BUSITEMA UNIVERSITY

Pursuing Excellence

MEANDER PLAN, SINUOSITY AND BANK EROSION ALONG RIVER SEMLIKI IN NTOROKO DISTRICT, WESTERN UGANDA

BY

ESTHER OSIKOL

REG. NO: BU/GS15/MCC/17

SUPERVISORS:

1. **DR. MOSES ISABIRYE**
2. **DR. ALICE NAKIYEMBA**

A DISSERTATION SUBMITTED TO THE FACULTY OF NATURAL RESOURCES AND ENVIRONMENTAL SCIENCES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN CLIMATE CHANGE AND DISASTER MANAGEMENT OF BUSITEMA UNIVERSITY

SEPTEMBER 2017

DECLARATION

I, Esther Osikol hereby declare that the information given in this report is entirely mine, valid and it has never been forwarded to any institution or organization for award of any degree.

Signature: .... Date: 18th Sept - 2017

APPROVAL

This dissertation is submitted with the approval of the undersigned supervisors

Dr. Moses Isabirye

Busitema University

Faculty of Natural Resources and Environmental Sciences

P.O. Box 236, Tororo Uganda

Signature: .... Date: 19/09/2017

Dr. Alice Nakiyemba

Senior Lecturer

Busitema University

Faculty of Natural Resources and Environmental Sciences

P.O. Box 236, Tororo Uganda

Signature: .... Date: 19/09/2017

DEDICATION

I dedicate this thesis to my family, friends, and relatives; to them I give my deepest expression of love and appreciation.

ACKNOWLEDGEMENT

First and foremost, I want to acknowledge the Almighty God for His guidance throughout this course and my education in its entirety. All glory and honor I owe unto Him.

This dissertation is a milestone in my academic career. I have been fortunate to learn theories and concepts which would have been impossible if I had not extensively carried out the needed research. I am grateful to a number of people who have guided and supported me throughout the research process and provided assistance for my venture.

Special thanks go to my supervisors, Dr. Alice Nakiyemba and Dr. Isabirye Moses who guided me in selecting the final theme for this research. They have been there throughout my preparation of the proposal and the conceptualization of its structure. I would not have been able to do the research and achieve learning in the same manner without their help and support. Their recommendations and instructions have enabled me to assemble and finish the dissertation effectively.

I would also like to thank the National Environment Management Authority (NEMA) family and these included Executive Director Dr. Tom O. Okurut, Dr Jerome Lugumira, Mr Waiswa Ayazika, Ms. Margret Aanyu, Ms. Nancy Allimadi, Mr. Richard Mugambwa, Dr. Evelyn Lutalo, Prossy Kanzira and Anna Kisakye. My gratitude also goes to my Lecturers and family, who throughout my educational career have supported and encouraged me to believe in my abilities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

LIST OF ACRONYMS

DRC	Democratic Republic of Congo
FAO	Food and Agricultural Organization
GIS	Geographic Information System
NEMA	National Environment Management Authority
SAR	Sodium Adsorption Ratio
TSS	Total Soluble Salts
UNEP	United Nations Environment Programme
UNMA	Uganda National Meteorological Authority

ABSTRACT

The study was conducted on River Semliki in Ntoroko District on the Ugandan side of the River. This River has severally burst its banks and is characterized by bank erosion which results into loss of land and the associated side effects. This study was therefore designed to (i) demonstrate changes in the plan and stream sinuosity over the periods between 1986-1990, 1990-2000, 2000-2010, 2010-2016, (ii) quantify the amount of land lost in the cut banks of the River (iii) examine the vegetation and soil characteristics along the River banks. This study used 30m resolution ortho-rectified Landsat TM/ETM images of the study area to map out the meander plan of the River, identify the hotspots of land loss and quantify the amount of land lost in those areas using ArcGIS software version 10.1. Vegetation and soil sampling was carried out in the hotspots of land loss and a control site all within four villages in Ntoroko District.

The results obtained showed that River Semliki has continuously changed its meander plan (course) over the time series examined. The sinuosity of the River was majorly meandering. There was a glaring evidence of land loss on the Ugandan side of the River. The loss of land ranged from 10.06 ha in Nyakasenyi village, Butungama Sub-County to 22.53 ha in Bweramure village, Bweramure Sub-County. The Riverine vegetation was mainly woodlands and grasslands with the major plant species being *Phragmites mauritianum, Typha domingensis, Sporobolus pyramidalis, Echinochloa pyramidalis, Cynodon dactylon* while the soil type was mainly the red brown loam soil.

In order to safeguard the River, its bank and the adjacent land, communities surrounding the River should be sensitized on the protection of River banks; enforcement of the recommended 100m free zone along the River bank; reduction of land use pressure along the River banks especially that resulting from livestock by creation of valley dams for watering livestock; restoration of the degraded sections of the River using native plant species; riprapping meander bend walls with stones to stabilize and reduce the scouring effect of water on channel walls.

CHAPTER ONE: INTRODUCTION

1.1 Background

Rivers are systems in dynamic equilibrium that continuously balance water flow and sediment transport (Das et al., 2014). Das et al., (2014) further assert that diverse bank erosion processes occur throughout the River network starting from upper reach to lower reach. In the upper reach, near its source, the River has a huge amount of material to cut through to reach base level, so it primarily erodes downwards, creating a steep-sided v-shaped valley. In the middle reach, the River continues to cut downwards but it is also starting to cut sideways or laterally. Once the River has reached the lower course (lower reach), it has almost reached its base level, so most of its erosive energy is concentrated on cutting laterally and creating features such as meanders. This inherent activity of Rivers has made flood and River bank erosion become almost regular phenomena throughout the world (Das et al., 2014).

The process of River meandering, bank erosion and deposition are accelerated by anthropogenic activities such as deforestation, gravel mining, over grazing, construction of dams and bridges, artificial cut offs, bank revetment and land use changes (Kondolf, 1997, Das et al., 2014). These activities interrupt the equilibrium of the River dynamics and accelerate the rate of bank erosion since they are much stronger in terms of changing River dynamics than natural events such as floods, droughts and landslides (Yamani *et al.*, 2011). For example, deforestation and inappropriate land use upstream leads to excessive sediment load into the Rivers (Davinroy *et al.*, 2003; Arohunsoro *et al.*, 2014) while the presence of riparian vegetation stabilizes River banks by increasing shear strength of the soil, reducing water velocity and armoring the bank (Ott, 2000). However, this stabilization is dependent on plant vigor, density and rooting depth (Ott, 2000).

The loss of land due to River bank erosion is permanent and has far reaching impacts on the economy (Das *et al.*, 2014). For instance, it results into displacement of the local communities thereby subjecting them to economic insecurity (unemployment, erosion of capital and indebtedness) and social insecurity (deprivation of civic rights, health insecurity) (Das *et al.*, 2014). In addition, it also affects the River's ecology (Das *et al.*, 2014). According to the Atlas of Our Changing Environment by NEMA (2009) although River Semliki is in its old stage, it has characteristic meanders and forms oxbow lakes in some places and has enormous erosive power which is realized when it emerges from the forested Semliki National Park onto the Semliki flats in Rwebisengo and Bweramule sub-counties, Ntoroko District. This River activity has contributed to loss of land and dynamism in the international boundary between Uganda and the Democratic Republic of Congo (DRC).

1.2 Statement of the problem

River Semiliki has burst its banks severally and the associated meanders have extended variously in the environs contiguous to the River. The report further asserts that major impacts of meanders and River bank erosion include the loss of land through extension of River banks and an equivalent shrinkage of available land for animal grazing, cultivation and settlement. (Indeed, the incidences of flooding in River Semliki have been mutedly reported as the uptake of land that accompanies the floods (Tenywa 2015). Randerson (2010) also reported that local farmers are losing out as increased flooding reroutes Semliki River and robs them of their land. He further opined that this activity is making Uganda smaller). In spite of this situation, there is no local literature that demonstrates the attempts to track changes in River Semliki's meander plan and sinuosity quantifies land losses and relates these changes to landscape characteristics such as soil and the adjacent plant types. It is therefore on this background this study sought to demonstrate changes in meander plan and sinuosity of river Semliki over time, quantify the land losses at cut banks on the Ugandan side in Ntoroko district and examine the nature and characteristics of vegetation and soils along the river banks.

1.3 *Justification*

The study was intended to address the environmental issues such as silting, land use among others by providing the appropriate information on river bank stabilisation and restoration. The data and information generated from the research provides policy makers and neighbouring communities on strategies to control and address the problems of river meander migration, bank erosion, land loss which is the main cause of the ongoing land wrangles between Congo and Uganda and also threat to Semliki National Park, Toro Wildlife Reserve, Virunga National Park which are important tourism sites.

1.4 Objectives

1.4.1 General Objective

The overall objective of this study was to demonstrate changes in meander plan and sinuosity of River Semliki over time, quantify the land losses at cut banks on the Ugandan side in Ntoroko District and examine the nature and characteristics of vegetation and soils along the River banks.

1.4.2 Specific objectives

i. To demonstrate changes in plan and sinuosity of River Semiliki over the periods of 1986-1990, 1990-2000, 2000-2010 and 2010-2016

ii. To quantity the extent of land loss at cut banks on the Uganda's side of River Semliki, in Ntoroko District

iii. To examine the influence of vegetation and soil characteristics along River Semliki on the extent of bank erosion in Ntoroko District

1.5 Research Questions

This study was hinged on the following questions;

1. What has been the plan of River Semliki since 1986 in Ntoroko District, Uganda?
2. How much land (hectares) has been lost at cut banks on the Uganda's side of River Semliki since 1986?
3. What is the influence of soil characteristics along River Semliki on River bank erosion?
4. What is the influence of vegetation characteristics along River Semliki on River bank erosion?

1.6 Hypotheses

1. There have been major changes in the plan of River Semliki in Ntoroko District, Uganda since 1986
2. There is significant land loss at cut banks of River Semliki on the Uganda's side of the River in Ntoroko District due to its changing plan
3. The soils and vegetation characteristics along River Semliki in Ntoroko District influence the extent of bank erosion

1.7 Conceptual framework

This study was undertaken to provide relevant scientific information for effective management of River Semliki. In this regard, the variables that were investigated were the plan and sinuosity changes of the River over the periods 1986-1990, 1990-2000, 2000-2010 and 2010-2016; identification and quantification of the land (hectares) loss at various cut banks along River Semliki and the types of soils and vegetation along the River banks. It was envisioned that over the time periods, the plan of the River had changed and this brought a significant loss of land at cut banks. It was further assumed that the vegetation and soil characteristics had a major influence on the extent of bank erosion. The investigation of these linkages was accomplished through repeated analysis and digitization of satellite images of a section of River Semliki over a given time period and field sampling to obtain information on vegetation and soil parameters along the River banks.

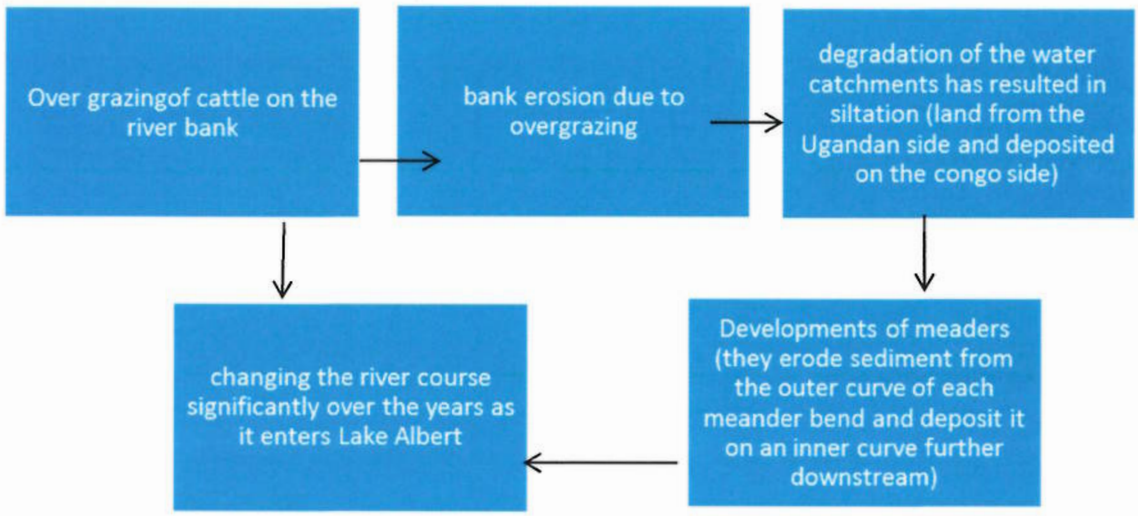


Figure 0-1: Conceptual framework

1.8 Significance of the study

The information generated in this study is useful for scientists (researchers) interested in modelling and predicting the futuristic plan of River Semliki. The study has also quantified the amount of land that has been lost over time and prioritized hotspots of this loss. These sites or hotspots of land loss can therefore be treated as priority candidates for any effort on Riverbank stabilization and restoration projects by the local community, government or civil society organizations. The identification of vegetation types along the River bank offers the reference dataset on which plant species for future restoration and River bank stabilization projects can be selected. This is based on the observation that certain plant types are more efficient in bank stabilization than others.

The information on human activity along the Riverbanks is also beneficial to regulatory authorities like the National Environment Management Authority (NEMA) and local government authorities mandated to manage Rivers in Uganda. This helps in the formulation of appropriate management interventions, lobbying for resources and monitoring the health of the River systems.

River Semliki has geopolitical importance, the information on plan changes that has been generated in this study forms an important reference dataset for resolving border disputes in the future due to the changing course of the River's meander plan. There is already evidence that such information is critical in resolving conflicts basing on the report by Aluma and Okello (2015) that there is tension between the Democratic Republic of Congo (DRC) and Uganda whereby the former is accused of encroaching on the latter's boundaries. The availability of geo-referenced information data sets like the one generated in this study makes it easy to resolve border disputes.

1.9 Scope

This study was carried out along the stretch of River Semliki in Ntoroko District bordering the Democratic Republic of Congo. The study analyzed the changes in the meander plan and stream sinuosity of the River over the period 1986-1990, 1990-2000, 2000-2010 and 2010- 2016) using satellite imagery. In addition, this study identified the major cut banks along River Semliki on the Ugandan side and quantified the acreage of land (ha) that has been lost. The study also examined the vegetation and soil types along River Semliki in Ntoroko District with a view of relating them to River bank erosion.

CHAPTER TWO: LITERATURE REVIEW

2.1 River plans

Das *et al*., (2014) classifies River channels into four (i) straight Rivers which are almost non-existent among natural Rivers and but only extremely short reaches of the River may be straight, (ii) meandering which is a sinuous channel of River formed when moving water in a River erodes the outer banks and widens its valley, and the inner part of the River has less energy and deposits silt, (iii) braided which is a channel that consists of a network of small channels separated by small and often temporary islands called braid bars. Braided channels occur in Rivers with high slope and/or large sediment load and (iv) anastomosing Rivers which are like braided channel branching of small channels from a single occurs at first, but after that separated channels again merge.

The meandering activity of the River continuously reshapes their landscapes (Das et al., 2014). According to the static and dynamic characteristics, alluvial River patterns are in general categorized as straight, meandering and braided Rivers (Leopold and Wolman, 1957). It is vital to note that Rivers are systems in dynamic equilibrium that continuously balance water flow and sediment transport (Das et al., 2014). When River channels are altered under naturally dynamic hydrologic conditions, the River readjusts itself with respect to dimension, profile and pattern to reach its former balance or equilibrium (Couture, 2008). Through meandering, Rivers fill sedimentary basins thereby creating an irregular topography favouring the formation of diverse ecological niches (Lombardo, 2016).

The primary factor controlling River development is the amount of sediment that the River carries (Das *et al.*,2014). Once the water way crosses a threshold value for sediment load, it will convert from a single channel meandering River to a braided channel (Leopold and Wolman, 1957). Bank erosion, however, occurs mainly in meandering Rivers. In meandering Rivers, River-channel migration takes place through erosion of the cut bank and deposition on the point bar. River channel migration is the lateral motion of an alluvial River channel across its floodplain due to processes of erosion of and deposition on its banks and bars (Das *et al.*2014). Due to natural or human or both activities, most Rivers in the world such as the Mississippi-

Missouri River System of North America, Ganges, Brahmaputra and Mekong Rivers of Asia, Amazon River of South America, and River Nile of Africa are subject to meandering along with bank erosion (Das et al., 2014). In addition, due to high precipitation (>2200 mm), steep slope, soft soil cover in the hills and alluvial formation in the valleys, there is high velocity and discharge of water laden with high silt discharge. All these factors result into meandering of the River and cause severe erosion in the concave bends (Mithun *et al.*, 2012).

2.2 Stream sinuosity

A River's sinuosity is its tendency to move back and forth across its floodplain in an S-shaped pattern over time. As the stream meanders across the flood plain, it may leave behind scars of where the River channel once was. A stream which doesn't meander at all has a sinuosity of 1. The more meanders in a stream, the closer the sinuosity value is to 0. In the case of Rivers, the conventional classes of sinuosity indices (SI) are $SI < 1.05$ is almost straight, $1.05 \leq SI < 1.25$ is winding, $1.25 \leq SI < 1.50$ is twisty and $1.50 \leq SI$ is meandering.

Sinuosity studies help in understanding the topographical and hydrological characteristics of the drainage basin (Krishnanu and Gopinath, 2015). Although Rivers are usually described as being straight, meandering or braided, there is in fact a great range of channel patterns from straight through meandering to braided and anabranching or anastomosing. According to Krishnanu and Gopinath (2015), sinuosity analysis helps in defining the channel pattern of a drainage basin. It also enables evaluation of the effect of terrain over the River course and vice versa. Sinuosity analysis for example Krishnanu and Gopinath (2015) used topographic maps of Bharathapuzha River to identify the sinuous, meandering and braided channel patterns in the River basin.

2.3 River bank erosion and land loss

River bank erosion is one of the critical public concerns in some countries of the world because it has long term consequences on human life (Das *et al.*, 2014). This is because the loss of land due to River bank erosion is permanent for instance once residential and productive land is lost due to River bank erosion, it can hardly be replaced which significantly impacts on the economy. It also affects River ecology (Das *et al.*, (2014). In a study by Sarma and Acharjee (2012) on Brahmaputra River bank erosion in Assam, land loss has been documented. These authors further assert that little effort has been made to quantify the land loss due to this erosion although it is often reported that Brahmaputra River bank erosion causes poverty since it has wiped out large areas including human settlements, productive crop land and reserve forest area.

The impacts of River bank erosion are multifarious and these include social, economic, health, education and sometimes political. The first and foremost impact is social namely homelessness due to land erosion which compels people to migrate (Figure 2.1) (Das *et al.*, 2014). After forced migration they suffer from economic crisis, namely loss of occupation and loss of property, and they are at the risk of poverty and sometimes involvement in criminal activities (Iqbal, 2010). Identity crisis is inevitable to these migrated people as their belongingness to any particular District or state or country is often denied. These effects become a disaster when riparian buffers are not maintained and human settlements are situated too close to eroding banks (Das *et al.*, 2014).

