EFFECTS OF LAND USE CHANGE ON THE PLANFORM OF THE KAFUBU RIVER CHANNEL IN NDOLA URBAN, ZAMBIA (1993-2015)

BY

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A dissertation submitted to the University of Zambia in partial fulfilment of the requirements for the award of the degree of Masters of Science in Geo-information Science and Earth Observation

The University of Zambia

Lusaka

2022

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DECLARATION

I, Annie Swali (2017013105), do hereby declare that this dissertation represents my own work, and that it has not been previously submitted for a degree, diploma or any other qualification at this university or any other university. Any published work or material from other work that has been incorporated has been duly referenced and acknowledged.

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APPROVAL

This dissertation of Annie Swali (2017013105) has been approved as partial fulfilment of the requirements for the degree of Master's in Science in Geoinformation Science and Earth Observation by the University of Zambia.

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ABSTRACT

This study sought to investigate the extent to which land use changes in Ndola Urban during the 22 years (1993-2015) have affected the planform of the Kafubu River using GIS and remote sensing techniques. The major objective was to assess the extent to which land use changes in Ndola urban have affected the size of the Kafubu River in the study period. For primary data, field observations on river channel were made and five local council planners as well as 13 respondents who had lived in Ndola for more than 20 years were interviewed for information on factors that may have caused land use and river planform changes. For secondary data aerial photographs taken in 1993 and 2015 and a 2009 IKONOS satellite image were used in assessing changes in land use and on the river morphology. The semi structured interviews were analysed using inductive thematic analysis. For analysis, aerial photographs covering the study area taken in 1993 and 2015 and a 2009 satellite image were georeferenced using 11ground control points. ArcGIS 10.5 software was used to generate object based classification land use maps which were later used to compare land use changes and river planform changes. A total of 10 evenly spaced transects were marked and made onto river polygons for each year to aid comparison of channel width with time using AutoCAD 2018. Findings of the study were that, most of the river buffer zone 50m on either side of the river had changed from crop land use to residential areas. The built up area had increased from 41.54ha in 1993 to 198.46ha (377.76%) in 2015 over the whole study period. Between the years 1993 and 2009 there was an increase in channel width at transects 6,7,8,9 and 10 while the other transects showed a width reduction. Similarly, between 2009 and 2015 there was an increase in channel width at transects 1, 2, 3 and 4 while reduction was observed at the other transects. For the entire study period the river width had reduced at all transects except at transects 2 and 10, in terms of channel growth or accretion and reduction due to erosion. The maximum annual rate of accretion was found to be 1.27m/year higher than that of erosion (maximum 0.2m/year) indicating an overall reduction in channel width. In terms of land coverage in the 22-year period, the surface area of Kafubu River reduced from 17.14ha in 1993 to 8.02ha (53.21%) by 2015. Factors attributed to causing land use changes were shortage of state land, corruption in allocation of land, proximity to central business district, population increase, ignorance of environmental issues, and poor planning by the Municipal Council. Similarly, channel planform changes were influenced by building houses in the buffer zone and by the expansion of the river Hyacinth weed. It is concluded that Kafubu River in the 22 years period has been affected by land use change in the river buffer zone from crop land to residential area which led to narrowing of channel width because of deposition of sediment into the river and consequently the reduction of the surface area of the river by 53.21 percent. It is recommended that the local government should implement strict land allocation policies, put more effort in water Hyacinth removal and protect the river buffer zone. Because of the inevitability of urbanisation, Kafubu River channel banks should be made permanent by construction of concrete banks in the town reach which will also protect residents from effects of flooding during wet years.

Keywords: *Remote Sensing, Accretion, Erosion, Kafubu River*

DEDICATION

This study is dedicated to my husband Innocent for his unwavering belief and support. I also dedicate this to my three sons Peniel, Jethro and Gianni who have been my main source of inspiration and motivation throughout the study.

ACKNOWLEDGEMENT

I am most grateful to my Lord Jesus Christ for his great provisions, protection and support throughout the duration of my study.

I am thankful to Prof. H.M Sichingabula my supervisor for his guidance though out the research and Mr. M. Chisola for guidance in the proposal stage of my study. I am thankful to Dr. B Umar from the Department of Geography and Environmental Studies for bringing this course to my attention and for motivating me to participate in this course. I would also like to thank Mr. Lungu from the Survey Department in Lusaka for his effort to locate aerial photographs used in this study without which image analysis would have been complicated. I am thankful to the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) for their financial sponsorship during the time of study.

I am grateful for my parents who have always believed in my academic capabilities and made me believe that I can do anything. I also thank my brothers and sisters for their constant encouragement. I thank Yvonne Magawa for your hospitality during my studies.

I acknowledge all the respondents for my interviews for agreeing to participate and giving me the information required. I would love to appreciate all my course mates during the study as they helped in different ways especially Martha, Mbanga and Adrick always stay blessed.

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ACRONYMS

CBD	Central Business District
CSO	Central Statistical Office
GCP	Ground Control Point
GIS	Geographical Information Systems
DGPS	Differential Geographical Positioning System
GPS	Geographical Positioning System
NCC	Ndola City Council
RS	Remote Sensing
WARMA	Water Resources Management Authority
ZAFFICO	Zambia Forestry and Forest Industries Corporation Limited
ZEMA	Zambia Environmental Management Agency

CHAPTER ONE: INTRODUCTION

1.1 Background

Water can be used for purposes that include; domestic uses, industry, environmental, agriculture, mining, hydro-electric power, navigation and municipal purposes (GRZ, 2011). This makes water a vital resource that should be used in an efficient and sustainable manner in order for future generations to be able to have access to it as well. In Zambia, rivers are the main sources of water intended for various uses. However, their capacities and life span are often threatened by land use activities. In the Copperbelt province, the major river is the Kafue River and the Kafubu River is one of its tributaries.

Land use is the manner in which human beings employ the land and its resources. It reflects on how humans use the land, for example, industrial zones, residential zones, agricultural fields etc. (Zubair, 2006). Land use change has potentially large impacts on water resources (Stonestrom *et al.*, 2009). Rapid socio-economic development drives land use changes, which include changes of land use classes, e.g., conversion of cropland to urban area due to urbanization, as well as changes within classes such as a change of crops or crop rotations.

Changes in catchment hydrology occur mainly due to alterations in interception, infiltration, evapotranspiration and groundwater recharge which are linked to land use changes (Baker and Miller, 2013). Urban streams are highly vulnerable to impacts associated with land use changes resulting from increasing urbanization. The term “urban stream syndrome” summarizes the degradation of streams in urban areas, characterized by flashier hydrograph, changes of channel stability and morphology, deterioration of water and sediment quality and changes of the ecological status/ecological health of the recipients (Komínková, 2012). Therefore, land use change detection studies using GIS and remote sensing have become extremely important for monitoring the environment and using the resources of the Earth in a sustainable manner. They also help to identify resources at risk as well as the agents of change.

In most instances, land-cover changes occur naturally in a progressive and gradual way. However, sometimes it may be rapid and abrupt due to anthropogenic activities. Remote sensing data of high resolution at different time interval help in analysing the rate of changes as well as the causal factors or drivers of changes. Satellite imageries provide the opportunity of rapid acquisition and thus provide time series data of land cover due to their broad spatio-temporal coverage. Their capacity for routine and unobtrusive updating and their ability to provide self-consistent measurements of critical physical properties that would be difficult or expensive to obtain in situ make them important tools. Aerial photographs possess excellent spatial detail which makes them valuable in detecting land use and river planform changes. It is in this light that this study used GIS and remote sensing to investigate the extent to which land use changes around the Kafubu River in Ndola, Zambia have had an effect on the width and planform of the river in the period of 22 years, 1993 to 2015. A planform of a river is its outline as seen from above.

1.2 Statement of the problem

The Kafubu River basin is among the most highly urbanized in Zambia (Nkaka, 2000). It is characterized by industrial, urban and agricultural land use types. In order for the Kafubu River to continue providing water needed for all the land use types it supports, it has to be sustainably developed and used. However, these land use types especially built up, have expanded so much that they are now too near to the Kafubu River. This has resulted in limited water supply to the southern part of Ndola city. As such the width and planform of the river is expected to have reduced due to siltation and encroachment. (Chanda, 2014).

Previous studies in the area have focused on; the water hyacinth (*Eichhornia crassipes*); water quality; pollution; and geology (Mbula, 2016; Nkaka, 2000; Mwiinga, 1990; Moore, 1967). Thus, none of the previous studies attempted to assess the impacts of human activities on the river planform. A spatio-temporal analysis of the impacts of land use change on river planform especially the river width could help inform land use planning decisions and guide sustainable development of the area. The lack of spatio-temporal analysis of the impacts of land use change on the planform of Kafubu River could result in no information to use in the prediction of the availability of water in the future. This would prevent unexpected water shortages in the future as the authorities in charge of surface water would put up measures to prevent it from happening. In this regard, GIS and remote sensing provide a cheaper, more accurate and faster assessment method than in situ measurements. Therefore, this research assessed the extent to which the Kafubu River in Ndola Urban has changed in width over the 22-year study period.

1.3 Aim

The aim of this study was to determine the extent to which land use changes in Ndola Urban have affected the width of the Kafubu River during the 22-year study period using GIS and remote sensing techniques.

1.4 Objectives

1.4.1 General objective

The general objective of this study was to assess the extent to which land use changes in Ndola urban have affected the size of the Kafubu River between 1993 and 2015.

1.4.2 Specific Objectives

The three specific objectives are:

(i) To determine the areal extent of land use changes around the Kafubu River in Ndola over the 22-year study period.

(ii) To determine the changes in the channel width and planform of the Kafubu River during the 22-year old study period.

(iii) To assess the factors that have influenced land use and planform changes along the Kafubu River over the 22-year study period.

1.5 Research Questions

The research questions derived from specific objectives are:

(i) To what areal extent have land uses changed between 1993 and 2015 along the Kafubu River in Ndola?

(ii) What river planform changes have taken place between 1993 and 2015?

(iii) What factors have influenced land use and planform change along the Kafubu River?

1.6 Significance of the study

This study will provide a change detection graphic display of the planform of the Kafubu River over the 22-year study period as well as land use changes associated with it. This will help institutions such as the Ndola City Council, Zambia Environmental Management Agency (ZEMA) and the Water Resources Management Authority (WARMA) to understand the extent to which land use changes are affecting the width and planform of the Kafubu River. Such information can be used to make predictions about how long water resources will be available if land use changes affecting the Kafubu River are left uncontrolled. This study will also contribute to knowledge on how water resources in Zambia are affected by land use changes over time.

1.7 Organization of the Dissertation

This dissertation comprises of six chapters. Chapter One is the introduction to the study. Chapter Two reviews the relevant Literature on land use change, river planform change, the use of GIS in land use change and river planform studies and the factors that influence these changes. Third chapter presents a description of the study area. Chapter Four describes the methods used to collect and analyse data. Research findings and discussion are presented in chapters Five and Six, respectively. Chapter Seven provides a summary of findings and conclusion followed by the recommendations arising from the findings.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter is presenting the various literature reviewed on the meaning of land use, the factors influencing land use change, the effects of land use change on urban hydrology and the use of remote sensing and geographical information systems in detecting and analyzing land use change and river planform change.

2.2 Definitions of Land Cover and Land Use

Land cover is defined by the attributes of the earth's land surface and immediate subsurface, including biota, soil, topography, surface and groundwater, and human structures which correspond to the physical condition of the ground surface (Lambin *et al*., 2003; Chrysoulakis *et al*., 2004). Land use is the intended employment of and management strategy placed on land cover type by human agents, or land managers. For example; forest - a land cover, may be used for selective logging, for resource harvesting, such as rubber tapping, or for recreation and tourism. Shifts in intent and/or management constitute land-use changes (Baulies and Szejwach, 1997). Land-cover and land-use changes may be grouped into two broad categories: conversion or modification. Conversion refers to changes from one cover or use type to another. This may include for example conversion of grazing to cropping, vegetation removal and conversion to non-agricultural uses (Quentin *et al*., 2006). In contrast, modification involves maintenance of the broad cover or use type in the face of changes in its attributes. Thus, a forest may be retained while significant alterations take place in its structure or function for example involving biomass, productivity, or phenology. Land use changes are as a result of various natural and human factors within social, economic and political contexts.

2.3 Rationale of Land Use Change Studies

Land use change plays an important role in global environmental change and sustainability, including response to climate change, effects on ecosystem structure and function, species and genetic diversity, water and energy balance, and agro-ecological potential (Codjoe, 2007).

2.4 Factors Influencing Land Use Changes

At longer timescales, both increases and decreases of a given population also have a large impact on land use. Demographic change does not only imply the shift from high to low rates of fertility and mortality (as suggested by the demographic transition), but it is also associated with migration and urbanization (Geist and Lambin, 2002). Apart from the population growth, the division of land parcels and failure to restore or maintain protective works of environmental resources all lead to resources scarcity causing pressure of production of resources which in turn leads to land use changes (Lambin *et al.,* 2003). Humphries (1998) indicates that land use change is also as a result of decrease in land availability due to encroachment by other land uses, such as land zoning for forest reserves, wilderness areas or agro industrial plantations, which leads to the so-called tragedy of enclosure.

Many land-use changes are due to ill-defined policies and weak institutional enforcement, as exemplified by the widespread illegal logging in Indonesia linked to corruption and to the devolving of forest management responsibilities to the district level (Jepson *et al.*, 2001). Policies influencing land use change include low investments in monitoring and formally guarding natural resources (Agrawal and Yadama, 1997). Land use change is influenced by loss of adaptive capacity and increased vulnerability of land resources which can be as a result of weak buffering capacity. Lack of public education and poor information flow on the environment contributes to land use change too (Lambin *et al.,* 2003). Land use change is caused by lack of community's ability to cope with a deteriorating environmental situation, combined with absence of political will to mitigate damage and to alter the trajectory of change, which leads to delayed and ineffective social responses (Kasperson *et al.,*1995).

2.5 Effects of Land Use change on Urban Hydrology

Chakraborty and Mukhopadhyay (2015) investigated riverbank erosion and channel width adjustments across a meandering channel of North Bengal, India, and indicated that, being a natural riverine element, riverbanks can move away (erosion) or can advance (deposition), which can result in meander migration, channel avulsion and changes in channel width. They found that riverbank composition, riparian vegetation and seasonal discharge variations have been found as the significant controllers of the bank erosion processes along with certain moderating effects of human interventions. Similarly, channel width adjustments were random, tended towards expansion along lower courses while headed for contraction along the middle one, guided predominantly by the opposite processes of erosion-deposition.

Clark and Wilcock (2000), researched on effects of land-use change on channel morphology in northeastern Puerto Rico and indicated that land-use changes alter the water and sediment supplied to rivers, which, in response, alter their geometry and composition toward a condition capable of passing the supplied sediment with the available water. Examining along-stream variations in channel geometry and sedimentation can provide evidence of river response to land-use change. Channel response to changes in water and sediment supply can take a variety of forms, including changes in width, depth, and planform geometry. Their findings included that there was land use change in their study area from agriculture to forest, suburban, and industrial use, which reduced sediment and water supply resulting in reverse (downstream) channel geometry.

Ahmad *et al*., (2018) used GIS techniques and satellite imagery to carry out a planform analysis of Teesta River in Bangladesh and found that the river was prone to changes in the form of constant erosion and deposition and from the analysis, it was seen that the rate of erosion was higher than for deposition. The river experienced high level of flow during the wet season leading to more erosion.

According to a study on the urban stream syndrome by Kominkova in 2012, increasing amounts of impervious surfaces and decreasing area of natural vegetation cover belong to the most pronounced characteristics of urbanization. These changes significantly alter the hydrological conditions in the catchment and the behaviour of streams. The high number of impervious surfaces causes a substantial increase of surface runoff components, along with a decrease of groundwater recharge and base flow. The findings of Kominkova (2012) are similar to those of Sharma (2017) who examined the effects of urbanization on water resources in Bhopal India and concluded that there was increase in river discharge and occurrence of flash floods because of increased built up areas. Similarly, Gyamfi *et al*., (2016) examined hydrological responses to land use /cover changes in the Olifants Basin, South Africa and concluded that urbanization and agriculture led to increased surface runoff generation and water yield in the basin. Farley *et al*., (2005), examined the effects of afforestation on water yield globally by analyzing 26 catchment data sets and concluded that there was reduction in runoff after afforestation of grasslands and shrub lands.

Other studies that addressed river planform changes include Gilvear *et al*., (2000) who used air photo interpretation and field survey to examine rates and patterns of planform change over the previous 40 years on an 80 km reach of the Luangwa River, Zambia. He found that the patterns of meander development observed varied and could be described in relation to traditional geomorphic models. He also explained that floodplain sedimentology rate of bank erosion, and valley-side channel deflection apparently cause spatial variability in bank resistance. Hickin and Sichingabula (1988) used air photo interpretation to determine the geomorphic impact of the catastrophic October 1984 flood on the planform of Squamish River, Southwestern British Columbia. They found that despite its large size, the 1984 flood accomplished little more floodplain modification in the meandering and transitional semi braided reaches than had previous smaller floods of similar duration. Conversely, in the braided reach, the 1984 flood caused floodplain erosion and major reorganization of the channel to an extent previously unrecorded, apparently here exceeding a threshold for channel stability.

Similarly, although the literature on the Kafubu river in Ndola is fairly good and is easily accessible, most studies about the Kafubu river are about the hyacinth, water quality, pollution, and geology (Mbula, 2016; Nkaka, 2000; Mwiinga, 1990; Moore, 1967). Nkaka (2000) found that the water quality in the 20km portion of Kafubu River between Itawa swamps and Kafubu dam deteriorated in downstream direction as a result of sewage and trade effluents discharged into the river mostly with minimal pretreatment. Mbula (2016) assessed the impacts of water hyacinth on major socio-economic activities on Kafubu River and found that the hyacinth damaged fishing nets, reduced the fish catchability and caused a reduction in water available for irrigation. The water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), is a clonal aquatic plant native to South America, primarily Brazil and Argentina, but has spread to more than 50 countries, including tropical, subtropical and temperate zones (Zhang *et al*., 2010). In Zambia, the water hyacinth infested massively freshwater bodies during the early 1960s and rapidly spread in many areas such as Kafue River, Lake Tanganyika, Lake Kariba and Kafubu River (Villamagna and Murphy, 2010).

2.6 Why use Remote Sensing and Geographical Information System techniques?

In order to carry out land use change research to understand the impacts on river planform/ morphology, it is crucially important to consider multiple sources of information and to acquire temporal, spatial and other non-spatial forms of data. This is because scientific approaches to land cover change have major demands for temporal and spatial consistency. The use of time-lapse historical imagery data has become indispensable to better understanding the recent past land cover change dynamics (Baulies and Szejwach, 1997). In order to display this spatial and temporal data, it is necessary for it to be mapped and in this way the changes over time can clearly be seen. Geographical Information System is the systematic introduction of numerous different disciplinary spatial and statistical data, which can be used in inventorying the environment, observation of change and constituent processes and prediction based on current practices and management plans. Satellite remote sensing helps in acquiring multi-spectral, spatial and temporal data through space borne remote sensors (Ramachandra, 2004). However, the high spatial resolution of satellite imagery is relatively a recent phenomenon and may not indicate the condition of the river in its relatively undisturbed state. This is because a large area may be captured in a single pixel so the changes taking place there may not be detected. It is here that aerial photographs become complimentary because they possess excellent spatial detail (Hudak and Wessman, 1998). The aerial photographs can be scanned and loaded in GIS software.

2.7 Use of RS and GIS for Land Use Change Studies

Scanned maps and historical data usually do not contain spatial reference information and so have to be aligned to a map coordinate system. A map coordinate system is defined using a map projection- a method by which the curved surface of the earth is portrayed on a flat surface. This is called georeferencing. Georeferencing allows for raster data to be viewed, queried, and analyzed with other geographic data (ESRI, 2018). The transformation parameters can be determined by Ground Control Points (GCPs). The GCPs are features present on the image as well as on the ground. Generally speaking, control points should be chosen in distinct feature positions such as the top of mountain, the crossing of roads or rivers and so on. These positions are easy to be recognized from satellite orthophoto (Zhu *et al*., 2008) Once georectification is done on an aerial photo, and an orthophoto is produced and it allows for same distance measurements across the entire image which can be used to detect changes. The discrepancies between measured and transformed coordinates of the GCPs are called residual errors. The total error is computed by taking the root mean square sum of all the residuals to compute the root mean square error (RMSE) (ESRI, 2018). The overall accuracy of a transformation is stated by GIS software as the Root Mean Square Error (RMSE) and is only valid for the area bounded by the GCPs. Therefore, the selection of the GCPs should be well distributed and include locations near the edges of the image.

