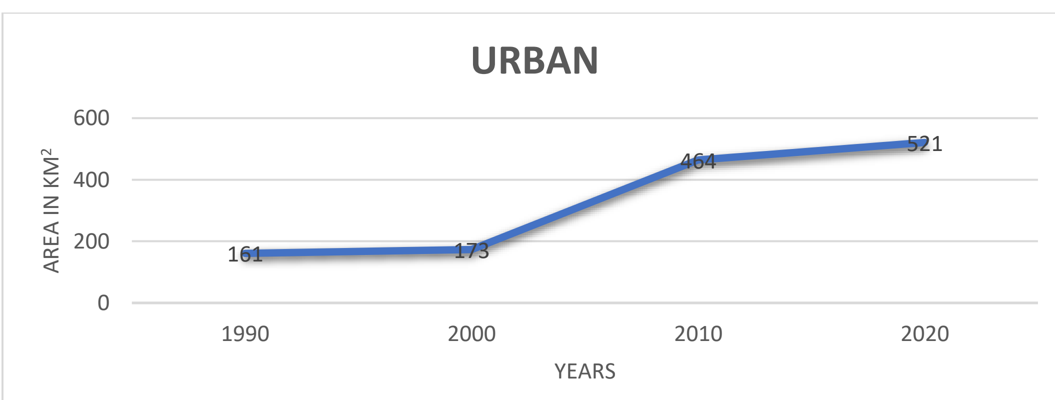
WATER TREND



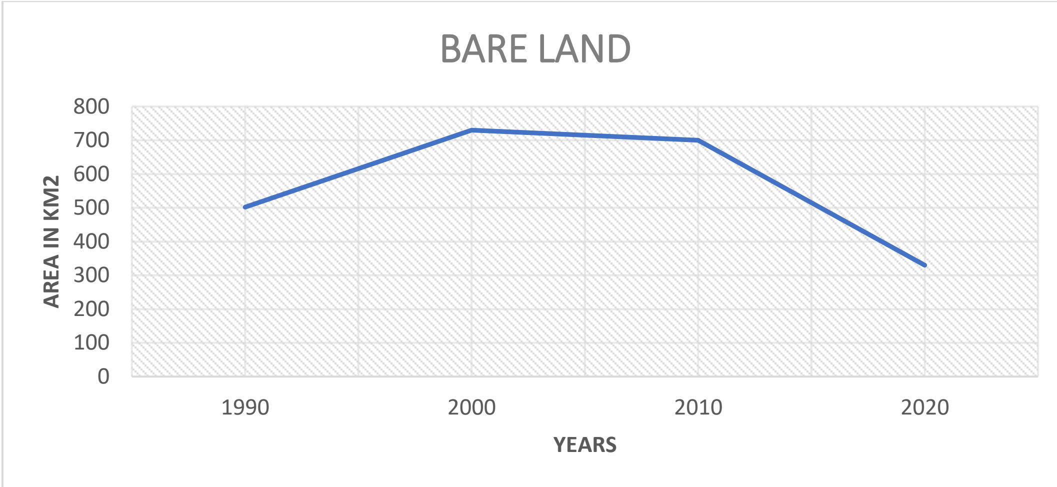
