EFFECT OF LAND USE/COVER CHANGES ON SOIL EROSION RISK IN MITANO CATCHMENT, SOUTH WESTERN UGANDA

BY

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DECLARATION

I hereby declare that this research thesis entitled Effects of Land use/cover Changes on Soil Erosion Risk in Mitano Catchment, South Western Uganda, is my original work and has not been presented to any other University for any other degree award.

Signature: …………………. Date: ……………………………

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APPROVAL

I hereby declare that this dissertation entitled "Effect of Land Use/Cover change on soil erosion Risk in Mitano Catchment in South Western Uganda" has been supervised and submitted with my approval.

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SECOND SUPERVISOR

DEDICATION

I dedicate this piece of work to my father Mubale Milton, my mother Byankatonda Christine and my son Mukisa Precious Milton.

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I extend sincere appreciation to my Supervisors Dr. Turyabanawe Loy and Dr. Barasa Bernard for mentorship and thorough feedback on several versions of write-ups. Their guidance and persistent help, especially in developing the proposal, data collection and analysis, gave me an amazing opportunity to perfect the art of scientific writing.

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Lastly, am thankful to God for the protection, and my family who supported me all through the training period.

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ACRONYMS

LULC Land use Land Cover

MWE Ministry of Water and Environment

RUSLE Revised Universal Soil Loss Equation

UBOS Uganda Bureau of Statistics

USGS United states Geologic Survey

HWSD Harmonized World Soil Data Base

FAO Food and Agricultural Organization

ABSTRACT

Quantifying the response of a catchment to land use/cover change is imperative for the proper management of water resources within a catchment. River Mitano catchment has undergone significant land use/cover changes (LULC) underpinned by numerous socio-economic and environmental factors. However, its effect on soil erosion has not yet been fully recognized. This study therefore investigated the extent and transitions in land use/cover changes in the River Mitano catchment for the period 2000-2020 and the effect of these changes on soil erosion. To quantify the extent and transitions of land use/cover change in the River Mitano catchment, Landsat-7(2000), Landsat-8 (2010), and Sentinel-2A and 2B images for 2020 were obtained from United States Geologic Survey (USGS). LULC change analysis using the supervised classification of the Landsat and Sentinel images was done to reveal Land use/cover changes in the catchment for the period 2000 to 2020. To determine the effect of LULC change on soil erosion, soil erosion modeling was performed using Revised Universal Soil Loss Equation (RUSLE). Results of the LULC change revealed a decrease in grassland, wetlands, and woodland by 6.7% and 5.9%, 0.12% and 0.14%, 0.01% and 0.29% for the period 2010 and 2020 respectively. However, subsistence farming, built-up and tree plantation steadily increased by 2.96% and 3.59%, 0.70% and 2.33%, 3.14% and 0.11% for the period 2010 and 2020 respectively was detected. The major LULC transitions were the conversion of grassland to subsistence farming at a rate of 16.48% while 11.95% of subsistence farming converted to grassland for the period 2000 to 2020. Soil erosion rate varied from very high (10-500 t $ha^{-1}yr^{-1}$) with an increase of 11% and 5% for the LULC of 2010 and 2020 in the catchment. The study concludes soil erosion of the catchment was influenced by Land use/cover change through conversion of grasslands, tropical high forests and wetlands to subsistence farming which has persistently increased both soil erosion risk. Based on these findings it is recommended that there is a need to adopt soil and water conservation practices to minimize soil erosion and ensure proper protection of the River Mitano catchment.

CHAPTER ONE: INTRODUCTION

1.1 Background

Land use is a series of operations on land, carried out by humans, to obtain products and/or benefits through using land resources (Kiggundu et al., 2018; Obeidat, et al., 2019); it is comprised of subsistence farming, commercial farming and infrastructure (Bai, Sheng, Zhao & Zhang., 2020). Land cover refers to the natural biophysical features that exist on land surfaces (Food and Agricultural Organization, 2018). Land cover includes vegetation, water, ice, bare rock, soil and wetlands (Majaliwa et al., 2018). Land use/cover change is a process of human modification of the earth's terrestrial surface (Ellis, 2013; Sushanth et al., 2019). Land use/cover transition refers to the rate at which one form of land use/cover is transformed into another. (Lü, Gao, Xiao & Fu., 2020).

These Land use/cover (LULC) changes are driven by environmental, social-economic, institutional and political factors (Betru, Tolera, Sahle & Kassa., 2019) like the expansion of agriculture, unsustainable exploitation of forest resources and infrastructure development (Geist & Lambin, 2002). LULC results in a high soil erosion rate thus, contributing to catchment degradation and deterioration of living conditions (Kabeja, Guo, Rwatangabo, Manyifika, Gao & Zhang., 2020). Natural as well as human-induced land use land cover change (LUCC) has significant impacts on regional soil degradation, including soil erosion, soil acidification, nutrient leaching, and organic matter depletion. Since the last century, soil erosion accelerated by human activities has become a serious environmental problem (Osman, 2018).

Globally there is a contraction in wetlands at a rate of 64-71% in the 20th century (Gardner et al., 2015). This is followed by an increase in the extent of cropland. The expansion in cropland has caused an increase in the rate of soil erosion by 2.5% (35.59 tonsyr-1) (Borrelli, Robinson, Fleischer, Lugato, Ballabio, Alewell, & Panagos., 2017). In Western Africa, there has been a conversion of forest to farmlands at a rate of over 60% in the Niger and Lake Chad basins. This has increased surface run-off and soil erosion (Ramankutty et al., 2006). In East Africa, there is the conversion of catchments into agriculture and residential areas has increased surface runoff thus increasing the rate of soil erosion (Gabiri, 2020).

Morgan (2009) defines soil erosion as the displacement and deposition of soil from where it was formed to another location and concluded that precipitation, runoff, wind and gravitational forces are responsible for soil erosion which is ideal under natural conditions. Studies have revealed a strong correlation between soil erosion and land use/cover change (Chiwera, 2015; Tsegaye, 2019). It has been revealed that human activities and related land-use change are the primary cause of accelerated soil erosion with the greatest increases predicted to occur in Sub-Saharan Africa at a rate of 11.1 % (Borrelli, Robinson et al., 2017). Sun et al. (2016) note that human activities like agriculture and deforestation can increase soil erosion in a catchment area that would ideally be low under natural conditions. Africa is predicted to be experiencing an annual increase in soil erosion by 10% due to increased deforestation and expansion of cropland (Borrelli et al., 2017). Studies carried out by Liu et al (2015) indicate that land cover patterns conversion from forest to agriculture caused an increase in the amount of soil loss by 0.25t/ha/yr. In Uganda, the Conversion of slopes to cropland has intensified the rate of soil erosion on steep slopes of Mountainous areas (Bolwig, 2002).

It is predicted that by 2040, subsistence agricultural land is likely to increase by about 1% while the tropical high forest is expected to decrease by 0.2% and woodland by 0.07% in Uganda (Majaliwa et al., 2018). Studies in Ugandan indicate that agriculture and built-up environments within watersheds increase annual rates of soil erosion and its subsequent effects (Wateu, 2019).

In Western Uganda highland catchments indicate that small-scale farming increased by 5% from 1975-1999, tropical forests decreased by 16% from 1975 and 1987 in Kanungu (Barasa et al.,2010) yet wetlands were decreasing by 1% (Kizza et al., 2017). LULC accelerates soil erosion especially in cases of severe deforestation, overgrazing and over-tilling of the land (Hayichoet al.,2019). Soil erosion accelerated by human activities has become a serious environmental problem (Issaka & Ashraf, 2017) by negatively affecting the water supply, reservoir storage capacity, agricultural productivity, and freshwater ecology of the region (Saffari, Nouri & Karami, 2018). In Mitano catchment, soil erosion rates have been reported in some of the Districts (Karamage, Zhang, Liu, Maganda & Isabwe, 2017) and land use/cover changes are also reported.). Different Remote Sensing and Geographical Information System approaches have been applied to detect how LULC changes affect soil erosion on varying scopes which include the use of Universal soil Loss Equation, Soil and Water Assessment Tool, Water Erosion prediction project technology (Yan, Zhang, Yan & Chen, 2018). These have been applied on global (Borrelli et al., 2017), regional and catchment scales. However, the Revised Universal Soil Loss Equation has been extensively accepted in determining soil erosion at the catchment scale (Somasiri, Hewawasam & Rambukkange, 2021). Thus in the current study, Remote Sensing and Geographical information system was combined with Revised Universal Soil Loss Equation (RUSLE) to determine the effect of Land Use/cover changes on soil erosion in River Mitano catchment in South Western Uganda for the period 2000,2010 and 2020

1.2 Statement of the Problem

Mitano catchment experiences a high rate of soil erosion risk. This has been induced by the unsustainable practices of cultivation on fragile catchment slopes, deforestation, bush burning and open cast mining that have caused changes in Land use/cover. These practices have been increased by the swelling population growth rate within Districts in Mitano Catchment. As such practices continue, there has been a change in surface runoff thus triggering the rate of soil erosion risk in the catchment.

An increase in soil erosion rate in Mitano catchment has led to a loss of surface soils, reduced soil fertility and sedimentation to the sub-catchments in Mitano catchment. As such, there has been a decline in crop yields, increased turbidity, flooding and loss of biodiversity. Declining crop yields have reduced farmers' income and resulted in encroachment on wetlands and fragile slopes as an alternative way of increasing production thus leading to catchment degradation.

Previous studies conducted in this area have focused on land-use change and soil degradation (Bolwig, 2002), dynamics of land use in Kanungu (Barasa et al., 2010) and the effect of land cover change on soil properties (Majaliwa et al., 2010). However, little information is available concerning the effect of land use/cover on soil erosion risk. Therefore, this study bridges this information gap by assessing the effect of land use/cover change on soil erosion risk in River Mitano catchment using.

1.3 Objectives of the Study:

(i) General objective

The main objective of this study was to establish the effect of land use/cover changes on soil erosion risk in Mitano catchment to contribute to proper catchment management planning.

(ii) Specific objectives

The specific objectives were:

1. To quantify the extent of land use/cover changes in Mitano catchment between 2000 and 2020.
2. To determine the transitions and trend of land use/cover changes in Mitano catchment between 2000 and 2020.
3. To establish the effect of land use/cover change on soil erosion risk in the catchment.

1.4 Research Questions

From the specific objectives of this study, the following research questions were developed to guide the study:

1. What is the extent of land use/cover changes that have occurred in the Mitano catchment over the last two decades (2000-2020)?
2. What is the transition and trend of land use/cover changes that have occurred in the Mitano catchment over the last two decades (2000-2020)?
3. Which effect does Land use/ cover change cause on soil erosion in the Mitano catchment?

1.5 Scope of the Study

This study was conducted in river Mitano catchment in South Western Uganda with an area of 3,730 km^2 and along profile of 178km in the districts of Kanungu, Rukungiri, Ntungamo, Mitoma, Bushenyi, Shema and Rukiga but with its largest portion found in Kanungu and Rukungiri. This catchment was selected due to the existence of increased population, land use/ cover change, soil erosion and flooding (MWE, 2018). The study concentrated on mapping land use/cover using remote sensing and GIS and using the outcomes of the mapped land use/cover to model the effect of land use/cover changes on soil erosion in the River Mitano catchment.

The study considered land-use changes that occurred from 2000 to 2020. This period was selected because this is the period that the basin experienced much agricultural intensification. Field activities were conducted in June and July 2020 to obtain the land use/cover types for ground-truthing to aid in developing land use/cover maps using supervised image classification

1.6 Significance of the Study

Understanding the effect of land use/cover change on soil erosion in an area prone to soil erosion is important in solving soil erosion effects like silting, turbidity and flooding at the catchment scale. This study therefore is important in contributing towards identifying the most appropriate Land use/cover practices that can minimize the intensity of both soil erosion and streamflow in an integrated watershed planning for Mitano catchment and other highland tropical catchments.

The findings may be useful to local government, farmers, NGOs and researchers in River Mitano catchment and other tropical catchments that experience soil erosion to adopt the most appropriate land use/covers that minimize soil erosion, provide maximum benefits to land at the same time protecting the catchment hydrology.

The findings may guide local farmers and the local government to identify soil erosion hot spots within the River Mitano catchment. This in the long run promotes the adoption of site-specific methods of soil erosion control bearing in mind the concept of catchment degradation.

1.7 Conceptual Frame Work:

The conceptual framework in this study shows how soil erosion responds to changes in land use/cover (Figure 1). It is conceptualized that Land use/cover has an impact on the hydrological processes that take place within a catchment in a normal setting. As man interacts with the features on the earth's surface through bush burning, fuelwood harvesting and animal grazing, there is expansion, contraction, or transition in either Land use or land cover. This change impacts the hydrological processes of evaporation, infiltration, and percolation that either increase or reduce surface runoff. As runoff changes, there is a drift in water energy on the earth's surface thus determining the rate of soil erosion. However, the rate of soil erosion determines the rate of flooding, water pollution or eutrophication and turbidity within the catchment raising the need for proper catchment management planning on catchment land use/cover.