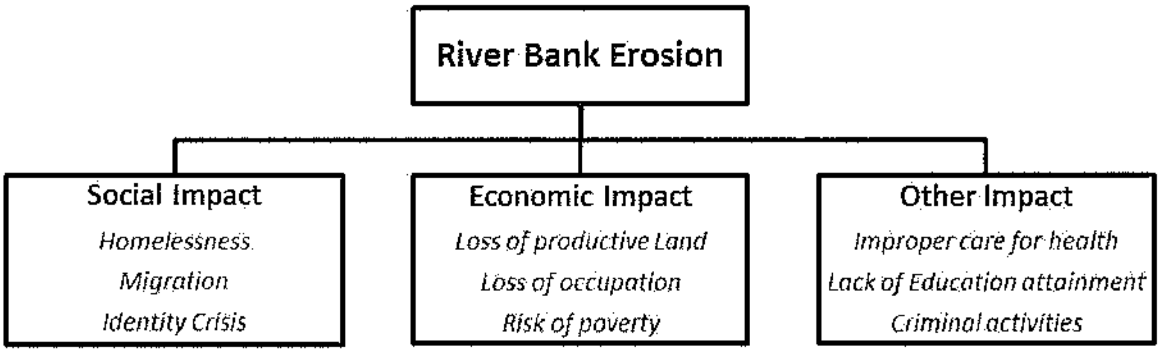


Figure 0-1: Impacts of River bank erosion (Adapted from Das et al., 2014)

In River Semliki, the Atlas of our changing environment by NEMA (2009) asserts that approximately 100 km long section of the River in the Semliki flats has seriously eroded its banks. The human and livestock activities have greatly affected the natural vegetation along its course, thus leading to River bank breakage. It estimates that over 10 m of the River bank on Uganda's territory is eroded annually at various points and as a result, it seems to have doubled its width within the last ten years. This has two implications namely (i) the boundary between Uganda and Democratic Republic of Congo (DRC) is no longer fixed and this is a potential threat to security between the two countries and (ii) loss of land means extension of buffers and an equivalent shrinkage of legally available land for animal grazing, cultivation and settlement. The outcome of the latter are land conflicts as the land becomes increasing limited for use by herders and cultivators. This observation forms the basis of this study with the sole aim of demonstrating how these changes have occurred over the different periods.

Naturally a river responds by rejuvenation of flow in a bid to behave as though it is in the youthful stage of the cycle of stream maturation (Sparks, 1983). It aims to create a straight deep V-shaped channel after initial meander cuts which form islands and ox-bow lakes along the channel. However, bank erosion is increased by anthropogenic activities deforestation and inappropriate land use in the upper reach which ultimately leads to excessive sediment load (Arohunsoro *et al.*, 2014; Dayinroy *et al.*, 2003). The presence of vegetation stabilizes River banks by increasing shear strength of the soil, reducing water velocity, and armoring the bank (Ott, 2000). The ability of vegetation to stabilize a bank is dependent upon factors such as plant vigor, density and rooting depth. Some studies revealed that bank erosion in the upper reach was primarily due to destruction of riparian vegetation by people's access and the effect of bridge constrictions on high flow, and secondarily to poorly installed channel revetments (Madej *et al.*, 1994).

2.4 Riparian vegetation

A River and its surrounding riparian vegetation are two dynamical systems that interact through several hydrological, geomorphological, and ecological processes (Perucca *et al.* 2007). A dense cover of vegetation absorbs the energy of rainfall, reducing soil detachment by raindrop impact (Coppin and Richards, 1990). Sheet and rill erosion are decreased several orders of magnitude due to interception storage, improved infiltration, increased flow resistance, and the stabilizing influence of roots on surface soils (Gurnell and Gregory 1984, Thorne 1990). Along streams with forested riparian buffers, fallen trees create series of step pools, dissipating stream energy and providing sediment storage (Beschta and Platts, 1986). Additionally, vegetation can act as a nucleus for the creation of sediment bars; vegetation is effective in trapping washload (Hupp, 1999).

Vegetation insulates the stream bank from extreme temperature fluctuations (Abernethy and Rutherfurd, 1998). This insulation minimizes the occurrence of freezing and cracking due to desiccation (Thorne, 1990). Amarasinghe (1992) found a decrease in evaporation improved soil moisture retention in vegetated banks, as compared to bare banks, reducing the risk of desiccation and slaking. Vegetation also provides increased channel roughness, directing flows towards the center of the channel and reducing flow velocities and shear stresses along the banks (Tsujimoto, 1999). It is paramount to note that the spacing of vegetation along a stream is a crucial determinant of the distribution of hydraulic stresses (Thorne *et al.* 1997). Vegetation also indirectly affects soil erosion by changing soil physical and chemical properties including soil organic matter, aggregate stability and bulk density (Mamo and Bubenzer, 2001).

Both herbaceous and woody vegetation provide increased hydraulic roughness, although the effects of herbaceous vegetation are reduced at high flows because grasses and forbs bend over in the flow (Wynn, 2004). In addition, herbaceous vegetation is absent or reduced during the winter when most channel erosion occurs. As a result of reduced stream width, velocities in grass channels have been found to be greater than those with forested vegetation (Horwitz *et al.,* 2000). Given the fact that riparian vegetation has a significant impact on stream stability and morphology, it has become an integral part of stream restoration designs (Wynn, 2004). Basing on the report in the Atlas of our changing environment by NEMA (2009) that human and livestock activities have greatly affected the natural vegetation along the course of River Semliki, it was pertinent for this study to examine the current vegetation along the banks and it is influencing River bank breakage and ultimately erosion.

2.5 Soils along River banks

A number of soil parameters influence the susceptibility of a cohesive soil to erosion, including grain size distribution, soil bulk density, clay type and content, organic matter content and soil pore water content and chemistry (Thorne, 1990; Allen *et al.,* 1999). Research has shown that increases in the silt-clay content of soils increases their resistance to entrainment (Osman and Thorne, 1988). In contrast, soils with high silt-clay contents are more susceptible to the effects of sub-aerial processes which make the soils less resistant to erosion by hydraulic forces (Couper, 2003).

According to Wynn (2004), cohesive soils are often eroded as entire aggregates. In this case, aggregate size distribution and aggregate stability play an important role in the erosion of cohesive soils. The author further asserts that aggregate breakdown creates smaller particles which are more susceptible to erosion. In addition, aggregate stability is most influenced by soil texture, clay mineralogy, organic matter content, type and concentration of cations and soil sesquioxide and Calcium carbonate content. It is important to point out that the loss of aggregate stability is the result of slaking, differential swelling, raindrop impact and physico-chemical dispersion (Le Bissonnais, 1996). Slaking is the breakdown of soil aggregates from the compression of entrapped air during rapid soil wetting. Wynn, (2004) sums it that "both internal and external forces reduce aggregate stability that is; differential swelling and shrinking occur during the wetting or drying of clay soils, creating internal stresses due to non-uniform volume changes".

CHAPTER THREE: MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location of River Semliki

This study was conducted in River Semliki located in Ntoroko District, Uganda. The District is located approximately 126 kilometres Southwest of Hoima District and approximately 307 kilometres North West of Kampala, the Capital city of Uganda (Musoke *et al., 2010*). The District comprises of 3 sub-counties, 10 parishes and 54 villages. Ntoroko became a District effective July 2010 following the creation of new Districts by the parliament of Uganda (Musoke *et al., 2010*). It was curved out of Bundibugyo District and used to be part of Tooro Kingdom. The District has a moderate population density of 252 persons per km^2 and is characterized by small-scale subsistence farming of crops and a high prevalence of pastoralism.

River Semliki derives its origin from Lake Edward through the Albertine Rift (Western Rift Valley) and drains into Lake Albert. In the first 40 km, the River travels through a heavily forested Semliki National Park, while for the remaining distance it flows through grasslands that are inhabited by the Batuku pastoral community. The River is geopolitically important because it defines the border between Uganda and the Democratic Republic of Congo (NEMA, 2009).

Semliki catchment area is a biodiversity hotspot and contains several Protected Areas such as the Semliki National Park, Toro Wildlife Reserve, Virunga National Park (DRC) which makes it an important tourism site especially for birders and plant lovers, as well as for sport fishing. The other wildlife species includes elephants, hippos, crocodiles, buffaloes, pygmy flying squirrels, various species of antelopes in abundant numbers, and more than 400 species of birds.

3.1.2 Vegetation in Ntoroko District

The District has diverse land cover types including swamps, forest reserves and grass (www.ntoroko.go.ug). The steep slopes of Mt. Rwenzori ranges (forest reserve) characterise Karugutu and Nombe Sub Counties with smaller hills (farmland) terminating into the flat plains (grazing land). Along River Semliki, there are four major plant types namely grassland, scrub woodland, Riverine forest and swamp vegetation in Bweramure, Nyakasenyi and Kayanja villages, Bweramule and Butungama Sub-Counties. (See Appendix 25)

3.1.3 Climate

According to www.ntoroko.go.ug (Accessed 15/6/2017), Ntoroko District experiences a bimodal rainfall pattern. The first rains are shot and occur during March - May, and the longer rains from August-November. Annual rainfall ranges from less than 800mm to 1600mm and is greatly influenced by altitude. Rainfall distributions of the District enable arable agriculture to take place all through the year. For most at the foot and slopes of the Rwenzori Mountains, the rainfall amounts are comparatively reliable; the majority of the crops can be grown in both seasons. There is a wide temperature variation influenced by altitude, temperatures that fluctuate from very high (25^0C) at the plains to below zero degrees high in the Mountains, and the low land temperatures range from 8^0C to 30^0C, similarly the humidity varies from over 80% in the highlands to 72% in the low lands (See Appendix 26).

3.1.4 Soils in Ntoroko District

The soils are rift valley sediments, grey alluvial clay soils that tend to be alkaline and of poor fertility. Plate tectonism dictates that the tectonic plates and subsequent movement along the rift valley floors created igneous and metamorphic bedrocks in the Regions Mountains and escarpments. The rocks are mainly granites; gneisses and schist, of the steep slopes are the nutrient source of the soil deposits along the River floors. Rivers distribute gravel and sands over the wider areas of the valley before depositing sands and clay sediments into Lake Albert (Verner and Jenik, 1984). The Main soil types along River Semliki include Pellic Vertisols, Mollic Andosols, Orthic Ferralsols, and Humic Gleysols.

3.1.5 Topography

The topography of Ntoroko District is similar to that of Mountain block of the Rwenzori and the related escarpments to the east. These continue sloping down towards Lake Albert. In between are gorges and valleys through which River Wasa, River Mugiri, River Wango, River Kandida flow as major/permanent rivers. Numerous seasonal Rivers form tributaries to the above mentioned rivers (but have a major hydrological importance to the ecosystem). They all drain into the Semliki Flats (Controlled Hunting Area) mainly flooded during the rain seasons. The rivers carry sediments and boulders depending on volume and speed of water. The main River sources are Rwenzori Mountain Block and the Escarpments to the north that are richly endowed with tropical and Riverine forest ecosystems.

3.1.6 Land use in Ntoroko District

In Ntoroko District, agriculture majorly livestock is the main income earner and households obtain their livelihoods from it (UBOS, 2009). In 2009, Ntoroko county then and Bundibugyo District were divided into 4 food economy zones. These included the highland zone, the lowland agricultural zone, the mixed cattle–cultivation zone and the cattle and fishing zone (UBOS, 2009). A food economy zone being a geographical area where the majorities of households obtain food and cash income through similar combination of means. Bananas, beans, cocoa, coffee, palm oil and vanilla are equally grown in all the food economy zones except the dry cattle and fishing zone. Cassava is predominately grown in the highland and lowland zone whereas sweet potatoes and groundnuts are common in the lowland zone. Many households rely on crop and livestock, sales as their main source of income. Maize, cassava and beans are actively traded in the cattle keeping and fishing zone, and cocoa as well as oil palm in the highland and lowland zones. However, along the River Semliki banks, grazing lands for livestock are an important form of land use.

3.2 METHODOLOGY

3.2.1 Study design

This study adopted a longitudinal design, which involves repeated observations of the same variables over time (William *et al.*, 2002). In this case, satellite images of a section of River Semliki in Ntoroko District were analyzed over the period between 1986-1990, 1990-2000, 2000-2010, and 2010-2016. This approach allowed for the investigation of changes in the course of the same segments of the River over time. Since longitudinal studies are observational and may have less power to detect causal relationships than experiments (William *et al.*, 2002), this study relied on data analysis from changes in meander plan and stream sinuosity of River Semliki. This led to identification of cut banks and quantification of the amount of land that has been lost. However, because of the repeated observations at the individual level, they have more power than cross-sectional observational studies, by virtue of being able to exclude time-invariant unobserved individual differences and also of observing the temporal order of events.

On the other hand, the descriptive design was adopted when surveying the vegetation and soil parameters along the River banks.

3.3 DATA COLLECTION

3.3.1 Meander plan

This study used 30m resolution ortho-rectified Landsat TM/ETM cloud-free images. These were downloaded from www.usgs.gov for the years 1986, 1990, 2000, 2010, 2016 to examine the changing meander plan of River Semliki (path 173, row 059). The Landsat data consists of a global set of high-quality, and high-resolution satellite images with global coverage over the Earth's land masses. Digital enhancement was then carried out to facilitate better visual interpretation and for automated classification of targets and features entirely by the computer.

ArcGIS 10.1 software was then used for radiometric corrections and this involved correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data so that they accurately represent the reflected or emitted radiation measured by the sensor. Image enhancement was then carried out to improve the appearance of the imagery to assist in visual interpretation and analysis. Here, contrast stretching to increase the tonal distinction between various features in a scene and spatial filtering to enhance (or suppress) specific spatial patterns in an image were done.

Arithmetic operations were then performed to combine and transform the original bands into "new" images which better display or highlight certain features in the scene. River Semliki was then digitized from the various images of different years to see how its meander plan has changed over time.

3.3.2 Stream sinuosity

The sinuosity index was calculated by taking continuous points along the entire length of the River channel using the formula RL/VL where RL is the River length between two points on a River, and valley length is the straight line distance between the same two points. The sinuosity of River Semliki was determined using ArcGIS 10.1 software whereby the images for the five time series were digitized and the datasets were used to identify the meander sections of the River. Four segments (A, B, C and D) were selected in areas where the meanders have been consistent over the years and (E and F) segments of the River that were meanders have not been so aggressive to show the difference in the sinuosity (See Appendices 1, 2 and 3). The sinuosity of the River was then determined as a ratio of length of the River channel to valley length per segment (Sinuosity Index (SI) = Channel length/ down valley length) as shown in Figure 3.4. The valley slope (S_{val}) is measured as the water surface elevation difference between the same bed features (e.g., riffle to riffle) along the fall line of the valley divided by the valley length between the selected bed features.

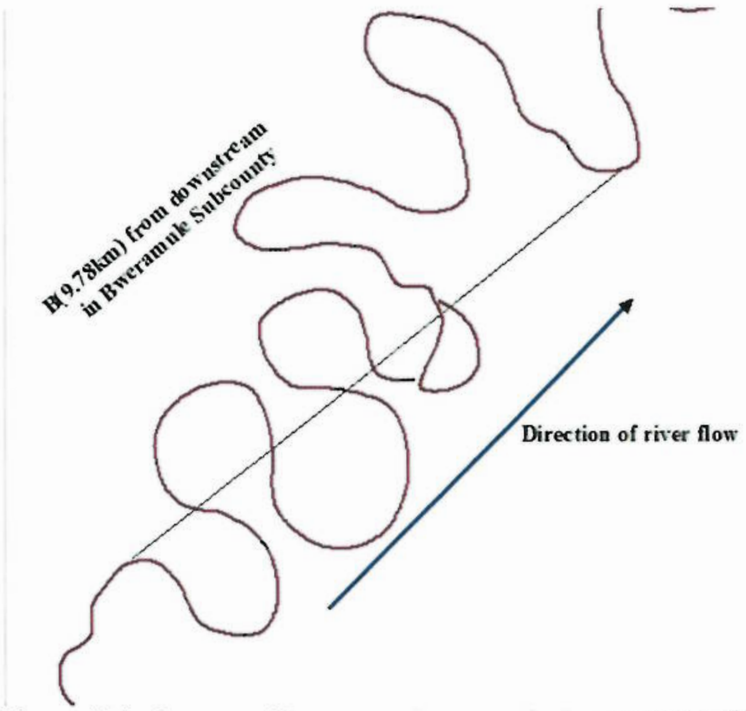


Figure 0-1: shows an illustrates the meandering pattern of River Semliki and formation of ox-bow Lake as a result of neck cut off.

3.3.3 Quantification of land loss at cut banks

Land loss at cut banks was determined by digitization of satellite images of the River Semliki for period between 1986-1990, 1990-2000, 2000-2010 and 2010-2016 in ArcGIS software version 10.1. The earlier year was used as the base year to show any diversion of the River that is; 1986 was used as the base year for the 1990 image, likewise 1990 was used as the base year for 2000 image and so on. The digitized River of 1986 was overlaid on the digitized River of 1990 to show how much the River meanders had moved into the Ugandan side and thus the difference in between the two digitized was measured and recorded. The areas that had lost land as a result of the River changing course and meanders into the land was then mapped out.

3.3.4 Vegetation characteristics along the River banks

The vegetation was sampled in three villages of Nyakasenyi, Bweramure, and Kayanja that border River Semliki. These sites were purposively selected basing on the extent of land loss (cut banks) due to erosion while those with minimum bank breakage were taken as control sites. These control sites had consisted of a vegetated and intact Riverbank. The sampling transect was randomly established and thereafter, quadrats of 5x5 m were established at intervals of 50m from the River course. In these quadrats, estimation of vegetation and plant species were made. All the geographical coordinates of the quadrats sampled were recorded using a hand held Garmin Global Positioning System (GPS) model which is typically accurate to within 10metters. The vegetation classification of Langdale *et al.* (1964) was used to classify the vegetation types along the River banks while the Cronquist (1981) system of classification, Kalema (2005) was in identification plant species within the different vegetation types. The Cronquist system places flowering plants into two broad classes, magnoliopsida (dicotyledons) and liliopsida (monocotyledons) and within these classes, related orders are grouped into respective sub classes. The plant species that could not be identified in the field were collected, coded with collection numbers, pressed with descriptive notes and deposited at Makerere University Herbarium for identification.

3.3.5 Soil characteristics along River Semliki

The texture, type, consistency and plasticity of soil along the in River Semliki were determined as follows;

a) Soil texture

The ribbon method was used to determine the soil texture in the field in the areas of Bweramure Village in Bweramule Sub-County, Kayanja Village in Bweramule Sub-County and Nyakasenyi Village in Butungama Sub-County. In this method, a small amount of dry soil was collected in palm, approximately enough to make a small ball of soil about 3/4 inch in diameter when wetted, water was added drop wise to the dry soil until it takes on the consistency of modeling clay, the soil sample was formed into a ball, about ½ - ¾ inch in diameter. Where a ball did not form because the soil was not 'sticky' enough, the texture of that sample was grouped as sand. However, where a ball was formed, it was between the thumb and forefinger, and gently kneaded the ball into relatively flat ribbon shape. Ribbon were developed, and left to extend over the forefinger until it broke due to its own weight. Where the soil sample did not form any ribbon, the texture of the sample was grouped to be loamy sand texture. Where the soil sample formed a ribbon that is less than 1 inch and the soil had a gritty feel to it, its a sandy loam texture. Where a ribbon formed and it was less than 1 inch and the soil had a smooth feel to it formed, then its silty loam texture. Where a ribbon formed and was less than 1 inch with either a noticeable gritty or smooth feel, it was grouped to be of loam texture. Where the ribbon was between 1-2 inches long with a noticeable gritty feel to it, it was grouped to be sandy clay loam texture. Where a ribbon formed between 1-2 inches long with noticeable smooth feel to it, it was grouped as silty clay loam texture. Where a ribbon formed between 1-2 inches long and the soil does had either a noticeable gritty or smooth feel to it, it was grouped as clay loam texture. Where a ribbon that was more than 2 inches long was formed and the soil had a noticeable gritty feel to it, that was grouped to be sandy clay texture; and where a ribbon more than 2 inches long was formed and the soil had a noticeable smooth feel to it, it was grouped as silty clay texture (Ritchey *et al.*, 2015).

b) Soil types

The sampling of soils along River Semliki was done simultaneously with vegetation surveys. The soil samples were collected from the River bank from three villages of Bweramure, Kayanja Village and Nyakasenyi Village. These were purposively selected basing on the extent of land loss (cut banks) due to erosion while those with minimum bank breakage as control sites. These control sites had consisted of a vegetated and intact Riverbank. From each of the sites, a sample of soil (1 kg in total) was collected using an auger for determination of the soil texture, consistency and plasticity as described hereunder (Sanchez *et al., (2009)*).

c) Soil plasticity

This refers to the degree to which puddled or reworked soil can be permanently deformed without rupturing. In order to test for plasticity of wet soil, a small amount of wet soil was rolled between the palms of hands until it forms a long, round strip like a wire about 3 mm thick. Thereafter, the plasticity is rated as; (i) non-plastic that is no wire can be formed and if formed, cannot support itself if held on end, (ii) slightly plastic that is if a wire can be formed but can easily be broken and returned to its former state, (iii) plastic if a wire can be formed but, when it is broken and returned to its former state, it cannot be formed again and (iv) very plastic if a wire can be formed which cannot be broken easily and, when it is broken, it can be rolled between your hands and be reformed several times (Sanchez *et al., (2009)*).

d) Soil consistency

Soil consistency is the strength with which soil materials are held together or the resistance of soils to deformation and rupture. Soil consistency was measured for wet, moist and dry soil samples. The test to determine wet-soil consistency was done when the soil is saturated with water (Appendix 22). To check for the stickiness of wet soil (Appendix 23), a tablespoon of wet soil was pressed between the thumb and forefinger to see if it will stick. The fingers were then slowly opened and slickness rated as (i) non-sticky where there was no soil sticking on the fingers, (ii) slightly sticky where soils where observed to begin sticking in between fingers but not stretching when the fingers are opened, (iii) sticky where the soil sticks to both the thumb and forefinger and tends to stretch a little and pull apart rather than pulling free from the fingers, (iv) very sticky where the soil stuck firmly to both thumb and forefinger and stretches when the fingers are opened (Sanchez *et al., (2009)*).