Thereafter, the images can be classified according to the land uses found in the study area. Land use classifications can take supervised and unsupervised pixel-based approaches or can be object oriented. Weih and Norman (2010) compared the accuracy of object-based, supervised and unsupervised pixel-based classifications when applied to medium spatial resolution satellite imagery and high spatial resolution aerial imagery and concluded that an object-based classification out performs both supervised and unsupervised pixel-based methods with a higher accuracy as well.

Object based image classification is a classification approach that consists of two stages: image segmentation and classification. Object based classification procedures analyze both the spectral and spatial/contextual properties of pixels and use a segmentation process and iterative learning algorithm to achieve a semi-automatic classification procedure that promises to be more accurate (Weih and Norman, 2010). Segmentation, the first step in the object-oriented approach, involves merging the pixels in the image into image object primitives called objects or segments with a certain heterogeneous and homogeneous criterion (Gitas *et al.*, 2004). In the process of creating objects, factors such as colour, area, geometry and texture are considered based on the scene. Because this approach essentially averages the values of pixels and takes geographic information into account, the objects that are created from segmentation more closely resemble real world features in imagery and produces cleaner classification results. After segmentation, some randomly sampled segments are used as training samples and a classifier definition file is created. The classifier definition file is used to train a classification method such as Maximum likelihood classification. Maximum likelihood classifier is a parametric classifier so requires a minimum of twenty (20) samples per class in order to be statistically significant.

An accuracy assessment of the classification is done to by comparing the classification with actual reference data that is known to reflect the true land uses in the study area. The reference data includes field or ground truth data, high resolution satellite or aerial photographs or topographical maps derived from aerial photographs. Samples for each land use are collected from the reference data and compared to the classified image. Goodchild (1994) recommends thirty (30) to fifty (50) samples can be collected for each land use category from the reference data.

The confusion matrix is one common method of determining the accuracy assessment of a classification. The confusion matrix consists of a table that relates the classes of classified pixels to their actual classes based on reference data. It is used to calculate the producer's accuracy which is the probability that a certain land use of an area on the ground is classified accurately. The user's accuracy which is the probability that a pixel labeled as a certain land use class on the classification map is really this class can also be calculated from the confusion matrix. Thereafter, the overall accuracy can be calculated to provide an estimate of the correctness of the classification considering both the users and producers accuracy. Finally, the Kappa accuracy which reflects the difference between the actual difference and the difference expected by chance (Foody, 2002).

Once the classification maps for each year under study are generated, a change detection technique to show quantitative areal change in each land use that has taken place can be employed. Object-based post-classification comparison is one method that is used for change detection of object based classified multi temporal data. Post-classification comparison methods detect land cover change by comparing independently produced classifications of images from different dates (Singh 1989). Jensen (2004) indicates that post-classification comparison method can not only locate changes but can also provide “from-to” change information. Furthermore, Yuan (1998) explains that post classification comparison minimizes the problems caused by variation in sensors and atmospheric conditions as well as vegetation phenology between different dates since data from different dates are separately classified. Finally, a change detection matrix can be used to explain the changes that took place in each land use over a study period. A change detection matrix shows the quantitative areal changes that took place in land uses as well as the areas of land uses that did not change. To analyse river planform changes, Ahmad *et al*., (2018) used river shapefiles generated by the GIS software to make some evenly spaced cross sections and using Microsoft Excel, the rates of erosion and accretion on each riverbank that had taken place during the study period were calculated.

All the studies on the Kafubu River give information on the effects of different human activities on the quality of water in the river and how interventions can be made. But there is limited understanding concerning the extent to which these activities especially land cover change has affected the channel planform of the Kafubu river. The paucity of studies focusing on land use impacts on river planform could be due to limitations in the availability of data with high temporal and spatial resolution in the past. GIS and remote sensing can provide researchers with valuable multi-temporal data for mapping, monitoring and analyzing land use patterns and processes (Lambin *et al*., 2001; Hualou *et al*., 2006). Hence, a GIS and remote sensing approach was used for this study in order to provide a spatio-temporal analysis of the quantitative extent of the impacts of land use change on the Kafubu river planform in terms of the river width.

CHAPTER THREE: DESCRIPTION OF STUDY AREA

3.1 Introduction

This chapter is about the selection, location and description of the study area, focusing on the physical characteristics as well as socio-economic characteristics of the area.

3.2 Selection of Study Area

Studies about the Kafubu River report about the pollution and reduced water quality. There is also increased built up area around the river. Owing to the relationship between built up areas and water resources, the researcher was motivated to carry out a study to show the extent of the land use changes near the river and the associated planform changes of the river.

3.3 Location and site of study area

The Kafubu River mainly lies in Ndola District of Copperbelt Province in Zambia. The Kafubu River is a sub catchment of the Kafulafuta River that drains into the Kafue River. Its source is the Itawa Swamps located north of Ndola city and joins the Kafulafuta River south of Luanshya. It is about 40 km long (Nkaka, 2000). The study focused on the part of the river that is in the urban area of Ndola covering a distance of 3.6 km. Ndola District is located between $12^0$45'S and $13^0$10'S and extends from $28^0$27'E to $28^0$34'E. The study area lies between $12^0$58'30''S and $13^0$0'0''S and extends from $28^0$37'0''E to $28^0$38'30''E covering a total area of about 555.14ha. The location map of the study area is given in Figure 3.1.

3.4 Physical Characteristics

3.4.1 Climate

Ndola falls in the third agro-ecological region in Zambia. It has a mean annual temperature of 20.7^0C. Zambia has three identifiable seasons, namely; rainy season (October-April), the cold dry season (May-August) and the hot dry season (September- October). The rainy season start in November ending in April with a total annual rain fall ranging from 1000 to 1300 mm (Golden Lay Limited, 2013).

3.4.2 Relief, Geology and Soils

Most of the Kafubu River lies on a plateau varying in elevation from about 1200m to 1300m. For the Kafubu catchment area, aquifers of basement rocks (formed by gneiss and granite) and the lower Roan series (formed by quartzite) prevail (Fahle *et al*., 2017). The types of soil found in the area are generally acrisols (JCAF, 2008).

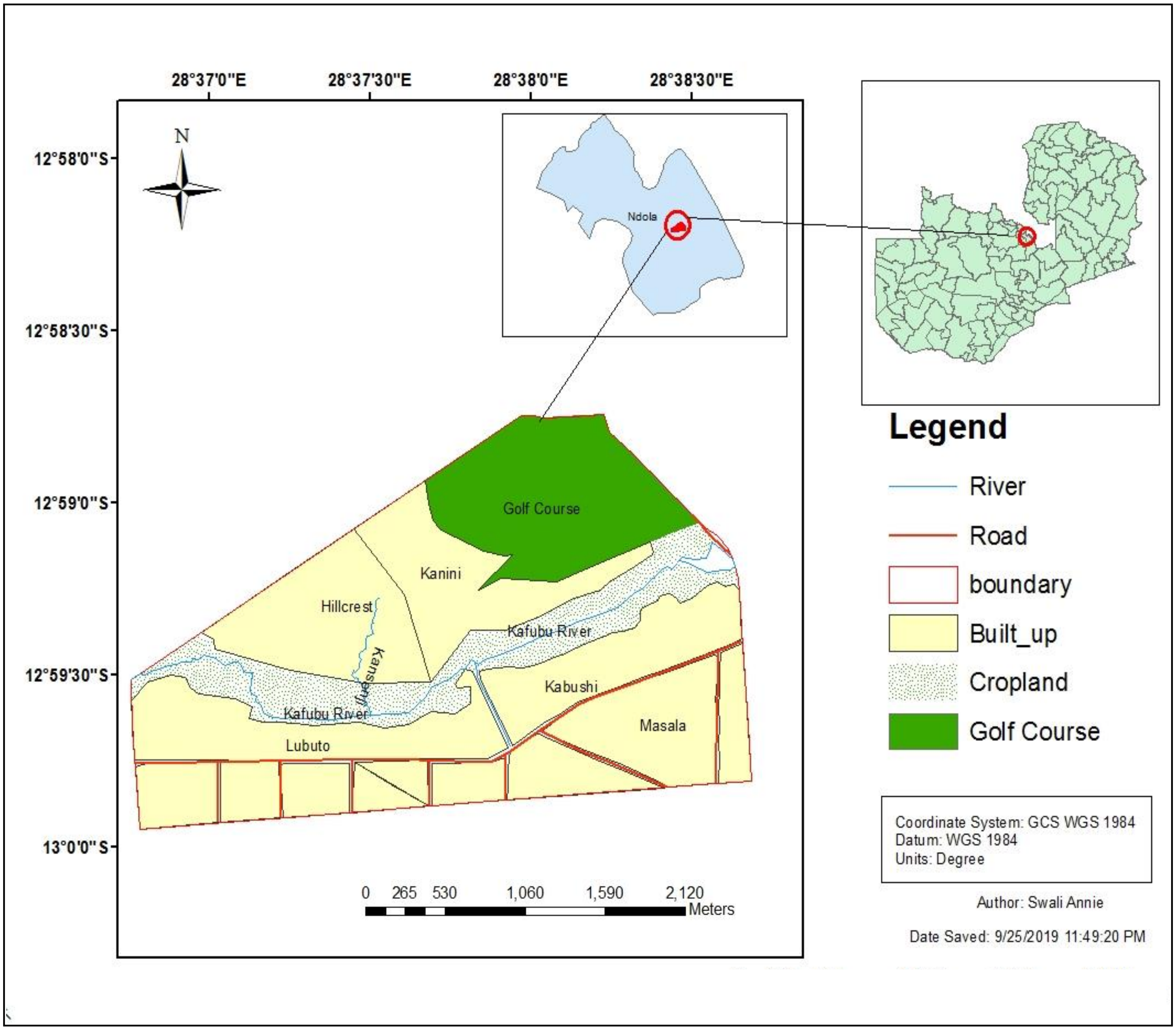

Figure 3. 1: Location of the study area, Kafubu, Zambia.

Source: Air photographs (1993 and 2015) and Satellite Image (IKONOS 2009)

3.4.3 Vegetation

Ndola has natural *Miombo* woodland with tree species such as *Brachystegia-Julbernardia* (Chidumayo, 1997). The Zambia Forestry and Forest Industries Corporation Limited (ZAFFICO) has forest plantations dominated by exotic species such as pines with the main species being *Pinus kesiya* and *Pinus* oocarpa and Eucalyptus the main species being *Eucalyptus gandis* and *Eucalyptus cloeziana*. ZAFFICO grows these trees and processes them into timber after harvesting.

3.4.4 Land use

The land use of Ndola's total land is composed of agriculture, forestry and plantations, mining, recreational facilities and residential areas. There are dairy, poultry and fresh vegetable farms mostly for local supplies. There is also some small-scale gardening within the buffer zone of the study area where crops like maize and fresh vegetables such as rape are grown throughout the year. The plantations are owned by ZAFFICO. The low-density residential areas near the study area are Kanini and Hillcrest while Masala, Lubuto and Kabushi are high density residential areas.

3.5 Socio- economic characteristics

3.5.1 Social amenities

The population of Ndola District is 451,246 (CSO, 2014). Ndola has several educational facilities such as primary schools, basic schools, secondary schools, colleges, trade schools and universities. There are two high level hospitals; Ndola Teaching Hospital and Arthur Davison Children's Hospital and several health centres all over the districts. The Kafubu Water and Sewerage Company renders sanitation services to some parts of the district. There are a number of recreational facilities such as Levy Mwanawasa Football stadium, Ndola Golf Course, Wanderer's Rugby Field, a Tennis Club, a Museum and some social clubs. The town has the Zambia Railways line passing through it for transportation of goods and passengers. It also has the Simon Mwansa Kapwepwe Airport.

3.5.2 Livelihoods

By the year 2010, the Copperbelt province had a total population of 1,972,317 of which 981,887 were males and 990,430 were females. 40.9 percent of the population is below 15 years old and those above 65 years old were 2.3 percent of the population. The median age for the province is 18.5 years old. In terms of employment by sector for the Copperbelt, the majority (64.2%) of people depend on the informal sector for employment while the remaining 35.8 percent are engaged in the formal sector (CSO, 2014). There is small scale fishing activities of in the Kafubu river.

3.5.3 Economy

Ndola has a number of cement producing industries such as Dangote Cement, Portland cement and Lafarge Cement. There is also Ndola Lime and Neelkanth lime plants. Mining activities such as Emerald mining by Kagem Mining and copper processing by First Quantum Bwana Mukuba mine exist. Petroleum refinery at Indeni Oil Refinery is also another notable economic activity. Global industries producers of cooking oil and washing soaps is another big industry in Ndola. There is also presence of food producing industries for tinned food and juice. There is an electrical company called Elswedy Electrical that is mainly responsible for the manufacturing of transformers and electric metres.

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This chapter outlines the source of data, and methods used in data collection, sampling procedure and data analysis. The philosophical orientation of the study is positivism. Positivism deals with methodological techniques of the physical sciences that aim to uncover universal laws that provide probable causal explanations and empirical observations free of personal feelings or judgements (Marvasti, 2004).

4.2 Data Collection

The data collected was of two types: primary and secondary data types. These are discussed below.

4.2.1 Primary Data

Key informant interviews targeting 5 key informants from the Ndola City Council (NCC) Planning Department and semi structured interviews with 13 local residents were conducted. These interviews were carried out in order to get views on the land use changes as well as river planform changes over time and on factors contributing to land use changes and river channel planform changes. The sample of 13 local residents was selected through snowball sampling targeting those that have lived in Ndola for more than 20 years because they were to a large extent able to witness changes of both land use and river planform in the study area. There were only 13 respondents because when respondents were asked to recommend a possible participant, it was either the ones they knew were deceased or they moved to places away from the river and had not been paying close attention to notice changes in the river planform. The respondents from NCC were purposefully sampled as they have in-depth knowledge of the land use changes and their implications in the study area. All but one interview was voice recorded after informed consent was obtained. One interviewee was not comfortable with being recorded. He preferred to write down his responses to all questions on the interview schedule.

Eleven Ground Control Points which are places that have been in the study area since 1974 and 1993 had their GPS coordinates recorded in order to be used in the georeferencing of images. These places include the Kanini sewage treatment plant, the Kabushi foot bridge, the Ndola golf club, the main T4 road and some road crossings found in the residential areas of the study area. Ground truthing of the river channel at each of the 10 transects made across the river channel polygon for each year was carried out. This was done by getting the map coordinates of each of the river banks from the images and using them to locate their position on the ground. Measurements of the river channel width at each transect was carried out using a measuring tape. This was done in order to be sure that each transect on the river polygons extracted from the images was on the exact position on the ground. Additionally, this was to confirm that what was being measured was indeed the river channel width. Thereafter, the Root Mean Square Error of the measured dataset was calculated to determine how accurate the measured channel width values were. The ground truthing was also done in order for the researcher to observe physical features on the river banks that can give an indication of what could have caused the planform changes detected if any and if they were related to land use on the river banks. Photographs of the river banks were taken by the researcher using a camera with a resolution of 720 X 1280.

4.2.2 Secondary Data

Aerial photographs covering the Ndola urban area along the Kafubu River from the years 1974, 1993 and 2015 were obtained from the Survey Department in Lusaka. For the year 1974, only one aerial photograph was available and it did not cover much of the study area but was used mostly for georectification purposes. Five (5) aerial photographs from the year 1993 were obtained and two (2) aerial photographs of the study area were obtained for the year 2015. Additionally, a high resolution IKONOS satellite image for the year 2009 was obtained from the Ndola City Council. This study required images with a very high spatial resolution. Images with high spatial resolution are expensive to acquire. With limited resources, the researcher could only get free images from the survey department, the Ndola City Council, National Remote Sensing Centre or the United States Geological Survey (USGS) Earth Explorer website. However, the images from the National Remote Sensing Centre and USGS Earth Explorer website were all of low spatial resolution and the classification was very unsatisfactory. After making requests for images of the study area from the survey department and Ndola City Council, only those from 1974, 1993, 2009 and 2015 were available. Hence the time intervals used in this change detection study.

4.3 Data Analysis

4.3.1 Images and Map Analysis

To cover the intended period of study, different images were acquired with some having different properties. All the images used in the analysis were of the month of July or August. This is because vegetation cover and other ground conditions, particularly the water level, are relatively consistent from year to year which is essential for assessing the inter-year change of the river. In addition, July and August fall in the dry season during which the chances of getting a relatively cloud free atmosphere is higher and the planform generally shows the boundary and pattern of channels clearly. The details of the images acquired are shown in Table 4.1.

In order to carry out a change detection study, maps of the study area had to be constructed using the images available for the different years.

Table 4. 1 Details of images used

Date	Sensor Type	Format	Bands	Spatial resolution (m)
September 1974	Air photo	TIFF	4	0.3
July-August 1993	Air photo	TIFF	4	0.3
01/07/2009	IKONOS satellite image	TIFF	3	10
24/07/2015	Air photo	TIFF	3	10

Source: Air photographs and satellite image

The software used is ArcGIS 10.5 (ESRI, 2016). Using the mosaic to new raster tool, the two 2015 air photos were joined to make a mosaic called 2015 mosaic. The well distributed 11 collected GPS coordinates were plotted and used to geo reference the 2015 mosaic with a root mean square error of 0.24m. The spatial reference UTM WGS 84 35S was used. The five (5) over lapping aerial photos from the year 1993 covering the study area were joined to form a mosaic named 1993 mosaic. The 1993 mosaic and the 2009 satellite image were both registered to the 2015 mosaic which was used as the base image using the same spatial reference. After the georeferencing was complete, prominent features in all images that were nearest to the edges of the 1993 image and covering the area of interest were used to draw a polygon to represent the study area. The 1993 image was used to define the study area because for the year 1993, the imagery available did not cover an area as large as 2009 and 2015 and the same study area for each year is needed to make comparisons. The polygon was named study area. The area covered by the study area polygon on the images was clipped using the extract by mask tool resulting in three images, one for each year under study, showing the study area only. The images were named 1993 image, 2009 image and 2015 image as shown in Figure 4.1.

Object based classification which happens in two stages: segmentation and classification, was then carried out on all three images. The images were segmented using the segment mean shift approach, which is a technique that uses a moving window that calculates the average pixel value to determine which pixels should be included in each segment and assigns it a colour. Thereafter, training samples made up of at least 20 segments to define each feature class were obtained from each segmented raster image. The train maximum likelihood classifier was used to generate the classifier definition file which is used during the classification process. Maximum likelihood classification was carried out with 5 main classes: built up, vegetation, crop land, river and bare land. The classified raster images were converted to polygons. The total areas for each land use in each year were computed using the calculate geometry and summarize tool.

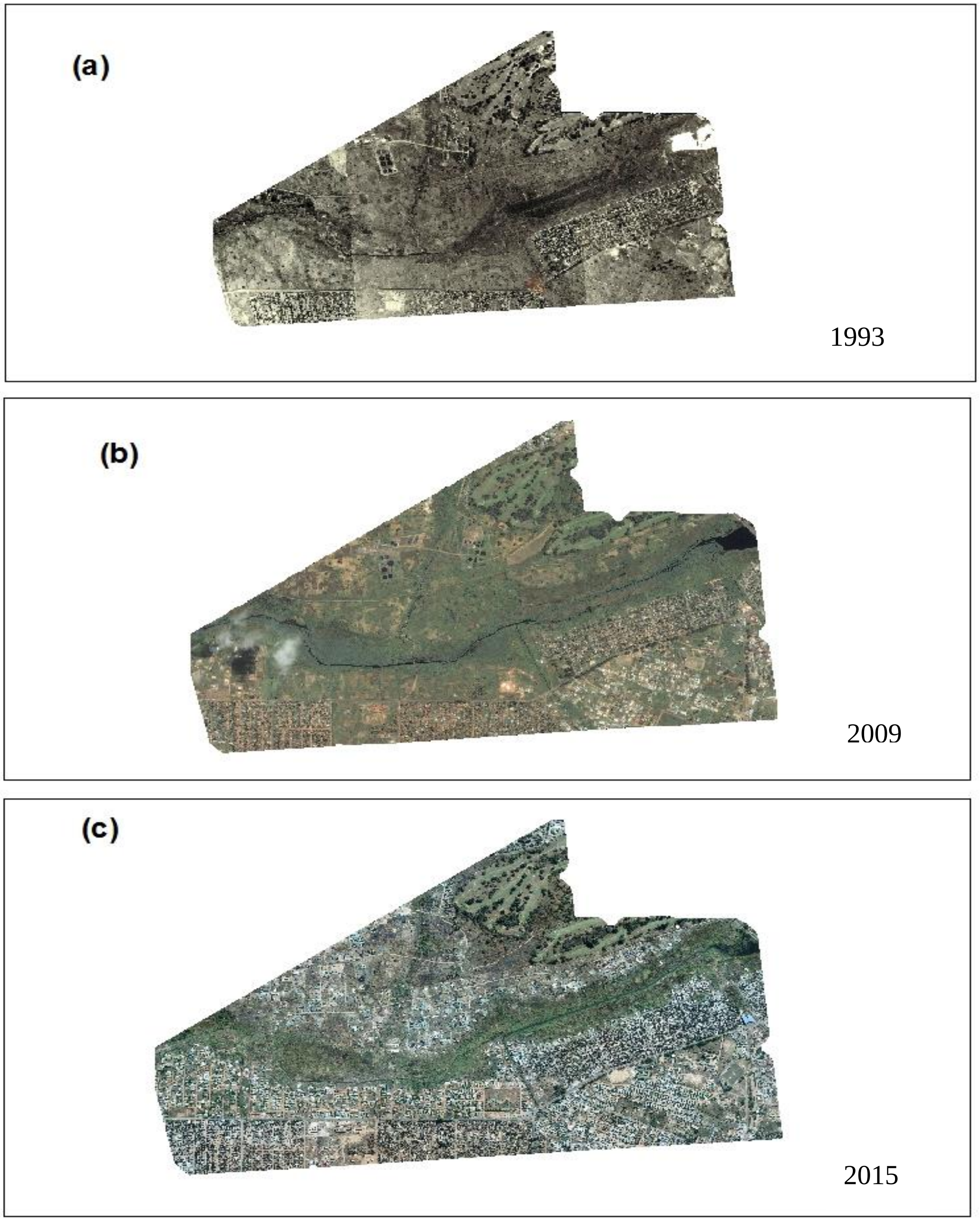

Figure 4. 1: Images of study area at different times (a) 1993, (b) 2009 and (c) 2015.