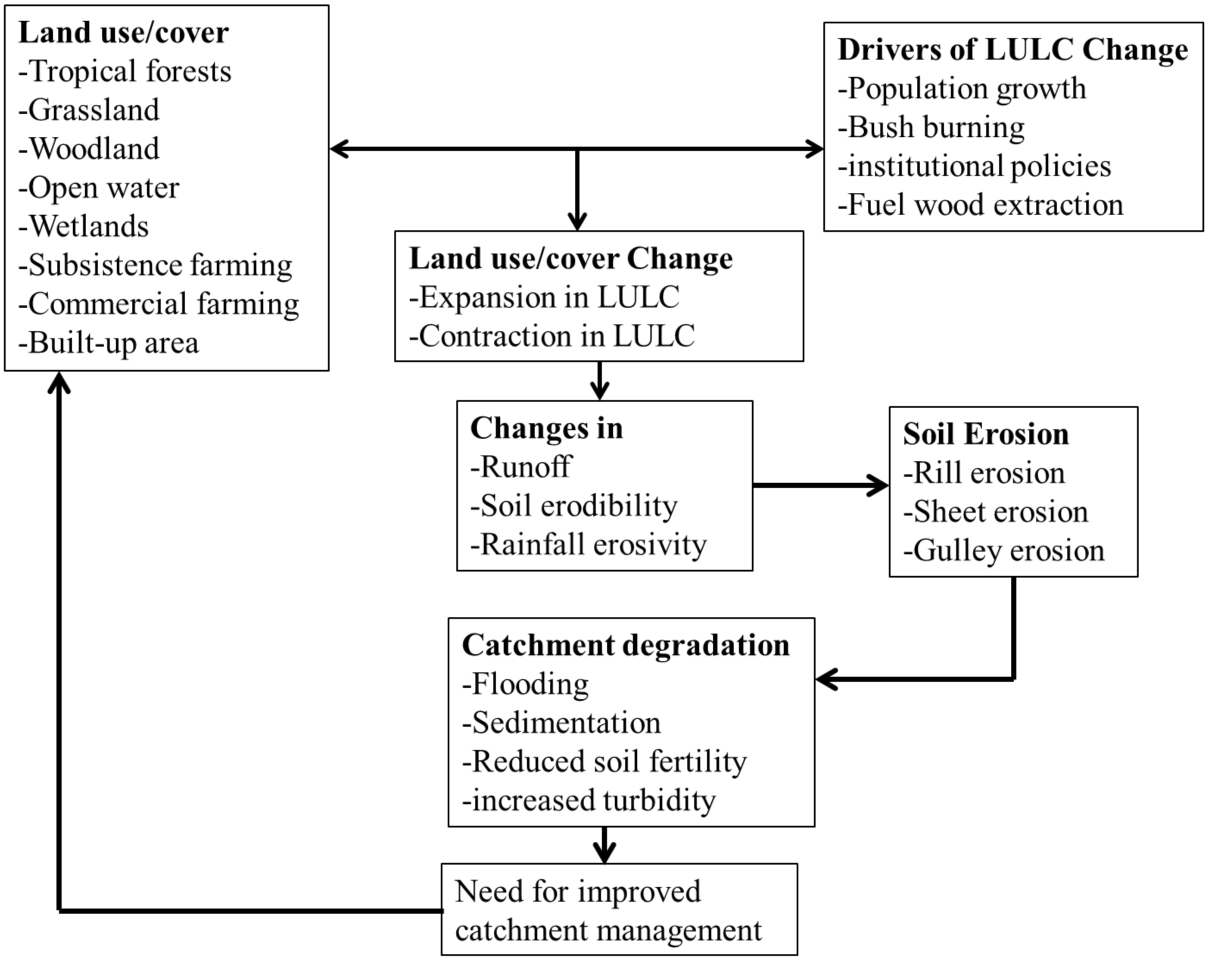

Figure 1.1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of related literature in line with Land use/cover change with more concentration on temporal and spatial variations. It also covers the review of how land use/ cover changes affect soil erosion.

2.2 Land use/cover changes

Land use refers to a series of operations on land, carried out by humans, intending to obtain products and/or benefits through using land resources (Ellis & Robert, 2007; Kiggundu et al., 2018); thus Land use change is a process of human modification of earth's terrestrial surface (Ellis, 2013; Sushanth et al., 2019). Land cover is commonly defined as the vegetation (natural or planted) which occurs on the earth's surface. Water, bare rock, sand and similar surfaces also count as land cover (Kiggundu et al., 2018).

There are various types of land use and cover on the earth's surface. But these can be broadly classified as; land cover with open waters that is composed of lakes, wetlands that are waterlogged in form of seasonal and permanent swamps (Wright & Wimberly, 2013). Tropical high forests are composed of intact natural forests, woodlands composed of trees less than 4 meters scattered and grasslands (Majaliwa et al., 2018). Land use is composed of planted trees, Subsistence farming, Commercial farming and Built-Up areas (Bai et al., 2020).

Land use in various watersheds around the globe is changing briskly and extensively as a result of the growing demand for natural resources from an ever-increasing human population (Gessesse et al., 2015). Globally land use is changing evidenced by a six-fold increase in cropland at a rate of 1.56% per annum from 1700 to 1990 (Goldewijk., 2001), decrease in natural forested area and grassland where the world's forest areas declined from 4.1 billion hectares in 2000 to 4 billion hectares in 2015 (Rumann et al., 2018), It is projected that by 2050 over 70 % of the world's population will be living in the urban centers promoting urban expansion **(** Seto & Shepherd, 2009). As this happens there is a contraction in wetlands since the global extent of wetlands is now estimated to have declined between 64-71% in the 20th century, and these losses continue worldwide (Gardner et al., 2015). However, despite these changes in LULC with a projected increase in urbanization by the increasing population; little is known in the 21st century about the global trends in LULC changes.

In the USA there has been a land-use change from 2006 to 2011 in the Western Corn Belt (WCB) in the five states of North Dakota, South Dakota, Nebraska, Minnesota, and Iowa where grasslands have been converted to corn and soya bean cropping at a rate of 5.4% annually (Wright & Wimberly, 2013). In the European Union's (EU's), Urban expansion and intensive commercial agriculture are expanding (2006-2018) at the expense of low intensive agriculture (Schulp, Levers et al., 2019). This indicates that different countries in different environments and with varying development goals experience heterogeneous trends of LULC change raising the need to develop LULC for each country. This study thus seeks to develop LULC change maps for Mitano catchment that can be used as an input to develop the national LULC maps with a high level of precision.

In Africa, Western Africa has experienced the conversion of forest to farmlands at a rate of over 60% in the Niger and Lake Chad basins. This has increased the surface run-off and soil erosion (Ramankutty et al., 2006). In Uganda; land use is changing with the highest gains in the land use experienced in subsistence agricultural land and grasslands protected, while the highest losses are seen in grasslands unprotected and woodland/forest with low livestock densities; it is predicted that by 2040, subsistence agricultural land is likely to increase by about 1% while the tropical high forest is expected to decrease by 0.2%, and woodland/forest unprotected by 0.07% (Majaliwa et al., 2018). Given this trend, there is a need to map and document the status of LULC change since the human population as the driver of LULC change is not static.

In southwestern Uganda there has been changes in land use where small scale farming increased by 5% from 1975-1999, tropical forests decreased by 16% from 1975 and 1987 in Kanungu (Barasa et al., 2010) yet wetlands are decreasing by 1% (Kizza et al., 2017). Whereas developed countries have the technological capacity to handle dynamics in terrestrial ecosystem hazards resulting from land-use change, developing cannot rapidly adjust (Ojima. et al., 1994). This compels the need to establish the most plausible land use or cover that developing countries like Uganda can recommend and adopt in the least trifling costs to reduce the conversion of natural surfaces to unsustainable land use/cove forms.

Despite this evidence of Land use/cover changes occurring on different spectrums, little has been done to determine the extent and trend of Land use/cover change based on the River Mitano catchment yet this is necessary for developing catchment management plans. This justifies the need to determine the extent of land use/cover change in the River Mitano catchment for the period 2000 to 2020.

2.3. Effect of Land use/cover changes on soil erosion

Morgan (2009) defines soil erosion as the displacement and deposition of soil from where it was formed to another location, and concluded that precipitation, runoff, wind and gravitational forces are responsible for soil erosion which is ideal under natural conditions. However, Studies conducted by Hassan et al., (2016) reveal that modifications on the ecosystem have been there since time immemorial, but are now being exacerbated by anthropogenic factors in a bid to sustain their livelihoods through the overexploitation of natural resources. These changes in land use and land cover have negatively affected the protective uses of sub-catchments like Mitano sub-catchment and rendered the exposed and fragile ecosystem to soil erosion (Mwavu & Witkowski, 2008). Studies have revealed a strong correlation between soil erosion and land use/cover change (Chiwera, 2015; Tsegaye, 2019)

Human activities and related land-use change are the primary cause of accelerated soil erosion with the greatest increases predicted to occur in Sub-Saharan Africa at a rate of 11.1 % (Borrelli, Robinson et al., 2017). Sun et al. (2016) note that human activities like agriculture and deforestation can increase soil erosion in a catchment area that would ideally be low under natural conditions. Africa is predicted to be experiencing an annual increase in soil erosion by 10% due to increased deforestation and expansion of cropland (Borrelli et al., 2017). Studies carried out by Liu et al (2015) indicate that land cover patterns conversion from forest to agriculture caused an increase in the amount of soil loss by 0.25t/ha/yr. In Uganda, the Conversion of slopes to cropland has intensified the rate of soil erosion on steep slopes of Mountainous areas (Bolwig, 2002).

Agricultural expansion, settlements and poor cropping mechanisms lead to an increase in soil erosion (Lufafa et al., 2003). Ouyang et al., (2010) noted that in the Yellow river agricultural lands generate high rates of soil erosion of 81 t/ha/yr relative to forests and grassland even when on steep slopes. This is because these practices leave soils bare and when raindrops hit such surfaces soils are detached and transport (Hill, 1991). Ouyang et al., (2010) revealed that an increase in construction land has a positive trend with an increase in the rate of soil erosion. This signifies that as the population of an area increases and built-up areas are established, the rate of soil erosion increases. However, studies by Borelli et al. (2017) contradict this view by indicating that a dense population results in a decrease in soil erosion.

As a conservation mechanism, the planting of trees or forests can check on the impact of raindrops and increase soil binding structure thus reducing the rate of soil erosion occurring in a catchment. This view is supported by Ouyang et al, (2010) who revealed that in the Yellow River, planted flora decreases the rate of soil erosion since it checks on the rate of soil erosion release. Increased soil erosion ends up in the streams leading to increased streamflow (Valentin et al., 2008). Bamutaze et al., (2021) note that Soil erosion rates that are above 10 t ha^{-1} yr^{-1} are considered to be above the tolerable limit for the tropical mountainous environment and no catchment has similar spatial soil erosion by observing that in the Manafwa watershed soil erosion ranges from 0 to 151 t ha^{-1} yr^{-1}. Further studies indicate that the tolerable rate of soil loss in Uganda for crop production is 5 t ha^{-1} yr^{-1} (Lufafa et al., 2003). In Kigezi highlands slopes above 45% steepness experience un tolerable rate of erosion above 38.3 tons/ha/year (Owaruhanga, 2019)

Despite these corroborating pieces of evidence of land cover/cover change affecting soil erosion, very few studies have been conducted in Mitano catchment to ascertain land use/cover changes and how these changes influence soil erosion. If such studies are not conducted then increased accelerated erosion will continue to cause land degradation and fertility loss, increases siltation, streamflow and enhances flooding (Borrelli et al., 2017). Studies by FAO (2000) reveal that 75 billion tons of soil are eroded every year from arable lands worldwide, which equates to an estimated financial loss of US $400 billion per year. This is most prevalent in the least developed economies experiencing the highest rate of annual soil loss (20.7mgha-1yr-1) Uganda inclusive (IMF, 2001)

2.3.1 Methods for soil erosion estimation

Several models have been used to estimate soil erosion from catchments which include the Water Erosion prediction project technology (WEPP), Soil and Water Assessment Tool (SWAT) Model, and the Revised Universal Soil Loss Equation (RUSLE) model (Eekhout et al., 2021). The Water Erosion prediction project technology (WEPP) erosion model calculates erosion from rill and inter-rill areas and uses the concept that detachment and deposition rates in rills are a function of the portion of the transport capacity which is filled by sediment. This model partitions runoff between rill and inter-rill areas and calculates shear stresses based on rill flow and rill hydraulics. However, it does not consider other forms of erosion like sheet, Gulley and splash erosion (Eekhout et al., 2021). The current study exhausted the Revised Universal Soil Loss Equation where inputs like Rainfall erosivity, Soil erodibility, plant cover, slope steepness and slope length were used as inputs to model Annual soil loss. This model has been selected due to its ability to predict soil erosion on all surfaces by considering all soil erosion parameters (Gayen et al., 2020). The model input data is readily available and mostly on free access.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter focused on the description of the methodology employed in the study. It focused on the research design and methodology of data collection and analysis for the study objectives among others.