AGRICULTURE TREND



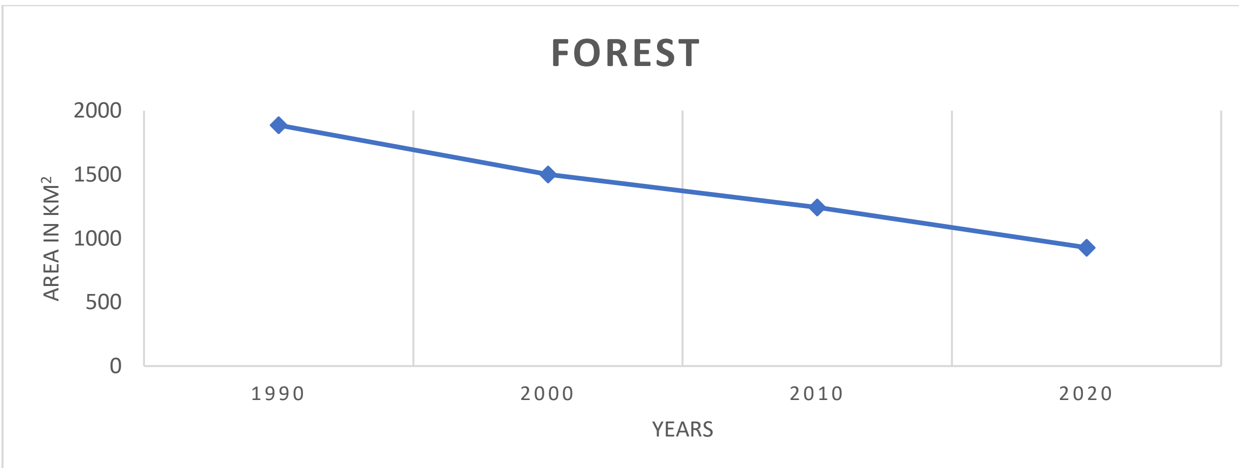
BUILT UP AREAS



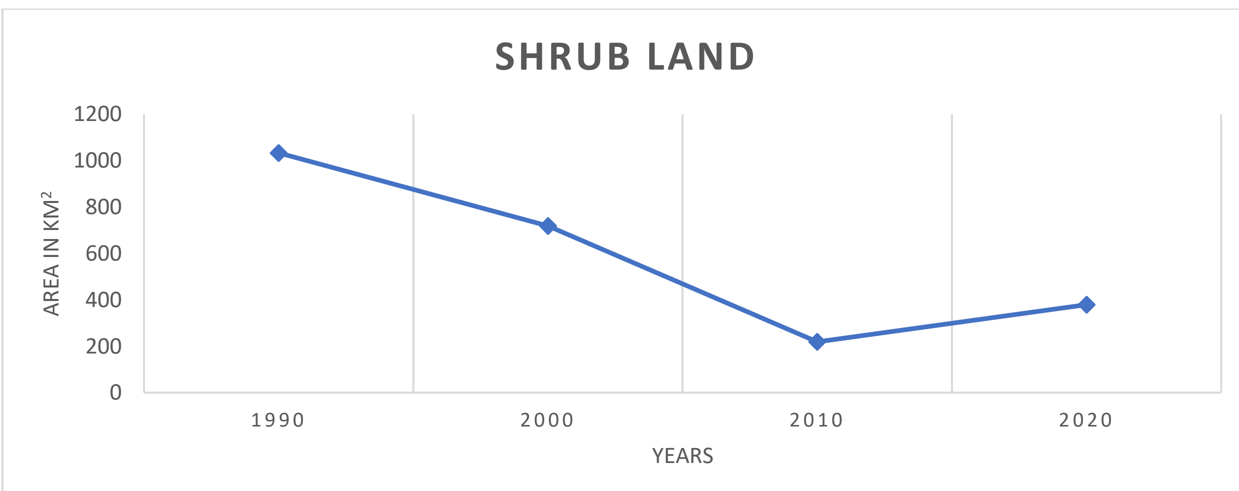