Sources: Air photographs (1993 and 2015) and satellite image (2009).

The land use areas were compared to determine the quantitative areal changes that took place during the study period. The results were displayed in bar graphs and tables. In order to carry out the accuracy assessment of the classification, the attribute table of the classified map was exported to Microsoft Excel where a pivot table was used to generate a confusion error matrix. Thereafter, the user accuracy, producer accuracy, overall accuracy and Cohen's kappa were calculated. According to Bharathar and Patel (2013), the overall accuracy, is calculated by dividing the correctly classified pixels (sum of the values in the main diagonal) by the total number of pixels checked.

Overall accuracy (%) = Correctly classified pixels/Total number of pixels

The User's accuracy is the ratio between the number of correctly classified pixels and the classified totals pixels of particular land use class

User's accuracy (%) = Correctly classified pixels /Classified total pixels

The producer' accuracy is the ratio between the number of correctly classified pixels and the reference total pixels for particular land use class.

Producer's accuracy (%) = Correctly classified pixels/Reference total pixels

The kappa coefficient (K) can be computed as follows,

$k = P_o - P_c / 1 - P_c$ …………………………………………………..Equation 1

Where,

P_o= overall accuracy

Pc = chance agreement

Chance agreement incorporates the sum of the product between the row and column totals.

Object-based post-classification change detection was carried out to determine the quantitative areal changes that might have taken place in the land use classes. For change detection between the years 1993 and 2009, the polygons made from the classified images for the two years were intersected. The same was done for the 2009 and 2015 polygons. The resultant polygons showed the locations where changes had occurred in some land uses and also showed where land uses did not change during the study period. The attribute tables of the intersect polygons were exported to Microsoft Excel and the pivot table was used to generate change detection matrices.

Thereafter, the river polygons were extracted from each image using the select by attributes and export tools. The extracted polygons of the river were named 1993 river polygon, 2009 river polygon and 2015 polygon. The total areas of the river polygons for each year were computed using the calculate geometry and summarize tool. A centerline in the middle of each river polygon was digitized. The river polygons were then exported to Autodesk's AutoCAD 2018. Ten (10) identical cross sections 370m apart were made on each river polygon in order to measure and compare their width in order to find out if there have been changes in the river width during the study period. The results were displayed using a bar graph and a table.

The distances of the left and right wetted extent of the river from the centerlines were calculated for each year. These measurements of distances were exported to Microsoft Excel for further analysis. The differences in these distances between the years revealed how much change in wetted extent of the river had taken place. These positive differences meant that the wetted river extent had widened and were translated as erosion distance while the negative differences meant that the wetted river extent had narrowed and were translated as accretion distance. The erosion and accretion rates were calculated by dividing the bank erosion distance or accretion distance by the time period. The results were displayed using line graphs, bar graphs and a table. The areas where erosion took place were shaded in green while those where accretion took place were shaded in orange for the areas of change for the entire study period between 1993 and 2015. The total areas of the polygons showing erosion and those showing accretion where computed and presented in a table. A summary of the image analysis methodology is shown in Figure 4.2. The measurements of channel width across the ten transects collected during ground truthing were compared with the measurements on the most recent photo (the 2015 image) measurements in order to establish if what was measured on the photos was really the channel width. Graphs and tables were used to compare the two sets of measurements.

4.3.2 Interview Data Analysis

The recorded responses from the interviews were transcribed and analysed using inductive thematic analysis in order to derive themes from the content of data collected from interviewees. The responses from the respondents for each question were coded. Some responses not relevant to the research questions were discarded. After that a number of themes emerged which were refined later on. Graphical presentations of the themes that emerged using graphs were done.

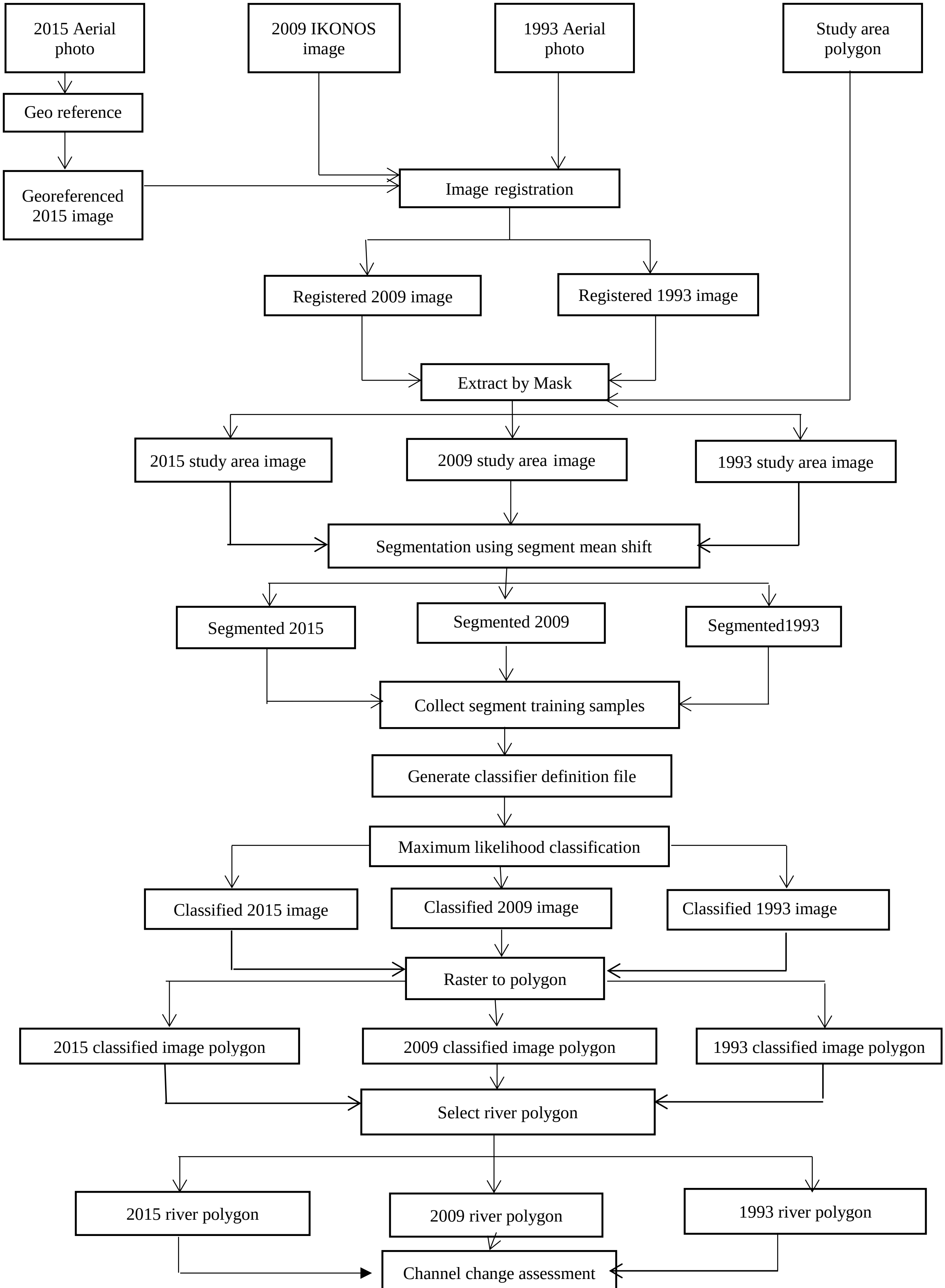

Figure 4. 2: Flow chart for image analysis methodology.

CHAPTER FIVE: RESULTS

5.1 Introduction

This chapter presents the results of the research. The fundamental outputs of this study were the land use maps for 1993, 2009 and 2015, the area gains and losses of the identified land uses, the change detection, the channel planform changes and the factors attributed to the land use changes and the channel planform changes. The organization of the results is based on the objectives starting with first objective, and then the same is done for all other objectives.

5.2 Extent of land use changes around the Kafubu River in Ndola Urban (1993 to 2015)

Five land uses were identified: vegetation, bare land, built up, crop land and river. Since all the raster images were converted to polygons, the total area covered by each land use was computed and compared for each year under study in order to determine the extent of the detected land use change. The respondents from the study indicated that there have been land use changes in the study area based on their responses shown in Figure 5.1.

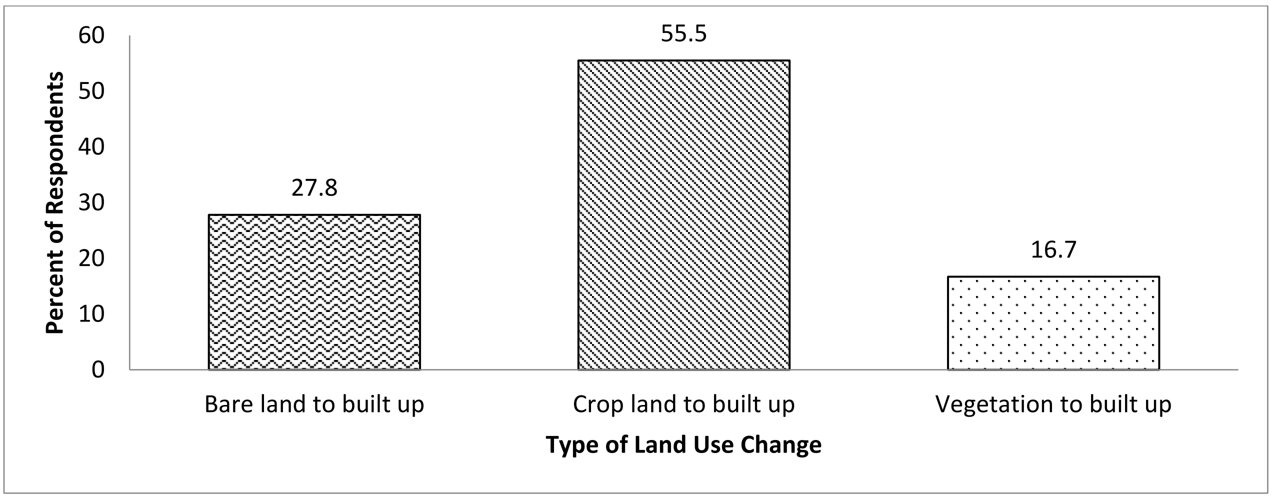

Figure 5. 1: Land use changes observed by respondents

Source: Field data, 2019

5.2.1 Areal Extent of Land use for the year 1993

The land use classification of the study area for the year 1993 is shown in Figure 5.2.

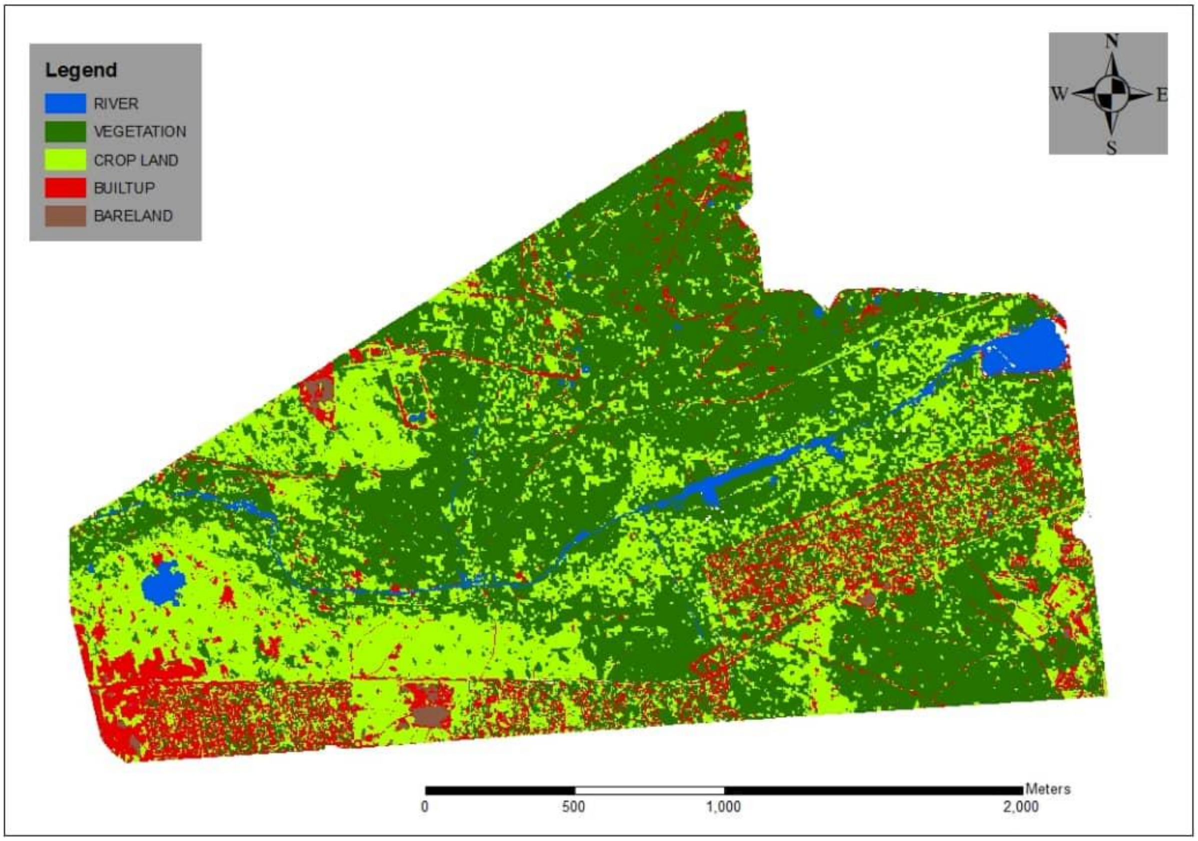

Figure 5. 2: Land use classification map of the study area for the year 1993.

Source: 1993 Aerial photographs

The areal extent of each land use in the 1993 image is shown in Table 5.1

Table 5. 1: Areal extent of land use types for the year 1993.

Land use class	Area(ha)	Area (%)
Vegetation	300.01	54.04
Built up	41.54	7.48
Bare land	25.78	4.64
Crop land	170.67	30.75
River	17.14	3.09
Total	**555.14**	**100**

Source: 1993 Land use map

5.2.2 Areal Extent of Land Use for the year 2009

The land use classification of the study area for the year 2009 from the IKONOS image is shown in Figure 5.3.

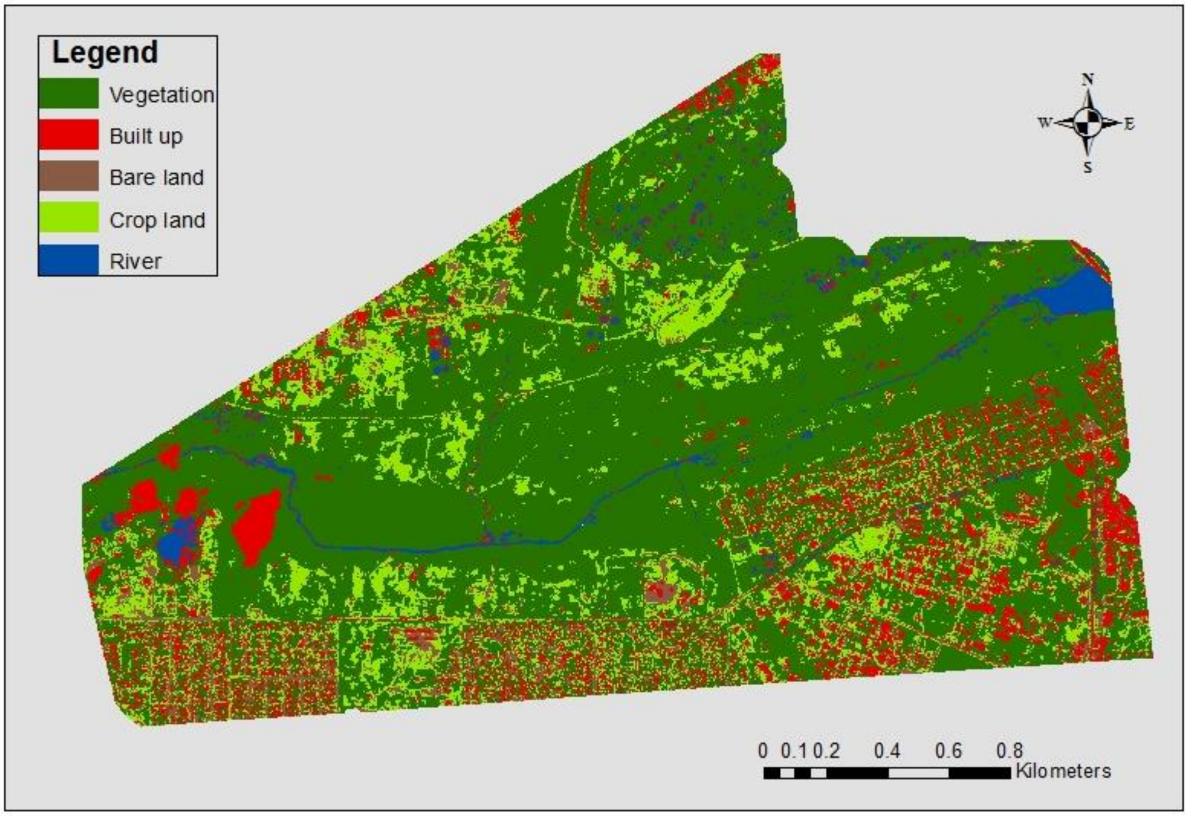

Figure 5. 3: Land use classification map of the study area for the year for 2009.

Source: 2009 IKONOS satellite image

The areal extent of land use types in 2009 is shown in Table 5.2.

Table 5. 2: Areal extent of land use types for the year 2009

Land use class	Area(ha)	Area (%)
Vegetation	345.39	62.22
Built up	97.35	17.54
Bare land	49.96	8.99
Crop land	45.49	8.19
River	16.95	3.06
Total	**555.14**	**100**

Source: 2009 Land use map

5.2.3 Areal Extent of Land Use for the year 2015

The land use classification of the 2015 aerial photographs for the study area is shown in Figure 5.4.