0 Non-sticky; 1 Slightly sticky; 2 Sticky; 3 Very sticky;

In order to test for moist-soil consistency, a tablespoon of moist soil was crushed and pressed between the thumb and forefinger. The moist soil-consistency was then rated as (i) loose where the soil was non-coherent (single-grain structure), (ii) very friable where the soil crushed easily under very gentle pressure, (iii) friable where the soil crushed easily under gentle to moderate pressure, (iv) firm where the soil crushed under moderate pressure but with noticeable resistance, (v) very firm where the soil crushed under strong pressure (soil dropped on the ground since it was difficult to do between the thumb and forefinger), (vi) extremely firm where the soil crushed only under very strong pressure (Sanchez *et al., (2009)*).

Dry-soil consistency was done on air-dried soil where a small amount of dry soil was pressed between the thumb and forefinger. The dry soil consistency was then rated as (i) loose where the soil was non-coherent (single-grain structure), (ii) soft where the soil was very weakly coherent and friable (breaking to powder or individual grains under very slight pressure), (iii) slightly hard where the soil resisted light pressure but easily broken between thumb and forefinger, (iv) hard where the soil resisted moderate pressure (barely be broken between the thumb and forefinger but broken in the hands without difficulty), (v) very hard where the soil resisted great pressure (not broken between the thumb and forefinger but could be broken in the hands with difficulty and (vi) extremely hard where the soil resisted extreme pressure (could not be broken in the hands).

e) **Soil resistivity**

The Wenner method was used to test the soil resistivity (expressed in ohm-meter) along River Semliki in Ntoroko District. In this method, soil texture is measured by taking sample of soil (>2 mm gravel, roots, organic material) by hand. The soils are moistened with little water and knead it into a bolus. Continual work of the bolus was done by adding more soil and water were necessary until the soil no longer got stuck on fingers and there was no apparent change in plasticity (left for 1–2 minutes). Using a clean, moistened hand, the bolus was placed between the thumb and forefinger and the thumbed across the soil (shearing) to extrude a ribbon. The length of the ribbon produced was measured and recorded using a calibrated rule. Soils with high clay content were further categorised by moulding the bolus into rods. Where the rods fractured, the soil was assigned a texture grade lighter than medium clay (Sanchez *et al., (2009)*).

3.4 DATA ANALYSIS

The meander plan of River Semliki was analyzed by digitization of the satellite images for the period 1986 to 2016. This resulted into generation of digitized maps showing the course of the River's plan thereby enabling a longitudinal comparison across the study period. The digitization led to the identification of cut banks along the River bank where land has been lost. The sinuosity was analysed using ArcGIS 10.1 software. This was followed by the quantification of the hectares lost at each hotspot. In order to determine whether there is any significant difference in the amount of land lost at each hotspot, the losses (hectares) at different sites were compared using an independent *t*-test in R-statistical package. The categorization of the vegetation types was done following Langdale *et al.*, (1964) while plant species were taxonomically identified at the Makerere University Herbarium.

CHAPTER FOUR: RESULTS

4.1 River Semliki Meander Plan

The meander plan of River Semliki changed over the 1986-1990, 1990-2000, 2000-2010 and 2010-2016 periods. See Figures 4.1 to 4.4.

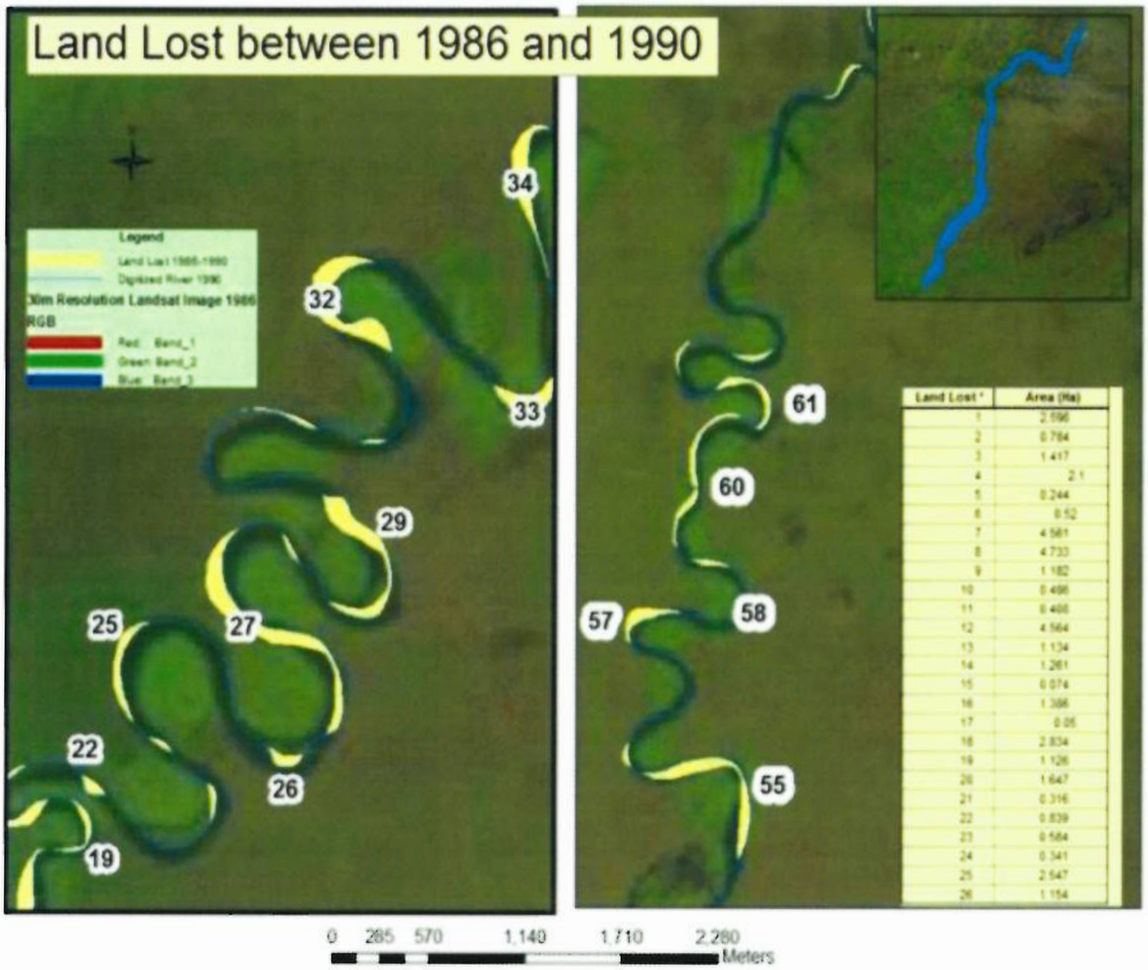
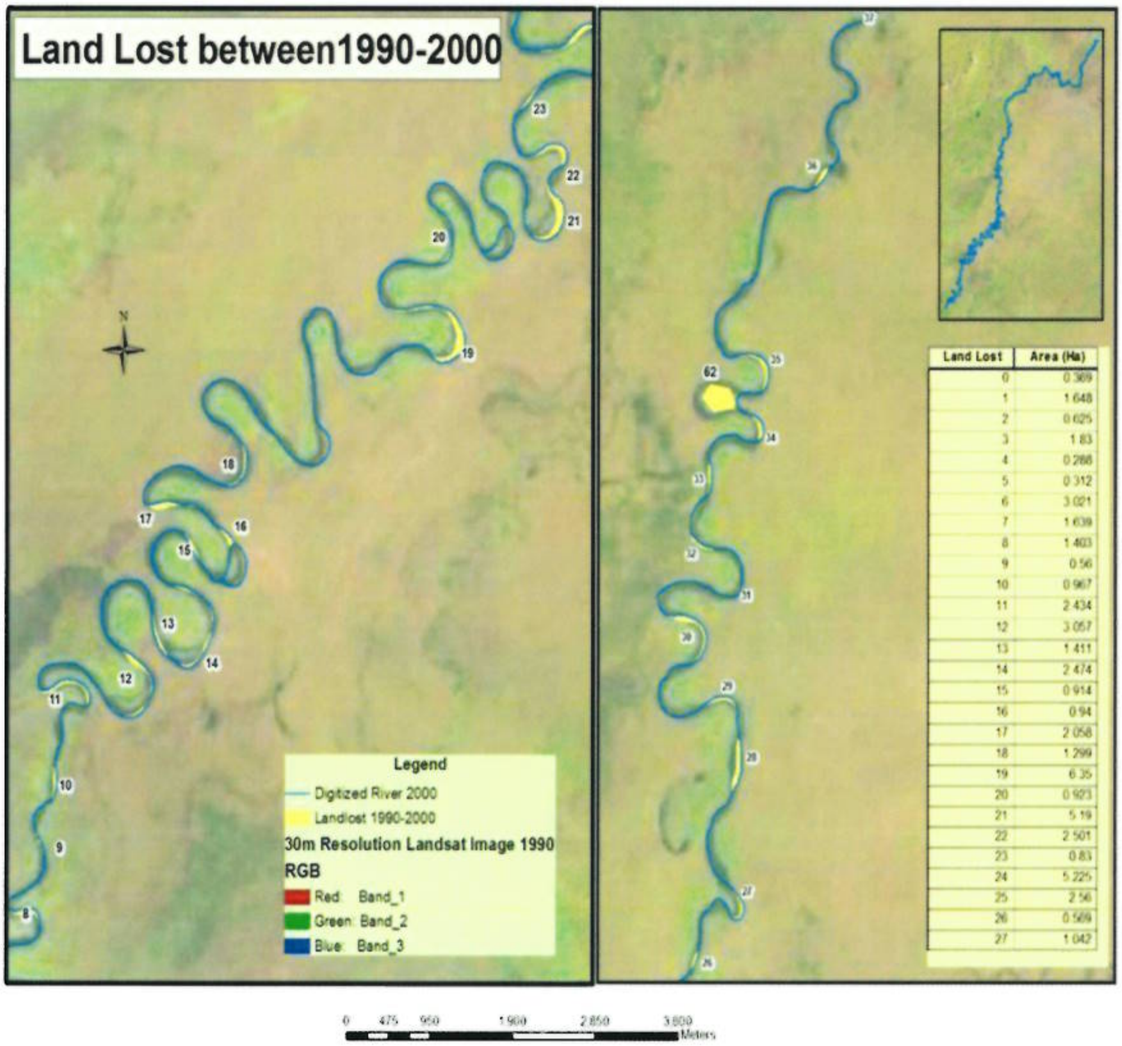


Figure 0-1: Meander plan (1986-1990)



Land Lost	Area (Ha)
0	0.369
1	1.648
2	0.625
3	1.83
4	0.288
5	0.312
6	3.021
7	1.639
8	1.403
9	0.56
10	0.967
11	2.434
12	3.057
13	1.411
14	2.474
15	0.914
16	0.94
17	2.058
18	1.299
19	6.35
20	0.923
21	5.19
22	2.501
23	0.83
24	5.225
25	2.56
26	0.569
27	1.042

Figure 0-2: Meander plan (1990-2000)

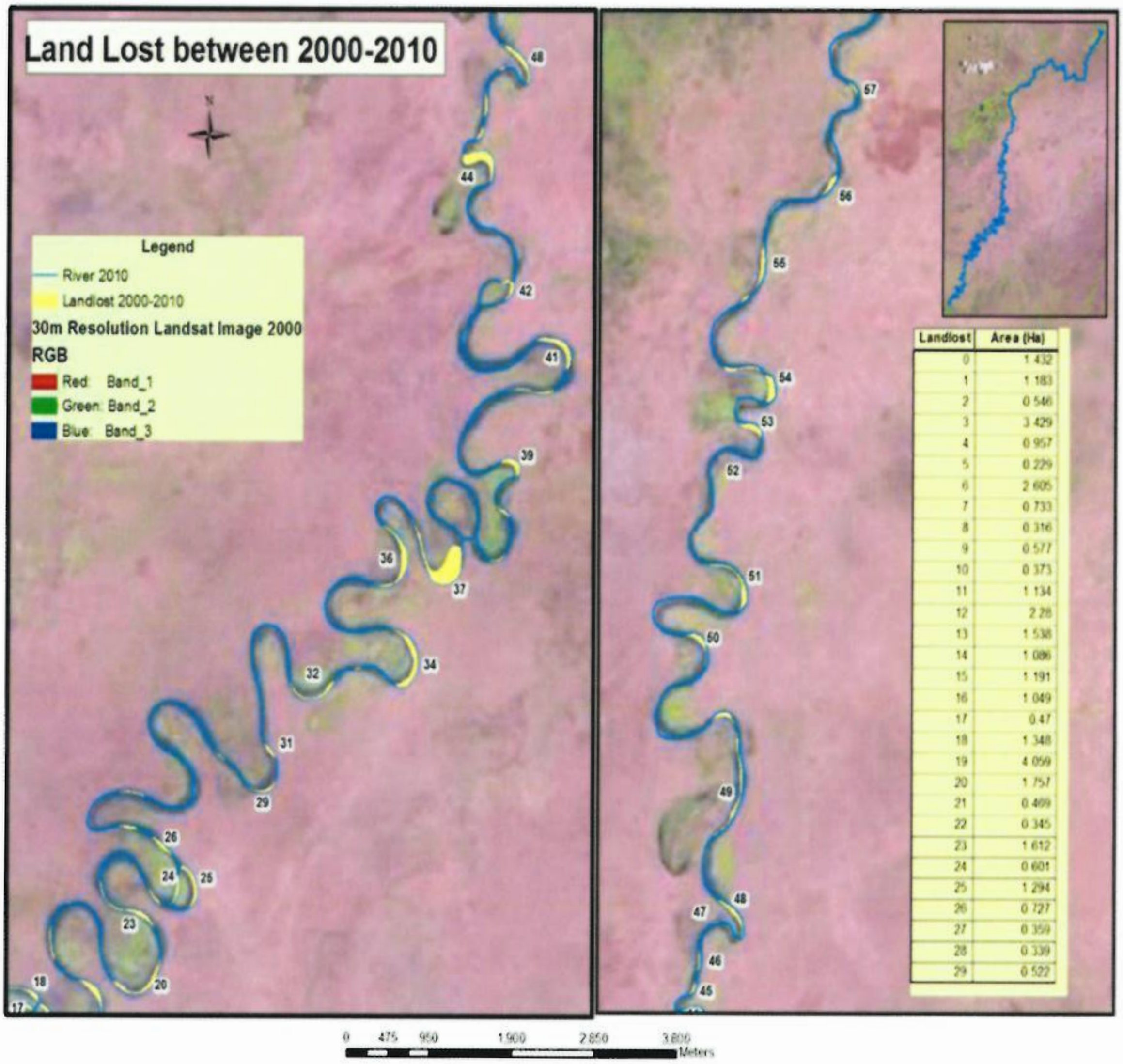


Figure 0-3: Meander plan (2000-2010)

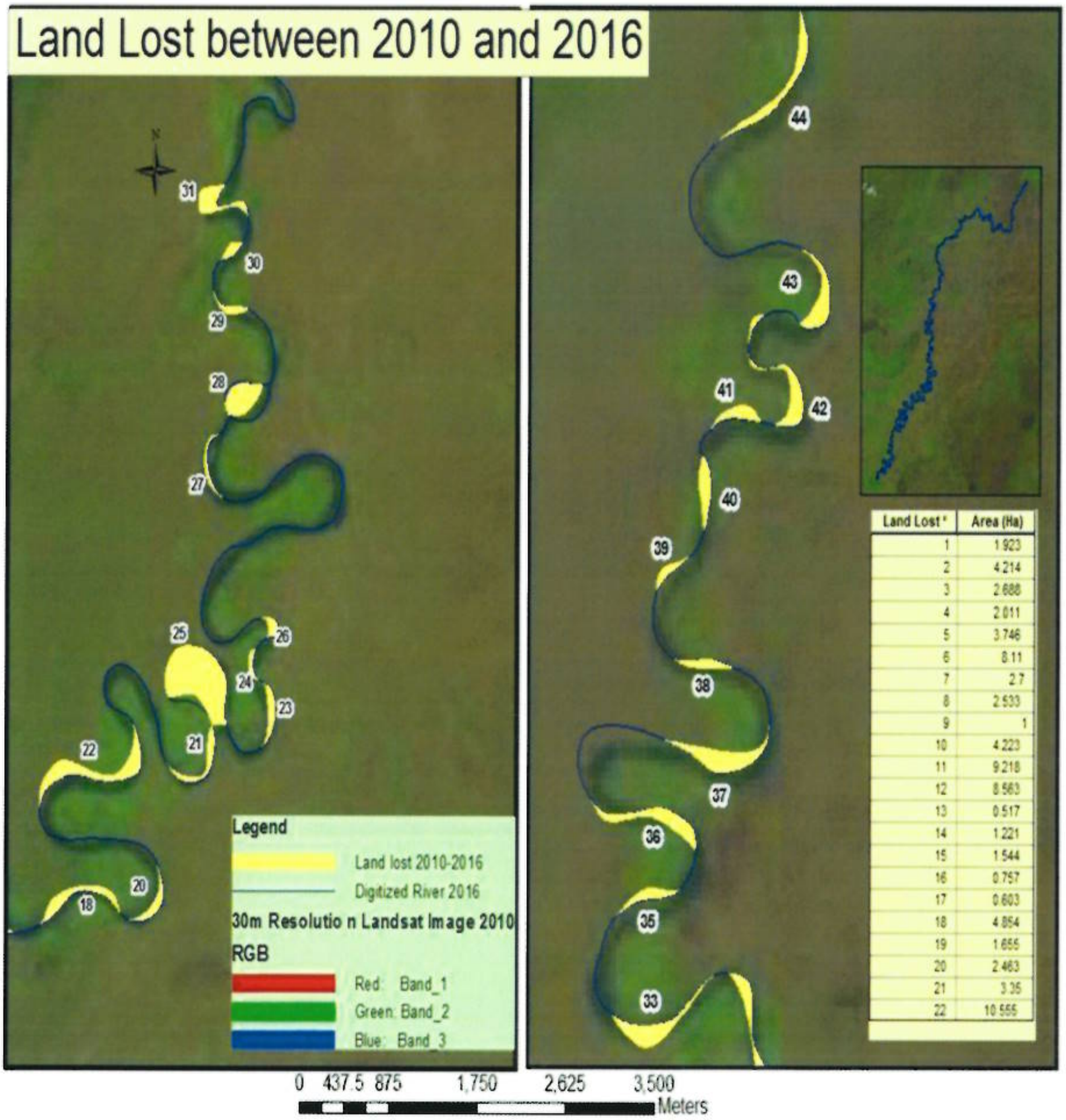


Figure 0-4: Meander plan (2010-2016)

4.2 Stream Sinuosity of River Semiliki

It was noted that most segments of the River Semliki are not straight with the majority exhibiting meanders as shown in Appendices 1, 2 and 3. The entire River and particular segments of the River (1986 to 2016) (Figure 4.5) were considered when calculating the sinuosity (Table 4.1). These individual segments are illustrated in Appendix 21.