3.2 Description of the study area

3.2.1 Location

The study was conducted in the River Mitano catchment located in the South-Western part of Uganda at the fringe of the Eastern part of the Democratic Republic of Congo (DRC). The drainage network is located in 10 districts which include Bushenyi, Mitooma, Rubanda, Kanungu, Kisoro, Kabale, Rukungiri, Sheema, Ntungamo and Rukiga. Within these districts, the river originates from the hills of Kigezi, with the furthest located in Bushenyi (Kyabugimbi Sub County) and Rukiga Districts (Kingston et al., 2010). The catchment size is about 3,730 km^2 with a length of 178km. The river flows westwards and drains its waters into Lake Edward; a transboundary freshwater Lake shared between the Democratic Republic of Congo (DRC) and Uganda (MWE, 2017). The catchment was delineated for all its micro-catchments as shown in **Figure 3.1**

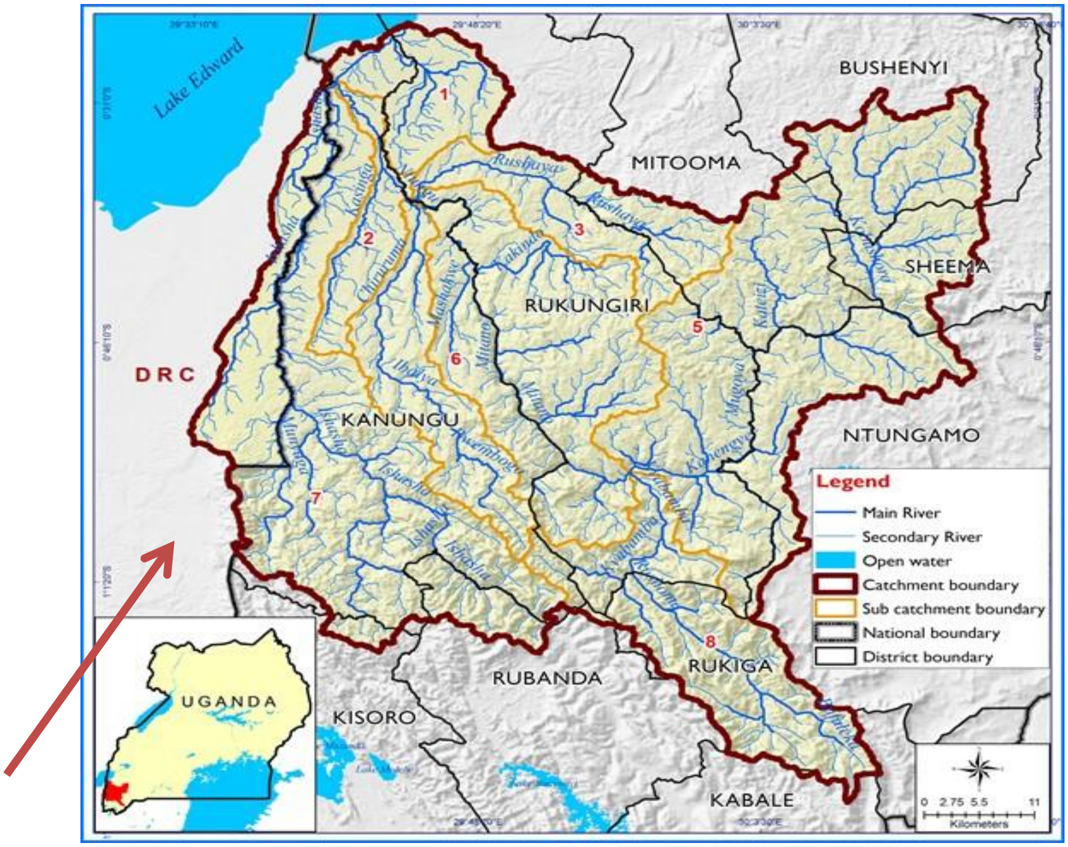

Figure 3.1: Location of Mitano catchment and its sub-catchments

3.2.2 Geology and soils

The catchment is comprised of deeply weathered Precambrian crystalline rocks which indicate gneiss, schist and phyllite of the Buganda-Toro system (Figure3.2). The catchment contains Cenozoic rocks (Albertine rift with silt, sand and gravel), Paleoproterozoic rock (Rukungiri Suite; granite, variable granitic gneiss; Porphyritic granite, Gikoro Group; shale, slate, phyllite, sandstone and Pindura Group; shale, slate, phyllite, quartzite) (Kingston et al., 2010), these rocks are covered by Acriferralsols and Luvisols that are characterized by black sandy loams and reddish sand clay loams respectively (API, 2011). Given these deeply weathered rocks located on fairly steep slopes any change in land use accompanied with heavy rainfall is likely to increase the rate of soil erosion in the catchment.

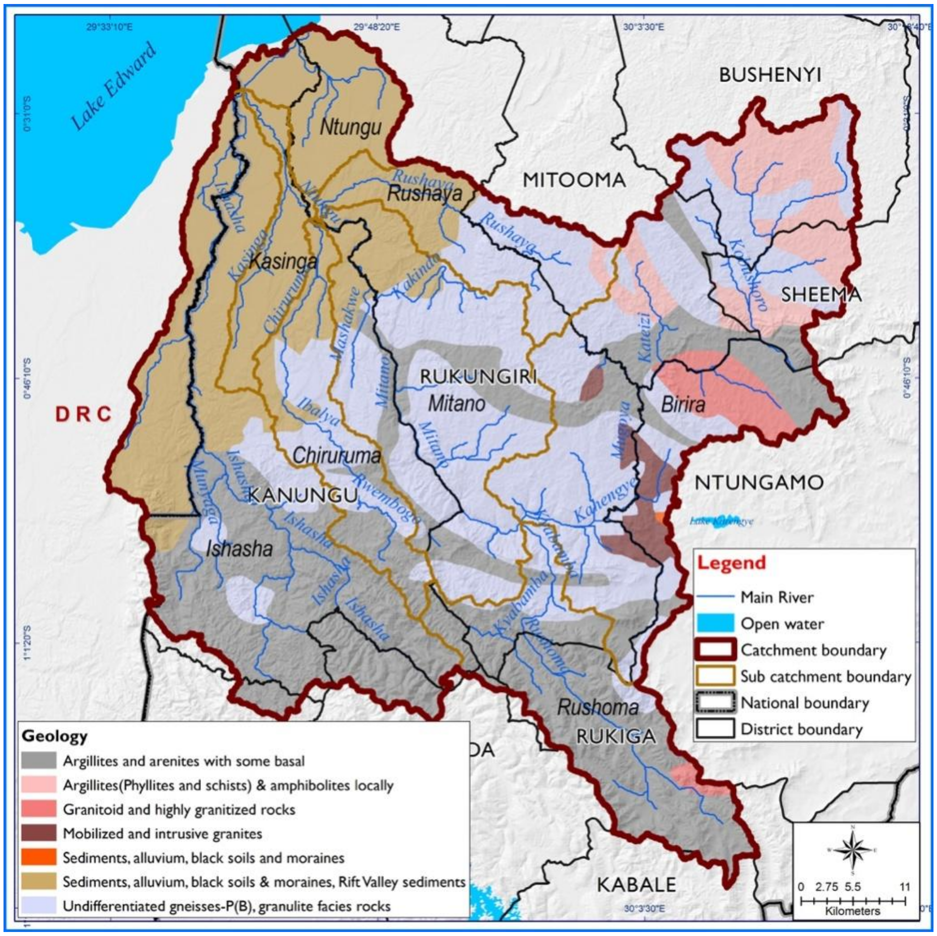

Figure 3.2: Geologic types of Mitano catchment.

3.2.3 Relief

The catchment stretches from an elevation of 2500 meters above sea level in the South to 975 meters above sea level in North West to Lake Edward (Kingston et al., 2010) (Figure 3.3). This gives variation in altitude of 1525 meters above sea level which increases the steepness of the catchment leading to high susceptibility to erosion. This steep gradient is created by the overlapping hills on the valley sides though it curves its way through gorges (API, 2011). This is further depicted in figure

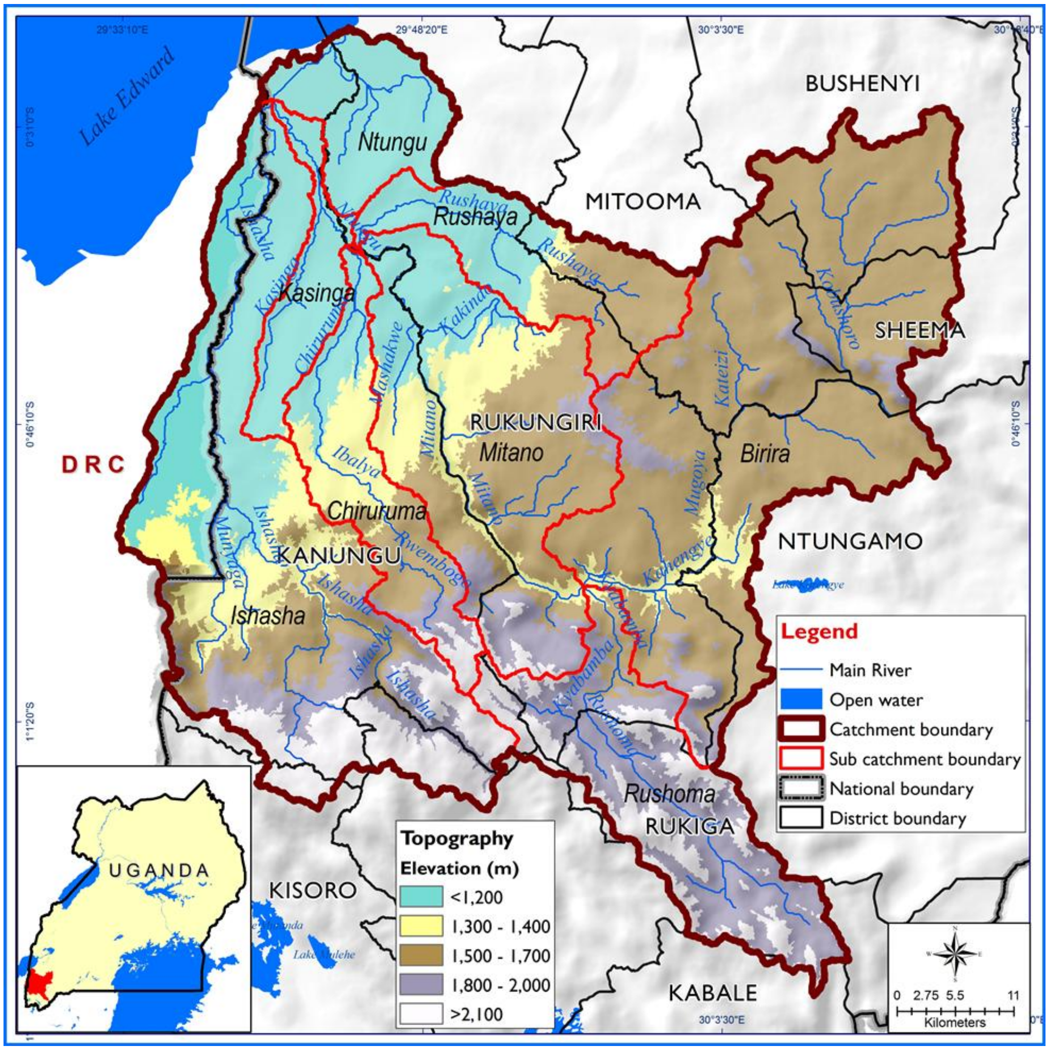

Figure 3.3: Topography of Mitano catchment

3.2.4 Climate

The study area experiences a bimodal rainfall regime with dominant modes occurring from March to May and September to November thus short rains and long rains respectively, Mean monthly minimum temperature ranges from 14.6 °C to 16.7 °C (Basalirwa, 1995). The districts in the catchment receive an average rainfall of 1200mm per annum. It has two main rainy seasons during March to April and September to November in each calendar year (Kanungu five-year development Plan II,2015/2016-2019/2020). The heavy rainfall increase streamflow and erosivity basing on the steepness of slopes thus increasing the problem of flooding and soil erosion.

3.2.5 Drainage

The catchment is characterized by a dendritic drainage pattern which is defined by up and down warping of the Western arm of the East African rift valley that influenced the direction of flow into Lake Edward with low elevation. The catchment was delineated into 8 sub-catchments (figure 3.3) and 28 micro catchments (figure3.4)

Figure 3.4: Mitano drainage

3.2.6 Vegetation

Of the total area of Mitano catchment, 17 % is covered by grassland vegetation with small areas of forest plantations and wetland vegetation (Kingston et al., 2010). This indicates that little natural vegetation exists in the area of study since even the forests that exist are planted like pine and eucalyptus.

3.2.7 Population

UBOS (2014) indicates that the population of Rukungiri was 314,694 people, with a population density of 219 persons per square kilometer, Sheema had 207,343 people, with a density of 297 persons per square kilometer and Kanungu had 252, 344 people, with a population density of 198 persons per square kilometer. In 2002, the population of Rukungiri was 275,200 people, that of Shema was 180,200 people and for Kanungu was 201,700. This implies that the population growth rate between 2002 and 2014 was 1.1 for Rukungiri and 1.2 for Shem and 1.7 for Kanungu (UBOS, 2014). This points towards increased pressure on land and temporal changes in land use leading to an induced rate of soil erosion and sediment generation that ends up in streams either physically or chemically.