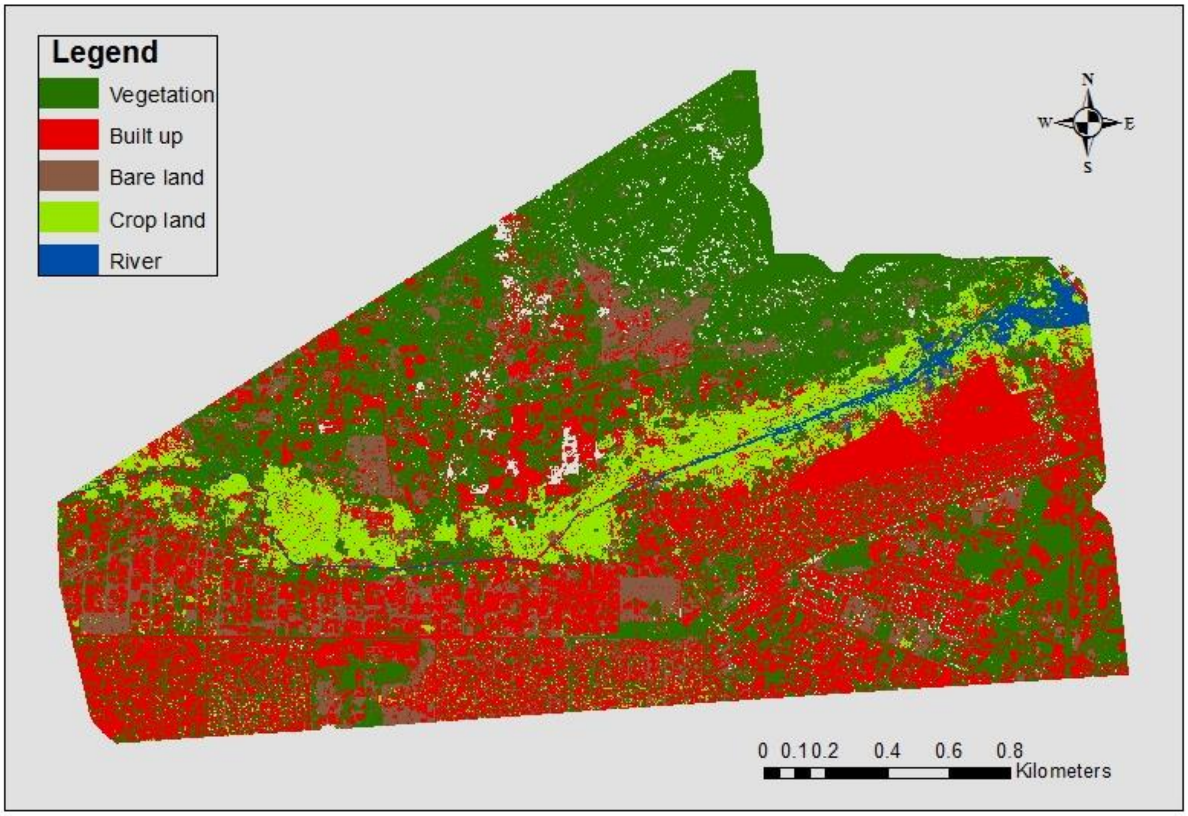

Figure 5. 4: Land use classification map of the study area for the year 2015.

Source: 2015 Aerial photographs

Table 5.3 shows the total areal extent of land use types of the study area for the year 2015

Table 5. 3: Areal extent of land use types for the year 2015

Land use class	Area(ha)	Area (%)
Vegetation	230.1	41.45
Built up	198.46	35.75
Bare land	59.34	10.69
Crop land	59.22	10.67
River	8.02	1.44
Total	**555.14**	**100**

Source: 2015 Land use map

5.2.4 Land Use Area Change

The observed or measured transitioning area coverage in hectares of the classified land use categories were calculated for each of the years 1993, 2009 and 2015 as presented in Table 5.4. Comparison of land use areas between years revealed both positive (increase) and negative (decrease) changes.

Table 5. 4: Transition in areal coverage of land use classes

Land Use Classes	1993 Area (ha)	2009 Area (ha)	Area change (ha) (1993-2009) 16 years	Annual rate of change	2015 Area (ha)	Area change (ha) (2009-2015) 6 years	Annual rate of change	Area change (ha) (1993-2015) 22 years	Annual rate of change
Vegetation	300.01	345.39	45.38	2.84	230.1	-115.29	-19.22	-69.91	-3.18
Built up	41.54	97.35	55.81	3.49	198.46	101.11	16.85	156.92	7.13
Bareland	25.78	49.96	24.18	1.51	59.34	9.38	1.56	33.56	1.53
Cropland	170.67	45.49	-125.18	-7.82	59.22	13.73	2.29	-111.45	-5.07
River	17.14	16.95	-0.19	-0.01	8.02	-8.93	-1.49	-9.12	-0.41
Total	555.14	555.14			555.14				

Source: 1993, 2009 and 2015 Land use maps

It was also important to analyse the areal change of the identified land use classes between time intervals over the period under study. Thus, Table 5.5 shows these changes between time intervals of 1993- 2009, 2009- 2015 and 1993- 2015. The negative values show a decrease while the positive values imply an increase in land use size. The column showing change is given as a percentage. For instance, there was 45.38ha (15.13%) of land increase in vegetation from 1993 to 2009 and a decrease of -115.29ha (-33.37%) between 2009 and 2015. The change in area for the land use classes varied from one category to another and also varied through the time periods.

Table 5. 5: Areal change in land use classes between 1993-2009, 2009-2015 and 1993-2015.

Land Use Classes	Change between 1993 and 2009		Change between 2009 and 2015		Change between 1993 and 2015	
	Area (ha)	Change (%)	Area (ha)	Change (%)	Area (ha)	Rate of Change (ha/year)
Vegetation	45.38	15.13	-115.29	33.37	-69.91	-3.18
Built up	55.81	134.35	101.11	103.86	156.92	7.13
Bare land	24.18	93.79	9.38	18.78	33.5	1.52
Crop land	-125.18	73.34	13.73	30.18	-111.45	-5.07
River	-0.19	1.11	-8.93	52.68	-9.12	-0.41

Source: 1993, 2009 and 2015 Land use maps

Generally, over twenty-two years (1993- 2015), the gross changes in area coverage varied from one land use class to another with built up area experiencing the most increase and crop land undergoing the most decrease in area coverage followed by river as shown in Figure 5.5. The rates of change of the land uses are depicted in Figure 5.6.

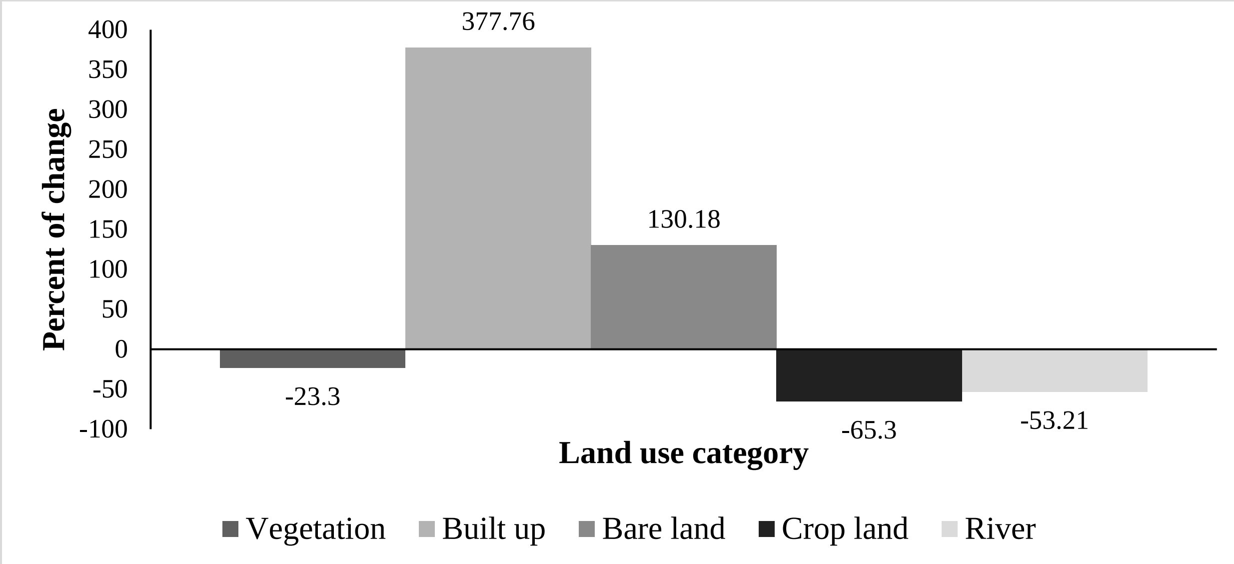

Figure 5. 5: Gross percentage change in land use categories from 1993 to 2015.

Source: 1993, 2009 and 2015 Land use maps

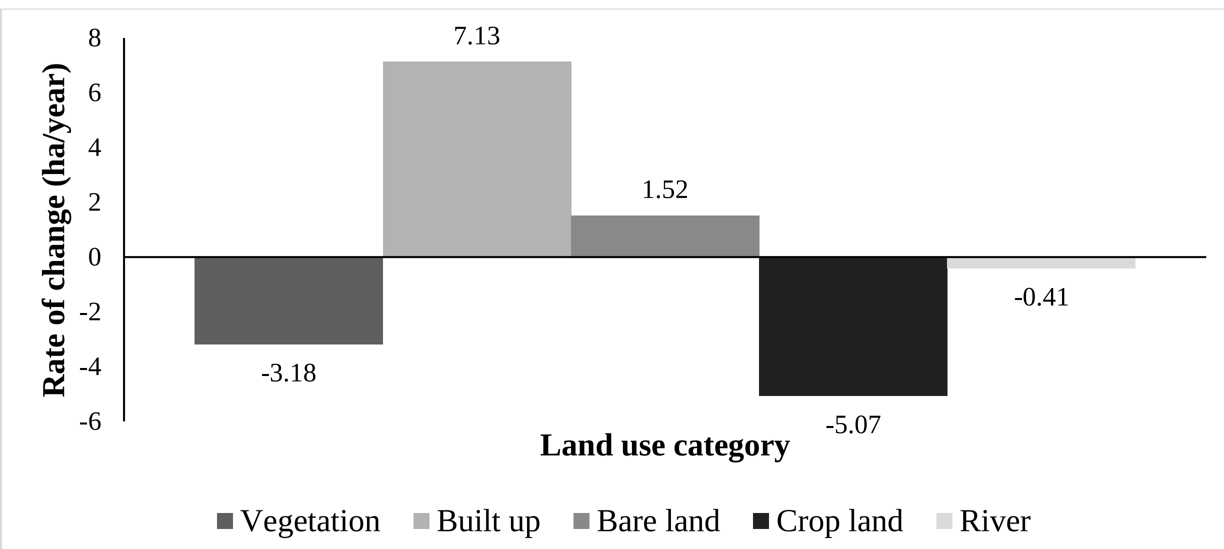

Figure 5. 6: Annual Rate of Land Use Change (ha/year).

Source: 1993, 2009 and 2015 Land use maps

5.2.5 Accuracy Assessment of classification

The results of the accuracy assessment reveal an overall accuracy of 0.89 or 89 percent and a Kappa of 0.87 or percent as shown in Table 5.6.

Table 5. 6: Confusion matrix of classification of the 2015 image

	Reference Data					
Classified Data	Vegetation	Built up	Bare land	Crop land	River	Total
Vegetation	55	2	0	18	0	75
Built up	0	53	3	0	1	57
Bare land	0	0	49	0	0	49
Crop land	0	0	3	36	0	39
River	0	0	0	1	54	55
Total	55	55	55	55	55	275
Producers Accuracy	1	0.96	0.89	0.65	0.98	
Users Accuracy	0.73	0.93	1	0.92	0.98	
Overall Accuracy	0.89					
Kappa	0.87					

Source: 2015 Land use maps

5.2.6 Change detection for the period from 1993 to 2009

Figure 5.7 depicts the change detection map showing the 'from-to' change information for the period 1993 to 2009. For example, in the legend 'Vegetation, Built-up' means that that area on the ground changed from being used for vegetation in 1993 to being a built up area in 2009. The areal changes in hectares are presented in a change detection confusion matrix in Table 5.7.

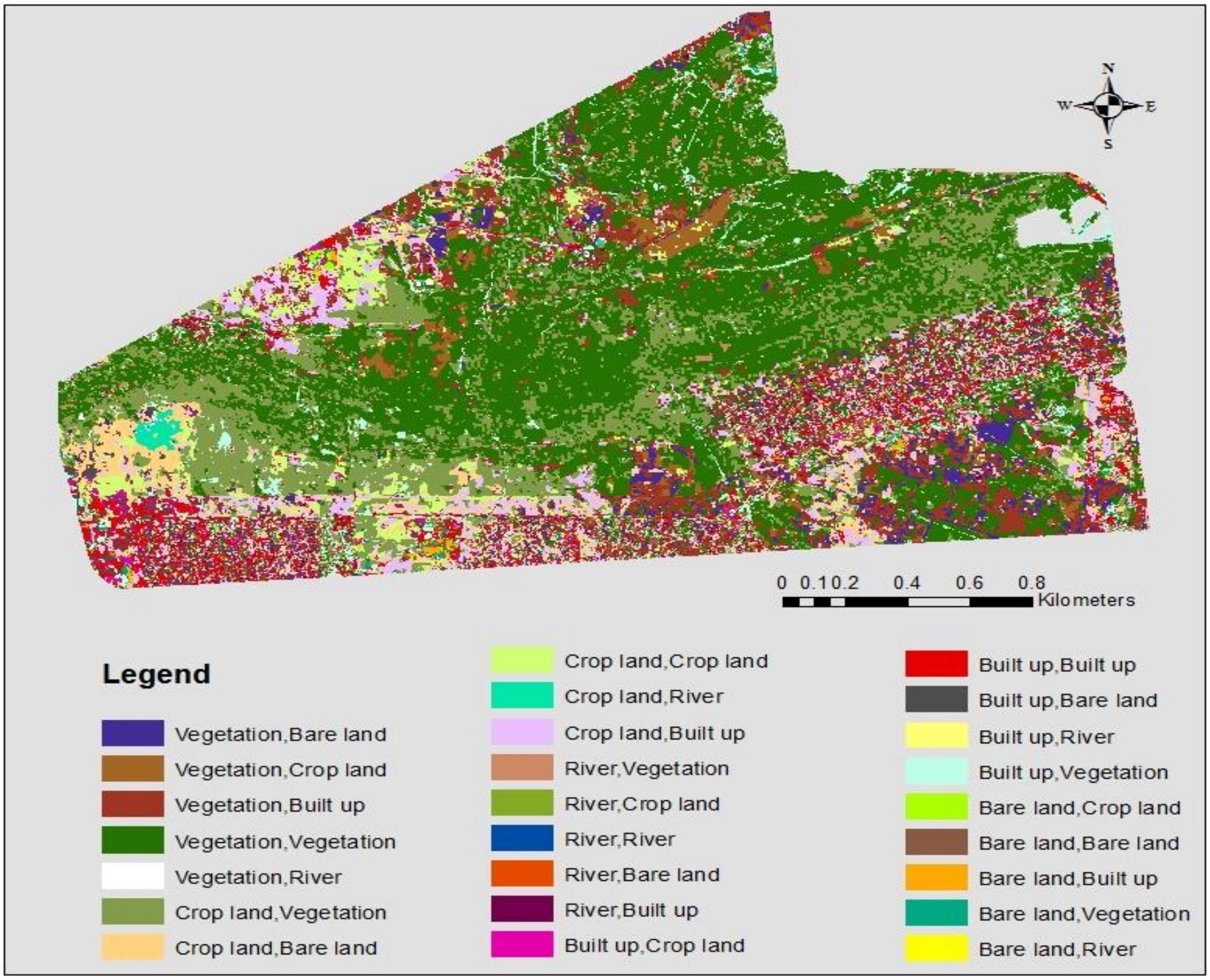

Figure 5. 7: Change detection map of the study area from 1993 to 2009.

Source: 1993 aerial photographs and 2009 IKONOS satellite image

Table 5.7 also shows changes between identified land class categories with regards to conversion of one land use class to another over the 16-year period.

Table 5. 7: Change detection matrix between 1993 and 2009

Land use in hectares for the year 1993	Land Class	Land use in hectares for the year 2009									
		Vegetated area		Built up area		Bare land area		Crop land area		River area	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
	Vegetated	**206.2**	**59.70**	43.58	44.77	19.81	39.65	20.17	44.34	10.25	60.47
	Built up	104.54	30.27	**31.71**	**32.57**	10.72	21.46	17.84	39.22	5.89	34.75
	Bare land	10.04	2.91	3.62	3.719	**1.64**	**3.28**	1.23	2.70	0.61	3.60
	Crop land	18.34	5.31	12.95	13.30	4.67	9.35	**5.48**	**12.05**	0.1	0.59
	River	6.27	1.82	5.49	5.64	13.12	26.26	0.77	1.69	**0.1**	**0.59**
	Total	**345.39**	**100**	**97.35**	**100**	**49.96**	**100**	**45.49**	**100**	**16.95**	**100**

Source: 1993 and 2009 land use classified maps

5.2.7 Change detection for the period from 2009 to 2015

Figure 5.8 depicts the change detection map showing the ‘from-to’ change information for the period 2009 to 2015. The areal changes in hectares are presented in a change detection confusion matrix in Table 5.8.

Figure 5. 8: Change detection map for between 2009 and 2015

Source: 2009 IKONOS satellite image and 2015 aerial photographs

Table 5. 8: Change detection confusion matrix between 2009 and 2015

Land use in hectares for the year 2009	Land Class	Land use in hectares for the year 2015									
		Vegetated area		Built up area		Bare land area		Crop land area		River area	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
	Vegetated	**156.31**	**67.93**	89.81	45.25	39.49	66.55	56.76	95.85	3.02	37.66
	Built up	30.18	13.12	**67.01**	**33.76**	0.1	0.17	0.06	0.10	0	0
	Bare land	20.06	8.72	18.97	9.56	**10**	**16.85**	0.93	1.57	0	0
	Crop land	19.01	8.26	17.58	8.86	8.46	14.26	**0.43**	**0.73**	0.01	0.12
	River	4.54	1.97	5.09	2.56	1.29	2.17	1.04	1.76	**4.99**	**62.22**
	Total	**230.1**	**100**	**198.46**	**100**	**59.34**	**100**	**59.22**	**100**	**8.02**	**100**

Source: 2009 and 2015 land use classified maps

5.2.8 Change detection for the period from 1993 to 2015

Figure 5.9 depicts the change detection map showing the ‘from-to’ change information for the entire 22-year period under study (1993-2015). Table 5.9 is the change detection confusion matrix showing not only the areal changes but also the percentage of change of land uses during the 22-year period.

Figure 5. 9: Change detection map for between 1993 and 2015.

Source: 1993 aerial photographs and 2015 aerial photographs

Table 5. 9: Change detection confusion matrix between 1993 and 2015

	Land Class	Land Use for the year 2015									
		Vegetated area		Built up area		Bare land area		Crop land area		River area	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Land Use for the year 1993	**Vegetated**	**139.4**	**60.60**	107.02	53.92	16.1	27.13	34.23	57.71	3.26	40.65
	Built up	6.89	2.99	**26.13**	**13.17**	5.85	9.86	2.37	3.99	0.3	3.74
	Bare land	0.9	0.39	3.76	1.89	**11.29**	**19.03**	9.53	16.07	0.3	3.74
	Crop land	70.72	30.75	61.35	30.91	25.1	42.29	**11.9**	**20.06**	1.6	19.95
	River	12.1	5.26	0.2	0.10	1	1.69	1.28	2.15	**2.56**	**31.92**
	Total	**230.01**	**100**	**198.46**	**100**	**59.34**	**100**	**59.31**	**100**	**8.02**	**100**

Source: 1993 and 2015 land use classified maps

5.3 Changes in channel width of the Kafubu River in Ndola Urban (1993 to 2015)

5.3.1 Changes in Channel Width

This section presents the findings of the detected extent of planform changes of the Kafubu River channel in Ndola Urban from aerial photographs and satellite image from 1993 to 2015. Figure 5.10 shows the river polygons for the years 1993, 2009 and 2015 and the ten identical chainages or transects of cross-sections located 370m apart from each other and numbered 1 to 10 in the downstream direction, which were used to compare the width of the river channel at the selected cross-sections on the same position for each of the three study years.