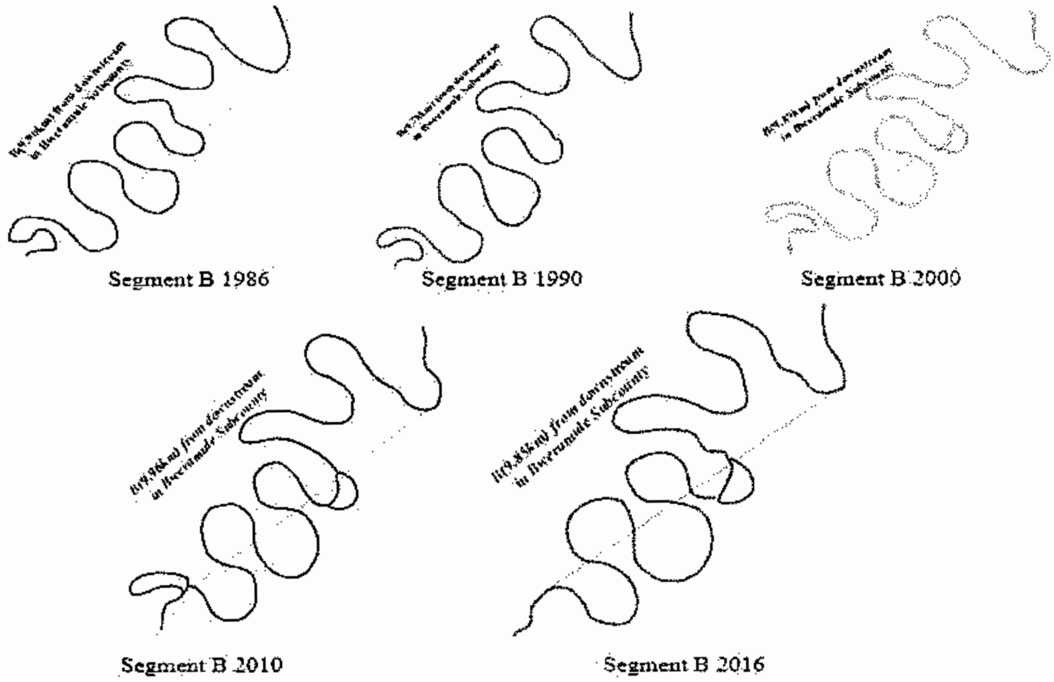


Figure 0-5: Changes in Sinuosity over the years along River Semliki

Table 0-1: Sinuosity Indices of meander segments along River Semliki

	Siuosity				
Year	1986	1990	2000	2010	2016
Segment (time series)					
A	2.57	2.63	2.65	2.18	2.75
B	3.79	3.71	3.84	4.09	4.01
C	3.24	3.09	3.25	3.76	3.83
D	2.54	2.42	2.29	2.54	2.73
E	1.27	1.26	1.31	1.34	1.31
F	1.15	1.9	1.23	1.2	1.18

4.3 Land Loss along River Semliki

During the continuous change in the meander plan of River Semliki, land has been lost (Table 4.2). This study identified areas that had experienced land loss consistently over the period under study and marked them as consistent 'hotspots' (Figure 4.6). An analysis of the amounts of land lost in each hotspot site using an independent *t*-test showed that there was a significant ($t=0.0001$, $d_f=13$) variation at these sites. The amount of land (hectares) lost ranged from 10.06 hectares in Nyakasenyi village, Butungama sub bounty to 22.53 hectares in Bweramure village, Bweramure Sub-County. The land lost was then plotted against the years and the gradient measured as shown in Appendices 5 to 20.

Table 0-2: Quantified land loss at different segments of River Semliki in Ntoroko District

ID/Hotspot	Coordinates (X)	Coordinates (Y)	Village	Sub-County	Land lost (Hectares)
8	185614	100970	Kayanja	Bweramule	11.73
12	185649	101006	Kayanja	Bweramule	12.88
15	185662	101106	Kayanja	Bweramule	11.12
21	185424	101468	Kayanja	Bweramule	13.32
23	187659	105573	Bweramure	Bweramule	11.92
26	187762	105612	Bweramure	Bweramule	13.95
27	187531	105570	Bweramure	Bweramule	22.53
35 Oxbow lake	187256	105609	Bweramure	Bweramule	10.57
36	191261	108864	Bweramure	Bweramule	12.96
42	191230	108867	Bweramure	Bweramule	13.15
44	191353	108926	Bweramure	Bweramule	10.25
47	191388	108928	Bweramure	Bweramule	10.48
70	203603	127223	Nyakasenyi	Butungama	10.07
55	203687	127276	Nyakasenyi	Butungama	22.37

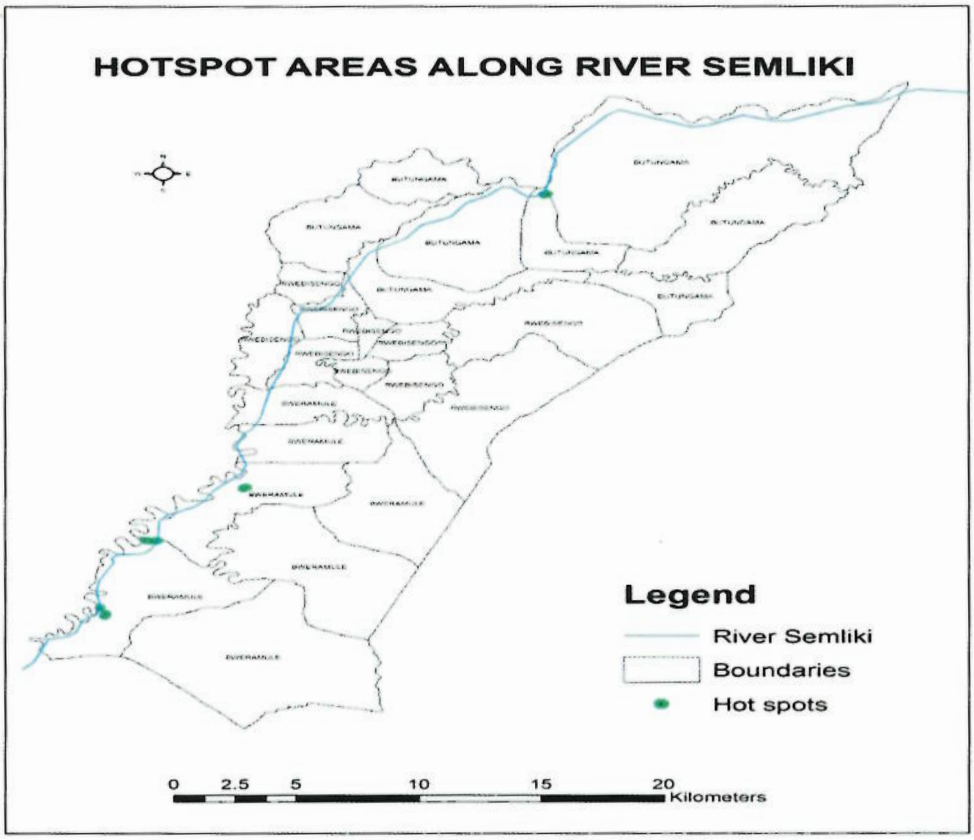


Figure 0-6: Hotspot of land loss along River Semliki in Ntoroko District, Uganda

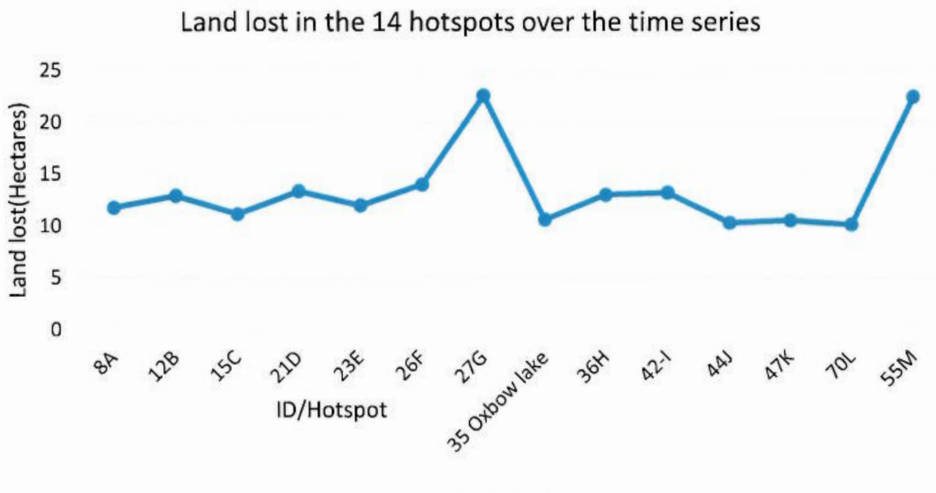


Figure 0-7: Land loss in Hectares at different segments over four time series in River Semliki

Potential hotspots	1986-1990 (Ha)	1990-2000 (Ha)	2000-2010 (Ha)	2010-2016 (Ha)
1	2.596	0.369	1.432	1.923
2	0.784	1.648	1.183	4.214
3	1.417	0.625	0.546	2.688
4	2.100	1.830	3.429	2.011
5	0.244	0.288	0.957	3.746
6	0.520	0.312	0.229	8.110
7	4.561	3.021	2.605	2.700
8	4.733	1.639	0.733	2.533
9	1.182	1.403	0.316	1.000
10	0.486	0.560	0.577	4.223
11	0.408	0.967	0.373	9.218
12	4.564	2.434	1.134	8.563
13	1.134	3.057	2.280	0.517
14	1.261	1.411	1.538	1.221
15	0.074	2.474	1.086	1.544
16	1.386	0.914	1.191	0.757
17	0.050	0.940	1.049	0.603
18	2.834	2.058	0.470	4.854
19	1.126	1.299	1.348	1.655
20	1.647	6.350	4.059	2.463
21	0.316	0.923	1.757	3.350
22	0.839	5.190	0.469	10.555
23	0.584	2.501	0.345	2.566
24	0.341	0.830	1.612	1.021
25	2.547	5.225	0.601	22.834
26	1.154	2.560	1.294	1.332
27	9.884	0.569	0.727	1.397
28	0.500	1.042	0.359	6.292
29	6.392	2.612	0.339	1.477
30	0.865	1.169	0.522	1.257
31	0.341	2.621	0.108	4.778
32	7.593	0.273	0.398	0.389
33	3.461	1.084	1.033	2.957
34	4.515	0.963	0.096	6.327
35	4.680	1.214	3.263	1.191
36	0.880	2.079	0.226	3.025

37	1.010	0.983	2.794	3.655
38	1.486	1.136	9.045	1.018
39	0.281	1.373	0.280	0.660
40	0.828	0.402	1.227	1.646
41	0.463	0.402	0.777	1.242
42	0.752	0.703	2.209	2.640
43	2.337	0.342	0.515	2.343
44	2.215	0.725	0.210	2.872
45	0.281	0.918	3.809	8.472
46	0.341	0.766	0.379	4.850
47	3.051	0.259	0.465	4.506
48	0.365	0.900	0.107	4.638
49	1.549	0.324	1.578	0.580
50	0.793	0.653	3.898	2.024
51	2.737	0.400	1.502	2.283
52	0.986	1.350	2.512	1.299
53	0.300	0.303	0.207	4.378
54	1.315	2.028	1.390	3.027
55	9.531	0.873	3.112	1.700
56	0.618	0.993	2.460	0.332
57	3.267	0.395	1.008	6.968
58	0.994	1.075	0.398	1.516
59	1.905	0.970	0.775	5.411
60	3.003	0.848	0.729	1.946
61	3.375	0.540	0.720	2.167
62	0.629	0.079	0.384	3.397
63	0.972	0.000	0.084	6.288
64	1.163		0.880	5.450
65	0.975		0.749	3.246
66	1.706		0.483	5.905

4.4 Vegetation along River Semliki

Four major plant types namely grassland, scrub woodland, riverine forest and swamp vegetation were recorded along the banks of River Semliki. Figure 4.4 shows the plant types encountered along River Semliki giving the major plant species.

i. **Grassland vegetation.**

Hyparrhenia-Themeda, *Hyperrhenia filipendula*, *H. dissoluta*, and *Themeda triandra* dominated the North-West of the River bank where there had been frequent fires and intensive cattle grazing. Other species included *Chloris; Sporobolus in moist wooded savana*, short to medium height grass which occurred in patches, *Imperata cylindrica*, and *Panicum echinochloa* a tall grass mainly covering large moist depressions such as watering holes and forming a thick band on non-forested River banks and lower grounds in the vicinity of Lake Albert.

ii. **Scrub woodland vegetation.**

The dominant wooded grassland characteristic of the *Acacia-Hyparhenia-Themeda* woodland with *Acacia sieberiana* was the dominant tree species associated with *Albizia grandibracteata*. Others included the *Acacia imperata* in a moist wooded savanna, dominated also by *Acacia sieberiana; Combretum-Hyparhenia-Themeda* which was a mixed wooded savanna dominated by *Combretum sp., Tamarindus indica;* and *Borassus -Hypahenia* a palm savanna dominant with other tree species scattered at lower densities. The *Borussus aethiopium* palm is the frequent species although *Acacia* and other leguminous species are also common.

iii. **Riverine forest**

This mainly occurs in narrow strips along the banks of River Mugiri, River Wasa and in Nyaburogo valley. Interspersed with the Riverine forests, are mainly bushland or thicket species mixed with low canopy forest species. The common forest vegetation type included the *Celtis-Chrysophyllum* Riverine forest, which occurs in thick bands along Mugiri and the southern end of Wasa. Here are numerous large tree species and high species diversity. The most common main canopy Riverine tree species was Ugandan ironwood (*Cynometra alexandri*), followed by *Millettia dura* and *Kigelia africana*. The understory was dominated by *Beilschmiedia ugandensis*, by far the most common tree in the Riverine forests. *Celtis africana, C. intergrifolia, C. mildbraedii, C. brownii, Albizia grandibracteata, A. coriaria, Chrysophyllum sp., Phoenix reclinata, Polyscias fulva*, and *Cola gigantea* were common. Other associated tree species included: *Alistonia bonnei, Strychnos mitis, Diospyros abyssinica, Funtumia africana, Ficus ovata and Phoenix reclinata*. The tree stature declines as one moves away from the water sources, sometimes transitioning gradually to open-habitat species such as *Acacia, Albizia* and bushy species, but more often the transition from forest to grassland is abrupt.

iv. **Wetland vegetation.**

These were mainly located on permanently water logged areas adjacent to the Riverine forests and along shores of Lake Albert. The areas were dominated by *Phoenix reclinata* swamp forest and *Cyperus papyrus* swamp.

Figure 0-8: Vegetation and major plant species along River Semliki

	The common Riverine forest vegetation type included the *Celtis-Chrysophyllum* Riverine forest. The main canopy Riverine tree species is Ugandan ironwood (*Cynometra alexandri),* followed by *Millettia dura* and *Kigelia africana.* The understory was dominated by *Beilschmiedia ugandensis*, by far the most common tree in the Riverine forests. *Celtis africana, C. intergrifolia, C. mildbraedii, C. brownii, Albizia grandibracteata, A. coriaria, Chrysophyllum sp., Phoenix reclinata, Polyscias fulva*, and *Cola gigantea*
	Scrub woodland vegetation with patches of open grassland located in Nyakasenyi Village, Butungama Sub-County. *Acacia-Hyparhenia-Themeda* woodland with *Acacia sieberiana* are the main dominant tree species associated with *Albizia grandibracteata*. Others included the *Acacia imperata* in a moist wooded savanna, dominated also by *Acacia sieberiana; Combretum-Hyparhenia-Themeda*

	Riverine open grassland dominated by *Cynodon dactylon, Echinochloa pyramidalis* and *Sporobolus pyramidalis* located at Bweramure village, Bweramule Sub-County, Kayanja village, Bweramule Sub-County and *Panicum repens* in Nyakasenyi village, Butungama Sub-County. These sites are highly disturbed by livestock overgrazing and trampling
	Riverine swamp dominated by *Typha domingensis*. The species is unpalatable to grazers which is accountable to rapid loss of vegetation cover and changes in vegetation structure at the site. The other species include *Phragmites mauritianum, Echinochloa pyramidalis and Cynodon dactylon* in Bweramure village, Bweramule Sub-County.

Table 0-3: Description of major plant species and their population along River Semliki

Family	Species	Growth fon	Root system	Sample site	Buturigama			Rwebisengo			Bweramule			Rwambale			Relative abundance
				Quadrat	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	
				Geo-location													
				Vegetation	Riverine swamp grassland	seasonally flooded open grassland	seasonally flooded open grassland	Riverine swamp grassland	seasonally flooded open grassland	seasonally flooded open grassland	Riverine swamp grassland	seasonally flooded open grassland	seasonally flooded open grassland	Riverine swamp grassland	seasonally flooded open grassland	seasonally flooded open grassland	
Poaceae	Cynodon dactylon	Grass	Adventitious and rhizomes; roots grow up to 2 meters deep; roots develop from nodes that touches the ground		20	85	90						90	90	80	85	0.40
Poaceae	Phragmites mauritianum	Grass	A ticket of adventitious roots and rhizomes, spreads up to 10ft deep in one growing season								70	10		80	25		0.14
Poaceae	Echinochloa pyramidalis	Grass	Adventitious and rhizomatous		55					60							0.08
Cyperaceae	Cyperus dives	Herb	Rhizomatous up to 25 mm, rhizomes form bulb like structures; forms dark reddish-brown tubers or chains of tubers											10			0.01
Poaceae	Panicum repens	Grass	Adventitious develop in tussocks		25	10		15	5		20	10		5			0.07
Poaceae	Sporobolus pyramidalis	Grass	tussocks		25	40	15	20	30	20	15	30	40	10	5	15	0.20
Typhaceae	Typha domingensis	Herb	Adventitious, rhizome, develop lateral roots											95	60		0.11

It was observed that most meanders astride devegetated land were rapidly migrating both on the Ugandan and Democratic Republic of Congo side. This implies that role of vegetation in holding together soil particles and the resultant reduction of River bank erosion is forfeited (Plate 4.1 and 4.2). It was also noted that all places along the River used as animal water points are degraded and weakened, setting up banks that are easily scoured by the River. (Plates 4.3 to 4.4).

Plate 4.1: Overgrazing along River Semliki

Plate 4.2: Bare land along River semliki

Plate 4.3: *Phragmites* along River Semliki

Plate 4.4: *Typha* on Semliki River bank

4.5 Soil Characteristics along River Semliki

The banks of River Semliki have red-brown loam soils (Figure 4.7). The red brown sandy loam soils are of duplex nature, with a layer of sandy loam to light clay loam overlying clay subsoil. The surface loam varied in thickness from 10 to 50 cm. Sub-soils were more crumbly and coarser in texture at depth compared with the overlying, uppermost part of the subsoil. It adheres to at least one finger, not soapy or sticky (Plates 4.6 to 4.9).