BARE LAND



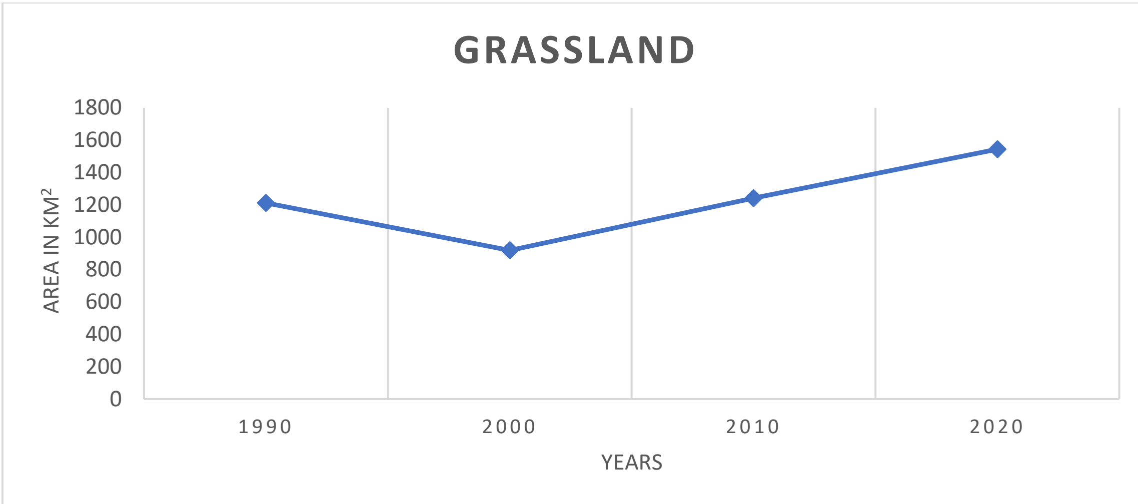
FOREST



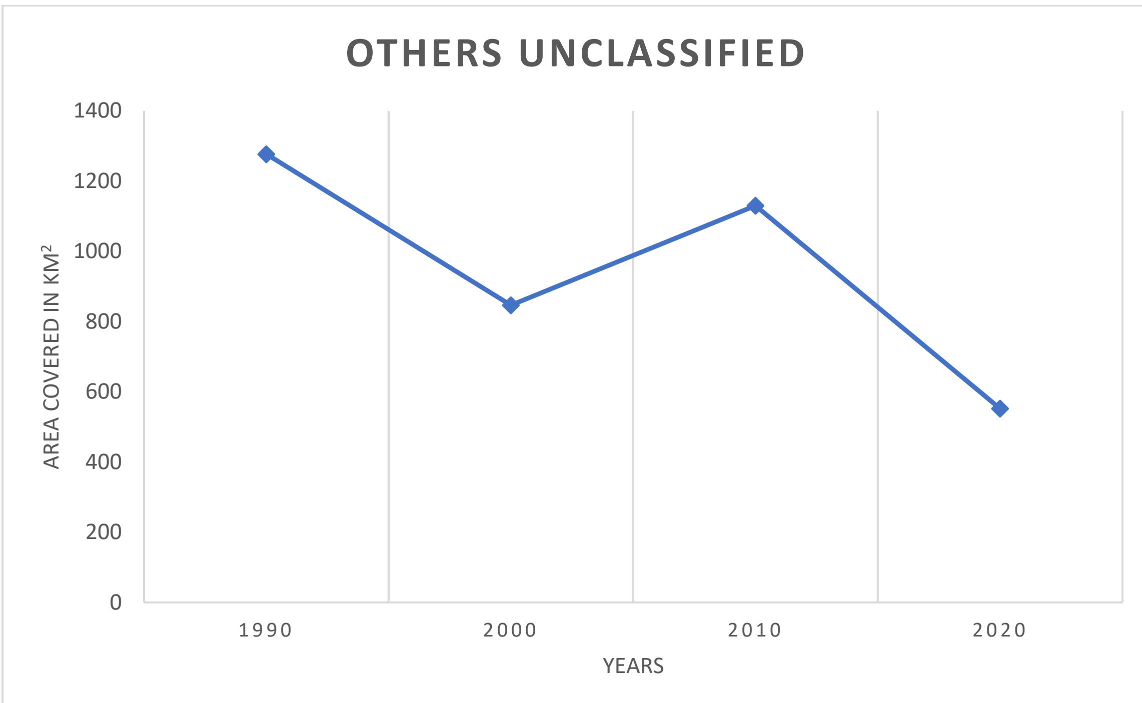