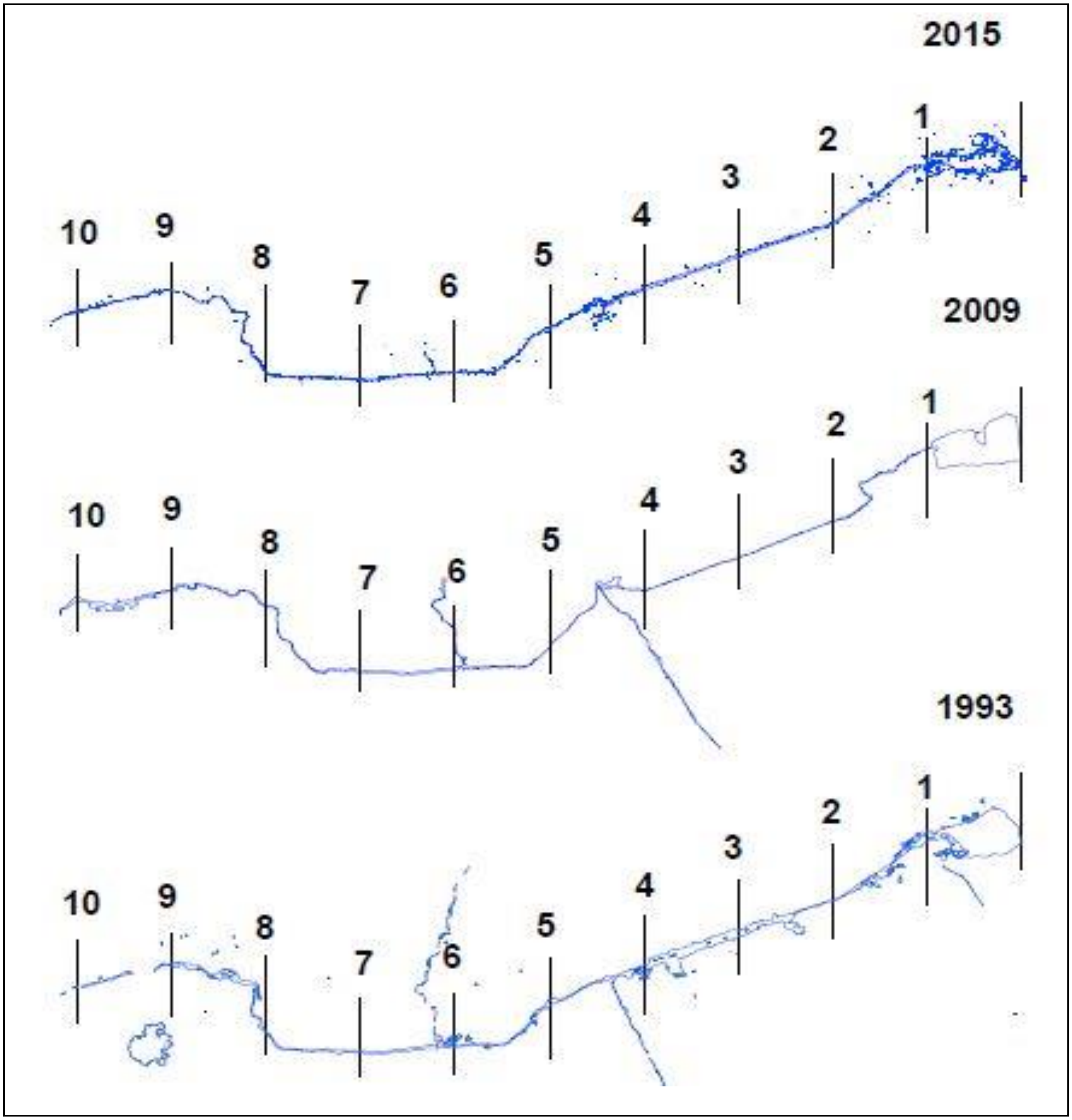

Figure 5. 10: Transects on river polygons for each year 1993, 2009 and 2015

Source: 1993 Aerial photographs, 2009 IKONOS Satellite image and 2015 Aerial photograph

Table 5.10 shows the extent of change in width for each of the cross sections shown in Figure 5.10.

Table 5. 10: Extent of channel width change at the ten transects for each year under study

No. Chainage /Transect/ Cross-section	Distance from Main road	River Channel Width (m)			Width Change from 1993-2015 (m)	Rate of annual change from 1993-2015 (m)	Percentage rate of change from 1993-2015 (m)
		1993	2009	2015			
1	333.4	37.99	5.81	16.45	-21.54	-0.98	-56.69
2	666.8	4.62	3.84	9.10	4.48	0.20	96.97
3	1000.2	23.50	4.38	9.90	-13.6	-0.62	-57.88
4	1333.6	18.12	4.01	12.23	-5.89	-0.27	-32.51
5	1667	22.07	2.53	2.41	-19.66	-0.89	-89.08
6	2000.4	5.25	11.17	1.36	-3.89	-0.18	-74.09
7	2333.8	6.03	8.02	3.94	-2.09	-0.1	-34.66
8	2667.2	5.65	6.53	4.02	-1.63	-0.07	-28.85
9	3000.6	6.33	7.02	2.49	-3.84	-0.17	-60.66
10	3334	4.43	18.89	4.86	0.43	0.02	9.71

Source: 1993, 2009 and 2015 land use classified maps

Overlay maps for different years of the study reach were also prepared to show channel changes in the study period from cross-section 1 to 10 divided into five segments. The maps of the river-segments (a, b, c, d and e) are shown in Figures 5.11 to Figure 5.15 in the downstream direction showing planform changes in the study period.

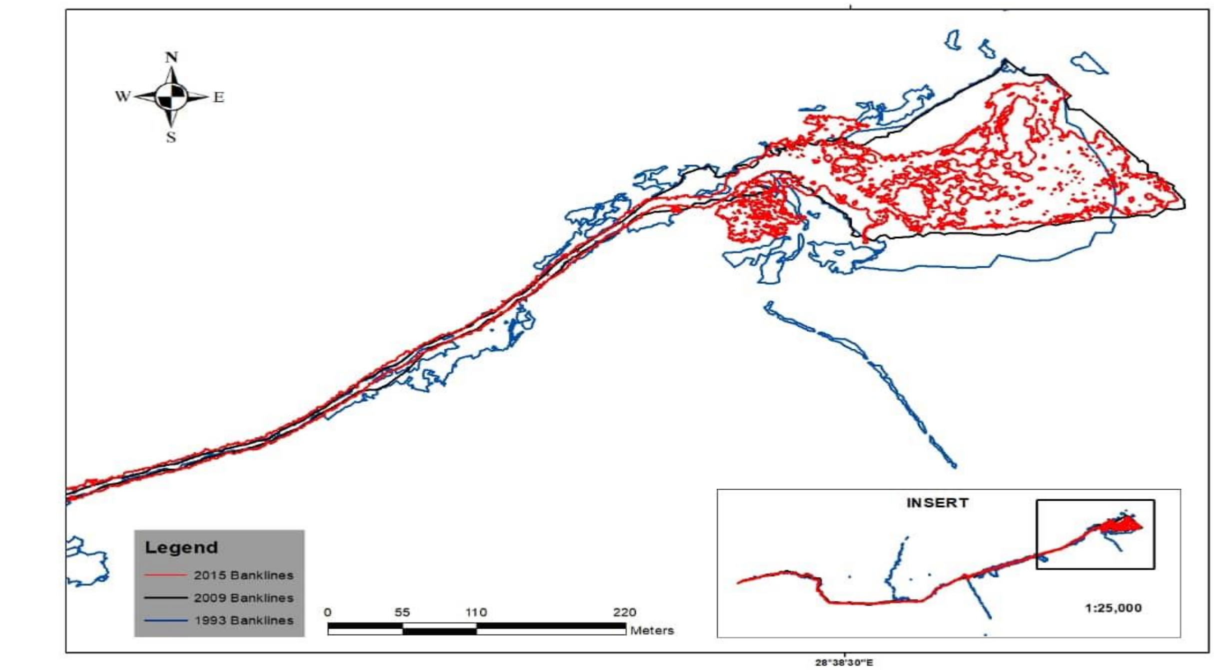

Figure 5. 11: Planform Changes during study period- Segment (a)

Source: 1993, 2009 and 2015 classified land use maps

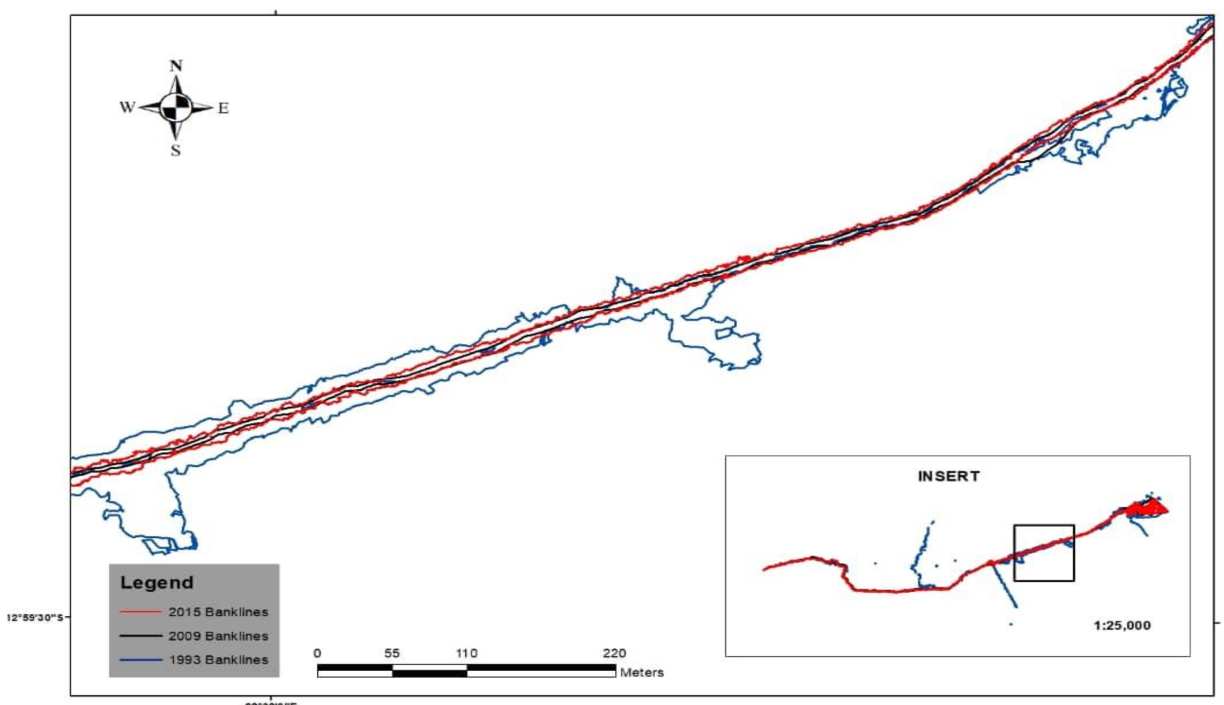

Figure 5. 12: Planform Changes during study period- Segment (b)

Source: 1993, 2009 and 2015 classified land use maps.

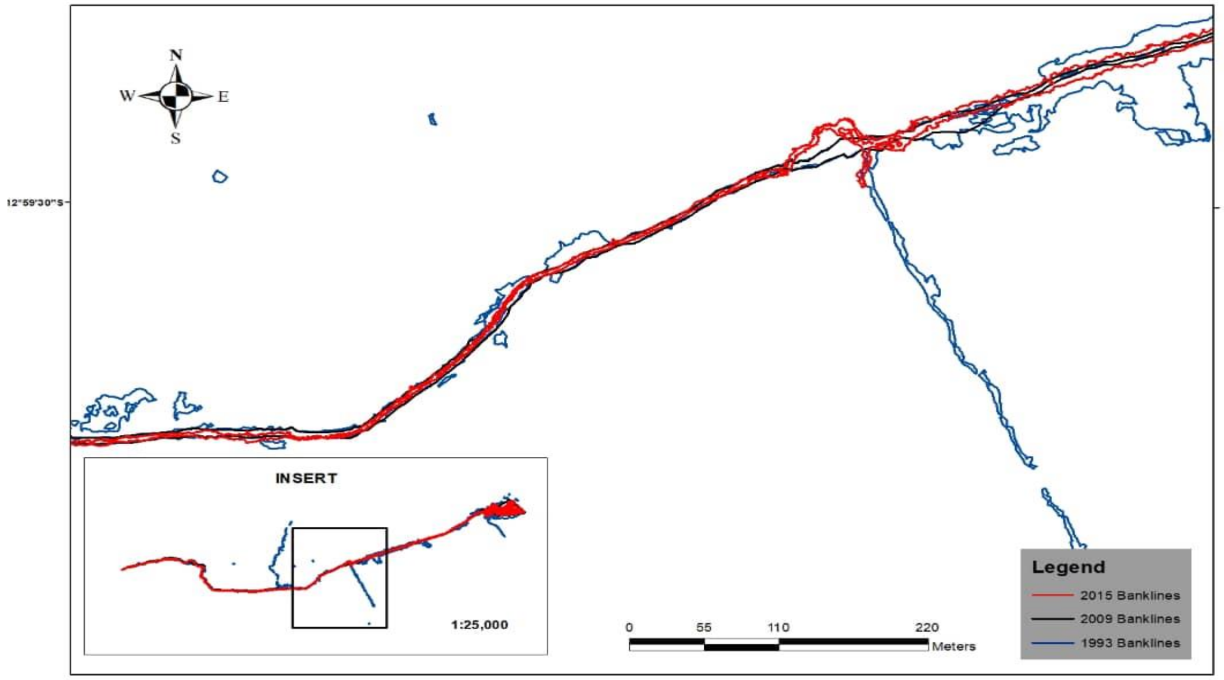

Figure 5. 13: Planform Changes during study period- Segment (c)

Source: 1993, 2009 and 2015 classified land use maps.

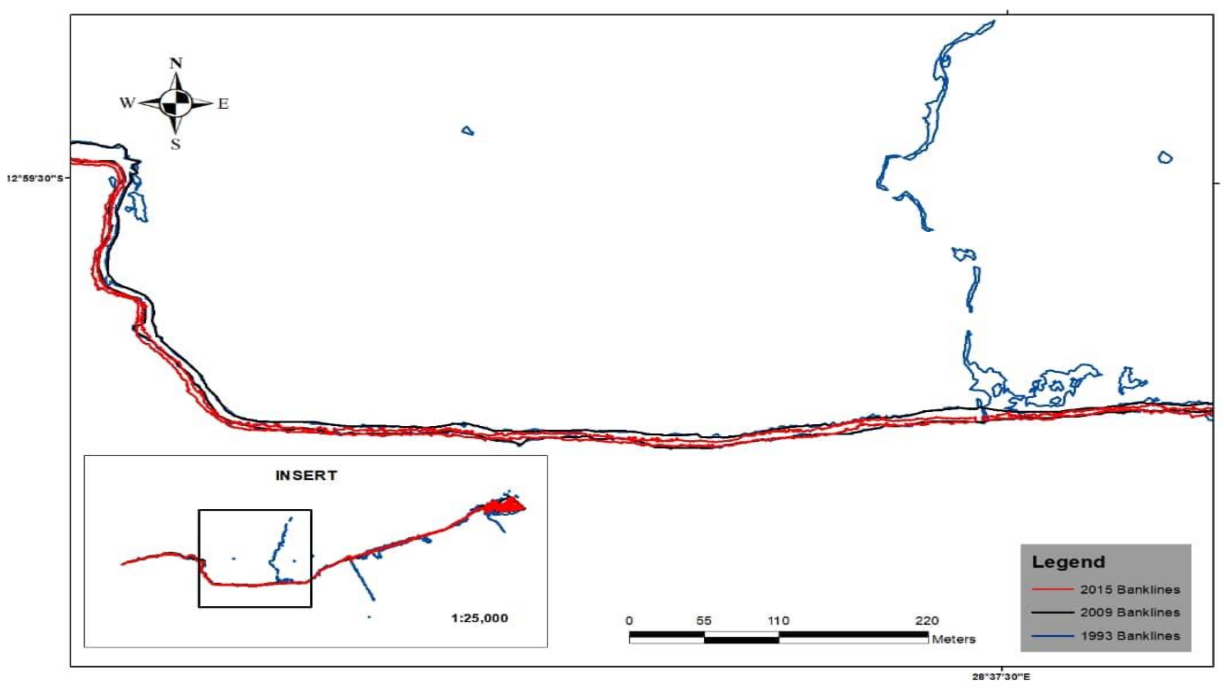

Figure 5. 14: Planform Changes during study period- Segment (d)

Source: 1993, 2009 and 2015 classified land use maps.

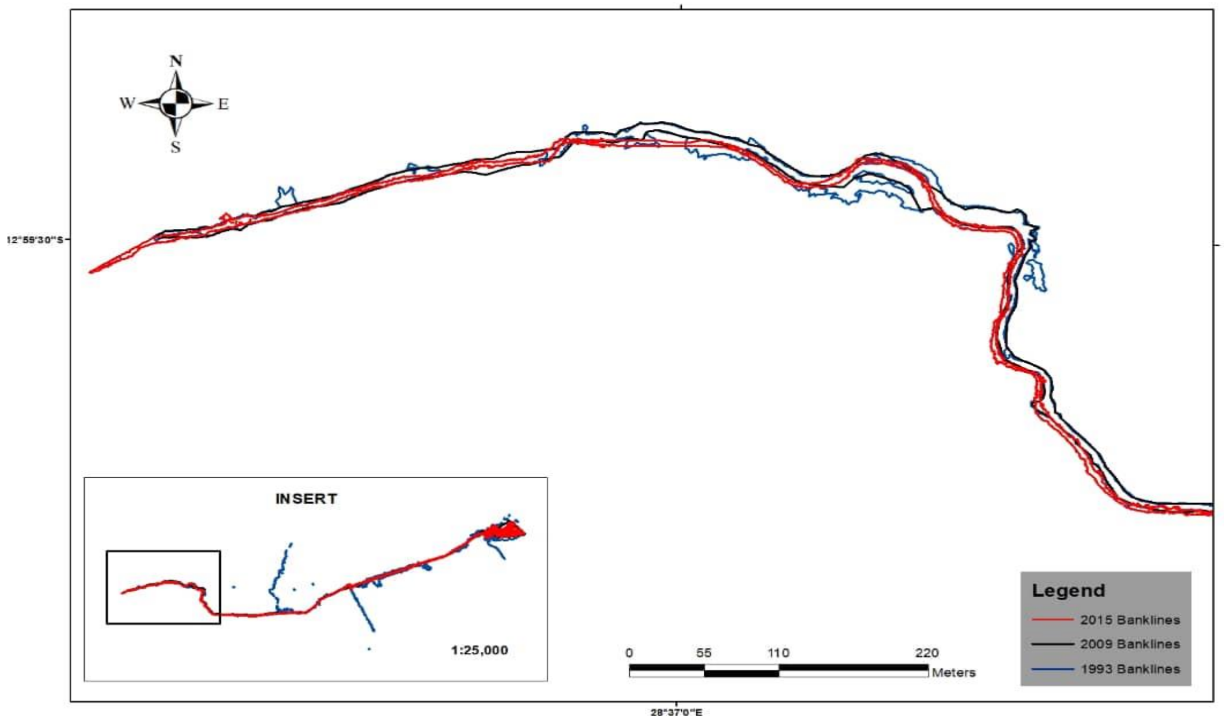

Figure 5. 15: Planform Changes during study period- Segment (e)

Source: 1993, 2009 and 2015 classified land use maps.

Figure 5.16 graphically shows the rate of change in channel width at each transect for the entire study period. The negative values indicate an increase in river width while the positive values indicate a reduction in river width. The results of the channel width for the entire study period show that the river width has reduced at all transects except at transects 2 and 10 (Table 5.10 and Figure 5.16). Table 5.10 also shows that between the years 1993 and 2009 there was an increase in channel width at transects 6, 7, 8, 9 and 10 while the other transects show a width reduction. Between the years 2009 and 2015 there was width increase at transects 1, 2, 3 and 4 while the rest of the transects showed a reduction in channel width.

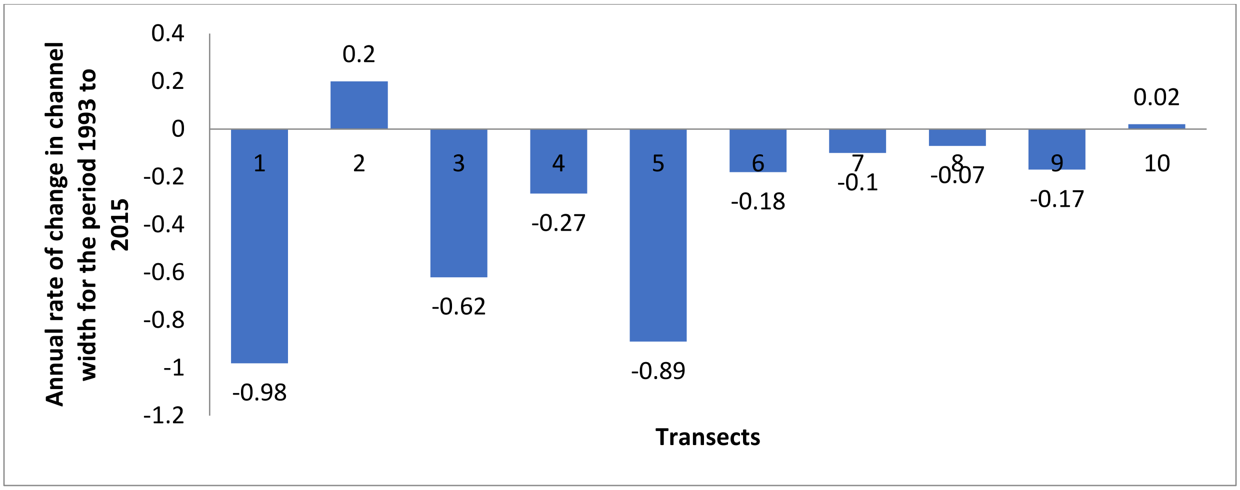

Figure 5. 16: Rate of annual channel change in width during study period at each transect

Source: 1993 and 2015 classified land use maps

The ground truthing revealed differences ranging from 0.91m to 4.77m with one at 8.05m. The banks of the river where transect 3 is located were inaccessible to the researcher because of high infestations of weed. Table 5.11 shows the measured river width at each transect for the 2015 image and the measured width at transects during field data collection and the differences in measurements. Figure 5.17 shows the differences in river width between the 2015 and the width measured during field data collection.