3.2.8 Land use activities

The major land use activity in the River Mitano catchment is agriculture occupying 79% of the total land-use area (Kingston et al., 2010) It is practiced on smallholding plots that are highly fragmented along the hilly slopes with dominant crops cultivated including bananas, tea, millet, cassava, ground-nuts and sugarcanes. Most of these are rain-fed (Kingston et al., 2010). Given the hilly landscape, these land-use activities pose a serious challenge to soil erosion.

3.3 Research design

A quantitative research design was adopted to collect quantitative databasing on the catchment scale. Since soil erosion does not stop at administrative borders. It is generated upstream in a different locality and can have a significant effect on the community downstream. Thus a catchment-based approach was appropriate. The catchment scale is an integrative scale used to evaluate the processes involved in streamflow (velocity and volume) and soil erosion of different catchment systems (Rodríguez et al., 2016). In this study, the boundaries of the River Mitano catchment were determined in Arc GIS using Automatic watershed delineation by Arc Swat to identify all locations that were connected to an outlet point by an overland flow path. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (30m) for Uganda was the major input data for catchment delineation.

3.4 Methods of data collection and analysis.

Data collection involved both primary and secondary data sources. Secondary sources included both published and unpublished information about satellite images, climate data, soil data and the Digital Elevation Model (slope data). Primary data was about the ground-truthing for different land use/ cover types was collected in the field. This was done using Geographical Positioning System (GPS) in the field. This was collected in Rukungiri, Kanungu and Bushenyi because they occupy the biggest portion of the River Mitano catchment.

3.4.1 Quantifying the extent of land use/cover changes in Mitano catchment between the years 2000 and 2020

3.4.1.1 Data sets

To determine changes in land use/cover, a series of Multi-temporal satellite images for Landsat (30×30m) was used. Two Landsat-7 satellite images for 2000 and Two Landsat-8 satellite images for 2010 were acquired from U.S. Geological Survey's (USGS) Earth Explorer website https://earthexplorer.usgs.gov. However, for 2020 Two Sentinel-2A images and Two Sentinel-2B (20x20m). These sentinel images were used after resampling them to a 30meter spatial resolution for proper analysis. All these images were acquired in the dry months as per the seasonal calendar of the river Mitano catchment. Both Landsat and sentinel data were selected and used in this study because they are free of charge and can accurately capture spatial-temporal variations in Land use and land cover over a given area. Details of the satellite images are reflected in table 3.1.

Table 3.1: Specifications of the satellite imageries

Year	Image	Satellite	Cloud Cover
2000	LE07_L1TP_173060_20000314_20170206_01_T1	Landsat-7	2.0
	LE07_L1TP_173061_20000314_20170206_01_T1	Landsat-7	6.0
2010	LC08_L1TP_173061_20100801_20170220_01_T1	Landsat-8	4.19
	LC08_L1TP_173060_20100801_20170220_01_T1	Landsat-8	18.32
2020	L1C_T35MQU_A015519_20200612T082541	Sentinel-2A	1.06
	L1C_T35MQV_A016377_20200811T082459	Sentinel-2A	0.86
	L1C_T35MRU_A007540_20200816T082305	Sentinel-2B	0.02
	L1C_T35MRV_A007540_20200816T082305	Sentinel-2B	1.00

3.4.1.2 Preprocessing and processing of Landsat images

By pre-processing, atmospheric correction (Dark Object Subtraction method) was applied to correct errors attributed to atmospheric sensor energy interaction. The images were geometrically and radiometrically corrected to define true geolocation positions of the images and improve feature distinctions on the earth's surface. The Landsat imagery spatial resolutions were upgraded from 30 to 20 meters to facilitate pixel to pixel change detection.

The processing and cataloging of these images were completed in ArcGIS 10.5. The unrefined image bands 4, 3, 2 obtained from the Landsat satellite were imported and stacked to form a single multispectral image using a composite band tool in ArcGIS. The area of interest was masked out from the composite images using the Mitano catchment boundary and later LULC classification preceded using maximum likelihood supervised classification algorithm.

Supervised classification was based on the clue that a user selects pilot pixels in an image that are archetypal of specific classes and guides the image processing software to the training spots for the classification of all other pixels in the image. Finally, nine classes were produced as reflected in **Table 3.2.**

Table 3.2: Description of Land use/cover types in Mitano catchment

Land use/cover types	Description
Open water	Lakes
Wetland	Waterlogged areas (seasonal and permanent)
Tropical high forest	Natural forest (intact)
Woodland	Trees >4 meters in height, scattered with grasslands underneath
Grassland	Savannah (composed of short and tall grass types)
Tree plantation	Planted trees and forests (composed of mainly Eucalyptus and pine)
Subsistence farming	Small-scale farming activities (crop, livestock, or mixed)
Commercial farming	Large Scale farming (Tea)
Built-Up	Towns and trading centers

3.4.1.3 Image Accuracy Assessment

For accuracy assessment of 2000, 2010 and 2020 land use/cover maps. A total of 450 points were randomly generated within the boundary of the study area. These points were exported as a kml file and imported into google earth to compare with what was on the real ground to obtain the user and producer accuracy matrix and kappa values.

Overall accuracy $= 1/\mathrm{N}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{xii}$

Where

x is the individual cell values, x_{ii} is the total number of observations in row i and column i N is the total number of classes, N=total number of samples.

Kappa coefficient

Kc= $\mathrm{N}\sum_{\mathrm{i}=1}^{\mathrm{r}} \mathrm{xii} - \sum_{\mathrm{i}=1}^{\mathrm{r}} \left(\frac{\mathrm{xit}\times\mathrm{xti}}{\mathrm{N2}}\right) \sum_{\mathrm{i}=1}^{\mathrm{r}} (\mathrm{xit} \times \mathrm{xti})$

Where Kc is the kappa coefficient, N is the total number of samples, xii is the sum of the correctly classified pixel, r is the number of rows in the matrix, xit and xti, are the marginal totals of row i and column i respectively.

3.4.2 Determining the transitions and trend of land use/cover changes in Mitano catchment.

The analysis of LULC change is mainly to conduct a spatial overlay with the land-use status quo spatial information at the two-time points under the ArcGIS geographic information software (Hong et al., 2011). Transition matrix and through statistical analysis, calculation and preparation, the land cover status quo map and dynamic evolution transition matrix for each studied period was acquired Using the LULC maps for 2000 and 2020. The matrix of LULC transition probabilities for twenty years was used. The Markov transfer matrix was derived from the quantitative description of the state and state transition over a certain period. Based on the vector data, the dynamic information of land use was measured by a transfer matrix at a certain period. Then, the land use transfer rate and change intensity between different land-use types was calculated by the following formula:

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} \dots P_{1n} \\ P_{21} & P_{22} \dots P_{2n} \\ \dots & \dots \quad \dots \quad \dots \\ \dots & \dots \quad \dots \quad \dots \\ P_{n1} & P_{n2} \dots P_{nn} \end{bmatrix}$$

= transition probability which denotes the transition from i into j.

This was integrated with ArcGIS through performing dissolving and intersecting the LULC maps of 2000 and 2020 to obtain the transition. These were transferred to excel to generate the Land use. cover transition statistics and transition graphs. For trends in Land use/cover changes, the Land use/cover tapes for successive years were regressively analyzed in response to time. This w3as done to determine whether the changes in trend were significant or insignificant with time.

3.4.3 Effect of LULC changes on soil erosion

3.4.3.1 Assessing soil erosion risk

To examine the effects of LULC changes on soil erosion, a GIS-based model known as the Revised Universal Soil loss equation was used to estimate and quantify soil loss in the Mitano catchment. The Revised Universal Soil Loss Equation (RUSLE) was first developed in the 1960s by Wischmeier and Smith of the United States Department of Agriculture as a field-scale model. It was later reviewed in 1997 and is still used up to date. According to Ganasri and Ramesh (2016), the RUSLE model is the most extensively used model around the world to envisage soil erosion subject to management practice. RUSLE quantifies the average annual erosion using Equation 1 which states as follows;

$$A = R \times K \times LS \times C \times P$$

Where, A is the amount of soil erosion calculated in tons per hectare per year, R is rainfall factor (in megajoules millimeter per hectare per hour per year), K is soil erodibility factor (ton hectare hour $hectare^{-1}$ $megajoule^{-1}$ $millimeter^{-1}$), L is slope length factor, S is slope steepness factor, C is cover and management factor, and P is erosion control practice factor.

3.4.3.2 RUSLE Model input data

The input data for the RUSLE model included the classified LULC for the years 2000, 2010 and 2020 derived from Landsat and Sentinel images, slope map, Rainfall and soil properties data. The classified land use/cover map for the years 2000, 2010 and 2020 was to determine the effects of LULC change on the soil erosion in Mitano catchment for the respective years. The slope map was derived from the 30-meter SRTM Digital Elevation Model (DEM) (STRM) obtained from U.S. Geological Survey’s (USGS) Earth explorer geoportal https://earthexplorer.usgs.gov/. In addition, other topographic parameters such as channel slope and terrain slope were developed from the DEM using Arc GIS. Rainfall data for the retro of 2000-2020 was extracted from the Nasa Power Agro climatology data geoportal. Soil properties were derived from the Harmonized world soil map. These properties included soil texture, soil organic matter, and permeability for each soil type in the sub-catchment necessary for determining soil erodibility.

3.4.3.3 Determination of RUSLE components

The Rainfall Erosivity Factor (R)

Rainfall erosivity refers to the effects of rainfall intensity on soil erosion and requires continuous precipitation data for its calculation and is often determined from rainfall intensity. In this study, daily rainfall data for the retro of 2000-2020 was acquired from NASA power climatology data (Table 3.3) and this was used to calculate R-factor.

Table 3.3: Rainfall data for Erosivity determination

			2000		2010		2020	
STATION	Y	X	Rainfall (mm)	R-Factor	Rainfall (mm)	R-Factor	Rainfall (mm)	R-Factor
5297	-0.46	29.68	1036	183.51224	882	165.8269	858	163.07072
5300	-0.46	30	707	145.72988	1057	185.9239	1512	238.17608
8297	-0.78	29.68	717	146.87828	1256	208.777	1488	235.41992
8300	-0.78	30	626	136.42784	1121	193.2736	1528	240.01352
11297	-1.09	29.68	770	152.9648	1539	241.2768	1674	256.78016
11300	-1.09	30	642	138.26528	1341	218.5384	1640	252.8756

The R factor was projected using an equation (Equation 2) proposed by Foster et al, (1985)

$R = 0.29(3.96*P+3122)-26.0$ Equation 2

Where, P is the mean annual precipitation in mm

The R values for six rainfall stations were imported into Arc GIS and projected. Erosvivty values between the rainfall stations were then estimates using the Inverse Distance Weighted (IDW) Interpolation. This was performed under spatial analysis and to the extent of the Mitano catchment boundary to obtain the R- factor rater map (**see Appendix 1**)

The Soil Erodibility Factor (K)

Soil erodibility factor (K-factor) is a numerical description of the inherent erodibility of a particular soil. It is a measure of the predisposition of soil particles to detachment and transport by rainfall and runoff. The soil erodibility factor (K) is affected by soil properties which include soil texture, structure, organic matter, and perviousness (Larionov et al., 2018).

Erodibility values were derived from the soil map (Harmonized World Soil Database) and the K- factor recommended by Food and Agricultural Organization (FAO) was adopted (see table 3.4) basing on soil color in the River Mitano catchment (see appendix 2)

Table 3.4 K-factor for Mitano catchment determined by FAO

SOIL TYPE AND COLOR	**K_FACTOR**
Peat or peaty sands and clays	0.15
Brown sand and sandy loams occasionally gravelly	0.2
Greyish-brown sands and sandy clay loams	0.2
Red and reddish-brown clay loams, occasionally lateralized	0.2
Red sandy clay loams	0.2
Reddish and reddish-brown gritty clay loams	0.2
Reddish-brown clay loams	0.2
Reddish-brown sands and sandy loams	0.2
Shallow dark brown or black sandy loams are often very stony	0.2
Humose loams with dark subsoil horizons	0.45
Yellowish red Clay Loams	0.45
Yellowish-brown loams and sandy clay loams with dark subsoil horizons	0.45
Humose sandy loams with dark subsoil horizons	0.65

Slope- Length Gradient Factor (LS)

The slope length and steepness factor (LS) is a product of slope length (L) and steepness (S). Slope Length is defined as the distance from point of origin of overland flow to the point where the slope decreases to the extent that deposition begins (Ganasri and Ramesh, 2016).