SHRUBLAND



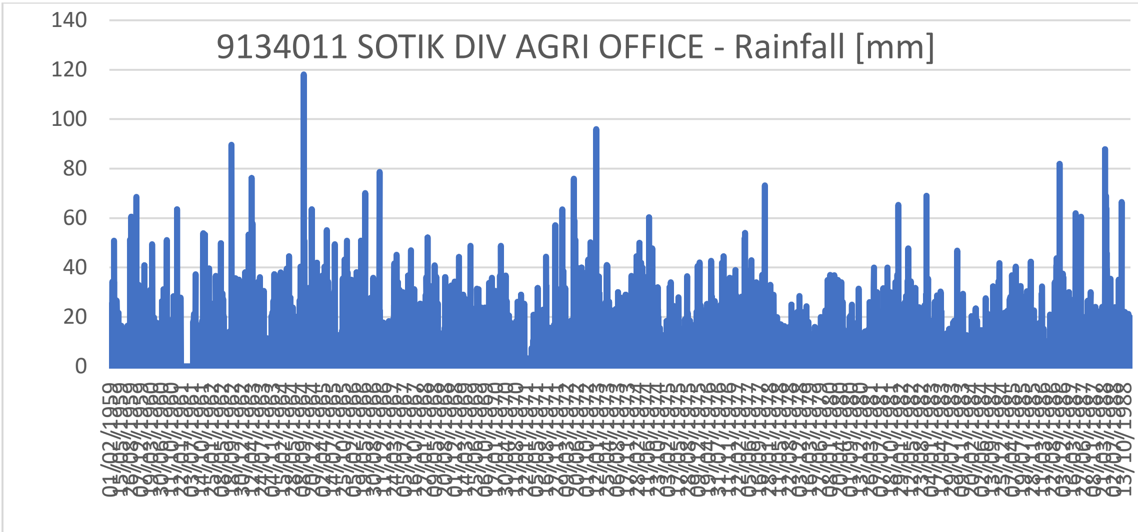
GRASSLAND

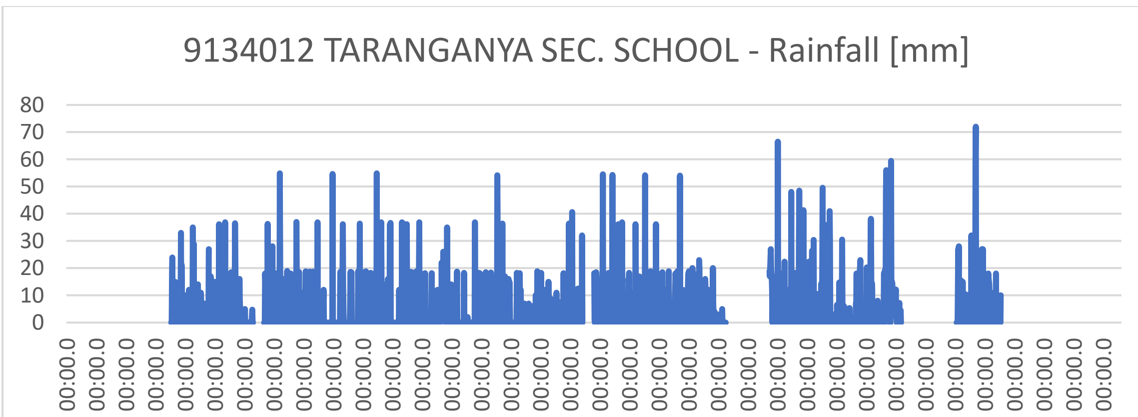