Table 5. 11: 2015 channel width Vs channel width during ground truthing.

Transect/ Cross section	River width in 2015 (m)	River width during ground truthing (m)	Difference in width (m)
1	16.45	24.5	8.05
2	9.10	13.87	4.77
3	9.90	Inaccessible	
4	12.23	10.2	2.03
5	2.41	4.45	2.04
6	1.36	5.8	4.44
7	3.94	7.58	3.64
8	4.02	6.5	2.48
9	2.50	5.89	3.39
10	4.86	5.15	0.29
Average			3.46

Source: 2015 classified land use map and field data

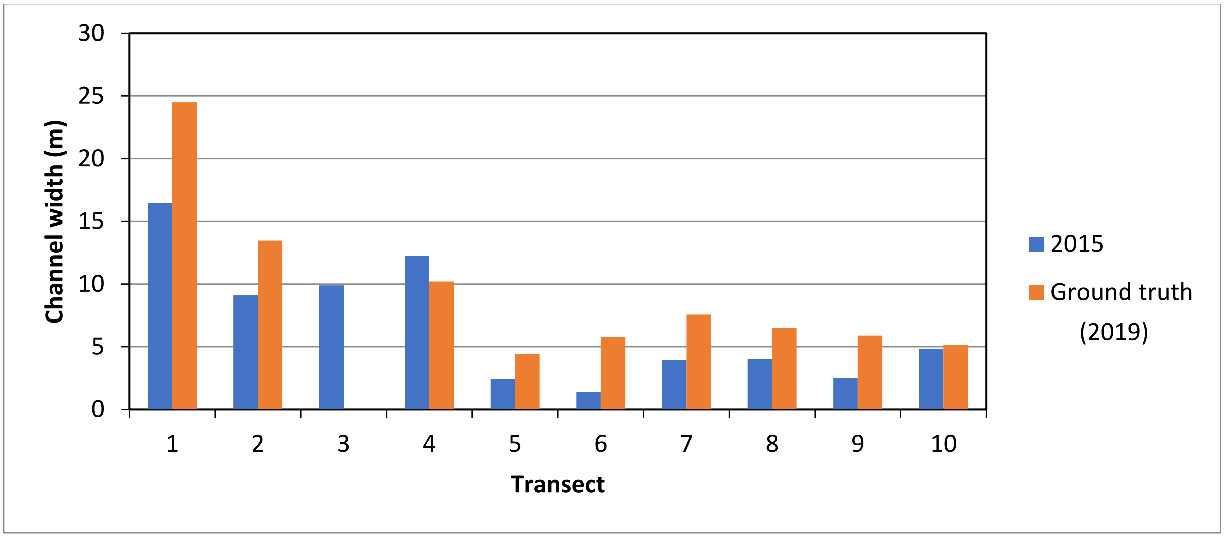

Figure 5. 17: Differences between satellite imagery derived measurements and ground truth data for 2015.

Source: 2015 classified land use map and field data

5.3.2 Erosion Accretion Rates Analysis

The processes of erosion and accretion result in changes in river planform. Therefore, an analysis of the rates of erosion and rates of accretion at the 10 transects was carried across the years and compared. Table 5.12 presents the maximum and average erosion and accretion over the years.

Table 5. 12: Maximum rate of erosion and accretion on both the left and right wetted extent of the river channel

Year	Number of years	**Left wetted river extent**				**Right wetted river extent**			
		Erosion rate (m/year)		Accretion rate (m/year)		Erosion rate (m/year)		Accretion rate (m/year)	
		Average	Max	Average	Max	Average	Max	Average	Max
1993-2009	16	0.09	0.14	0.45	0.88	0.09	0.19	0.51	0.91
2009-2015	6	0.20	0.2	0.32	0.67	0.16	0.2	0.33	1.27
1993-2015	22	0.04	0.12	0.35	0.61	0.04	0.11	0.35	0.61

Source: 1993, 2009 and 2015 classified land use maps

Figures 5.18, 5.19, 5.20, 5.21 and 5.22 show the results of the erosion accretion analysis.

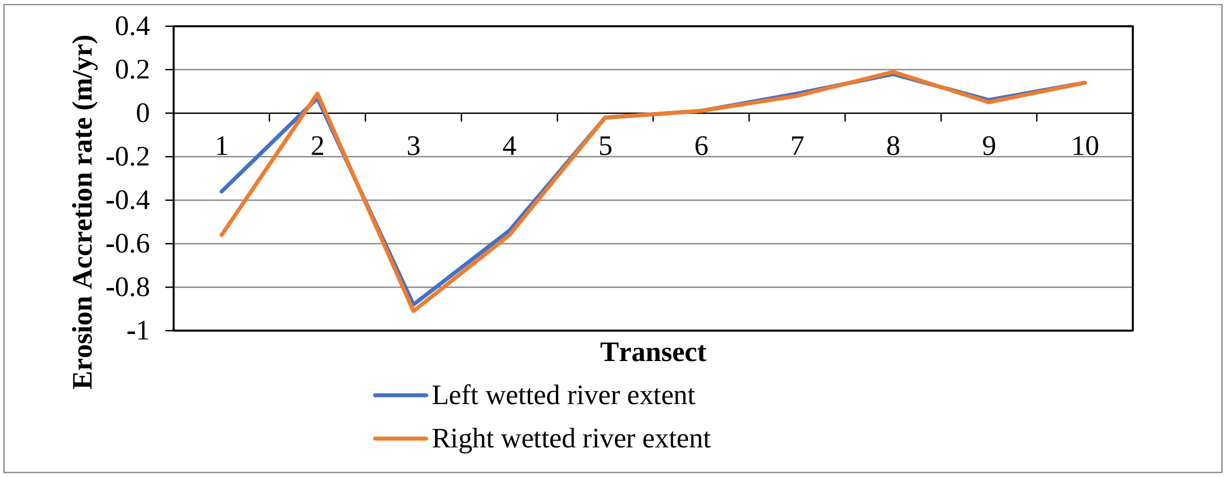

Figure 5. 18: **Spatial variation of maximum erosion and accretion for the period 1993-2009**

Source: 1993 and 2009 classified land use maps

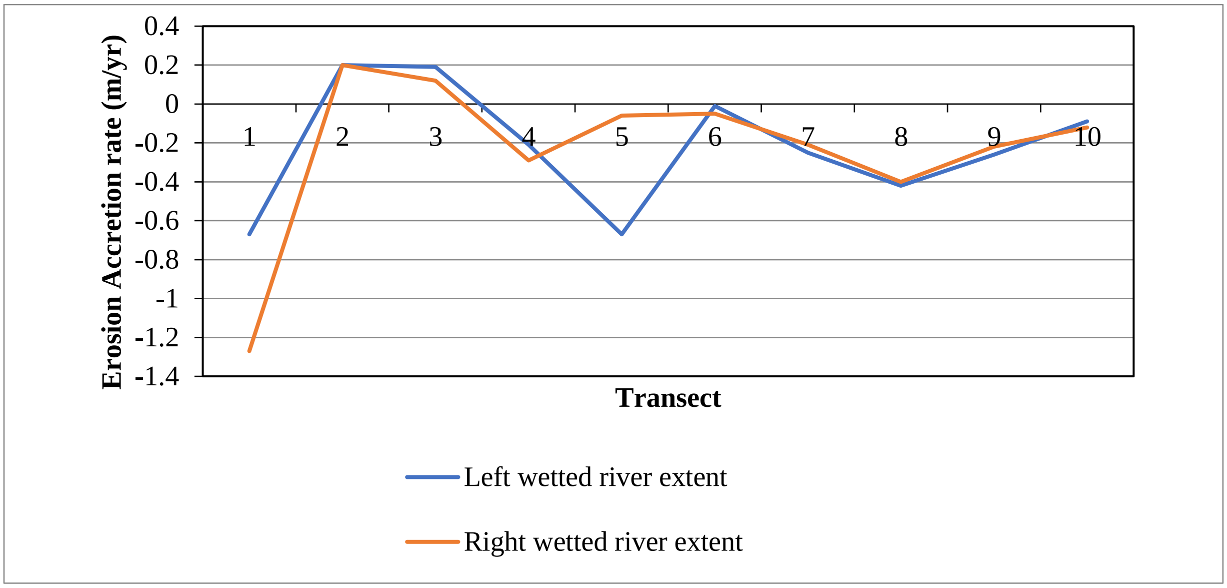

Figure 5. 19: Spatial variation of erosion and accretion for the period 2009-2015

Source: 2009 and 2015 classified land use maps

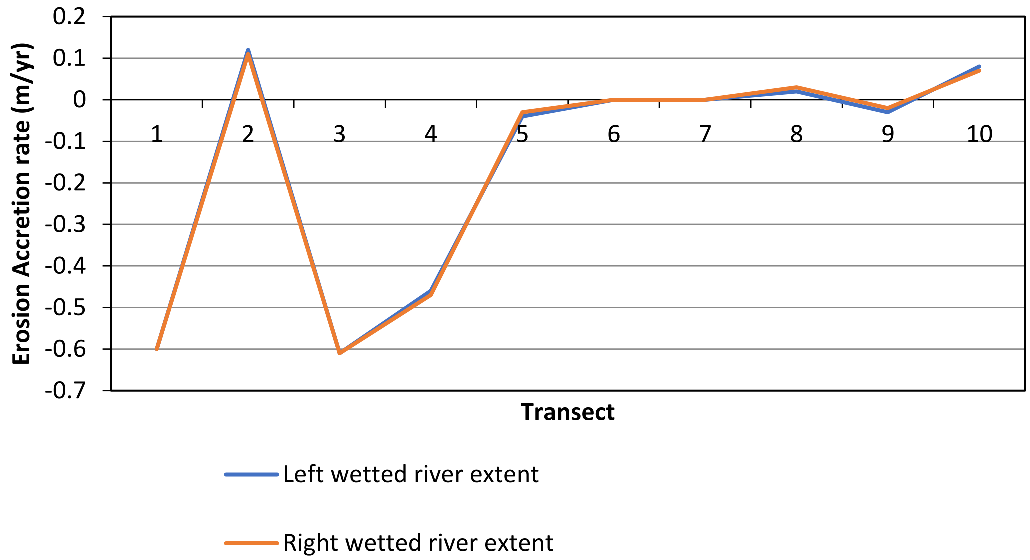

Figure 5. 20: Spatial variation of erosion and accretion for the period 1993-2015

Source: 1993 and 2015 classified land use maps

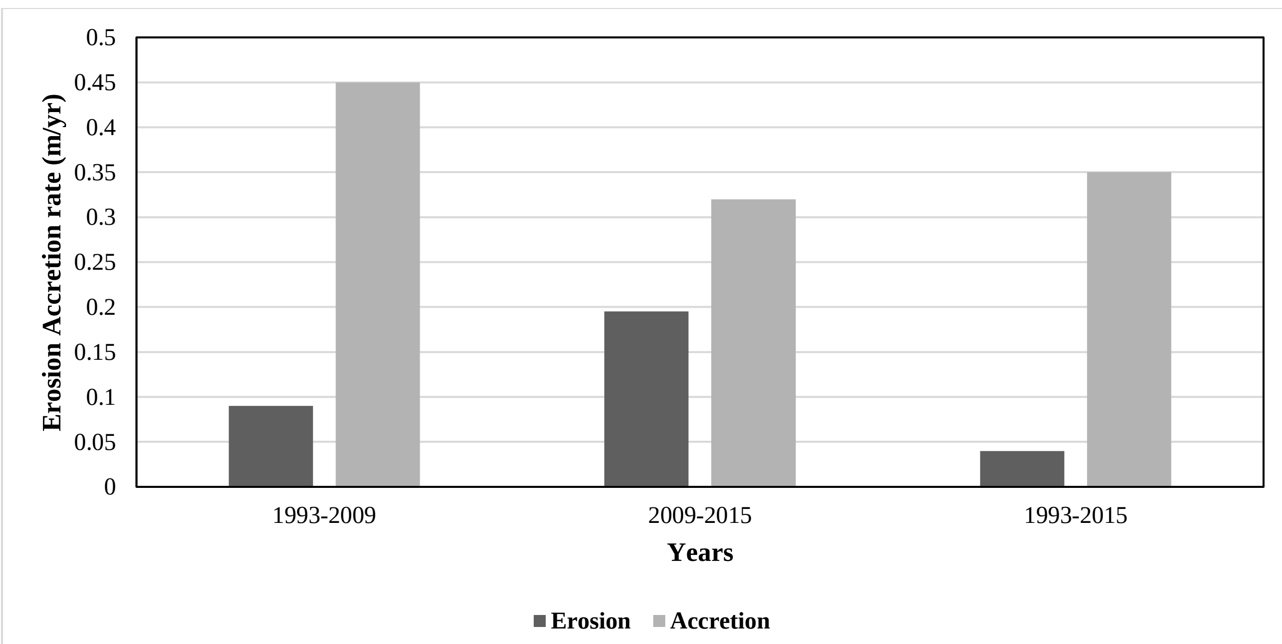

Figure 5. 21: Erosion and accretion rates of the left wetted extent over the years

Source: 1993, 2009 and 2015 classified land use maps

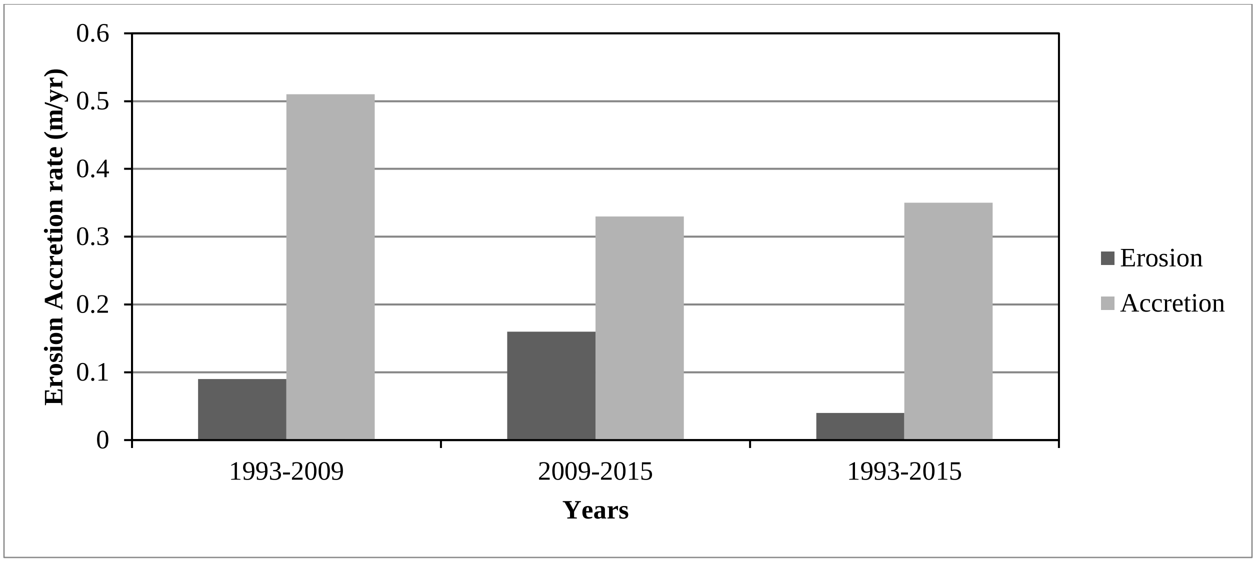

Figure 5. 22: Erosion and accretion rates of the right wetted extent over the years

Source: 1993, 2009 and 2015 classified land use maps

Figures 5.23, 5.24, 5.25, 5.26 and 5.27 are segments (a, b, c, d and e) that show the areas on the river channel where accretion or erosion took place and it was used to find the area of the river that had experienced accretion or erosion for the entire study period.

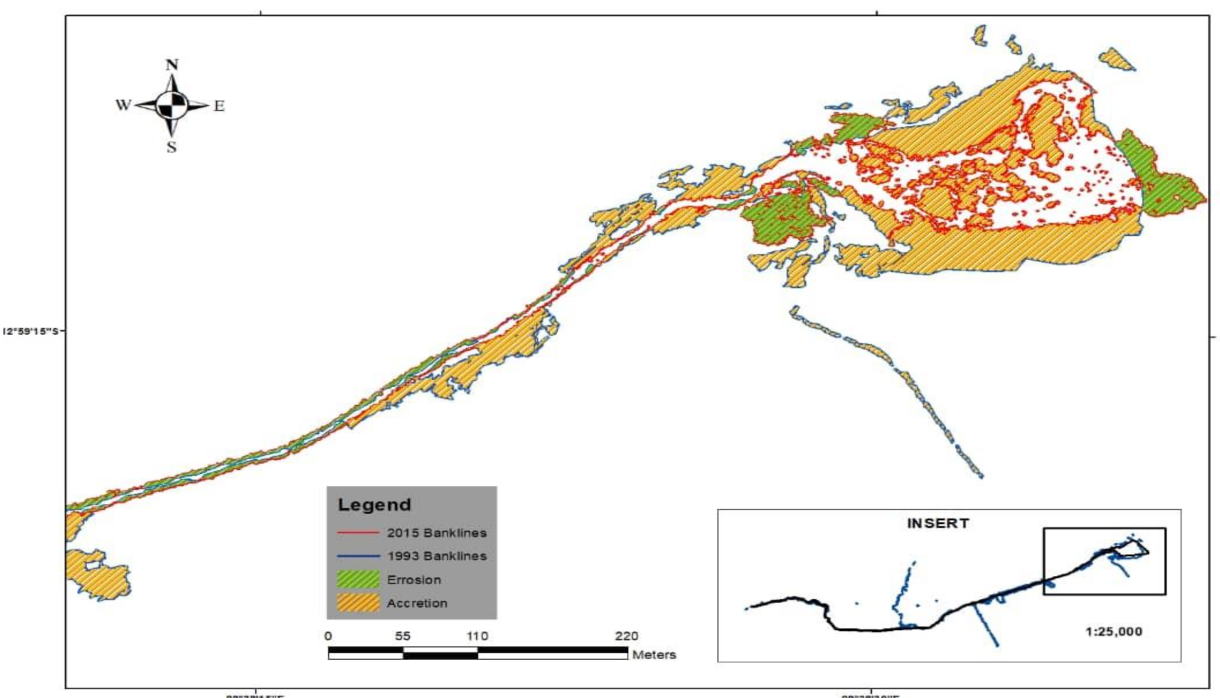

Figure 5. 23: Areas of accretion or erosion- Segment (a)