The LS factor was calculated using the DEM, slope map and flow accumulation. The slope of the sub-catchment was derived from the 30 m –resolution STRM DEM using spatial analyst tool in Arc-GIS. Flow accumulation was also derived using the hydrology under spatial analyst tools (i.e. fill, flow direction and flow accumulation) in ArcGIS. The LS factors were estimated using Equation 4 to 9 proposed by Desmet and Govers (1996):

Factor L: (Power(("flowacc"+625), ("Factor M"+1)) -Power("FlowAcc",("FACTOR_M"+1)))/(Power(25,("Factor M"+2)) *Power(22.13,"Factor M")) Equation 4

Where; m is the slope length derived from slope map for the respective grid using Equation 5:

Factor M: "Factor F" / (1 + "Factor F") Equation 5

Where;

Factor F: ((Sin("**slope**" ∗ 0.01745)) / (3 ∗ Power(Sin("slope" ∗ 0.01745),0.8) + 0.56))

Equation 6

Therefore,

L: (Power(("flowacc" + 625), ("Factor M" + 1)) − Power("FlowAcc", ("FACTOR_M" + 1)))/ (Power(25, ("Factor M" + 2)) ∗ Power(22.13, "Factor M")) Equation 7

Factor S: Con((Tan("slope" ∗ 0.01745) < 0.09), (10.8 ∗ Sin("slope" ∗ 0.01745) + 0.03), (16.8 ∗ Sin("slope" ∗ 0.01745) − 0.5)) Equation 8

Then;

LS: "factor_L" ∗ "factor_S" Equation 9

The derived Slope Length Factor (L), Slope steepness and Factor LS (appendix 4) were used as an input in the RUSLE model to derive the soil erodibility of the catchment.

Crop/ Vegetation Management Factor (C)

The Crop management factor (C) represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope and is used to account for positive impacts of those support practices (Ganasri and Ramesh, 2016).

These values range from 0 to 1 and the values close to zero; 0 indicates good conservation practice while the value approaching 1 indicates poor conservation practice. Factor C was computed from the LULC map. The values of the C factor were assigned to all the LULC classes basing on the review of related literature on C- factors in the tropics (Table3.5). Using ArcGIS raster calculator after adding a field in the table of attributes. These were converted to raster using the conversion tool under Arc tool to obtain C-factor maps for successive years (appendix 3). These were used as inputs in the RUSLE model.

Table 3.5 C-factor values obtained from Nearing et al (1994)

LULC class	C factor
Open water	0
Wetland	0.01
Tropical high forest	0.001
Woodland	0.05
Grassland	0.08
Tree plantation	0.003
Subsistence farming	0.38
Commercial farming	0.5
Built-Up	0.25

Support Practice Factor (P).

It represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope (Larionov et al., 2018). Therefore, the overall P-factor is computed as a product of P-factors for individual support practices that are used in combination to reduce erosion. Such practices include terracing, contour tillage, and permanent barriers or strips. For this catchment, the P-factor for terracing was the only one used since the other practices were absent or not consistent throughout the slopes. Values for the terracing factor were available from the RUSLE database software. Its value varied depending on the slope length and steepness.

3.4.3.4 Determination of soil erosion risk intensities

Using GIS tools, the soil erosion raster maps of the River Mitano catchment were classified into six soil erosion risk classes as accepted in Tropical catchments in the hilly environment (Table 3.6). This classification scheme was adopted by Morgan (2009). The selection of this classification scheme was justified by the hilly landscape where River Mitano flows from 2500 meters in the South to 975 meters in North West (Kingston et al., 2010) and being a tropical catchment.

Table 3.6: Soil erosion risk class classification by Morgan (2009)

Code	Category/class	Rate of erosion(tons/ha/year)
1	Very slight	0-2
2	Slight	2-5
3	Moderate	5-10
4	High	10-50
5	Severe	50-100
6	Very Severe	100-500

CHAPTER FOUR

PRESENTATION OF RESULTS

4.1 Introduction

This chapter presents the findings of the study as per the main objective of the Study as, establishing the effect of land use/cover change on soil erosion risk in Mitano catchment. The results are in line with the specific objectives of the study which included quantifying the extent of land use/cover changes, determining the trend and transition of land use/cover changes and determining the effect of these changes on soil erosion risk in Mitano catchment between 2000 and 2020.

4.1.1 The extent of land-use changes in Mitano catchment between 2000 and 2020.

Figure 4.1 indicates that the spatial extent of subsistence farming kept on expanding for the entire period of the study while wetlands kept on contracting. In 2000, the lower part of Mitano in the sub-catchments of Ntungu and Chiruruma were dominated by grassland and woodland but this was later replaced by built-up areas and subsistence farming in 2020. The findings also indicate that there was expansion in the Built-up area from 2000 to 2010. This expansion was towards the Rushoma sub-catchment in the upper part of Mitano catchment. In the lower parts of the catchment, the expansion in built-up and subsistence farming was towards Rushaya and Chiruruma sub-catchments. The spatial extent of Land use/cover change in River Mitano was determined and results were presented (Figure 4.1)

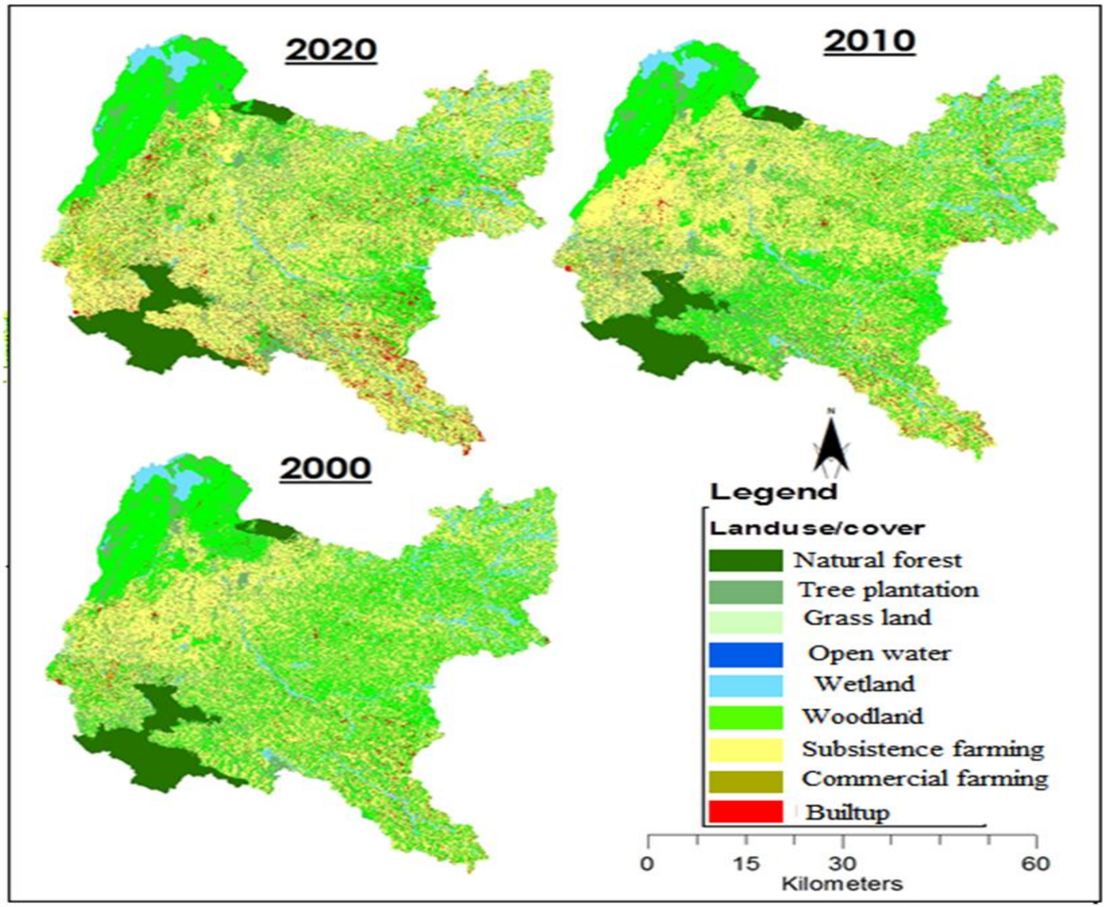

Figure 4.1: Land use/cover changes between 2000-2020 in Mitano catchment

The subsequent LULC maps for 2000, 2010 and 2020 shown in Figure 4.1 had an overall map accuracy of 75.57%, 80.97%, and 84.38%, respectively for all the images based on the error matrix. Kappa statistics indicated accuracy 0.71, 0.77 and 0.81 for 2000, 2010, and 2020, respectively (Table 4.1). Therefore, the overall results are viable for subsequent analysis and change detection.

Table 4.1 Accuracy assessment results

Accuracy	2000	2010	2020
Total accuracy	75.57%	80.97%	84.38%
Kapa coeff	0.71	0.77	0.81

Table 4.2 reveals that Grassland covered the largest land area in 2000 of 1562.14km^2 (39.79%) followed by subsistence farming covering 1543.41km^2 (39.31%). This was in contrast with open water which covered the least land area of 0.16 km^2 (0.00%) followed by commercial farming which covered 1.10 km^2 (0.03%) of Mitano catchment during the same study period. The results also indicate that in 2010 Subsistence farming covered the larges area of 1659.57km^2 (42.27%) of the catchment thus taking grassland as it was in 2000. Open water occupied the least land area in 2010 occupying 0.16 km^2 (0.00%) of the catchment. Similarly in 2020 Subsistence farming occupied the largest land area of 1800.38km^2 (45.86%) of Mitano while open water had the lowest spatial extent covering 0.00% 0.16 km^2 of the catchment. The extent of LULC change in the River Mitano catchment for the period 2000, 2010 and 2020 was determined and results were presented (Table 4.2)

Table 4.2: The extent of LULC change in Mitano.

	2000		**2010**		**2020**	
Land use/cover types	**Area (sq.km)**	**Area (%)**	**Area (sq. km)**	**Area (%)**	**Area (sq.km)**	**Area (%)**
Tropical high forest	243.09	6.19	242.98	6.19	247.83	6.31
Tree plantation	255.85	6.52	378.93	9.65	383.22	9.76
Grassland	1562.14	39.79	1300.49	33.13	1067.23	27.18
Open water	0.16	0.00	0.16	0.00	0.18	0.00
Wetland	171.78	4.38	167.13	4.26	161.74	4.12
Woodland	73.98	1.88	73.59	1.87	62.05	1.58
Subsistence farming	1543.41	39.31	1659.57	42.27	1800.38	45.86
Commercial farming	1.10	0.03	1.06	0.03	9.97	0.25
Built-up	74.49	1.90	102.08	2.60	193.39	4.93
Total	3925.99	100.00	3925.99	100.00	3925.99	100.00

The results also revealed that the dominant change in LULC for the study period occurred in grassland which changed from1562.14km^2 (39.79 %), 1300.49km^2 (33.13%) and 1067.23km^2 (27.18%) for the period 2000, 2010 and 2020 respectively. However, this change was in form of loss or contraction in land area under grassland. The second dominant change in LULC was registered in subsistence farming that changed from 1543.41km^2 (39.31%), 1659.57km^2 (42.27%) and 1800.38km^2 (45.86%) for the period 2000, 2010 and 2020 respectively. However, the changes in subsistence farming were in form of gain in the extent of land area as evidenced by its dominance on most slopes in the study area (plate 4.1).

Plate 4.1: Dominance of subsistence farming on Mitano sub catchment the slopes in between Rukungiri and Kanungu districts (Nengo June 2020)

4.1.2 Transition and trend of land use/cover changes in Mitano Catchment between 2000 and 2020

4.1.2.1: Transitions in LULC changes

Figure 4.2 reveals that subsistence farming gained more land by 24.53% followed by grassland with 19.7% woodland 7.37%, tropical high forest with 5.93% and wetland with 4.24%. It is also revealed that the dominant conversion was the conversion of Grasslands to subsistence farming at a rate of 19.7% for the period 2000 to 2020, conversion of subsistence farming to grasslands at a rate of 11.95%. Thus, the Mitano catchment slopes were being converted from grassland to subsistence farming as reflected by plate 4.2 Further analysis was carried out to identify the major LULC transitions between 2000 and 2020 and the results are presented in Figure 4.2

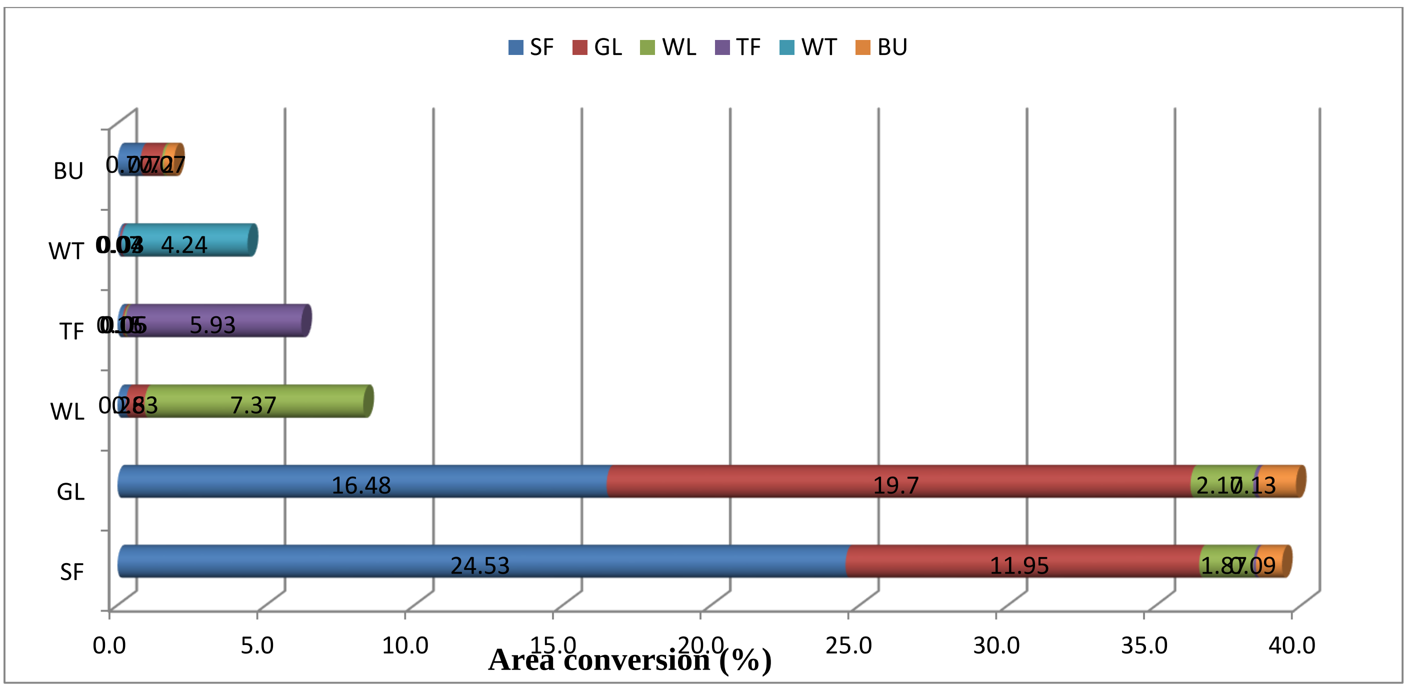

Figure 4.2 Major Land use/ cover transition for the periods of 2000-2020

Note SF, GL, WL,TF, WT and BU represent Subsistence Framing, Grass land, Woodland ,Tropical high forest, Wetlands and Built Up.