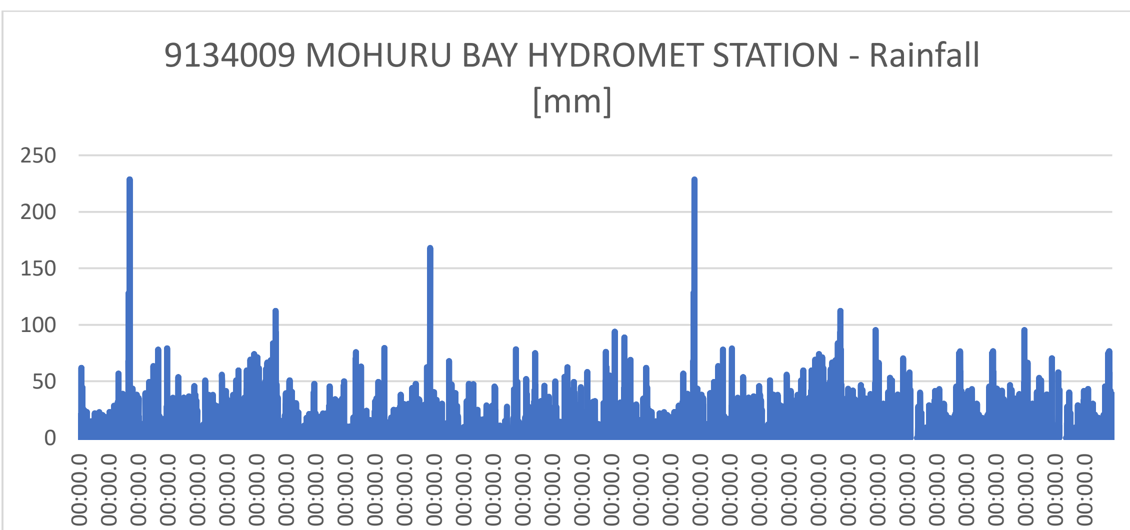
OTHERS UNCLASSIFIED

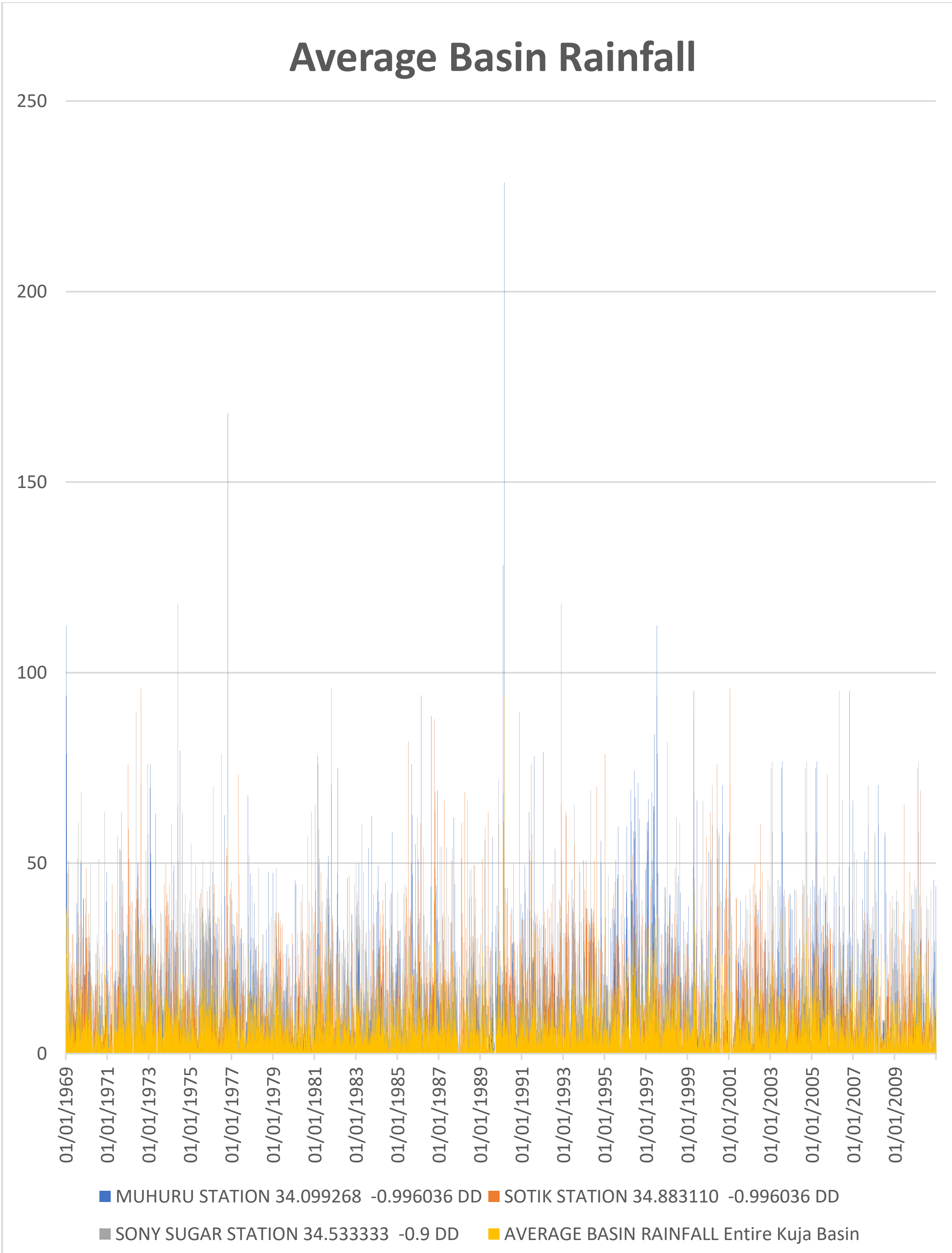