Source: 1993 and 2015 classified land use maps

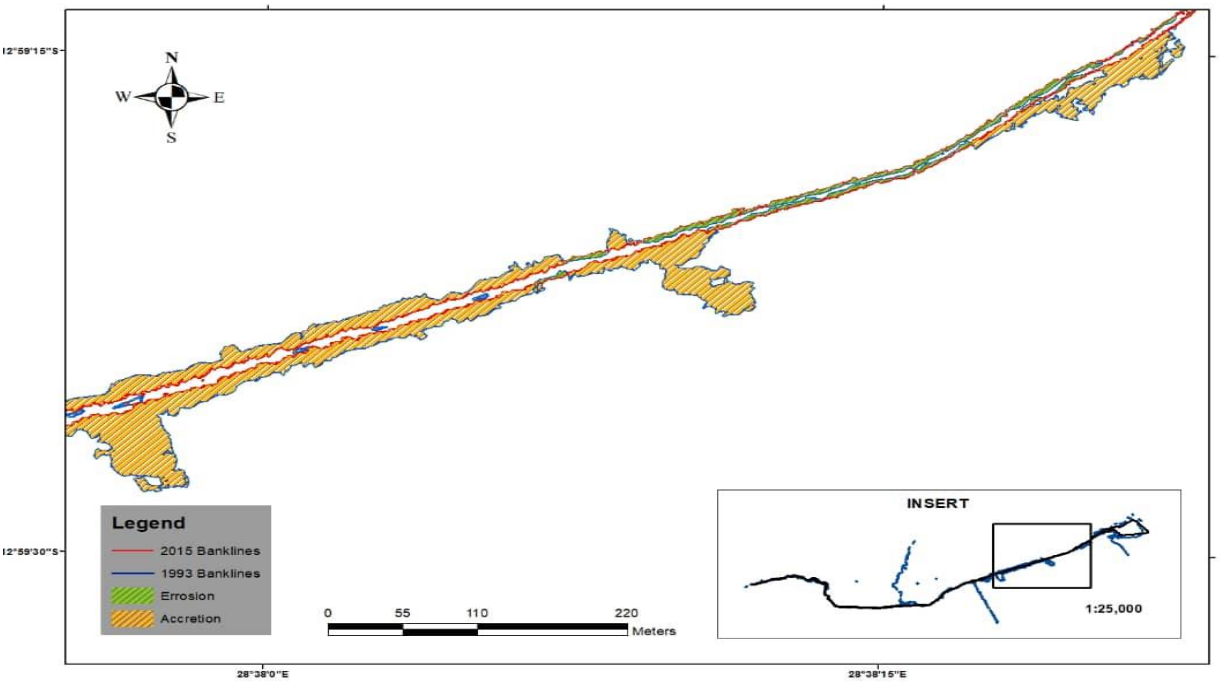

Figure 5. 24: Areas of accretion or erosion- Segment (b)

Source: 1993 and 2015 classified land use maps

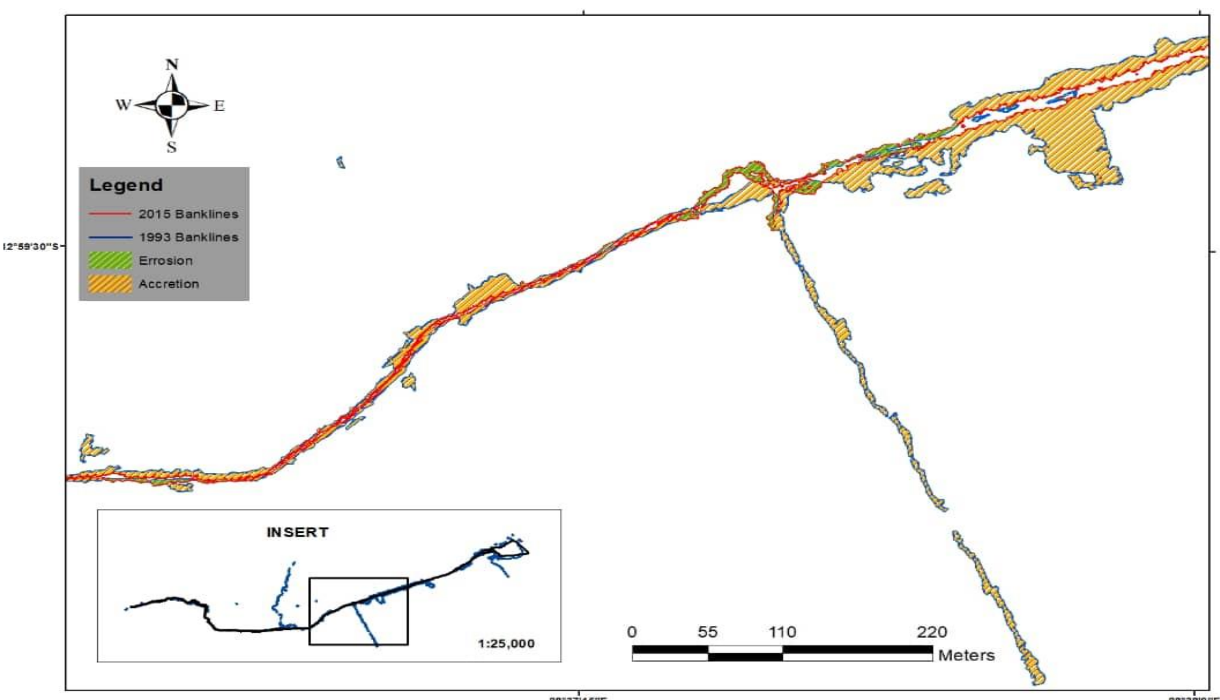

Figure 5. 25: Areas of accretion or erosion – Segment (c)

Source: 1993 and 2015 classified land use maps

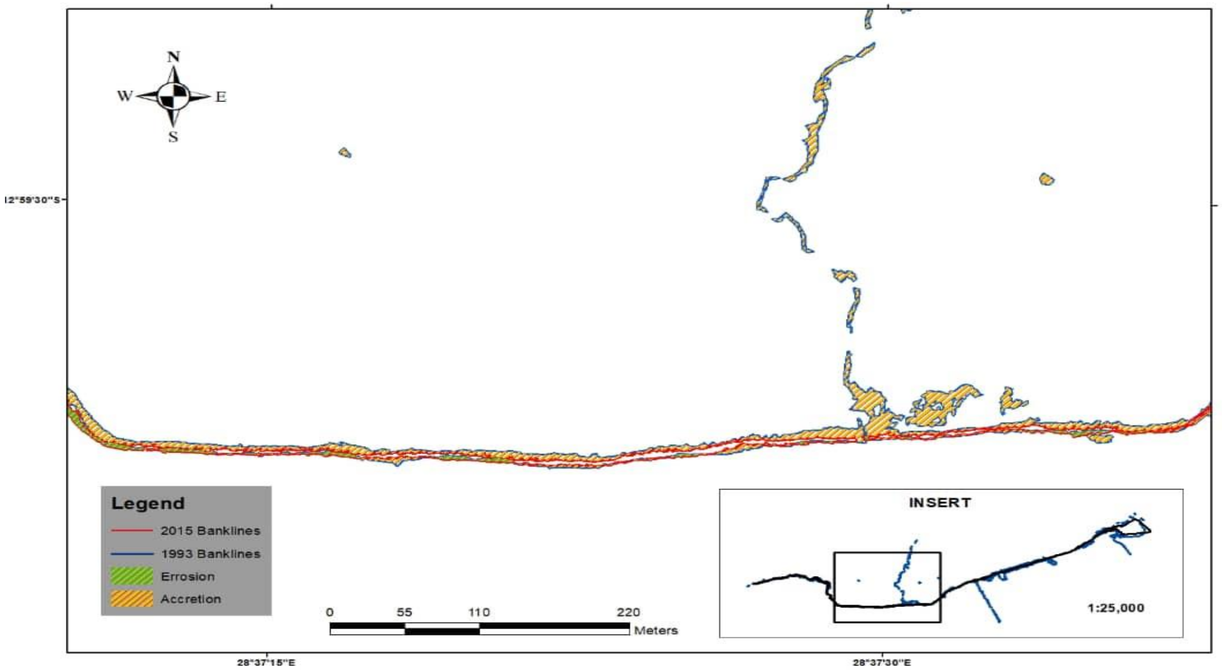

Figure 5. 26: Areas of accretion or erosion – Segment (d)

Source: 1993 and 2015 classified land use maps

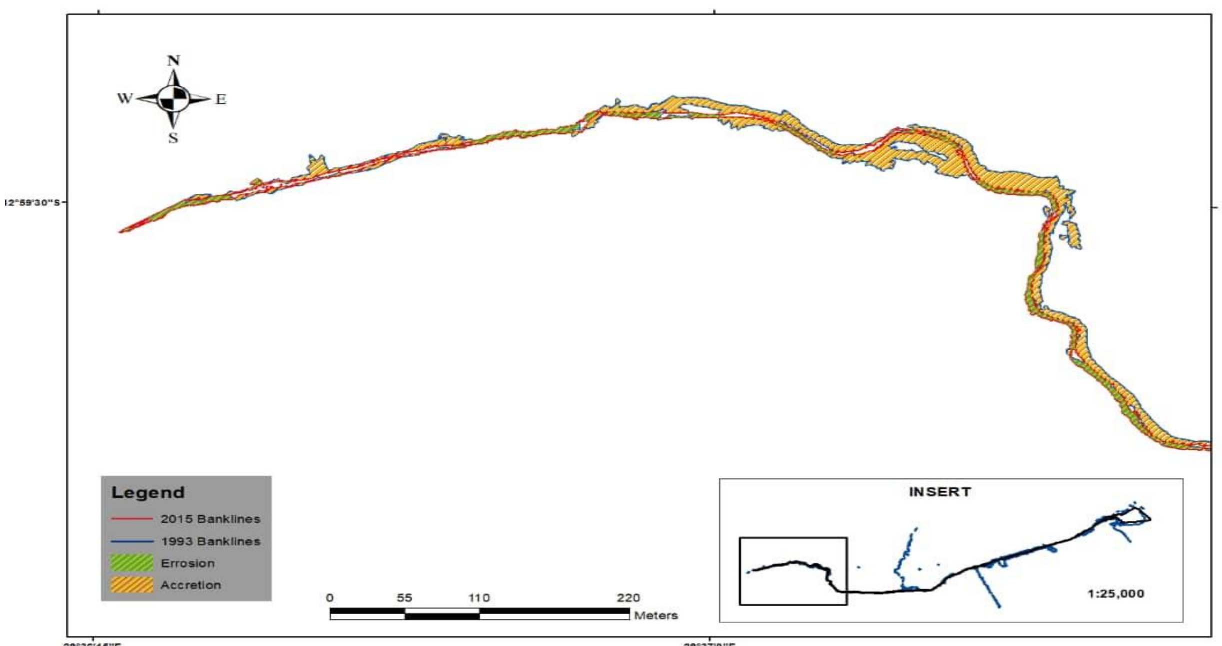

Figure 5. 27: Areas of accretion or erosion – Segment (e)

Source: 1993 and 2015 classified land use maps

Table 5.13 shows the total areas for erosion as well as for accretion for the entire study period. This shows that the whole study river reach experienced more channel contraction than widening due to erosion. The factors attributed to these changes are presented in subsequent sections.

Table 5. 13: Total areas of erosion and accretion, 1993-2015.

Process	Area (ha)
Accretion	6.73
Erosion	1.02
Total	7.75

Source: 1993, 2009 and 2015 classified land use maps

5.4 Factors influencing land use changes as well as planform changes

This section presents the findings of the factors influencing land use changes and the factors influencing observed planform changes from the interviews conducted on five urban planners from the NCC and thirteen local residents.

5.4.1 Factors influencing Land Use changes

All the key informants interviewed from the NCC indicated that the river has a buffer zone of 50 meters on the river banks where no activity unauthorized by the NCC is supposed to happen. All respondents indicated that there has been some land use changes in the river buffer zone. The respondents pointed out a number of factors as the possible reasons behind these land use changes (Figure 5.28).

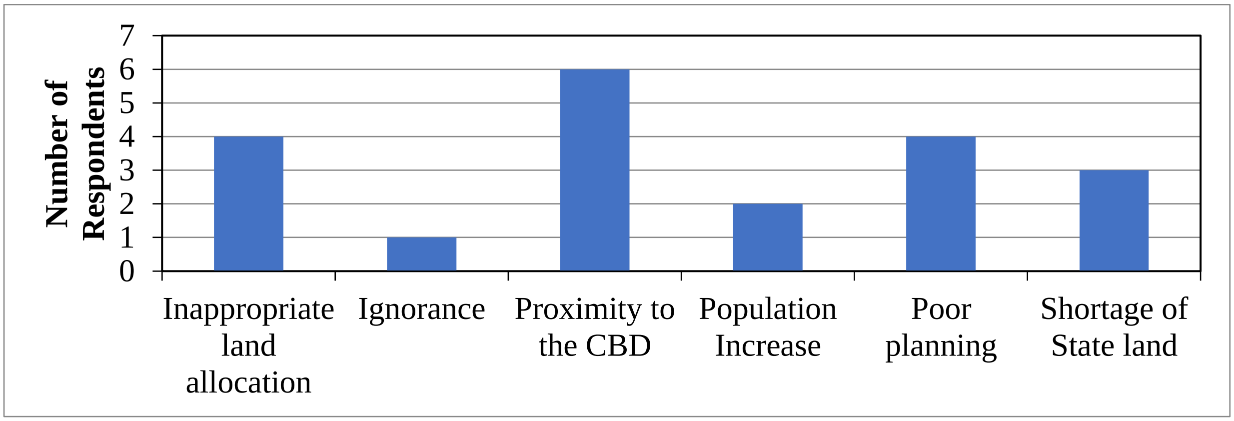

Figure 5. 28: Factors influencing land use changes in the study area

Source: Field data, 2019

5.4.1.1 Inappropriate land allocation

Two of the local residents interviewed as well as two key informants said that the people who have built residential structures in the buffer zone have been allocated plots in the area by corrupt NCC officers. It was also mentioned that some of the people who have built in the buffer zone are political cadres who feel they have the power to allocate land. The influence of political cadres is one of the challenges pointed out by the NCC key informants in land allocation. The key informants narrated that the cadres build wherever they want to regardless of laws governing the allocation of land for different uses.

5.4.1.2 Population increase

Two of the respondents said that there is population increase in Ndola and this has led to a shortage of land and as a result, some residents have built their houses in the river buffer zone. They indicated there are more migrants from other districts as well as migrants from outside the country who have migrated to Ndola.

5.4.1.3 Shortage of State land

Another major factor pointed out by two key informants as well as one respondent is a shortage of state land. The local resident indicated that the shortage of land is as a result of urbanization and the resulting economic development during the study period. However, two key informants indicated that the shortage of state land was because most of the land is owned by individuals that were allocated vast pieces of land a long time ago when the population of the city was low. The key informants also noted that the Ndola urban area is surrounded by Forest Reserve so the land in the river buffer zone has become highly sought after.

5.4.1.4 Proximity to the Central Business District (CBD)

According to six of the respondents, people want to have houses near to the Central Business District. This is in order to have easy access to social amenities which include hospitals, offices and shopping malls, thereby saving on transports cost. It was also pointed out by two respondents that some people want to have their houses near already established residential areas to reduce chances of being robbed as common in secluded locations.

5.4.1.5 Ignorance of Environmental Issues

One respondent as well as one key informant commented that those people who have built their houses in the river buffer zone are ignorant of the interaction between different land uses in this case, impervious surfaces and urban hydrology and so they did not know that construction of residential structures in the river buffer may cause some changes in the river channel.

5.4.1.6 Poor Enforcement of existing laws.

The last but not the least important factor mentioned was that the current situation where the river buffer has residential houses built on it is as a result of the poor enforcement of existing laws by the NCC. Four of the respondents strongly believe that there is no way a person can build on protected areas without being cautioned and stopped from doing so by the NCC. However, one key informant from NCC indicated that the equipment they use to record coordinates during plot allocation is outdated and the local authorities are reluctant to invest in modern equipment. The key informant further said that this has resulted in inaccurate coordinate measurements leading to allocation of plots that are now in the 50m river buffer (Figure 5.29)

Figure 5. 29: Residential house built in the Kafubu River buffer zone near transect 1

Source: Field data, 2019

5.4.2 Factor influencing river planform changes in study area (1993-2015)

All of the eighteen respondents mentioned that the channel of the Kafubu River in the study area has become narrow during the study period. One respondent went on to say that the river is narrowing in places with construction on the banks and widening in the parts without construction in the buffer. The increase in built up area and the uncontrolled weed in the river are the factors identified by the respondents influencing these channel planform changes.

5.4.2.1 Built Houses

The most significant land use changes revealed are from vegetation as well as from crop land to built up areas. All the five key informants and seven of 13 of the resident respondents suggested that the houses being built in the river buffer are making the water in the river to dry up. Figure 5.30 shows a house being very close to the river.

Figure 5. 30: Construction of houses very close to the river near transect 5

Sources: Field data, 2019

To illustrate the implications and challenges of constructing houses in the river buffer zone, Figures 5.31 and 5.32 show houses constructed in the Kafubu river buffer zone flooded after a heavy downpour on 30th January, 2022

Figure 5. 31 House in the Kafubu river buffer zone after a heavy downpour

Source: Field data 2022

Figure 5. 32: Houses in the river buffer zone flooded after heavy downpour

Source: Field data 2022

Figure 5.33 shows residents of a house flooded after the downpour carrying their belongings out of the houses after the water level had reduced and they could enter their houses.

Figure 5. 33 Residents carrying their belongings out of their flooded houses

Source: Field data 2022

5.4.2.2 River Weed

The weed found in the river is called the water hyacinth (*Eichhornia-crassipe*). Seven of the resident respondents indicated that there is too much weed growing in the river and this has led to narrowing of the river channel. One respondent emphasized that the local authorities are not doing enough weed control and it has chocked some parts of the river. Four of the five key informants mentioned that developers in the buffer zone are not connected to the Kafubu Water and Sewerage grid so some of them have poorly constructed and maintained septic tanks that end up allowing untreated sewage into the river. Figure 5.34 shows the weed near transect 2. During the field observations, at one point where the researcher expected to find the river according to coordinates from the air photographs, the river was not visible only the sound of flowing water could be heard as the water surface was completely covered by the water hyacinth.

Figure 5. 34: Portion of Kafubu River covered by weed, *Eichhornia-crassipe*

Source: Field data, 2019

CHAPTER SIX: DISCUSSION

6.1 Introduction

This chapter presents the discussion of the results obtained by the study. The organization of the discussions is based on the objectives starting with first objective, and then the same is done for all other objectives. Lambin et al (2003), reveals that the causes of land use changes involve situation-specific interactions among a large number of factors at different spatial and temporal scales. Similarly, this study shows that the factors attributed to the land use change as well as the river channel planform changes are specific to the study area location.

6.2 Extent of land use changes around the Kafubu River in Ndola Urban (1993 to 2015)

This section discusses the land use changes observed in each of the identified land use classes during the study period. The results of the classification accuracy assessment indicated an overall accuracy of 0.89 or 89 percent and a kappa of 0.87(Table 5.6). This is an acceptable accuracy given that results greater than 85 percent are acceptable according to the standard first suggested by Anderson (1976).

6.2.1 Change between 1993 and 2009

Based on the land use classification carried out, there were land use changes in the sixteen-year period. Table 5.4 shows that there was an increase in vegetation by 45.38ha (15.13%) at a rate of 2.84 ha/year as well as built up area by 55.81ha (134.35%) at a rate of 3.49 ha/year between 1993 and 2009. Meanwhile there was a great reduction in the crop land area by 125.18ha (73.34%) at -7.82 ha /year because most of it was converted to either built up area or vegetation This is line with what 55.5 percent of the respondents indicated about what land use changes have taken place in the study area. The cropland areas located along where the fifth, sixth and seventh chainages were abandoned because in the 2009 image there is absence of crops in the same area where there were crops in 1993 aerial photo. Another increase in land use is that of bare land by 24.18ha (93.79%) at a rate of 1.51 ha/year which was attributed to the clearing of croplands and vegetation. This could be because of an increase in the demand for space to build residential houses because of population growth in Ndola. To support this claim, the demographic dynamics of Ndola show that there had been population growth rate of 23.8 percent between 1990 and 2000 (CSO, 2003). The results of the land use change also shows that the river land use class reduced by 0.19ha (1.11%) during this period and was majorly converted to bare land that is; 13.12ha (26.26%) of the river was converted to bare land. This could be because of the process of accretion on the riverbanks over the years that resulted in deposits of soil that was bare.

6.2.2 Change between 2009 and 2015

The land use classification also showed that there were land use changes in the 6-year period. Table 5.5 shows increase in built up by 101.11ha (103.86%) at a rate of 16.85ha/year. This is because of increased number of residential houses built in the area. The annual population growth rate between 2000 and 2010 was at 1.9 percent (CSO, 2014) and could have led to increased demand for land to use as residential areas. Consequently, 18.97ha (9.56%) of the bare land and 89.81ha (45.25%) vegetation were converted to built-up area during this six-year period. It is evident from classified land use maps that on the locations where there was vegetation, bare land or cropland in 2009 there were residential houses in 2015. However, even though some portions of vegetation, crop land and bare land were lost to built-up areas, only the areas for vegetation and crop land reduced while the area covered by bare land increased by 9.38ha (18.78%) at a rate of 1.56ha/year (Table 5.5). This is because some portions of both vegetation and cropland were converted to bare land during this period as a result of more land being cleared in order to aid the construction of more residential houses in the study area. The areal extent of the river land use class greatly reduced by 8.93ha (52.68%) at a rate of 1.49ha/year during this period. This can be because of the advancement the riverbanks resulting from continued deposition of debris or sediments from the construction of houses near the river. These findings are similar to those of Chakraborty and Mukhopadhyay (2015) who investigated riverbank erosion and channel width adjustments across a meandering channel of North Bengal, India where they indicated that riverbanks can move away (erosion) or can advance (deposition) which can result in meander migration, channel avulsion and changes in channel width. The change detection showed that during this period, a portion of the river land class (1.97%) was converted to vegetation. This could be because of increase in water hyacinth infestation in the river which was classified as vegetation by the GIS.