Plate 4.2: Transition of catchment slopes from grass land to cropland in Rwerere, Rukungiri district (Rwerere June 2020)

4.1.2.2: Trend of LULC changes

The trend of LULC change in Mitano catchment was determined using the linear trend to determine the LULC type that increased or reduced by the highest magnitude from 2000 to 2020 and results presented in Figure 4.3. Figure 4.3 indicates that subsistence farming, built-up, tropical high forest, Tree plantation, open water and commercial farming had an increasing trend for the period of the current study. However, Grassland and wetlands were experiencing a decreasing trend from 2000 to 2020.

It was revealed that grassland had a very sharp increase from 2000 to 2020. This was indicated by the positive slope of the linear relationship. It registered the most significant R^2 of 0.99 which is there was a 99% increase in the trend of subsistence farming for the period of the current study. This was followed by built-up, tree plantation, open water, tropical high forests and commercial farming with R^2 of 0.91, 0.77, 0.75, 0.74 and 0.73 respectively. All these trends in LULC increase were revealed to be significant because they were above 0.5 for significance levels.

It was noted that Grassland and wetland had a decreasing trend in Land use/cover change from 2000 to 2020. The grassland though registered a very sharp decrease in its land use/cover indicated by a very high coefficient of determination (R^2) of 0.99. This was followed by wetland whose trend of Land use/cover declined significantly with R^2 of 0.99. However, the negativity of slope gradient for grassland was higher than wetland (-24.746x + 51048). This indicates that the trend of grassland was more decreasing than wetlands.

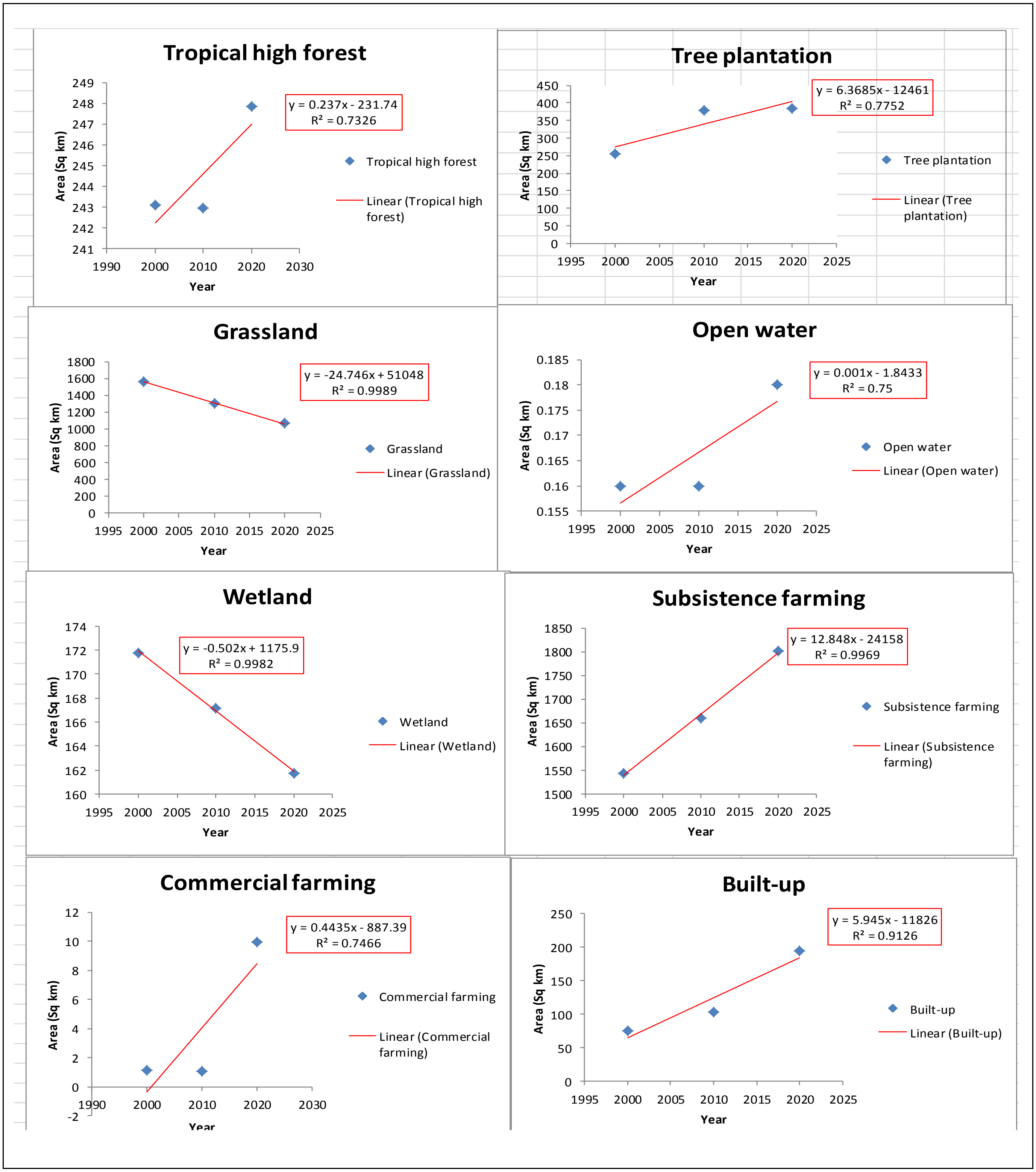

Figure 4.3: Trend in Land use/ cover changes in River Mitano catchment from 2000 to 2020

4.1.3 Effect of Land use/cover change on soil erosion

The land use/cover maps for 2000, 2010 and 2020 were used in the RUSLE model to assess the impact of temporal LULC change on soil erosion while maintaining the slope map, rainfall and soil properties data for the respective period. Using Arc GIS under arc tool the produced raster maps were converted into vectors and with the help of the raster calculator, the area covered by each soil erosion class was computed in km^2. The results are presented in Table 4.3. Results in table 4.3 indicate that by the year 2000, 67% of River Mitano catchment was experiencing a very slight, slight and moderate rate of soil erosion quantified as (0-2, 2-5 and 5-10 t $ha^{-1}yr^{-1}$) while the remaining 33% of the catchment experienced a high, severe and very severe rate of soil erosion quantified as (10-50, 50-100 and 100-500 t $ha^{-1}yr^{-1}$). In 2010 57% of the River Mitano catchment experienced a very slight to moderate rate of soil erosion while 43% ranged from high to very severe rate of soil erosion. For the LULC of 2020, the rate of moderate to very slight erosion covered 53% while high to moderate soil erosion in the catchment increased to 47%.

The results revealed that whereas moderate to a slight rate of soil erosion in the catchment decreased for successive LULC types by 10% (2000-2010) and 4% (2010-2020), the rate of high to a very severe rate of erosion in the catchment was increasing by 10% (2000-2010) and 7% (2010-2020) respectively. There was continuous expansion in the area under severe rates of soil erosion (50-100 t $ha^{-1}yr^{-1}$) in the River Mitano catchment. It was also revealed that the most significant percentage increase occurred in a high rate of soil erosion (10-50 t $ha^{-1}yr^{-1}$) by 8% for the period 2000-2010; and in severe and very severe rates of soil erosion (10-100 and 100-500 t $ha^{-1}yr^{-1}$) by 3% and 3% for the period 2010-2020.

Table 4.3 Changes in the rate of soil erosion in River Mitano catchment per LULC change in 2000, 2010 and 2020

RANGE	Erosion rate	LULC-2000		LULC-2010		LULC-2020		Rate of change (%)		
	Tons/ha/year	Area (sqkm)	Areas (%)	Area (sqkm)	Areas (%)	Area (sqkm)	Areas (%)	2000-2010	2010-2010	2000-2020
Very slight	0-2	1357.02	34	1072.31	27	1324.89	34	-7	*6	-1
Slight	2-5	677.65	17	571.82	15	339.73	9	-3	-6	-9
Moderate	5-10	617.83	16	573.96	15	398.12	10	-1	-4	-6
High	10-50	1063.12	27	1376.21	35	1338.72	34	*8	-1	*7
Severe	50-100	137.26	4	205.98	5	305.8	8	2	3	*4
Very severe	100-500	63.27	2	115.27	3	209.15	5	1	2	*4

To determine the spatial distribution of soil erosion in response to LULC change for the period of study, GIS and remote sensing methods with the help of the RUSLE model was used for successive LULC maps for 2000, 2010 and 2020 and the results were presented in Figure 4.4. Figure 4.4 reveals that for LULC of 2000, the largest portion of the catchment experienced very slight, slight and moderate rates of soil erosion (0-2, 2-5 and 5-10 t $ha^{-1}yr^{-1}$) in lower parts of the catchment in the sub-catchments of Ntungu and Rushaya in the districts of Kanungu, Rukungiri and Mitoma in parts of Nyakashuri, Bugongi and Katete in Kanungu, Bugangari and Ndere in Rukungiri. In 2020, areas like Ndorwa and Rukiga that were formally (2000 and 2010) experiencing moderate and high rates of soil erosion (5-10 and 10-50 t $ha^{-1}yr^{-1}$) were replaced by severe and very severe rates of soil erosion (50-100 and 100-500 t $ha^{-1}yr^{-1}$)

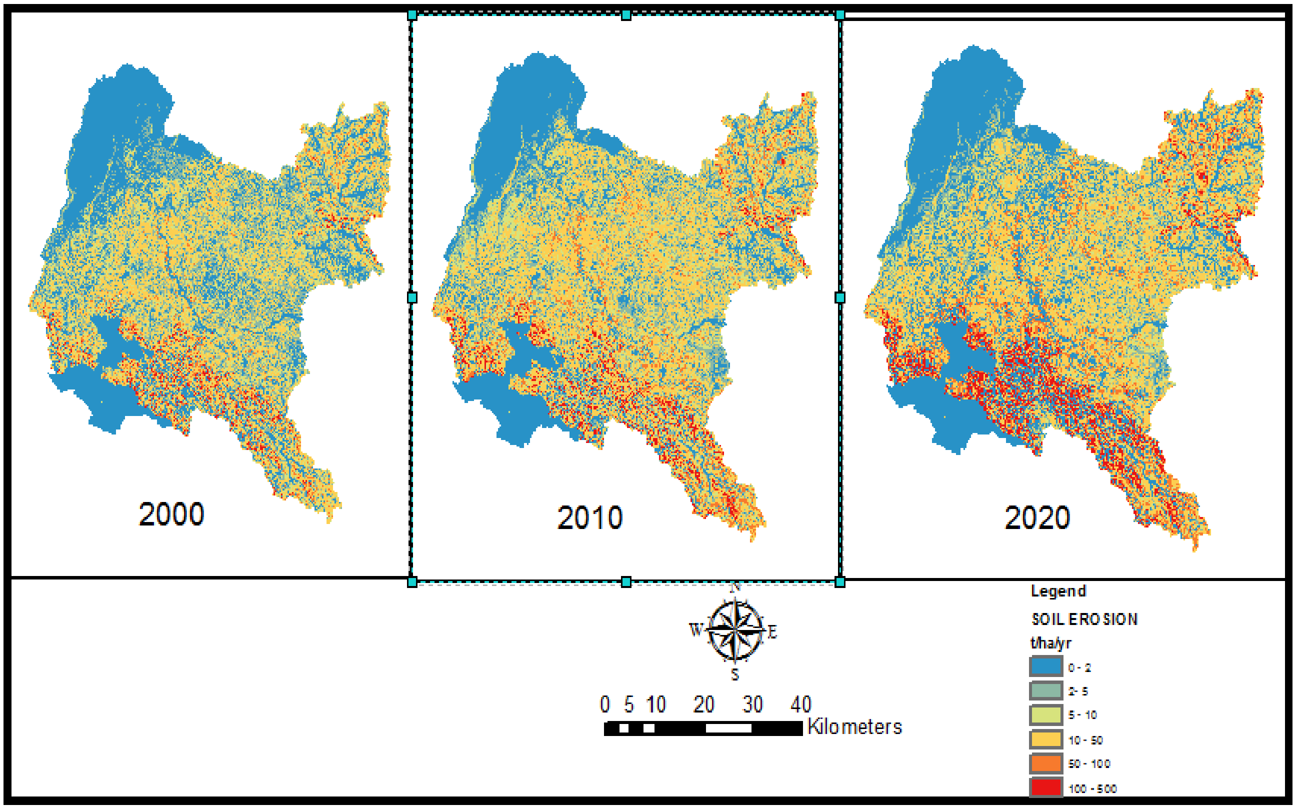

Figure 4.4: Changes in soil erosion due to changes in LULC for the period 2000, 2010 and 2020.