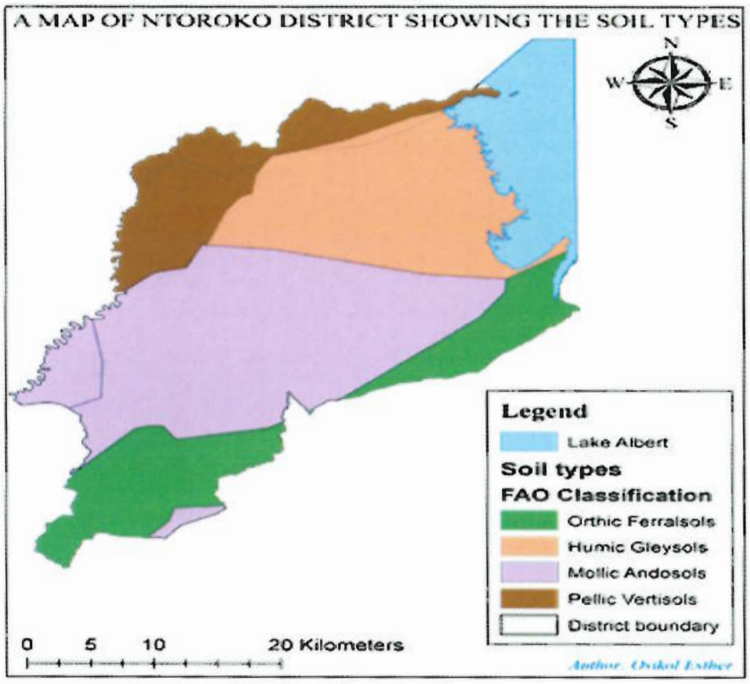


Figure 0-9: The soil types in Ntoroko District

The colour varies from red brown to light grey brown on the surface. Clay subsoils may vary from yellow to red to grey. 'Mottled' sub soils are common. Mottled refers to a mix of colors in a patchy appearance. The lower part of the loam topsoil above the clay subsoil is called the A2 horizon, and may be of bleached, white appearance. Deeper subsoils are usually yellowish or olive brown, and sometimes grey.

The topsoil (often called the 'A horizon') of a red brown sandy loam soil may set very hard with few cracks upon drying, showing very little structure. This feature is known as 'hard-setting'. It occurs frequently in soils that are high in fine sand and/or silt and low in organic matter. A hard surface layer up to 1 cm thick (known as a 'crust') may form in some soils for similar reasons. Despite this, many of these soils were favorably structured before excessive cultivation damaged their structure. In some instances, nearer to sand hills and prior streams, the topsoil may be sandy and loose. Clay subsoils (often called the 'B horizon') are of high clay content and often exhibit a coarse blocky to column-like structure. The topography of the red brown sandy loam soils is moderately sloping with occasional short, steep slopes at the rounded ends of drumlins. The soil parent material is a gray-brown calcareous sandy loam or loam till that contains numerous fragments of limestone and large boulders of granite.

On some of the till ridges the soil materials have been sorted by wave action that has produced sandy surfaces. They can contain a fair amount of organic matter. It is friable and well aggregated, and about 6 inches thick.

On the eroded slopes however the brown-colored B horizon becomes the surface layer, The B horizon is a brown to dark brown clay loam, 5 to 7 inches thick. Since it contains a greater quantity of clay than the surface it is less permeable to water.

Table 4.6: Description of soil characteristics along River Semliki

Depth (cm)	Description
0-15	Dark brown firm sandy loam with weak coarse platy structure.
15-54	Dark brown hard medium clay with strong coarse prismatic, breaking to angular blocky structure.
54-80	Yellowish red hard sandy light clay with weak coarse prismatic structure
80-110	Strong brown massive firm very highly calcareous coarse sandy loam.
110-160	Strong brown massive firm very highly calcareous coarse sandy loam with 2-10% quartz gravel and carbonate nodules to 6 mm.

In the Semliki flats, there were sections where the landscape bears evidence of profiles with two parent materials hence successive depositional cycles in places. Where clay seems to dominate the surface and sub-surfaces horizons, the structure of the soils is columnar (Plate 4.7). Sand seems to dominate sub-horizons in places (Plate 4.8).

Plate 4.5: Soil profile along River Semliki banks

Plate 4.6: Loose soil at River Semliki banks

Plate 4.7: Soil profile at a meander Plate 4.8: Blocky soil structure on River Semliki banks

A quick test of rupture resistance revealed that the soils along the banks of River Semliki were firm but weakly cemented and hence prone to erosion. This is also the reason they easily curve-in under stress from animal trampling and is the cause of the bank slumps that accompany light rains and bank-full flows (Plate 4.9 and 4.10).

Plate 4.9: Fragility of soils along River Semliki Plate 4.10: Weakly cemented soils

CHAPTER FIVE: DISCUSSION

5.1 River Semliki meander plan

River Semliki exhibits active meandering. According to the Atlas of Our Changing Environment by NEMA (2009), despite the fact that River Semliki is in its old stage, and like any aging River, it has characteristic meanders and forms oxbow lakes in some places. In spite of its old stage, it still has enormous erosive power which is realized when it emerges from the forested Semliki National Park onto the Semliki flats in Rwebisengo and Bweramule sub-counties in Ntoroko District. The Atlas further notes that the increased River bank erosion due to overgrazing and degradation of the water catchments has resulted in siltation changing the River course significantly over the years as it enters Lake Albert. Results from this research revile that River Semliki has exhibited changes since 1986 i.e the river meanders migrate downstream over time, which has led to the formation of Oxbow lakes along the river where meanders cut off from the main stream (Appendix 21) thus reduction in the length of the river.

5.2 River Sinuosity along River Semliki

The sinuosity indices obtained in this study increased towards downstream the River channel. The sinuosity index was highest as the River flows through the fluvial sediments region of the study area (Segment B). The sinuosity of the River varied from 1.18 to 4.09. Thus River Semliki may be termed as a highly meandering River based on the classification suggested by Leopold and Wolman (1957). The meandering nature of the River is responsible for frequent course change of the River as it flows through the plains of Ntoroko. Several types of meander bends along its bank line have been observed on overlaying the River layers of 1986, 1990, 2000, 2010 and 2016 thus leading to frequent shifting of the bank line of the River.

Following Sarma *et al.*, (2007), Meander bends along the bank line of River Semliki during the period 1986-2016 can be broadly grouped into two categories and these are; (i) neck cut-off at the meander loop leading to channel abandonment and straightening and (ii) progressive gradual change in meander bends as well as in straight parts of the channel (without neck cut-off). The neck cut-off occurs when the meander loop becomes either nearly circular or when the two ends of the loop come very close; consequently, the River straightens the course at the neck of the meander bend resulting in abandonment of the meander loop and formation of oxbow lake

(Appendix 21). The formation of new meander bends was observed in two places during this period which led to the shortening of the channel course. It was also observed that the River course in 2016 (101.6km) became shorter by 2.20 km than that in 1986 (Appendix 28).

The other types of meander bends observed by overlaying the River layers of 1986, 1990, 2000, 2010 and 2016 included rotation, translation, extension, lateral, narrowing/widening of the channel and complex following (Barman and Goswami, 2015). These types of meander bends occurring frequently caused shifting of the bank line of River Semliki. This leads to heavy loss of land as this process leads to meandering of the River channel and ultimately results in bank erosion. The highly meandering nature of channel as the River flows through alluvial sediments in the plains and excessive sediment discharge results in constant shifting of the bank line of the channel and has been continuing through ages.

5.3 Land loss along River Semliki

The degradation and extension of meanders has been noted at fourteen (14) hotspots and has impacted the international border of Uganda (Figure 4.6 and Table 42). The border has migrated many times on either side especially downstream were there are aggressive meanders and not so much up and mid-stream where the River is fairly straight. This migration is accompanied by land losses (Table 4.2 and 4.3). It was calculated from the fourteen (14) spots in the two Sub-Counties that had lost over 10 hectares of land on the Ugandan side between the four time series 1986-1990, 1990-2000, 2000-2010,2010- 2016 when meanders migrated along the stretch of the River. The process is expected to cause further changes in boundary and shrinkage and/or expansion of land in places if nothing is done to counter the forces at play.

It is evident that River Semliki has gradually eroded land along its banks on both Ugandan and DRC sides (Table 4.2). On the side of Uganda, Appendices 5-20 shows the 'hotspots' of this loss while table 4.1 gives the quantified amount of land lost on the Ugandan side. Das et al., (2014) asserted that the loss of land due to flood is temporary, but the loss due to River bank erosion is permanent and has a long term impact on the economy. River Semliki is a geopolitically important River because it defines the border between Uganda and the Democratic Republic of Congo (DRC) (NEMA 2009). Therefore, having its course changing is a precursor for border disputes and resource conflicts between the two countries.

According to the Atlas of Our Changing Environment by NEMA (2009), increased River bank erosion along River Semliki is due to overgrazing, melting of ice on the Mount Rwenzori and degradation of the water catchments which has resulted into siltation thereby changing the River course significantly over the years as it enters Lake Albert. NEMA further notes that in spite of its old stage, the River still has enormous erosive power which is realized when it emerges from the forested Semliki National Park onto the Semliki flats in Rwebisengo and Bweramule sub-counties, Ntoroko District. The processes governing River bank erosion are bank scour which refers to the direct removal of bank materials by the action of flowing water and the sediment it carries and mass failure in which simply section of the bank slides or falls into the River (collapse or slumping). It is thus likely that the human and livestock activities have greatly impacted the natural vegetation along its course, thus leading to River bank breakage. Furthermore, NEMA estimated that over 10 m of the River bank on Uganda's territory is eroded annually at various points and as a result, it seems to have doubled its width within the last ten years (NEMA, 2009).

It is important to note that earlier researchers (Das, T. K., Haldar, S. K., Gupta, I. D., and Sen, S. (2014)) have pointed out the factors that accelerate River bank erosion as flooding, land use and stream management, clearing of River bank vegetation, River straightening, rapid flow drop after flooding, saturation of banks from non-River sources, redirection and acceleration around infrastructure or debris in the channel, intense rainfall events and bank soil characteristics (easily erodible, poor drainage) (Das et al., 2014).The bank erosion process in several sections of the River network is influenced by the size of the channel, discharge, and flow strength (Florsheim *et al.,* 2008). This therefore implies that bank erosion is an ongoing natural process even at Rivers that are assumed to be stable, their well-defined channels shift over a long period of time through the processes of erosion and sedimentation.

5.4 Vegetation along River Semliki

The nature of vegetation cover along the River bank and the catchment area greatly influences the intensity and extent of River bank erosion. Researchers have overtime observed that bank erosion is increased by instability of the River behaviour due to deforestation and inadequate land use in the upper reach, which ultimately led to excessive sediment load into the Rivers

(Davinroy *et al.,* 2003; Arohunsoro *et al.,* 2014). Vegetation stabilizes banks primarily by increasing shear strength of the soil, reducing water velocity, and armoring the bank (Ott, 2000). Of course, the ability of vegetation to stabilize a bank is dependent upon factors such as plant vigor, density and rooting depth, etc. Some studies revealed that bank erosion in the upper reach was primarily due to destruction of riparian vegetation by people's access and the effect of bridge constrictions on high flow, and secondarily to poorly installed channel revetments (Madej *et al.,* 1994). Therefore, unprotected or poorly managed animal water points and over-grazing at or close to the River banks are directly associated with River Semliki bank instability, which is exploited by the swelling water levels and heavy discharge, especially during the rainfall season

The question as to whether meander extension would not take place under uninterrupted conditions can best be answered by looking at the nature of meanders where there is no disturbance. Here, vegetation and its roots hold the soil firmly, and the rough form of the bank increases boundary resistance to flow, so that the waves weakly cut the banks. In effect, the meanders have remained intact (Plates 4.9 and 4.10). This is mostly true where vegetation is dominated by *Phragmites* (Plate 4.10), otherwise where there is *Typha*, meander cut banks are easily scoured (Figure 4.11) but unfortunately *Typha* seems to outcompete *Phragmites* implying that the is need to increase on the population of Phragmites species along the river in order to restore the River banks.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The following conclusions can be drawn from this study:

1. The meander plan of River Semliki has changed overtime.

2. Land loss on both the Ugandan and DRC sides of River Semliki implies that the international boundary between these two countries is dynamic.

3. Although the migration of meanders is a natural process that accompanies stream adjustment to perturbations, this process has been accelerated by human activities along stream banks of River Semliki that have undermined channel bank stability.

4. Plant species which are deep rooted such as *Phragmites mauritianum* are more suited to stabilize River banks than the shallow roots ones like *Typha domingensis*.

6.2 RECOMMENDATIONS

In order to safe guard the Semliki River bank and minimize erosion and the resultant side effects including among others land loss, the following are practical remedies.

1. There is an urgent need to sensitize and or educate the masses along the River on the role of human activities in accelerating River bank erosion. This emanates from the observation that the misuse of the stream banks is responsible for the aggressive scouring of the River in places. There is evidence that where banks are intact and vegetated, meander migration is controlled.

2. Interventions that will reduce land use pressure on stream banks should be implemented. Such interventions can include alternative watering points for livestock for example creation of valley dams which are supplied with water pumped from the River. This will reduce the trampling effect of cattle on the rather fragile River banks. It was observed that cattle water points along the stream present weakness at such banks, which are exploited by water especially when flow is at or close to bank full. Therefore, instead of creating dams in the interior of the catchment, let animal water points be engineered at selected spots along the River. The water points should be constructed with a rough ramp

to allow delivery of cattle to the water while at the same time the cattle can retreat to the flood plain after drinking water. The ramp should be placed in a certain orientation not to significantly destabilize flow to cause turbulence at or close to the bank.

3. Deliberate efforts to vegetate the River bank ought to be implemented. While carrying out this exercise, priority should be given to indigenous species existing in the River bank and the adjacent catchment area.
4. The relevant authorities should enforce the protection zone of 100m. It is required that the protection zone of 100 m from the highest water is enforced. This can be achieved by sensitizing the community about the relevant provisions of the law, which demand the institution of the said limit. This should then be followed by monitoring to assess compliance, and then enforcement.
5. Restoration of the already degraded sections of the River bank. The degraded land within the 100 m should be restored by way of allowing it to regenerate with hydrophytic plants. It is plausible that once demarcated and the community is sensitized against encroachment, this can be achieved. Where degradation is severe, bio-engineering approaches should be used that is these must involve planting vegetation that suits the soil (saline characteristics) and climate of the area.
6. The River banks should be channelized at meander sections only. This will protect the channel wall against scouring. This is possible considering that such resistance would destabilize flow either upstream or downstream the structure with the results that weaker sections up or downstream the structure are undercut. The River would then extend the channel's width leaving the structures in the water.
7. Bio-engineer hotspots and susceptible meander sections. This will slow stream flow velocity using rebar meshes and hence engineer the environment to facilitate the growth of plants that can (i) accumulate "below ground" matter and soil, and grow to anchor the rest of the mass on neighboring rebars and bank. This approach means that the meander can be reconstructed to close to its former assembly which in turn helps recover lost land.

8. Riprapping meander bend walls. This can be achieved by use of rocks to stabilize and reduce the scouring effect of water on channel walls. This technique was used to successfully halt meander migration at sections of Sacramento River in California, USA (Larsen and Greco, 2002).

REFERENCES

Abernethy, B. and I. D. Rutherfurd. (1998). Where along a River's length will vegetation most effectively stabilize stream banks? Geomorphology. 23(1):55-75.

Aluma, C. and Okello, F. W. (2015) reported Tension as DRC is accused of encroaching on border.http://www.monitor.co.ug/News/National/Tension-as-DRC-is-accused-of-encroaching-on-border/688334-2745872-qj05giz/index.html

Amarasinghe, I. (1992). Effects of Root Reinforcement on Soil Strength and Bank Stability. PhD Thesis. Open University: Milton Keynes, UK.

Arohunsoro, S. J., Owolabi, J. T. and Omotoba, N. I. (2014). Watershed Management and Ecological Hazards in an Urban Environment: The Case of River Ajilosun in Ado Ekiti, Nigeria. *European Journal of Academic Essays,* 1(2): 17–23.

Barman, P., and Goswami, D. C. (2015). Evaluation of Sinuosity Index of Dhansiri (South) River Channel and Bank Erosion, Assam in GIS. *Evaluation, 2*(5).

Beschta, R. L., and Platts, W. S. (1986). Morphological features of small streams: significance and function. *JAWRA Journal of the American Water Resources Association, 22*(3), 369-379.

Coppin, N. J., and Richards, I. G. (Eds.). (1990). *Use of vegetation in civil engineering* (p. 292). London: Construction Industry Research and Information Association.

Couper, P. (2003). Effects of silt-clay content on the susceptibility of River banks to subaerial erosion. Geomorphology. 56: 95-108.

Couture, S. (2008), "River Dynamics and Erosion, Presented to Great Bay Siltation Commission,

Cronquist, A. (1981). *An integrated system of classification of flowering plants*. Columbia University Press.

Das, T. K., Haldar, S. K., Gupta, I. D., and Sen, S. (2014). River Bank Erosion Induced Human Displacement and Its Consequences. *Living Rev. Landscape Res.*, 8.

Davinroy, R. D., Rodgers, M. T., Brauer, E. J. and Lamm, D. M. (2003). Bank Erosion and Historical River Morphology Study of the Kaskaskia River: Lake Shelbyville Spillway To Upper End of Caryle Lake. Technical Report, M30, St. Louis, MO (U.S. Army Corps of Engineers, St. Louis District, Water Management.

December 1, 2008", conference paper. Online version: http://des.nh.gov/organization/divisions/water/wmb/coastal/ocean_policy/gb_commission.htm.

Florsheim, J. L., Mount, J. F. and Chin, A. (2008), "Bank Erosion as a Desirable Attribute of Rivers", BioScience, 58(6): 519–529.

Gurnell, A. M., and Gregory, K. J. (1984). Influence of Vegetation on Stream Channel Processes. *Catchment Experiments in Fluvial Geomorphology. Geo Books, Norwich England. 1984. p 515-535, 10 fig, 3 tab, 36 ref.*

Horwitz, R. J., W. C. Hession, and B. S. Sweeney. (2000). Effects of forested and unforested riparian zones on stream fishes. In: Wigington, P. J. and R. L. Beschta, eds. Riparian Ecology and Management in Multi-Land Use Watersheds, Proceedings, AWRA 2000 Summer Specialty Conference, August 28-31, Portland, OR.

Hupp, C. R. 1999. Relations among riparian vegetation, channel incision processes and forms, and large woody debris. In: Darby, S. E. and A. Simon, eds. Incised River Channels: Processes, Forms, Engineering, and Management. John Wiley and Sons: New York. pp. 219-245.

Iqbal, S. (2010). Flood and erosion induced population displacements: a socio-economic case study in the Gangetic Riverine tract at Malda District, West Bengal, India. *Journal of Human Ecology*, *30*(3), 201-211.

Kalema, J. (2005). *Diversity and distribution of vascular plants in Uganda's wetland and dryland important Bird Areas* (Doctoral dissertation, Ph. D. thesis, Makerere University, Kampala, Uganda).

Kondolf, G. M. (1997). Hungry Water: Effects of Dams and Gravel Mining on River Channels, Profile. *Environmental Management*, 21(4): 533–551.

Krishnanu, A., and Gopinath, G. (2015). Sinuosity Analysis using Geographic Information System (GIS): Case Study of a Tropical River Basin.