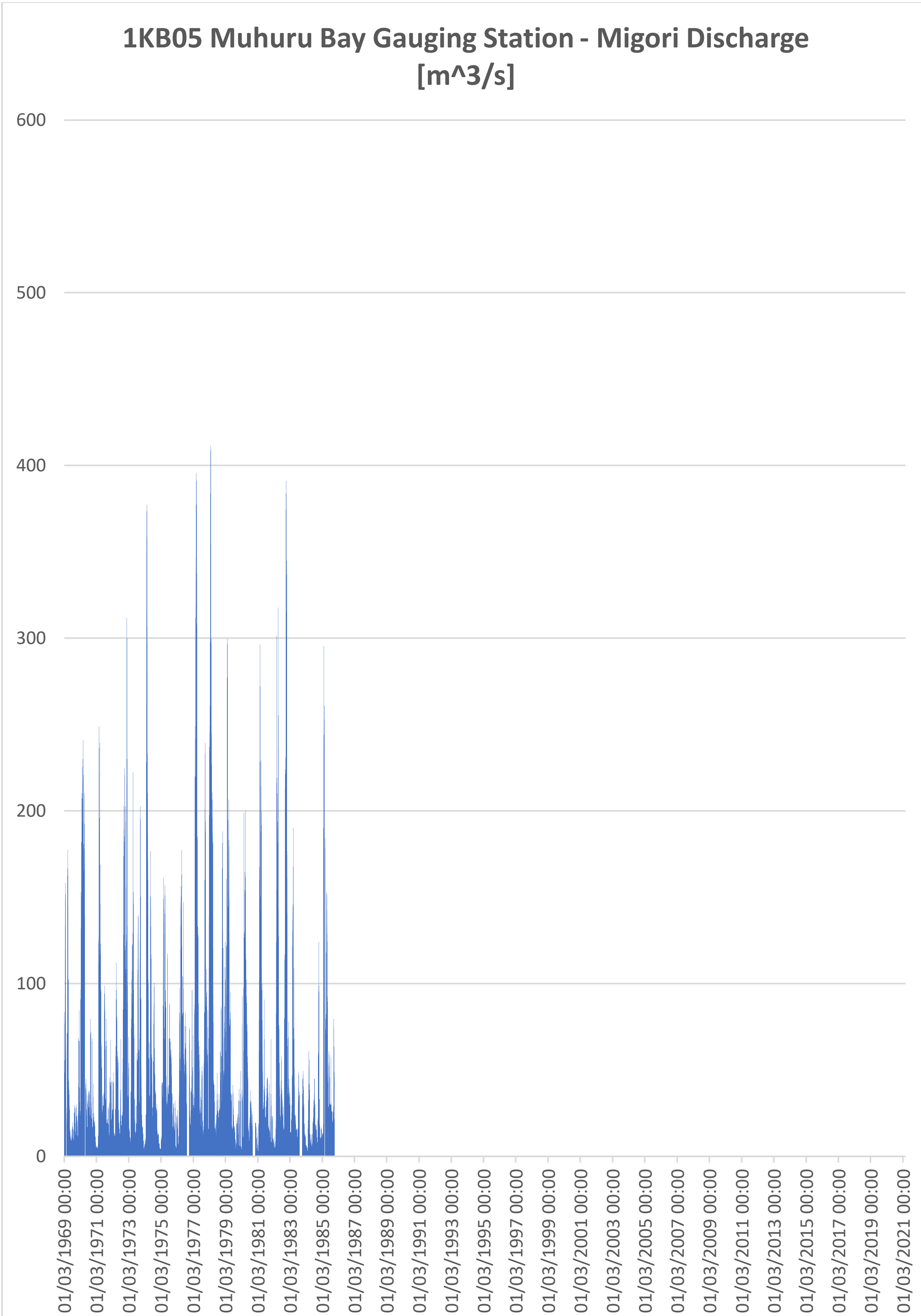
Annex XIII: Rainfall at Different Gauging Stations