Plate 4.3: One of farms with limited access to mulch materials for soil and water conservation in Rukungiri district (Rushaya Sub County, June 2020)

CHAPTER FIVE: DISCUSSION

5.1 The extent of land use/cover changes in Mitano catchment between 2000 and 2020.

The LULC changes for the period of study (2000-2020), reveal expansion and contraction in land use/cover changes in the Mitano catchment. Decrease and increase in land use/cover exposes the catchment to degradation processes of erosion, sedimentation and flooding.

The study revealed that grasslands covered the largest area in Mitano for the year 2000. However, it registered the highest rate of reduction of about 5.9% and 6.7% for the period 2000-2010 and 2010 -2020 respectively. This persistent decrease in grassland was attributed to an increase in the extent of subsistence farming for instance for the period 2000 to 2010, 16.48% of grassland was converted to subsistence farming yet for this same period only 11.5% of subsistence farming was converted to grassland. This implies that over time most parts of the catchment that were formally grasslands have been converted to farmlands. These findings are in line with Kizza et al., (2017) who noted that Grasslands in Lake Bunyonyi catchment in South Western Uganda were decreasing at a rate of 1% between 2005 and 2015 in contrast with small scale farming which expanded at a rate of 14 % for the same period. However, their percentage expansion and contraction were low compared to the current study, this could be due to the big area of Mitano catchment compared to Lake Bunyoynyi though in the same region and physical environment. Continuous conversion of catchment surfaces from grasslands to subsistence farming has reduced infiltration and increase surface runoff that increases erosive power thus increased soil erosion in Mitano catchment leading to a loss in soil fertility, sediment yield and flooding.

This study revealed that the extent of tropical high forest contracted over the study period; 2000 – 2010 by 0.1%. This was converted to subsistence farming where 0.15% of tropical high forests were lost to subsistence farming. During this same period, subsistence farming experienced an increase in areal extent. Since subsistence farming expansion is synonymous with population increase, it can be argued that the decrease in forest land in Mitano catchment over the study period was due to an increase in population. Barasa et al. (2010) also agreed with the current findings reporting that tropical forests decreased by 16% from 1975 and 1987 in Kanungu within Mitano catchment. Rumann et al. (2018) agreed with the study findings when aligned to the global scale by reporting that the world's forest areas declined by 2.4% (2000-2015). Kizza et al. (2017) noted that in the Lake Bunyonyi catchment in South Western Uganda, the decline in tropical high forests and grassland is only due to their conversion to small-scale farming. As tropical high forests are converted to subsistence farming, there is fluctuation in the hydrological processes and alteration in soil erodibility that increases surface runoff and rainfall erosivity thus triggering natural hazards like flooding, mudflow and soil erosion within the Mitano catchment.

5.2 Transition and trend of land use/cover change in Mitano catchment

It was revealed that the transitions in LULC change for land covers like Grassland, wetlands and woodlands was negative because all were reducing for the period of the current study. However, the land uses like subsistence farming, commercial farming built-up areas were experiencing a positive trend within Mitano catchment for the period of the current study. This is in line with Majaliwa et al. (2018) who predicted that in Uganda by 2040, subsistence agricultural land is likely to increase by about 1% while tropical high forest and woodland were expected to decrease by 0.2% and 0.07% respectively. Nampak et al. (2018) in a Tropical catchment in Malaysia revealed similar transitions by noting that urban areas and agricultural lands were expanding and gaining land from the forest. A continuation of these transitions will lead to the conversion of fragile surfaces in Mitano catchment to highly risky surfaces inform of urban areas that limit infiltration and farmlands that increase the rate of soil erosion. There is thus a need to integrate natural landscapes into land-use planning.

It was revealed that the trend of increase in subsistence farming was very high and conversely the trend of grassland decrease was negative. This indicates that the speed at which subsistence farming is increasing is directly proportional to the rate at which grassland is declining in the River Mitano catchment. The protective nature of grasslands within catchments is higher compare to subsistence farming thus once the grass is lost then there is an increase in the rate of soil erosion the catchment is highly being degraded. These findings are in line with Gebresamuel et al., (2010) who revealed that the rate of crop farming is persistently increasing in tropical catchments resulting in catchment degradation. Thus there is a need to ensure the protection of grasslands within the River Mitano catchment

5.3 Effect of LULC change on soil erosion risk

Modeling soil erosion by using Land use/cover change for the period 2000, 2010 and 2020 revealed that high to a very severe rate of soil erosion (10-500 t $ha^{-1}yr^{-1}$) increased by 11 % for the period 2000-2010 in the River Mitano catchment due to increase in subsistence farming while built-up area increased by 2.96% and 0.07% for the period 2000-2010 respectively. The transition matrix revealed that during this period 16.48% of the catchment was converted from grassland to subsistence farming while 0.15% was converted from Tropical high forests to subsistence farming. These conversions led to a loss of the binding force of trees and leaves as well as the loss in a protective cover on land and an increase in soil erodibility and rainfall erosivity within the River Mitano catchment. This has resulted in increased soil erosion and catchment degradation.

As the catchment is eroded, there is an increase in degradation of the River Mitano catchment producing sediments which end up in streams leading to increased sediments, siltation and flooding downstream. This view is supported by Sun et al., 2016) who noted that human activities like agriculture and deforestation can increase soil erosion in a catchment area that would ideally be low under natural conditions. For the same period 2000-2010 the extent of forests reduced by 0.11 km^2 (243.09 km^2-242.98km^2), this indicates that there was a conversion of tropical high forests to farmlands given the fact that they are located on dark soils with high humus content thus triggering soil erosion. This same period witnessed a decline in wetlands thus the increase in the high to very severe rate of soil erosion could also be attributed to declining in wetlands for the period 2000-2010. These findings concur with Bolwig (2002) who revealed that in Uganda, the Conversion of papyrus swamp valleys to dairy pasture and croplands has intensified the rate of soil erosion on steep slopes of Mountainous areas. This raises concern since the high to very severe rates of erosion are unsustainable as indicated by Bamutaze et al., (2021) who noted that Soil erosion rates that are above 10 t ha-1 yr-1 are considered to be above the tolerable limit for the tropical mountainous environment to sustain crop production. It thus indicates that for the year 2010, 43% of River Mitano catchment was not supportive to crop cultivation due to unsustainable rates of soil erosion.

For the period 2000-2010 very slight to moderate rate of soil erosion (0-10 t $ha^{-1}yr^{-1}$) was noted to have reduced by 11%. This decrease was due to an increase in tree plantation in the catchment by 3.14% for the same period. This implies that as trees were planted, the rate of soil erosion in River Mitano catchments reduced thus policy would ideally focus on converting farmlands to tree plantations since this rate of erosion is sustainable. This view is supported by Ouyang et al., (2010) who revealed that planted vegetation decreases the rate of soil erosion since it checks on the rate of soil detachment.

The period 2010-2020 witnessed a decrease in a slight to high rate of soil erosion (11%) but very slight rate of soil erosion increased by 6%. This was due to the adoption of some soil conservation practices on some slopes that were formally experience a moderate rate of soil erosion. This implies that for this period there was an increase in cultivatable land by 11% since such rates of erosion are sustainable to crops in tropical catchments.

During the period of this study (2000-2020), a very slight to moderate rate of soil erosion was decreased by16% while the rate of high to very severe soil erosion was increased by 15%. This indicates that more slopes were translated into severe rates of erosion. This was due to an increase in subsistence farming and built-up areas because for the same Period these increased by 6.55% and 3.03% respectively. It was also noted that during this period there was a continuous decrease in grasslands, woodlands and wetlands having been converted into subsistence farming and built-up areas. Thus, if this trend continues in this catchment severe soil erosion is predicted to increase for the coming 20 years and soil erosion-related problems within the catchment like siltation, flooding, water pollution and crop failure will be exacerbated. These findings are in line with Ouyang et al., (2010) who revealed that an increase in construction land has a positive trend with an increase in the rate of soil erosion. This is further confirmed by Liu et al (2015) who indicated that land cover patterns conversion from forest to agriculture caused an increase in the amount of soil loss by 0.25t/ha/yr.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction:

This chapter presents the conclusion and recommendations. The recommendations cover areas related to policy and future research needs.

6.2 Conclusion

Subsistence farming persistently increased from the year 2000 to 2010 and finally to 2020 indicating that much of the catchment dwellers are participating in small-scale subsistence farming. Grasslands, wetlands and woodlands persistently decreased from the year 2000 to 2010 and finally 2020. This indicates that Natural vegetation is being lost in the catchment and replaced by farms and built-up areas.

The findings revealed that there was a continuous conversion of grasslands, tropical high forests and wetlands to subsistence farming and built-up areas within the Mitano catchment. It was also revealed that fields that had been abandoned from subsistence farming were later converted into grasslands.

The finding revealed a significant increase in subsistence farming built up and open water, however, grassland and wetlands registered a significant decreasing trend in Land use/cover in the River Mitano catchment

Soil erosion in Mitano catchment is on the increase with a major increase experienced within high to very severe rates of erosion while very slight to moderate soil erosion rates reduced for the study period. There is a thus positive relationship between an increase in subsistence farming and built-up area with an increase in the rate of soil erosion for the entire catchment.

It was revealed that very slight and slight rates of soil erosion have persistently decreased with an increase in the spatial extent as the trend of planted trees within the River Mitano catchment. Indicating improvement in the protective nature of the catchment

6.3 Recommendations

In line with the findings of this study, the following should be considered to minimize Land use/cover changes and its related problems as well as control the rate of soil erosion in the River Mitano catchment:

Integrate land use and land use/cover changes into the River Mitano watershed management plan to ensure proper hydrological functioning of such catchment for sustainable ecosystem services provision.

Soil and water conservation strategies such as afforestation and reforestation should be implemented by the communities in the hilly regions of the catchment especially in Rwakahinda, Kitanga and Bukinda in Rushoma sub-catchment. This is because such areas are soil erosional hotspots and are experiencing expansion in subsistence farming.

There is a need for mass sensitization campaigns to the communities within river Mitano catchment the environmental and hydrological impacts of urban surfaces and cultivated surfaces on Streamflow and their livelihood that is connected to River Mitano.

Awareness should be made to the communities within river Mitano on soil erosion hotspots within the catchment to enable them to identify soil erosion risk zones. This will help them to employ site-specific strategies in order to mitigate soil erosion in the catchment.