Langdale-Brown, I., Osmaston, H. A., and Wilson, J. G. (1964). The vegetation of Uganda and its bearing on land-use. *The vegetation of Uganda and its bearing on land-use.*

Larsen, E. W., and Greco, S. E. (2002). Modeling channel management impacts on River migration: a case study of Woodson Bridge State Recreation Area, Sacramento River, California, USA. *Environmental Management*, *30*(2), 209-224.

Larsen, E. W., and Greco, S. E. (2002). Modeling channel management impacts on River migration: a case study of Woodson Bridge State Recreation Area, Sacramento River, California, USA. *Environmental Management*, *30*(2), 209-224.

Le Bissonnais Y. (1996): Aggregate stability and assessment of soil crustability and erodibility: Theory and methodology. Eur. J. Soil Sci., 47: 425–437

Leopold, L. B., and Wolman, M. G. (1957). *River channel patterns: braided, meandering, and straight*. US Government Printing Office.

Lombardo, U. (2016). Alluvial plain dynamics in the southern Amazonian foreland basin. *Earth System Dynamics*, *7*(2), 453-467.

Madej, M. A., Weaver, E. W. and Hagans, D. K. (1994), "Analysis of Bank Erosion on The Merced River, Yosemite Valley, Yosemite National Park, California, USA", Environmental Management, 18(2): 235–250.

Mamo, M. and G. D. Bubenzer. (2001). Detachment rate, soil erodibility, and soil strength as influenced by living plant roots, Part I: Laboratory Study. Transactions of the ASAE. 44(5): 1167-1174.

Mithun, D., Dabojani, D., and Misbah, U. (2012). Evaluation of meandering characteristics using RS and GIS of Manu River. *Journal of Water Resource and Protection, 2012*.

NEMA (2009). *Uganda: Atlas of Our Changing Environment*. National Environment Management Authority (NEMA), Kampala, Uganda

Osman, A. M. and C. R. Thorne. (1988). Riverbank stability analysis I: Theory. *Journal of Hydraulic Engineering*. 114:134-150.

Ott, R. A. (2000). Factors Affecting Stream Bank and River Bank Stability, with an Emphasis on Vegetation Influences. In Welbourn Freeman, M., ed., Region III Forest Resources and Practices Riparian Management Annotated Bibliography, pp. 21–40, Anchorage, AK (Alaska Department of Natural Resources, Division of Forestry).

Perucca, E., Camporeale, C., and Ridolfi, L. (2007). Significance of the riparian vegetation dynamics on meandering River morphodynamics. *Water Resources Research*, *43*(3).

Randerson, J. (2010). The shifting River that is making Uganda smaller. https://www.theguardian.com/environment/2010/dec/07/climate-change-rerouting-semliki-River.

Ritchey, E. L., McGrath, J. M., and Gehring, D. (2015). Determining Soil Texture by Feel. Agriculture and Natural Resources Publications, University of Kentucky.

Sanchez, P. A., Ahamed, S., Carré, F., Hartemink, A. E., Hempel, J., Huising, J., & Minasny, B. (2009). Digital soil map of the world. *Science*, *325*(5941), 680-681.

http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/

Sarma, J. N., and Acharjee, S. (2012). A GIS based study on bank erosion by the River Brahmaputra around Kaziranga National Park, Assam, India. *Earth System Dynamics Discussions*, *3*(2), 1085-1106.

Tenywa, G. (2015). River erosion: Uganda losing land to DRC. http://www.newvision.co.ug/new_vision/news/1322946/River-erosion-uganda-losing-land-congo.

Thorne C. R. (1990). Bank Erosion and meander migration of the Red and Mississippi Rivers. Hydrology for the Water Management of Large River Basins (Proceedings of the Vienna Symposium, August 1991). *IAHS Fubl.* no. 201,

Verner, P. H., and Jenik, J. (1984). Ecological study of Toro Game Reserve (Uganda) with special reference to Uganda Kob. *Praha: Czechoslovakia.*

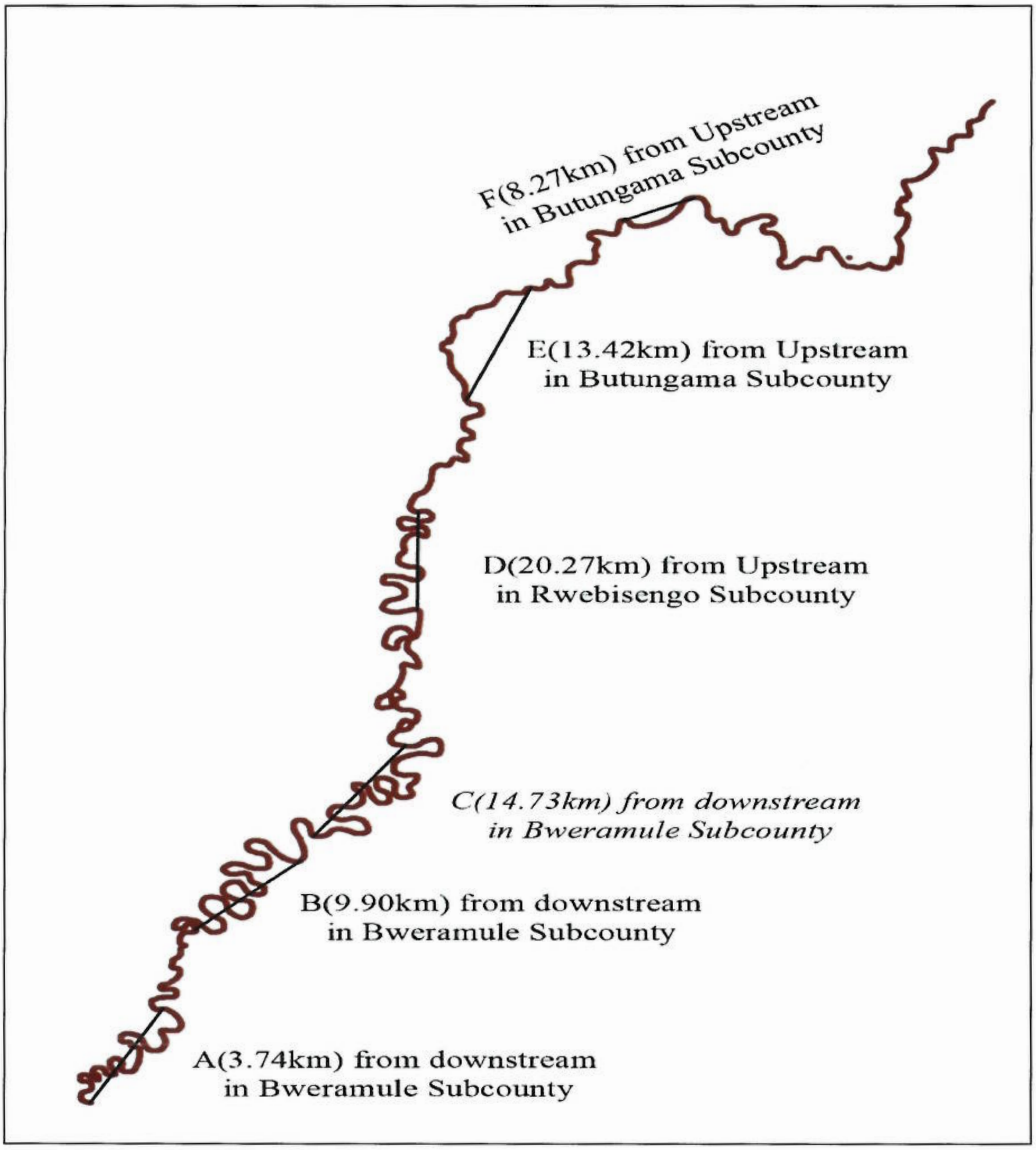
William R., Shadish, Cook, T. D., and Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Wadsworth Cengage learning.

Wynn T. M. (2004). The Effects of Vegetation on Streambank Erosion. PhD Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Available at http://scholar.lib.vt.edu/theses/available/etd-05282004-115640/

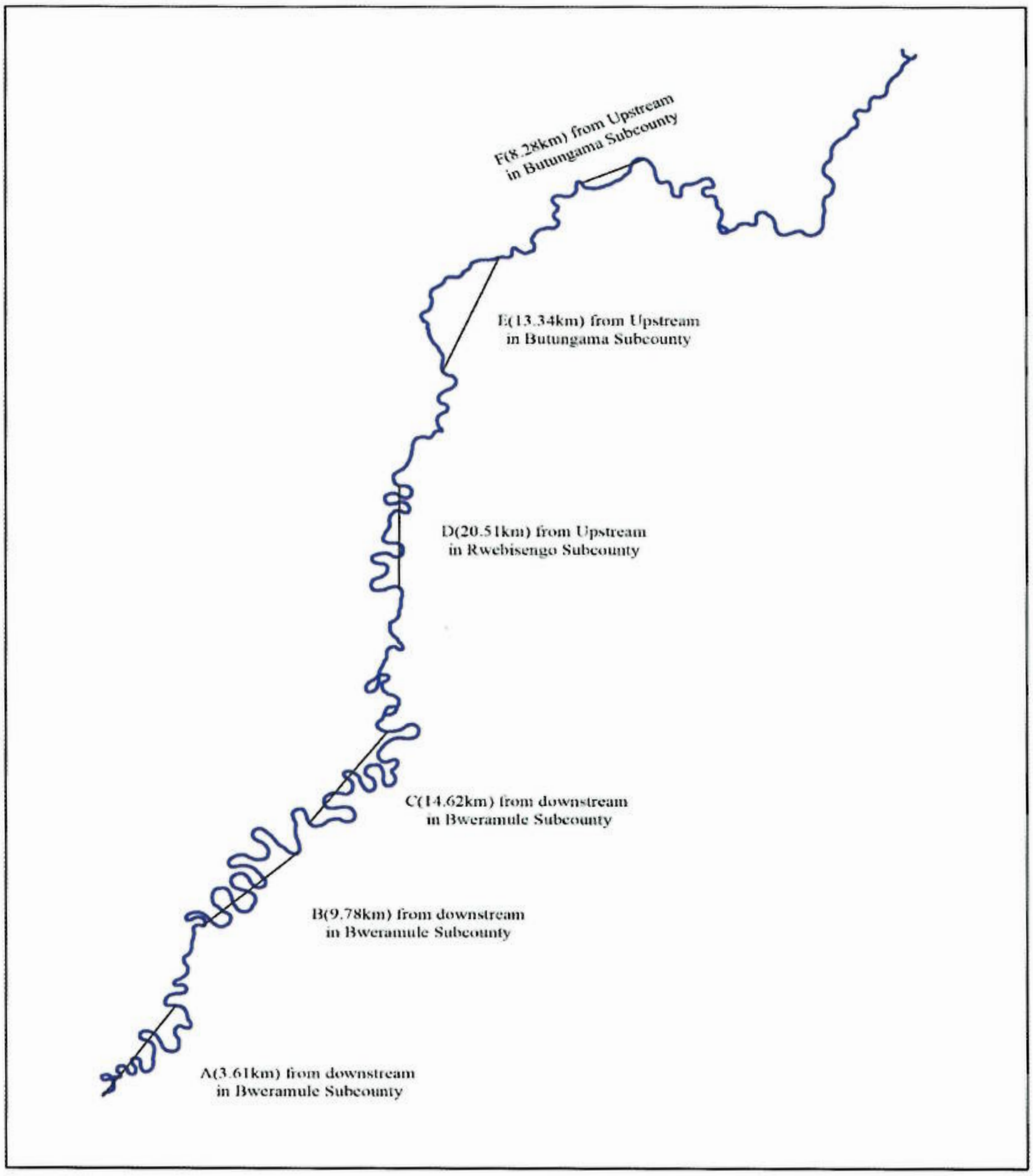
Yamani, M., Goorabi, A. and Dowlati, J. (2011). The Effect of Human Activities on River Bank Stability (Case Study). *American Journal of Environmental Sciences*, 7(3): 244–247.

APPENDICES

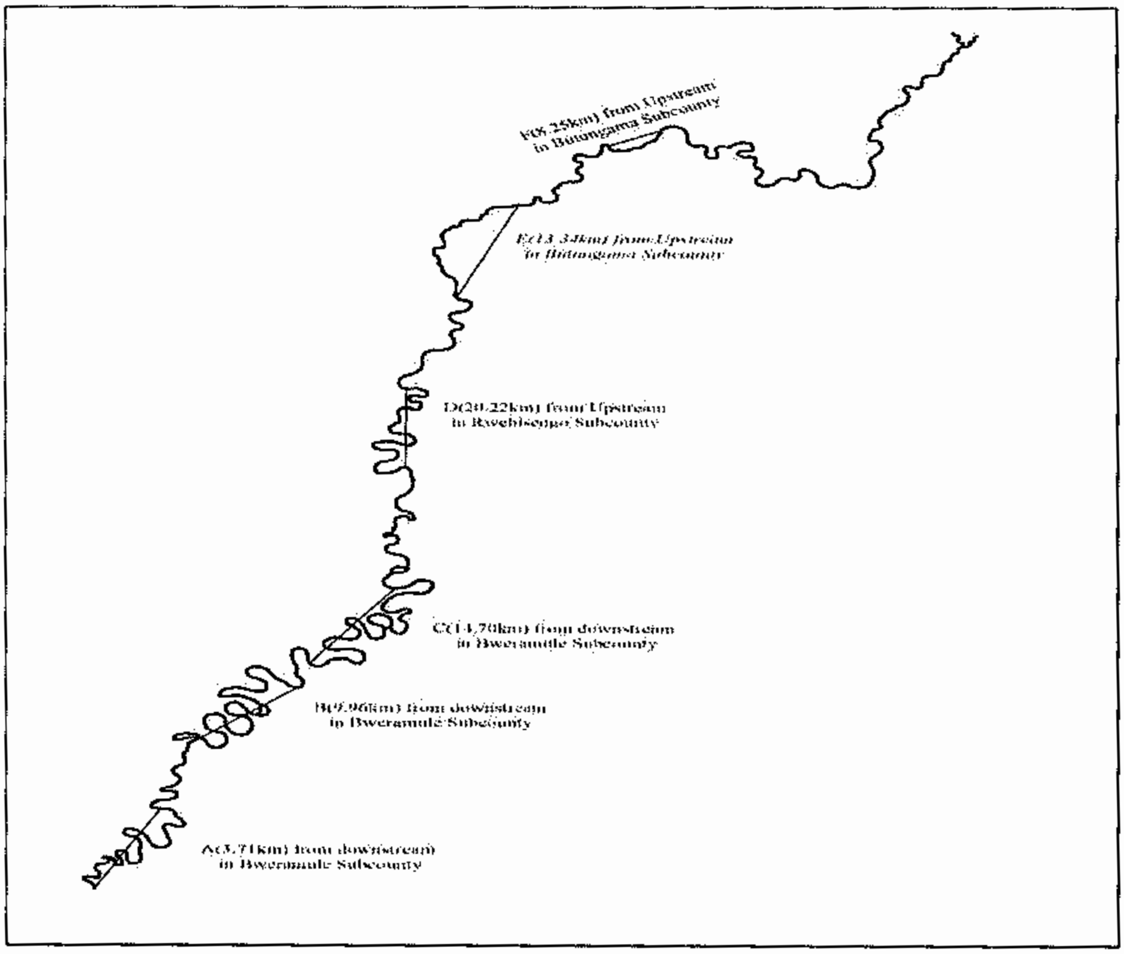
Appendix 1: River Semliki Sinuosity Index for 1990



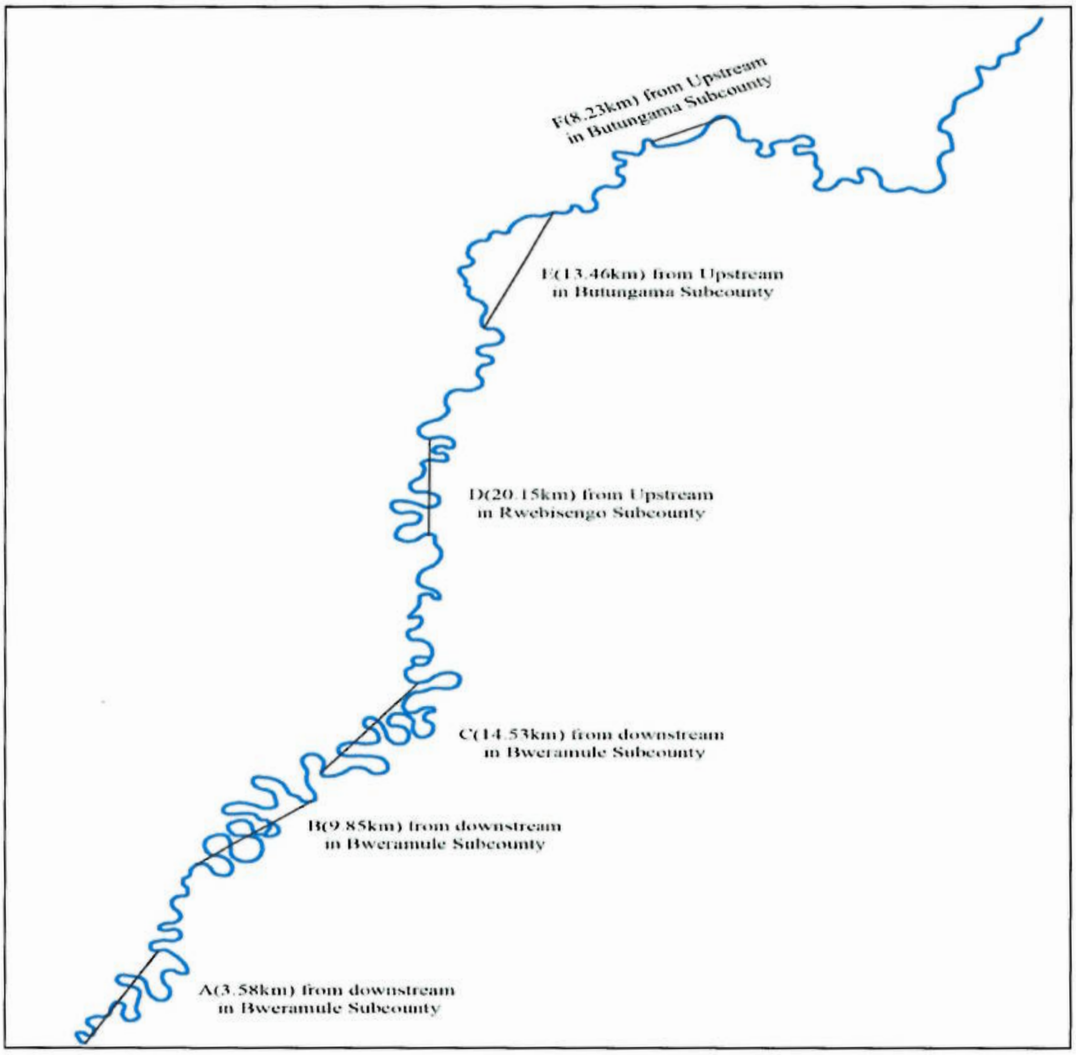
Appendix 2: River Semliki Sinuosity Index for 2000