Average Basin Rainfall
250
200
150
100
50
0
01/01/1969
01/01/1971
01/01/1973
01/01/1975
01/01/1977
01/01/1979
01/01/1981
01/01/1983
01/01/1985
01/01/1987
01/01/1989
01/01/1991
01/01/1993
01/01/1995
01/01/1997
01/01/1999
01/01/2001
01/01/2003
01/01/2005
01/01/2007
01/01/2009
MUHURU STATION 34.099268 -0.996036 DD
SOTIK STATION 34.883110 -0.996036 DD
SONY SUGAR STATION 34.533333 -0.9 DD
AVERAGE BASIN RAINFALL Entire Kuja Basin


1KB05 Muhuru Bay Gauging Station - Migori Discharge [m^3/s]
600
500
400
300
200
100
0
01/03/1969 00:00
01/03/1971 00:00
01/03/1973 00:00
01/03/1975 00:00
01/03/1977 00:00
01/03/1979 00:00
01/03/1981 00:00
01/03/1983 00:00
01/03/1985 00:00
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01/03/2003 00:00
01/03/2005 00:00
01/03/2007 00:00
01/03/2009 00:00
01/03/2011 00:00
01/03/2013 00:00
01/03/2015 00:00
01/03/2017 00:00
01/03/2019 00:00
01/03/2021 00:00

Annex XVI: Research Authorization

1. **School of Spatial Planning and Natural Resource Management**

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF SPATIAL PLANNING AND NATURAL RESOURCE PLANNING

From: Post Graduate Coordinator **Ref:** JOOUST/AA/SSPNRM/D/P/V1/ (I)

To: The Under listed **Date:** 24th January, 2022

RE: CONCEPT AND PROPOSAL PRESENTATION

The above subject refers.

Following the virtual presentation that was held on 14th January 2022, the following verdicts were made:

1. **Vincent Ogembo – PhD proposal – P162/4255/2019**

Title: Planning Water Resources by Integration of Water Resource Modelling and Remotely Sensed Satelite Image of Kuja River Basin, Kenya

Verdict: To proceed with data collection under the supervision of the supervisors.

Note: Students that have been cleared for data collection during the presentation to ensure that they get clearances and or necessary documents from JOOUST ethical review committee and Board of Postgraduate studies and from NARCOSTI.

FN

Dr. Zachary Kinaro
Coordinator, Postgraduate Studies

2. Board of Post-Graduate Studies

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY

BOARD OF POSTGRADUATE STUDIES

Office of the Director

Tel. 057-2501804
Email: bps@jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

Our Ref: P161/4255/2019

Date: 7th March 2022

TO WHOM IT MAY CONCERN

RE: VINCENT OGEMBO OBUYA – P161/4255/2019

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Spatial Planning and Natural Resource Management pursuing PhD in Planning. He has been authorized by the University to undertake research on the topic: ***"An Integration of Hydrodynamic Modeling, Spatio -Temporal Variations in Land Use/Cover and Socio-Ecological Factors of a River Basin".***

Any assistance accorded his shall be appreciated.