6.2.3 Change between 1993 and 2015

In this period, there were land use changes as shown by the change detection maps generated. The built-up area had the greatest increase in areal extent by 156.92ha (377.76%) at a rate of 7.13ha/year. This is a result of the conversion of other land uses such as cropland and vegetation to built-up areas as illustrated in the change detection map for this period. These findings are in concert with what all the respondents indicated that the cropland and vegetation land uses in the study period have been converted to built-up areas for residential purposes. There was reduction of the areal extent of the river by 9.12ha (53.21%) at a rate of -0.41ha/year. This accords well with what all the respondents' response observed narrowing of the river channel during the study period. The change detection maps also revealed that a portion of the vegetation land class was converted to river class. The explanation to this is the reduction of weed in some areas of the Kafubu river surface because of its removal using a dredger. Lumba (2015) reports that a dredger was commissioned by Minister of Transport, Work, Supply and Communications in 2014 but works to remove the weed was dragged on and only some areas of the river were cleared of the weed.

6.3 Changes in channel width of the Kafubu River in Ndola Urban (1993 to 2015)

6.3.1 Channel width analysis

River channel width has changed during the study period as shown by the small tributaries that were clearly visible in the year 1993 but almost completely disappeared by 2015 (Figure 5.10) and corroborated by field observations. The results of the measured channel width for the entire study period shows that the channel width at most transects had reduced during the 22-year period but at some point, during this period, they had widened (Table 5.10). This behavior of widening and narrowing of the river channel is as a result of the processes of erosion and deposition. Clark and Wilson (2000) report that land use changes alter the water and sediment supplied to rivers, which, in response, alter their geometry and composition. They also explained that examining along stream variations in channel geometry and sedimentation can provide evidence of river response which can take the form of changes in width, depth and planform geometry, to land use change. The field examination of the riverbanks during this study revealed that there was a lot of construction of houses as well as cement block making as near as five meters from the stream. This shows that there is a large quantity of sediment that may have been supplied to the river which caused deposition. This in turn altered the channel geometry by reducing the width of the river channel.

6.3.2 Erosion Accretion rate analysis

Further analysis of the rates of erosion and accretion revealed results that confirmed the changes in channel width. The positive differences in channel width between the years meant that the wetted extent of the river had increased indicating erosion while the negative differences indicated reduced channel width due to the process of accretion. In the entire 22-year study period, Table 5.10 reveals more negative values than positive values for width change at all transects which indicates that there was more of accretion than erosion changes on the river. Results of the river bank analysis shows that in the six-year period between the years 2009 and 2015, at all transects experienced accretion while transect 2 experience more of erosion. The results also show that for the 16-year period between the years 1993 and 2009 transects 1,2,3,4 and 5 undergo more accretion than erosion on both the left and right banks of the wetted river channel. Conversely, transects 6,7,8,9 and 10 showed more erosion than accretion. This can be attributed to the increase in the built-up area during this period by 101.11ha (103.86%) (Figure 5.4) which led to increased deposition of sediments from the construction debris. Furthermore Table 5.12 reveals that there were higher rates of accretion than erosion over the years. Further analysis showed that the left wetted extent of the river channel experienced a maximum rate of erosion of 0.14ha/year while the maximum rate of accretion was 0.88ha/year. Conversely, Figure 5.18 for the right wetted extent of the river channel shows that the maximum erosion rate was 0.2ha/year while the maximum rate of accretion was 1.27ha/year. The total area of accretion (6.73ha) was higher than that of erosion (1.02ha) after the overlapping of river polygons. Overall, the channel width of the Kafubu River reach under study generally reduced during the study period, 1993-2015. A similar method of river planform analysis was used by Ahmad et al. (2018) who did a planform analysis of the Teesta river in Bangladesh and found that the rate of erosion was higher than the deposition. It was done with the help of images generated from USGS and later from these images after generating the necessary shape files with the help of ArcGIS software, the erosion and deposition along the river bank was quantified by using MS Excel software.

6.4 Factors that have influenced areal land use and planform changes along the Kafubu River

This section discusses the findings of the factors that have influenced land use changes as well as planform changes in the study area for the period 1993 to 2015.

6.4.1 Factors that have influenced land use changes in the study area (1993-2015)

This study has shown that the river buffer zone of Kafubu River experienced great land use changes because of increased land under built- up areas where houses were built in the buffer zone. The interviewed respondents pointed out a number of factors as the possible reasons behind the areal increase of this built- up land use category.

6.4.1.1 Inappropriate land allocation

The study revealed that the inappropriate land allocation practices by political cadres and some corrupt NCC officers have contributed to the observed land use changes. This allegation is supported by a newspaper article in the Lusaka Times of 25 August 2017 which reported of the suspension of the Ndola City Council Town Clerk with 30 others over their involvement in illegal land deals. It was further reported that the Minster of Lands had revoked the land agency earlier in the year 2017. This is in line with what Jepson *et al.* (2001) indicates that many land-use changes are due to ill-defined policies and weak institutional enforcement, as exemplified by the widespread illegal logging in Indonesia linked to corruption.

6.4.1.2 Population increase

Another factor revealed by respondents is increase in population of the town as a result of migration which in turn led to a shortage of land for residential houses thereby requiring more houses to be built. Ndola has experienced an increase in economic activities such as more banking services, hotel services, shopping malls and entertainment services. The increase in the number of learning institutions such as the Copperbelt University School of Medicine and Northrise University has contributed to the rise in population as well. This is supported by the demographic dynamics which indicate that Ndola experienced population growth rate of 23.8 percent between 1990 and 2000 (CSO, 2003) and an annual growth rate of 1.9 percent between 2000 and 2010 (CSO, 2014). This is in concert with Geist and Lambin's (2002) assertion that at longer timescales, both increases and decreases of a given population have a large impact on land use. Demographic change does not only imply the shift from high to low rates of fertility and mortality (as suggested by the demographic transition), but it is also associated with migration and urbanization.

6.4.1.3 Shortage of State land

Another major factor pointed out by some respondents is a shortage of state land as a result of urbanization, vast individually owned land parcels and the presence of Forest Reserves in Ndola. These findings agree with Geist and Lambin (2002) who reports that urbanization is associated with demographic change. Urbanization leads to population increase as a result of immigration and consequently leads to a shortage of land available for residential purposes. This has resulted in people using corrupt and illegal means of allocating land. However, there are places like Twapia, Northrise and Minsundu in Ndola where residential plots can be developed especially if roads are made and electricity is brought there. Places like Minsundu mostly have farms some of which are underdeveloped such that some could be approached by the City Council to consider subdividing and be compensated using money that buyers of plots would pay.

6.4.1.4 Proximity to the Central Business District (CBD)

Another factor according to six (33%) of the respondents is that people want to have houses near to the CBD. This is in order to have easy access to social amenities which include the hospitals, offices and shopping malls, thereby saving on transports cost. It was also pointed out by six respondents that some people want to have their houses near already established residential areas to reduce chances of being robbed in a secluded location. A report by the Criminal Investigation Department

(CID) of Zambia Police Services reveals that for the period between the years 2008 and 2013, the Copperbelt Province recorded the highest number of criminal cases. The general crime report by CID for the 1st quarter of 2019 indicate that there were a total of 334 burglary and theft reported cases with only 87 arrests and 227 house break ins and theft reported cases with only 67 arrests made.

6.4.1.5 Ignorance of Environmental Issues

Ignorance of the interaction between different land uses in this case, impervious surfaces and urban hydrology is a factor that was mentioned by some respondents. This is in line with Lambin *et al*. (2003), who indicate that lack of public education and poor information flow on the environment contributes to land use change too. Kasperson *et al*. (1995) writes that land use change is caused by lack of community's ability to cope with a deteriorating environmental situation. However, in this situation, this ignorance of environmental issues could not have led to people building their houses in the restricted areas because to build any structure, a building plan is supposed to be approved by the local council before construction commences and they authorities should have rejected the building plan and educated them.

6.4.1.6 Poor Enforcement of existing laws

Poor enforcement of existing laws concerning land allocation by the council is the last factor identified. Kasperson *et al.* (1995) point out the absence of political will to mitigate damage and alter the trajectory of change, which leads to delayed and ineffective social responses to land use changes. The lack of more accurate modern survey equipment is something that would not occur if the local government paid more attention to the needs of the NCC. However, this reason given by these officers is not satisfactory because when they made the first miscalculations and allocated the plots wrongly they could have realized their mistake and adjusted plot sizes or relocated their clients before construction of houses began as beacons were being put. Another reason for the poor enforcement of regulations on land allocation is the lack of political discipline. This is more convincing and to be specific the misuse of authority by political cadres as they allocate land to themselves anywhere they desire. If addressed earlier the direction of the land use changes might have been altered.

Therefore, this study established that there were large land use changes in the 50m buffer zone of the Kafubu River in Ndola urban area over the study period. The most significant is the conversion to built-up area from crop land and from vegetation. These observed land use changes are a result of inappropriate land allocation practices, shortage of state land, population increase, proximity to CBD, ignorance of environmental issues and poor enforcement of existing laws by the local council.

6.4.2 Factors that have influenced River planform changes in the study area (1993-2015)

6.4.2.1 Built Houses

Ndola has indeed experience urbanization during the study period and this has led to an increase in the number of impervious surfaces in the district and consequently the study area. Komínková (2012) explains that increasing number of impervious surfaces and decreasing area of natural vegetation cover belong to the most pronounced characteristics of urbanization. These changes significantly alter the hydrological conditions in the catchment and the behaviour of streams. The high number of impervious surfaces causes a substantial increase of surface runoff components, along with a decrease of groundwater recharge and base flow. The ground truthing exercise showed that the construction of houses is characterised by debris being dumped into the river and this in turn results in sediment deposition downstream. Figure 5.31 showing a house being built too close to the river is an example of a location where deposition is taking place. Deposition causes a reduction in the channel width. This is in line with what Clark and Wilcock (2000) found on effects of land-use change on channel morphology in northeastern Puerto Rico. They indicated that land-use changes alter the water and sediment supplied to rivers, which, in response, alter their geometry and composition toward a condition capable of passing the supplied sediment with the available water.

One of the implications of constructing houses in the river buffer zone is flooding when the water levels rise. The flooding could lead to the loss of private property belonging to the residents of the flooded houses. The water passing through these houses can get contaminated by pathogens that can cause some waterborne diseases such as cholera and an outbreak could occur. The outbreak of cholera would require that the government spends money in order to contain the outbreak. All of this can be prevented if the river buffer zone is free of houses.

6.4.2.2 River Weed

Some of the respondents mentioned that the local authorities are not doing enough on weed control. Mbula (2016) writes that the Water Resources Department under WARMA which was then in charge of managing the river has inadequate human capacity and equipment to manage the water hyacinth efficiently in the Kafubu River. Mbula (2016) also stated that the removal of the weed using dredgers is a short-term measure as the weed debris is not sustainably dumped or utilised. It is dumped along the river banks of the Kafubu River after removal and finds its way back into the water body and re-establishes itself. Lumba (2015) reports that the dredger at Kafubu river was working at a very slow pace with most parts of the river still largely infested with the water hyacinth. It can be said the removal of weed is very poorly monitored and this is why it was not being effective.

Some of the key informants blamed the invasive weed on the poorly constructed and maintained septic tanks used by developers in the buffer zone that allow untreated sewage into the river. The untreated effluents allowed into the river results in eutrophication where the weed grows uncontrollably. Mashingaidze (2013) reported that reproduction rates for water hyacinth is higher in waters with high concentrations of mineral nutrients especially nitrogen and phosphate from effluent discharged from semi-processed and unprocessed wastewater into rivers. Mbula (2016) reports that nutrients such as phosphate, ammonia and nitrate from agricultural runoff and sewer effluent discharged at Kanini and Lubuto Sewerage Treatment Plants into the River were beyond the statutory limits. This has caused rapid growth of the water hyacinth in the Kafubu River. This suggests a high source area of pollution into the river leading to wide weed coverage and the river appearing to be narrowing from a planform view. The weed on the satellite images and air photos was classified as vegetation. Since the floating weed population is increasing because of poor intervention, this is why the results show that portions of the river land class were converted to vegetation land class and making the river planform appear narrower.

Overall, since urbanization is inevitable in Ndola urban area, it is time to re-think the maintenance of the Kafubu River. Encroachment of the built-up area into the river buffer zone will be difficult to contain as the city develops. Therefore, there is need to manage the river frontage differently. Some cities around the world have managed to protect the buffer zone of the rivers that pass through them. For example, London, a highly urbanized city, is protected against flooding from the River Thames primarily by walls, embankments and barrier gates (EA, 2009).

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter presents a summary of the study findings, conclusions and recommendations of the study for required actions.

7.2 Conclusion

The study has established that land use change has occurred in the Kafubu River buffer during the 22-year study period with the most significant being increase in areal extent of built up area by 156.92ha (377.76%) at a rate of 7.13ha/year because of the conversion of other land uses such as crop land and vegetation to built-up areas. This has been attributed to corrupt local council planners allocating land in the buffer zone and the power that political cadres seem to possess in the allocation of plots in the buffer even if they are instructed to stop building by local urban planners. Migrants from other districts in Zambia as well as from other countries have caused a rise in the population of Ndola district and this has led to the shortage of residential land resulting in people building more houses on the river buffer zone. This however, could have been resolved by developing other areas in Ndola as residential areas. The shortage of land is also because of most land being privately owned or falling under the forest reserve which can be resolved by convincing the owners of the land to subdivide and sell it. The need for people to be near to the CBD for economic as well as safety reasons has also contributed to people building in the buffer zone. Other people have built their house on the buffer as a result of ignorance of the interaction between the land uses and urban hydrology but construction could have been halted by the local council had they had the enforced the law and educated the people involved. The lack of modern survey equipment to obtain accurate coordinates during land allocation exercises leading to unintentional encroachment into the river buffer zone which is not a satisfactory factor as the surveyors, planners and inspectors should not have recommended the building plans while putting beacons on the plots which clearly fell within the restricted area.

The study also established that the river channel planform has changed during the 22-year study period where most of the channel under study had narrowed continuously during the study period and a few portions had widened between 1993 and 2009 but by 2015 had become narrower. The widened part of the river could be a result of increased runoff in places where there are more built up structures because they have caused an increase in the impervious surface in the river buffer zone. The narrowing parts of the river channel can be attributed to the deposition of sediments coming from construction of residential houses too close the river. The failed control of the Hyacinth weed in the river by local authorities has also influenced the channel planform of the river such that the water surface is less visible in some reaches of the river.

It is therefore concluded that the Kafubu River has undergone planform changes between 1993 and 2015. The major changes have been widening of some reaches of the river between 1993 and 2009 but by 2015 the same reaches had narrowed, while some parts of the river had continually reduced in width during the entire study period. The area of the entire river reach had decreased by 9.12ha (53.21%) over the entire 22-year study period. These changes have been attributed to the land use change in the river buffer zone, most importantly the increased area (12.95ha) change from crop land to built-up area while the cultivated land had reduced by 111.45ha (-65.3%). These land use changes are attributed to shortage of state land; inappropriate land allocation practices; population increase; ignorance of environmental issues and poor enforcement of the law by the Ndola Municipal Council. The rapid growth of weeds and their poor control in the river channel due to discharge of nutrient pollutants have also contributed to the observed river planform changes. It is concluded that Kafubu River in 22 years has been affected by land use change in the river buffer zone from crop land to residential area which led to narrowing of river planform because of deposition of sediment into the river and consequently the reduction of the surface area of the river by 53.21 percent. It is also concluded that flooding of houses in the river buffer zone is inevitable when the river water levels rise.

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7.3 Recommendations

Based on study findings, the following recommendations are made for concerned stakeholders to implement:

i. Ndola Urban local authorities should embark on sensitization programmes about the interactions between land uses and urban hydrology so that the residents can understand the importance of the river buffer zone, why it should be maintained and the laws that govern its protection.
ii. Ndola Urban local authorities should put in more effort in the managing the water hyacinth weed by combining the mechanical and biological methods of removal. The weed needs to be removed from all parts of the river and not only the part of the river that is visible along the main road that passes through Ndola town.
iii. The NCC should invest in modern survey equipment in order to improve cadastral maps for land allocation.

iv. The local council should launch an investigation of how each person who has built or is building on the river buffer obtained ownership papers if they have any and take corrective action on the local authorities involved.

v. The Water and Resources Management Authority (WARMA) that is now in charge of surface water should put up a wire fence along the river buffer to clearly show the area it covers so that no one can express ignorance about the extent of the buffer. This will prevent the construction of houses too near to the river on the banks of those reaches whose buffer has not yet been encroached.

vi. Resources permitting, lining up the river course in town area with concrete banks will not only preserve it permanently but prevent flooding in very wet years of the low-level areas which are continuously being turned into residential areas.

vii. The local authorities should make sure that each house near to the river is connected to the water and sewerage grid to reduce the levels of water pollution that are leading to eutrophication. This requires carrying out inspections of septic tanks built by developers near the river and ensure that they are built according to a specified standard in order to stop any seepage of sewage into the river.

viii. The local authorities should engage in negotiations with owners of undeveloped large parcel of land to entice them to subdivide their land parcels into residential plots to diffuse the pressure for more residential areas.

ix. It is recommended that the government further reconsiders allocation of plots in the river buffer zone to avoid destruction of property and likely loss of life in future should there be a recurrence of unprecedented flooding arising from cyclonic rainstorms.

x. It is recommended that future studies concerning the Kafubu river should attempt to predict future planform changes if the land use changes near the river are left uncontrolled. Other future studies could also be about the challenges and implications of constructing along river banks in Ndola.

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APPENDICES

Appendix 1: Interview Schedule for Ndola Residents

I am a Masters of Geo information Science and Earth Observation student at the University of Zambia. I am conducting a research aimed at assessing the effects of land use changes on the planform of the Kafubu river channel in Ndola urban, Zambia from 1974 to 2016. Part of my research involves collecting information on the causes of land use and river planform changes. I am asking for permission to interview you. I assure you that the information to be collected is for academic purposes only and will have no commercial value. Additionally, the source of the information will be specifically acknowledged in the report and will be kept confidential except for the purposes of the report. Please feel free to decline an interview if you do not wish to take part in this research. Thank you for your cooperation

Swali Annie

<u>Personal Data</u>

1. How old are you?
2. When did you start living in Ndola?

<u>Land Use</u>

3. What significant land use changes have you noticed over the years?
4. What do you think caused these land use changes?
5. What impacts of this land use changes have you observed?

<u>River Channel Planform</u>

6. What river channel planform changes have you observed over the years?
7. What do think has led to these changes in river channel planform?
8. What are the impacts of this planform changes?
9. Do you think that land use changes have led to the changes in the river channel planform?
10. What do you think should be done to reduce negative river planform changes?

Appendix 2: Interview Schedule for Key Informants (Ndola City Council Officers)

I am a Masters of Geo information Science and Earth Observation student at the University of Zambia. I am conducting a research aimed at assessing the effects of land use changes on the planform of the Kafubu river channel in Ndola urban, Zambia from 1974 to 2016. Part of my research involves collecting information on the causes of land use and river planform changes. I am asking for permission to interview you. I assure you that the information to be collected is for academic purposes only and will have no commercial value. Additionally, the source of the information will be specifically acknowledged in the report and will be kept confidential except for the purposes of the report. Please feel free to decline an interview if you do not wish to take part in this research. Thank you for your cooperation

Swali Annie

Personal Data

1. What is your position in the Ndola City Council?
2. For how long have you worked in Ndola?

Land Use

3. What significant land use changes have you noticed over the years?
4. How are these land use changes regulated by the city council?
5. What do you think caused these land use changes?
6. What impacts of this land use changes have you observed?

River Planform

7. What river channel planform changes have you observed over the years?
8. What are the impacts of this planform changes?
9. Do you think that land use changes have led to the changes in the river channel planform?
10. What challenges does the council face when planning for land use allocation in the city?
11. What is the recommended buffer distance of built-up away from the river from the planning point of view?
12. Is the recommended buffer distance of built-up from the river adhered to?
13. What challenges arise when the recommended buffer distance is not adhered to?