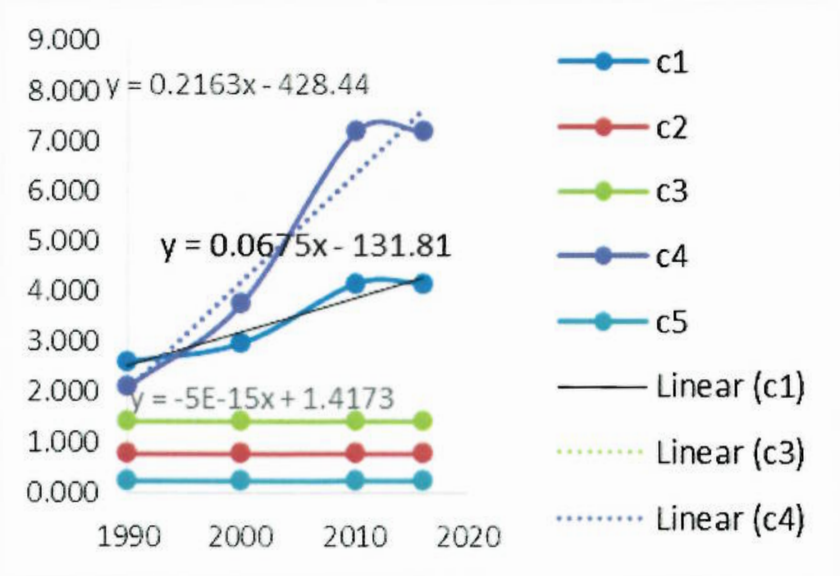
Appendix 3 : River Semliki Sinuosity Index for 2010



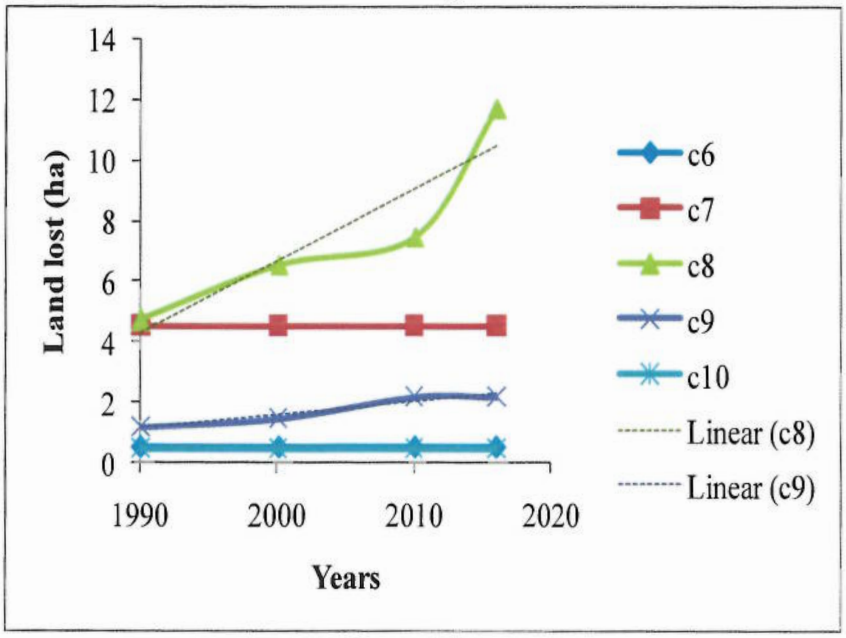
Appendix 4: River Semliki Sinuosity Index for 2016



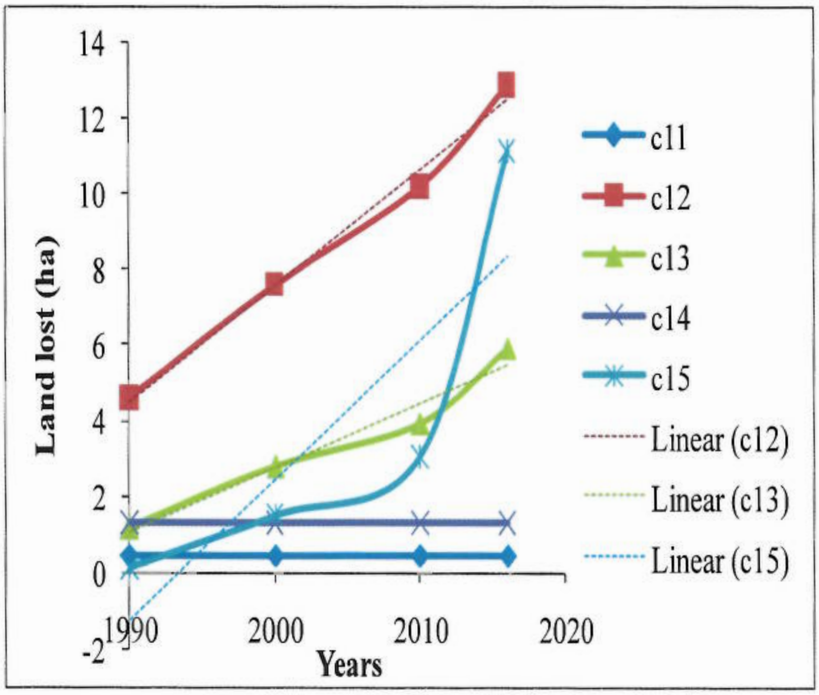
Appendix 5: Land loss in 1-5 'hotspots' (Calculating the radients for re-occuring Hotspots)



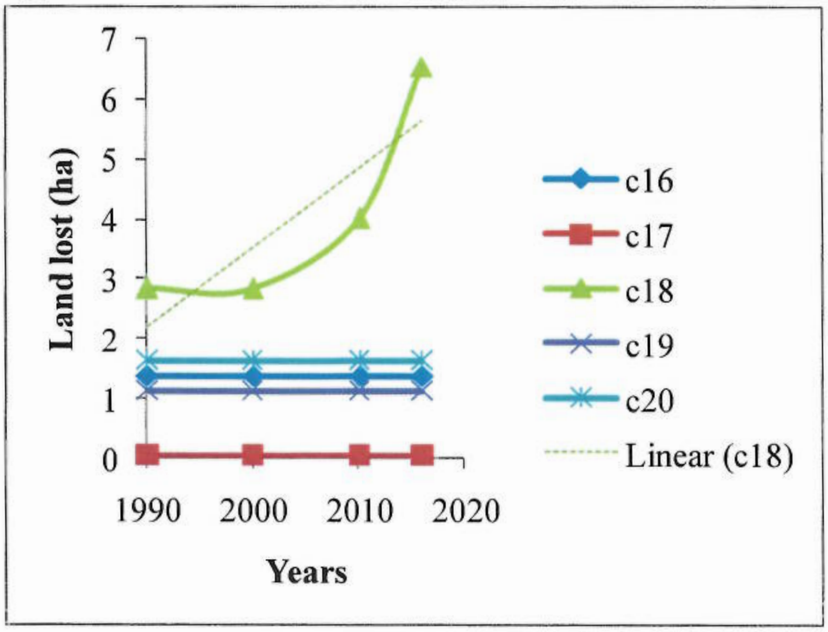
Appendix 6: Land loss in 6-10 'hotspots'



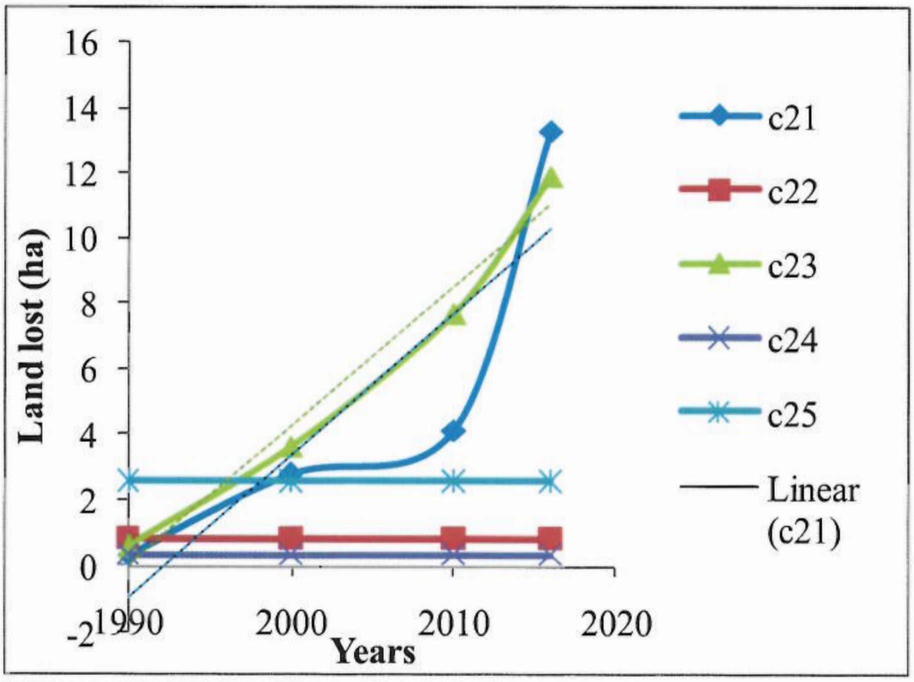
Appendix 6: Land loss in 11-15 'hotspots'



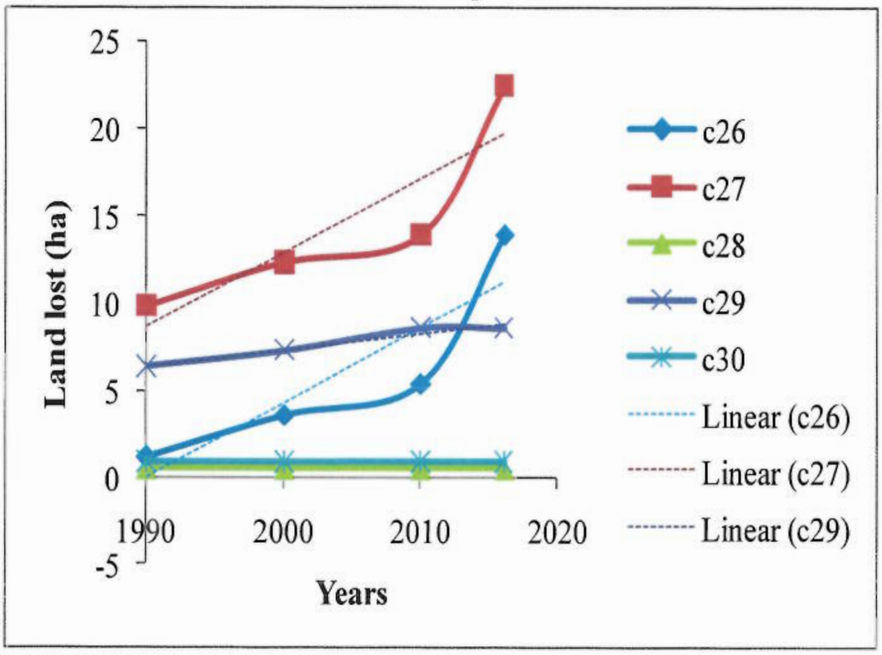
Appendix 7: Land loss in 16-20 'hotspots



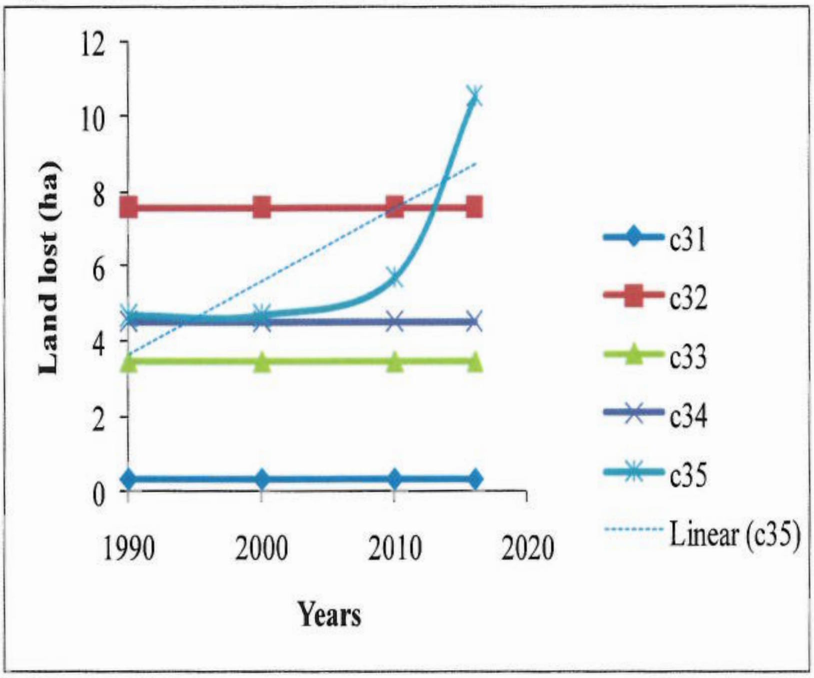
Appendix 8: Land loss in 20-25 'hotspots'



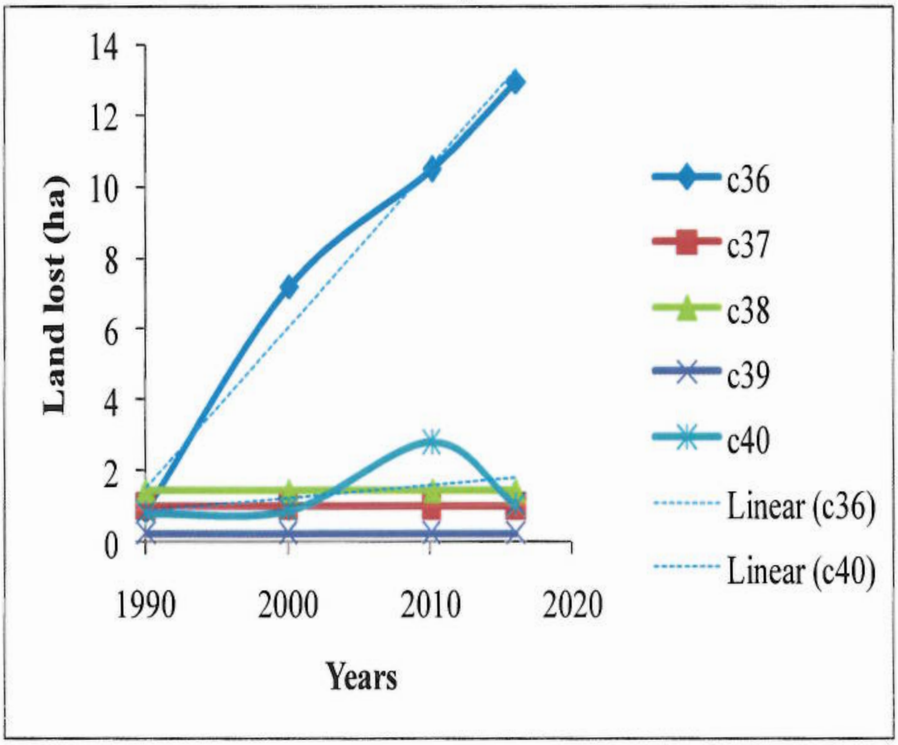
Appendix 9: Land loss in 26-30 'hotspots'



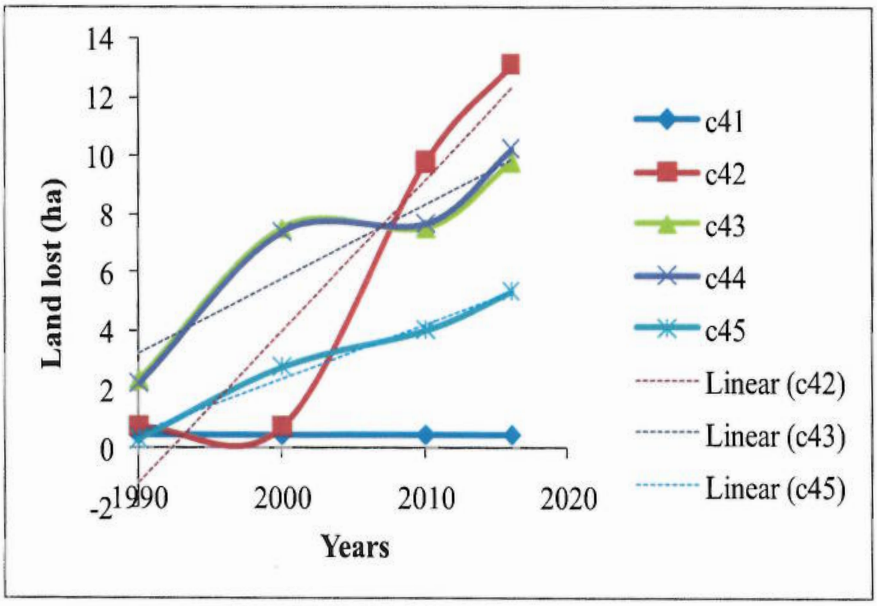
Appendix 10: Land loss in 31-35 'hotspots'



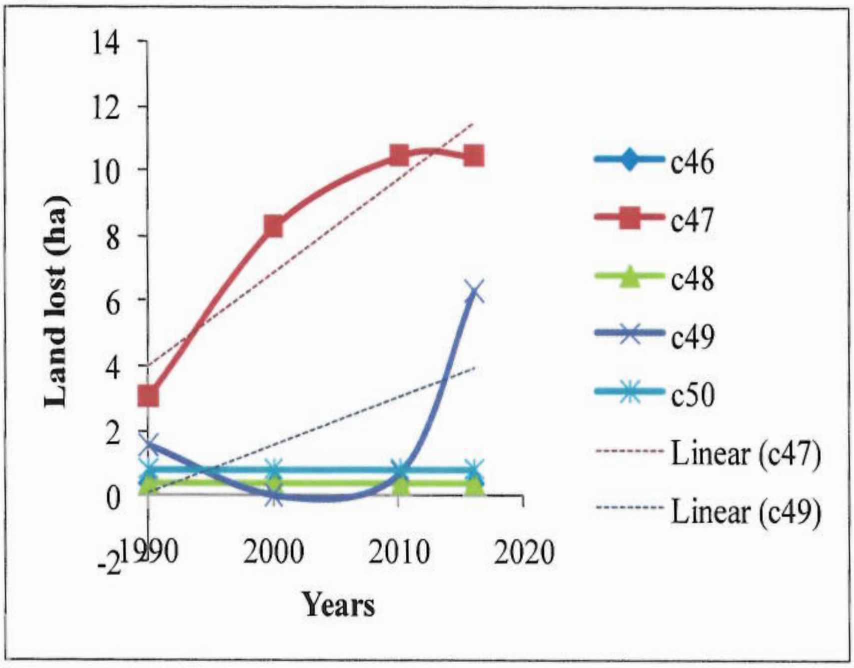
Appendix 11: Land loss in 36-40 'hotspots'



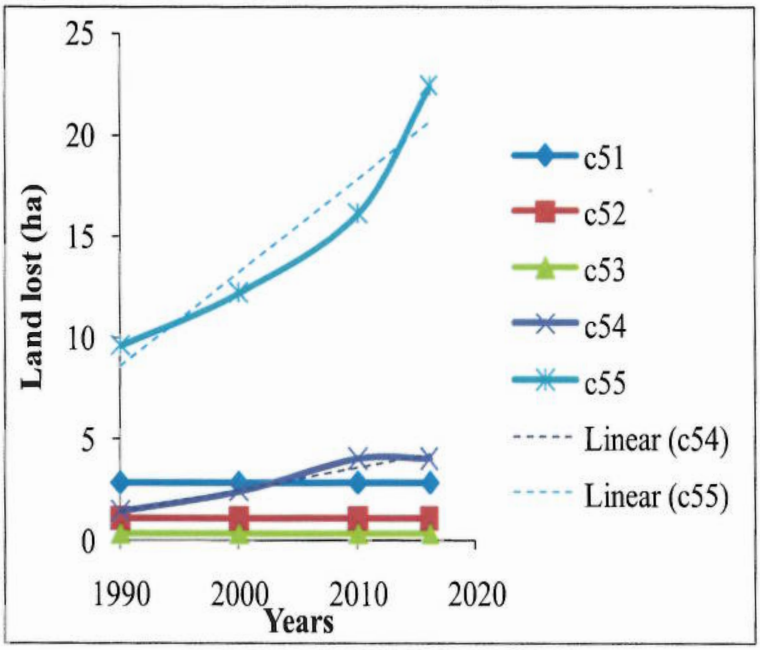
Appendix 12: Land loss in 41-45 'hotspots'