Thank you.

Prof. Dennis Ochuodho

DIRECTOR, BOARD OF POSTGRADUATE STUDIES

3. NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 104637

Date of Issue: 25/May/2022

RESEARCH LICENSE

This is to Certify that Mr.. Vincent Ogembo of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Homabay, Kisii, Migori, Nyamira on the topic: AN INTEGRATION OF HYDRODYNAMIC MODELING, SPATIO-TEMPORAL VARIATIONS IN LAND USE/COVER AND SOCIO-ECOLOGICAL FACTORS OF A RIVER BASIN for the period ending : 25/May/2023.

License No: **NACOSTI/P/22/17795**

104637

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013

The Grant of Research Licenses is Guided by the Science, Technology and Innovation (Research Licensing) Regulations, 2014

CONDITIONS

1. The License is valid for the proposed research, location and specified period
2. The License any rights thereunder are non-transferable
3. The Licensee shall inform the relevant County Director of Education, County Commissioner and County Governor before commencement of the research
4. Excavation, filming and collection of specimens are subject to further necessary clearence from relevant Government Agencies
5. The License does not give authority to tranfer research materials
6. NACOSTI may monitor and evaluate the licensed research project
7. The Licensee shall submit one hard copy and upload a soft copy of their final report (thesis) within one year of completion of the research
8. NACOSTI reserves the right to modify the conditions of the License including cancellation without prior notice

National Commission for Science, Technology and Innovation
off Waiyaki Way, Upper Kabete,
P. O. Box 30623, 00100 Nairobi, KENYA
Land line: 020 4007000, 020 2241349, 020 3310571, 020 8001077
Mobile: 0713 788 787 / 0735 404 245
E-mail: dg@nacosti.go.ke / registry@nacosti.go.ke
Website: www.nacosti.go.ke

4. Ethics Review Committee

JARAMOGI OGINGA ODINGA
UNIVERSITY OF SCIENCE AND TECHNOLOGY

DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE

Tel. 057-2501804
Email: erc@jooust.ac.ke
Website: www.jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E4

30th June, 2022

Vincent Ogembo Obuya
P161/4255/2019
JOOUST

Dear Mr. Obuya,

RE: APPROVAL TO CONDUCT RESEARCH TITLED "AN INTEGRATION OF HYDRODYNAMIC MODELING, SPATIO-TEMPORAL VARIATIONS IN LAND USE/COVER AND SOCIO-ECOLOGICAL FACTORS OF A RIVER BASIN"

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **ERC 29/06/22-19.** The approval period is from 30th June, 2022 – 29th June, 2023.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) https:oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

Prof. Francis Anga'wa
Chairman, JOOUST ERC
Copy to: Deputy Vice-Chancellor, RIO Director, BPS Dean, SSPNRM

ANNEX XVII: PUBLICATIONS

1. **Vincent Ogembo Obuya et, al. (2022)**. Mapping Land Use Land Cover Changes from 1990 to 2020 in River Kuja Basin, Kenya, *American Journal of Geographic Information System*, Vol. 11 No. 1, 2022, pp. 9-22. http://article.sapub.org/10.5923.j.ajgis.20221101.02.html

2. **Vincent Ogembo Obuya et, al. (2022)** "Hydrodynamic Modelling using HEC-HMS Model, River Kuja Basin, Kenya." *American Journal of Engineering Research (AJER),* vol. 11(06), 2022, pp. 139-153; https://www.ajer.org/volume11issu6.html

3. **Vincent Ogembo Obuya et, al. (2022).** Analysis of the Impacts of Population Growth and Land Use Changes on Water Resources in River Kuja Basin, Kenya, *World Environment,* Vol. 12 No. 1, 2022, pp. 4-16. http://article.sapub.org/10.5923.j.env.20221201.02.html