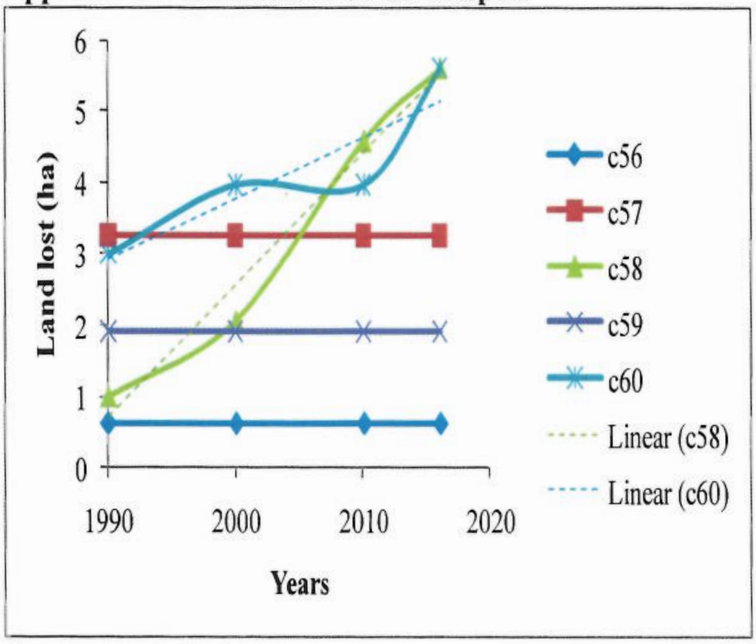
Appendix 13: Land loss in 46-50 'hotspots'



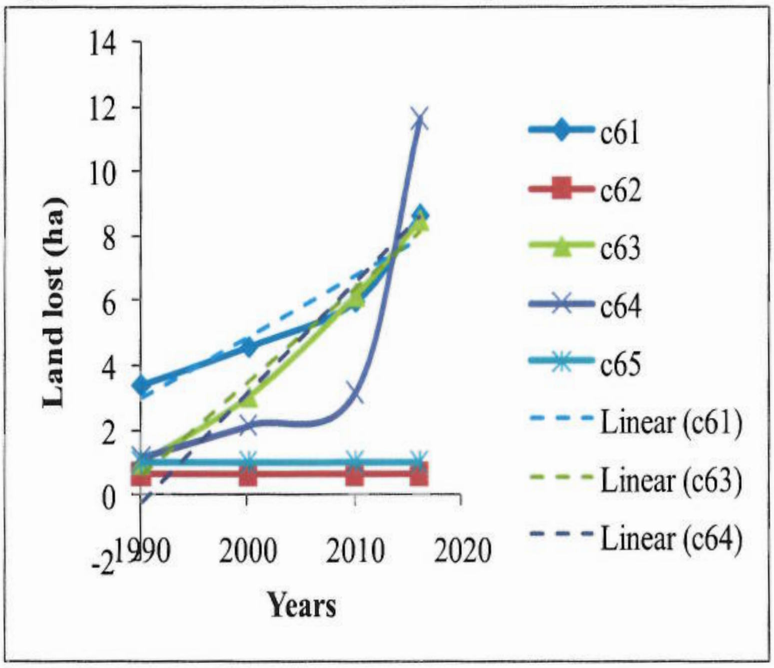
Appendix 14: Land loss in 51-55 'hotspots'



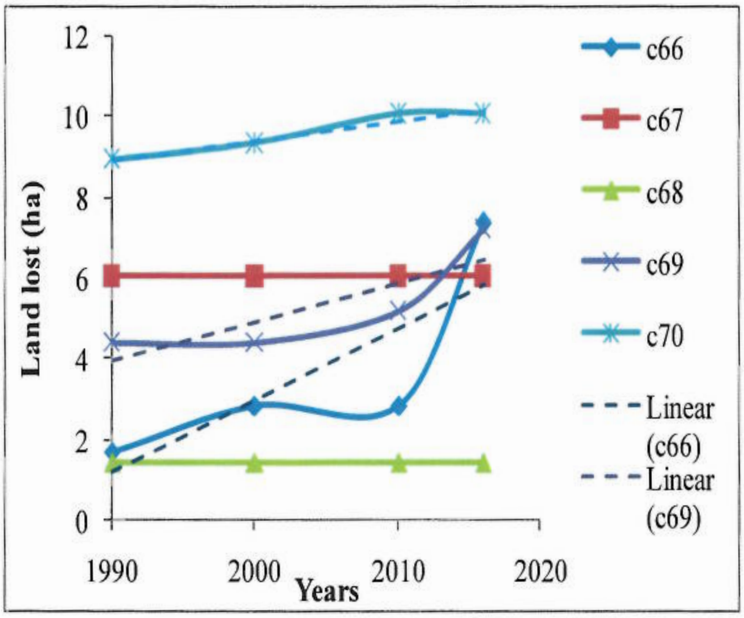
Appendix 15: Land loss in 56-60'hotspots'



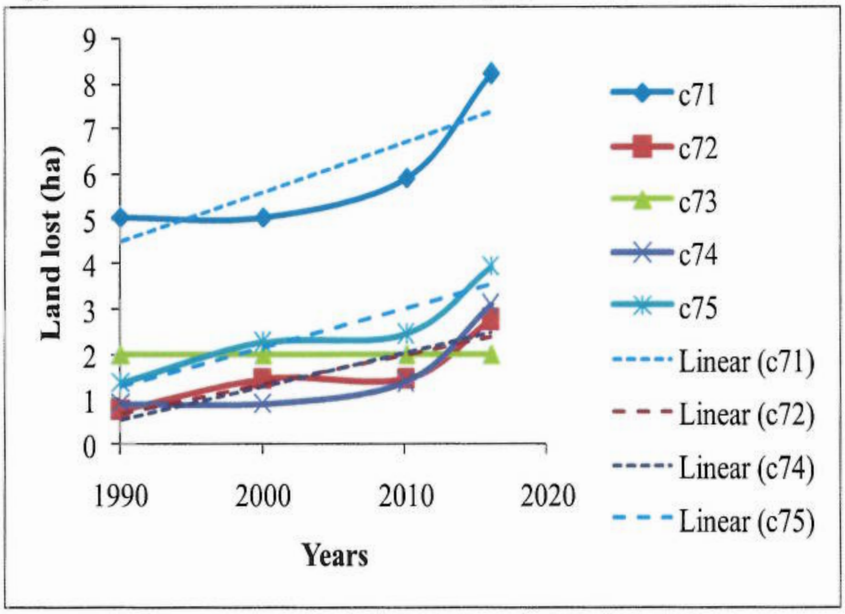
Appendix 16: Land loss in 61-65 'hotspots'



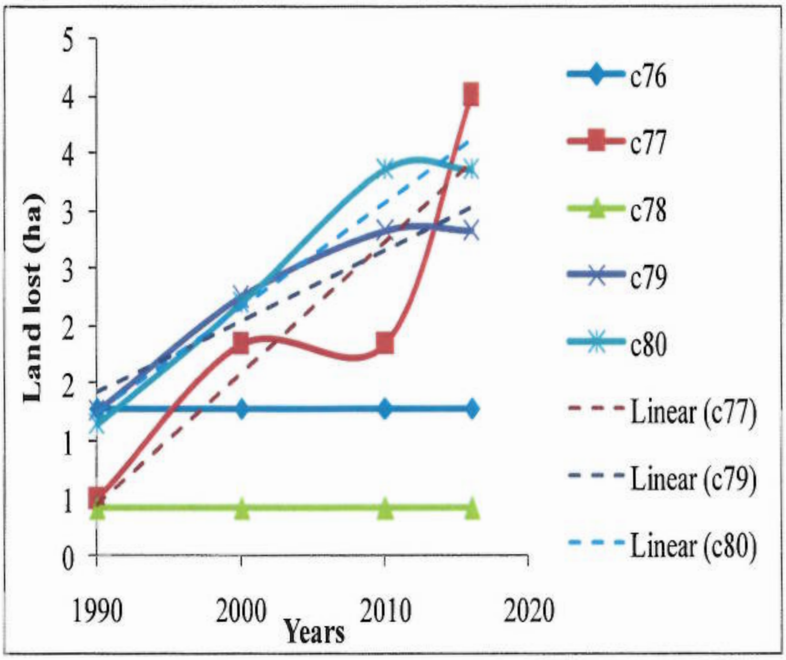
Appendix 17: Land loss in 66-70 'hotspots'



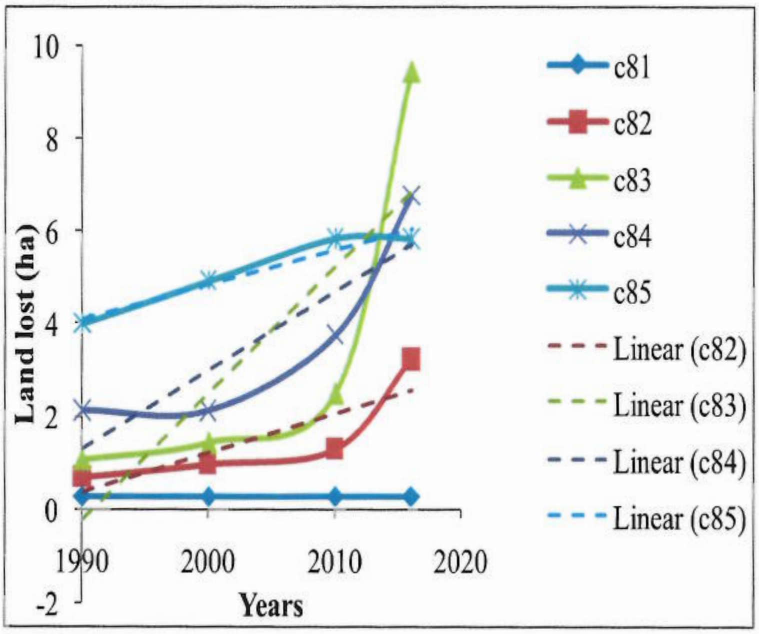
Appendix 18: Land loss in 71-75 'hotspots'



Appendix 19: Land loss in 76-80 'hotspots'

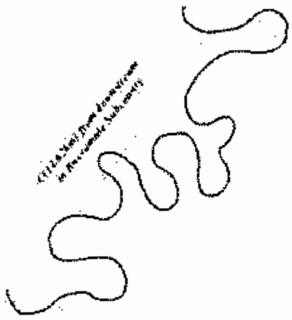


Appendix 20: Land loss in 81-85 'hotspots'



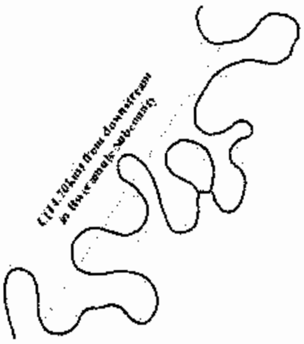
Appendix 21: Formation of ox-bow along River Semliki meander

Segment C 1986

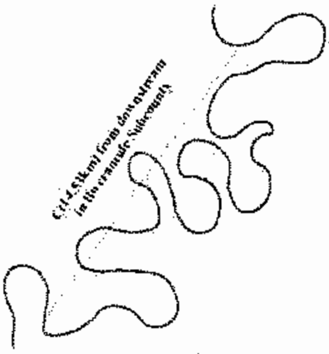


Segment C 1990

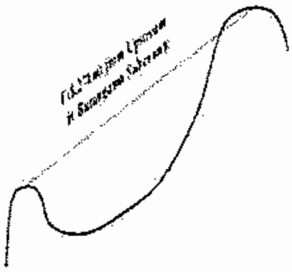
Segment C 2000



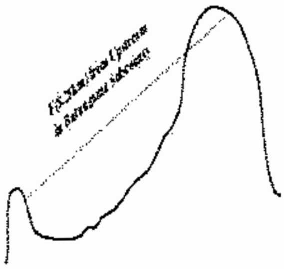
Segment C 2010



Segment C 2016

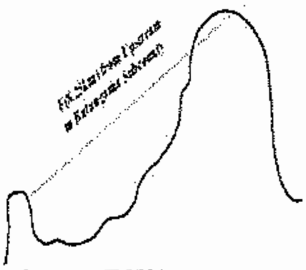


Segment F 1986

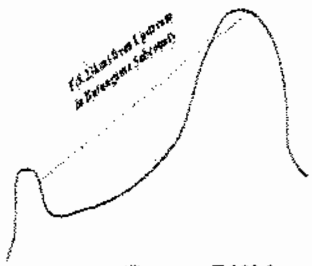


Segment F 1990

Segment F 2000



Segment F 2010



Segment F 2016

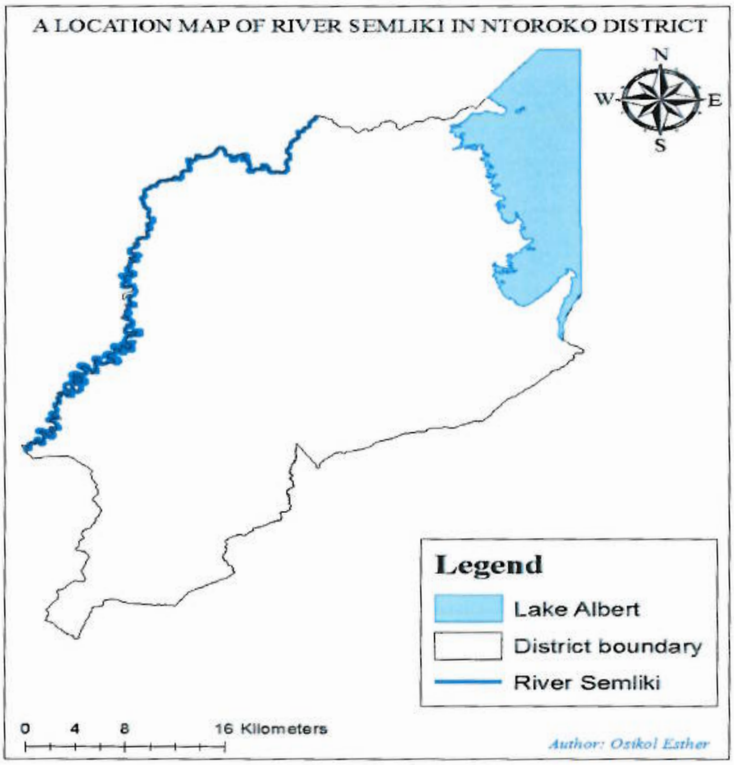
Appendix 22: Soil consistency test procedure

Appendix 23: Soil stickness test procedure

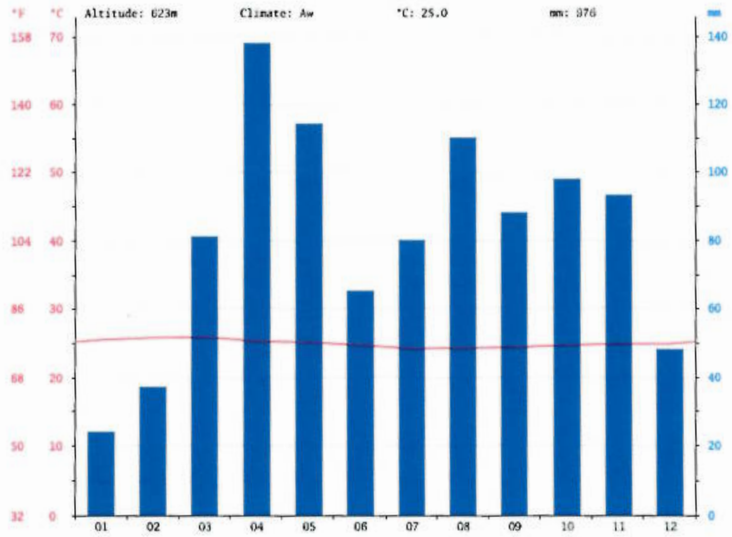
Appendix 24: Major Hotspots and quantified land losses over the time series

ID/Hotspot	Land lost (Hectares)
8A	11.73
12B	12.88
15C	11.12
21D	13.32
23E	11.92
26F	13.95
27G	22.53
35 Oxbow lake	10.57
36H	12.96
42-I	13.15
44J	10.25
47K	10.48
70L	10.07
55M	22.37

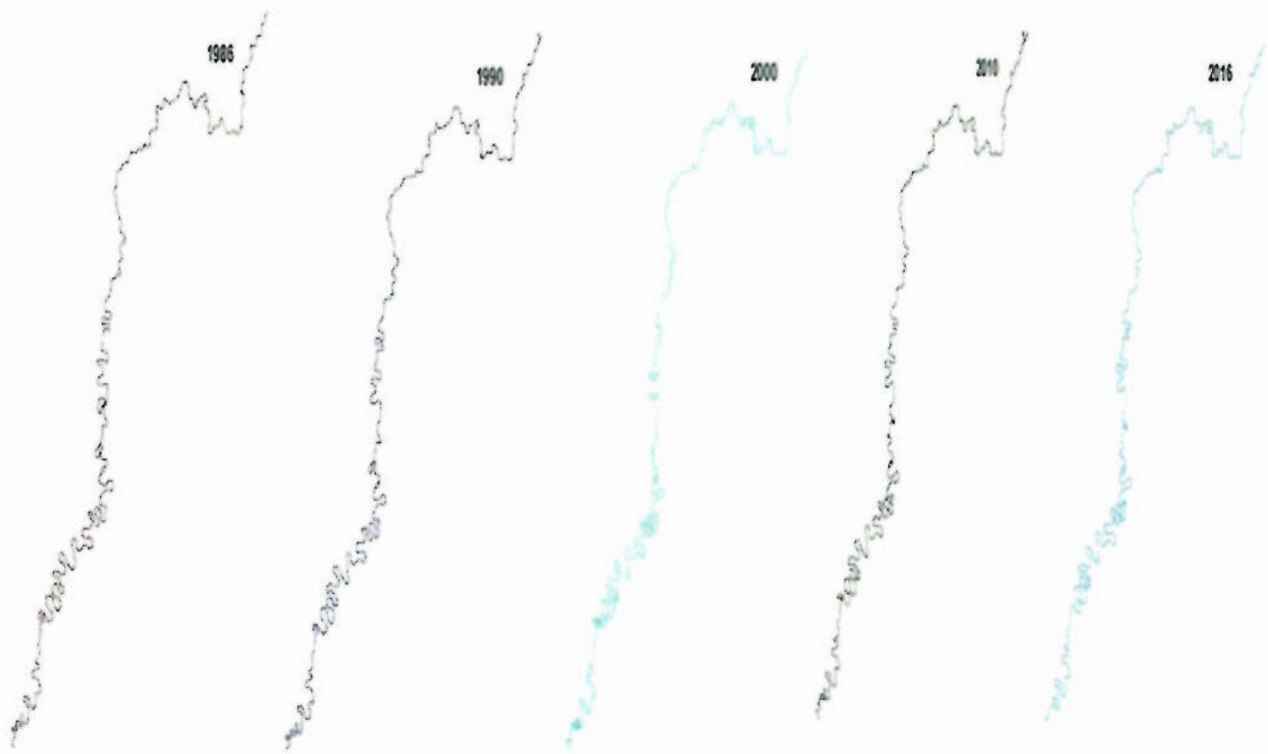
Appendix 25: Location of River Semliki in Ntoroko District, Uganda



Appendix 26: Temperature in Ntoroko District, Uganda (UBOS, 2009)



Appendix 27: showing changes in Sinuosity over the years along river Semliki



Appendix 28: Shows the river length, River Valley and Sinuosity for the time series

Year	River Length(Km)	River Valley	Sinuosity
2016	101.6	42.0	2.42
2010	100.9	42.0	2.40
2000	96.8	42.0	2.31
1990	94.5	42.0	2.25
1986	99.4	42.0	2.37