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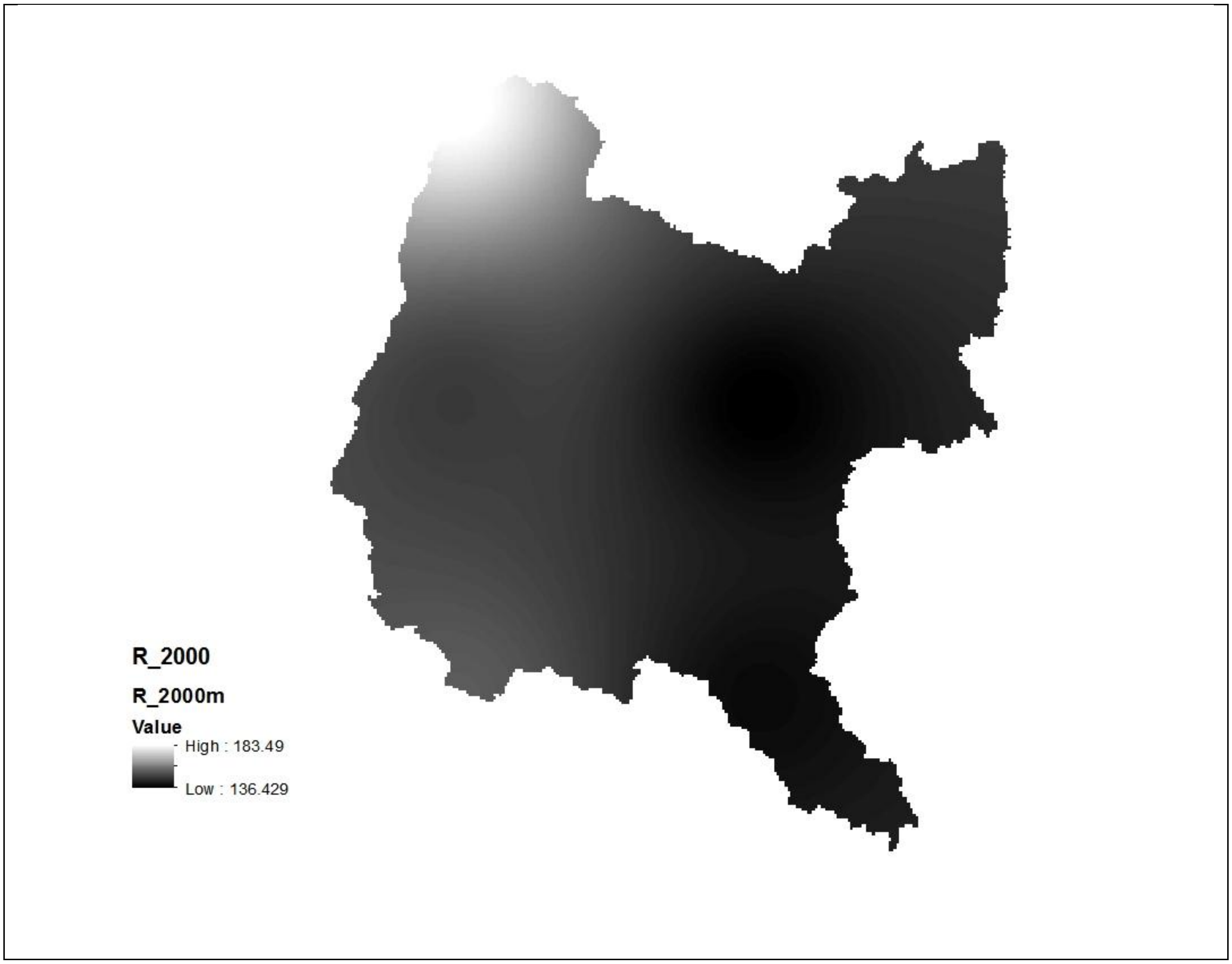
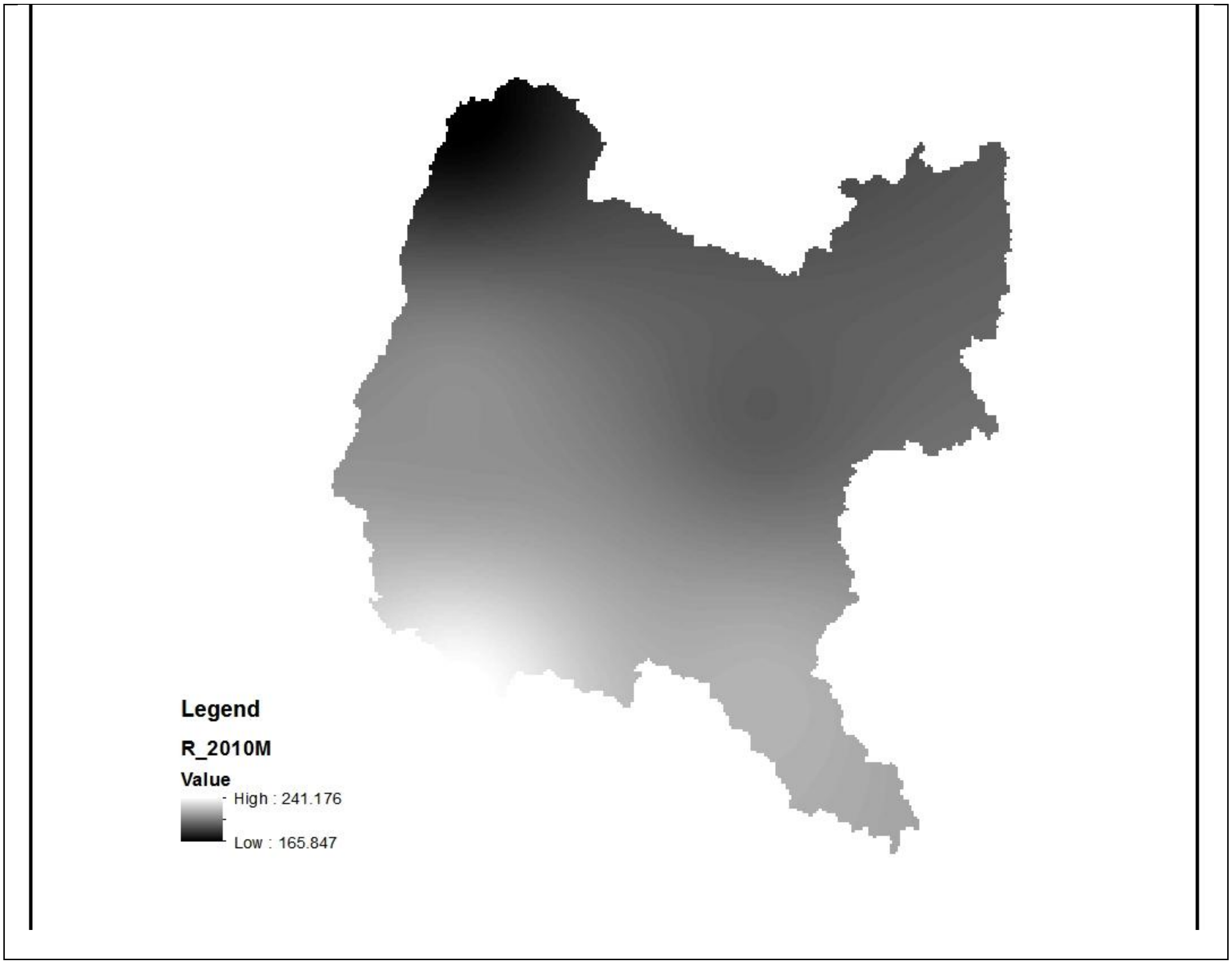
APPENDICES

Appendix 1: Rainfall Erosivity Maps (R-factor)

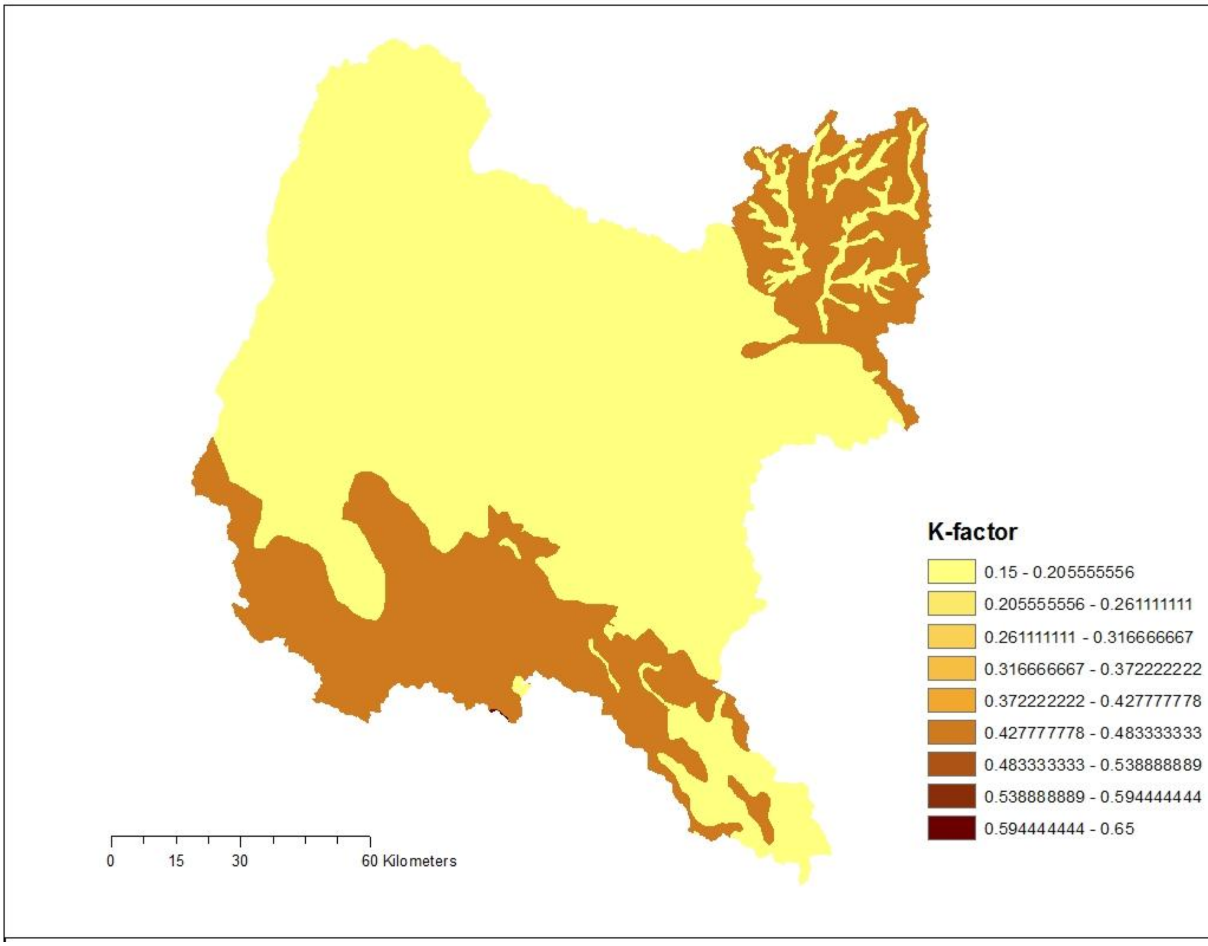




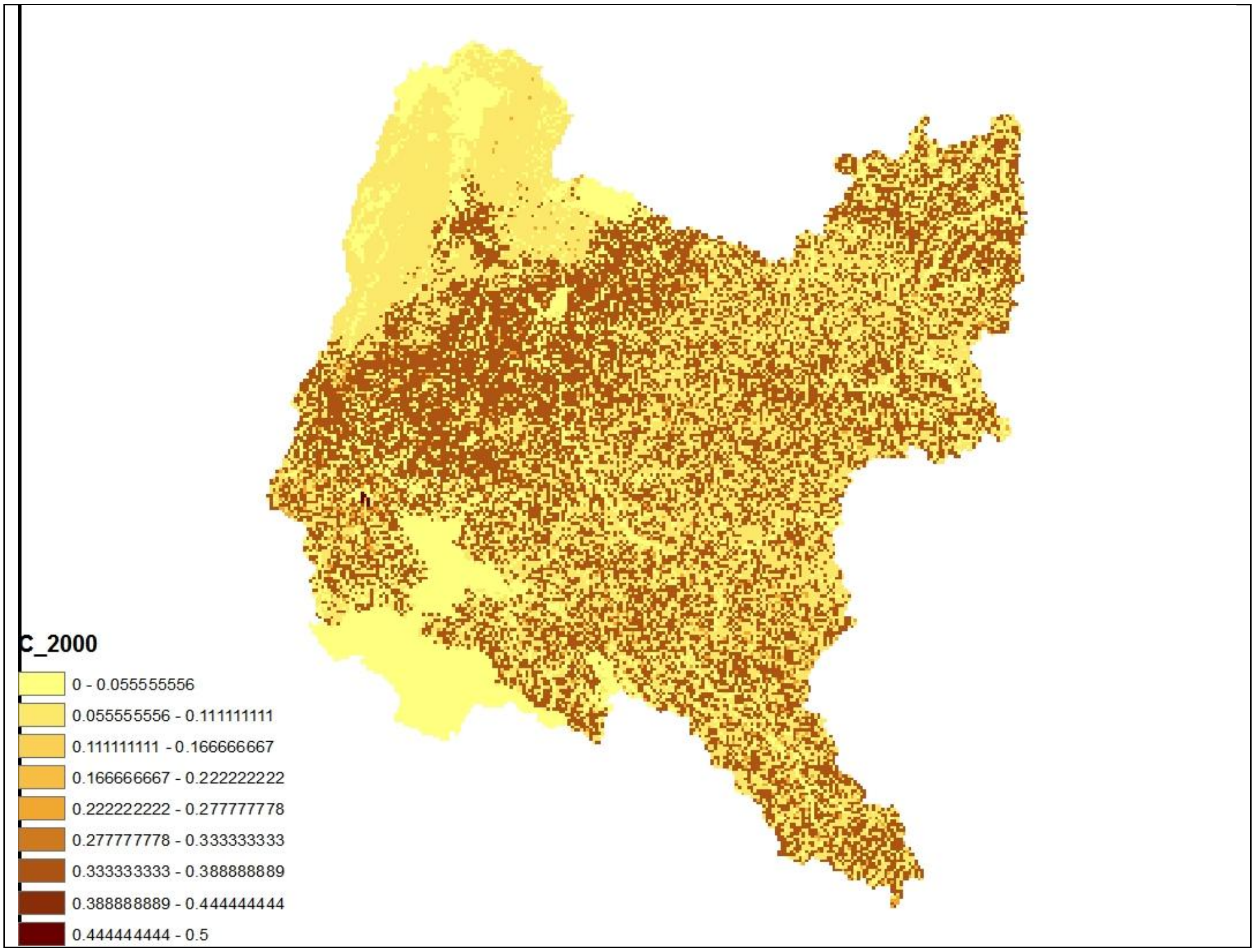
Legend
R_2010M
Value
High : 241.176
Low : 165.847

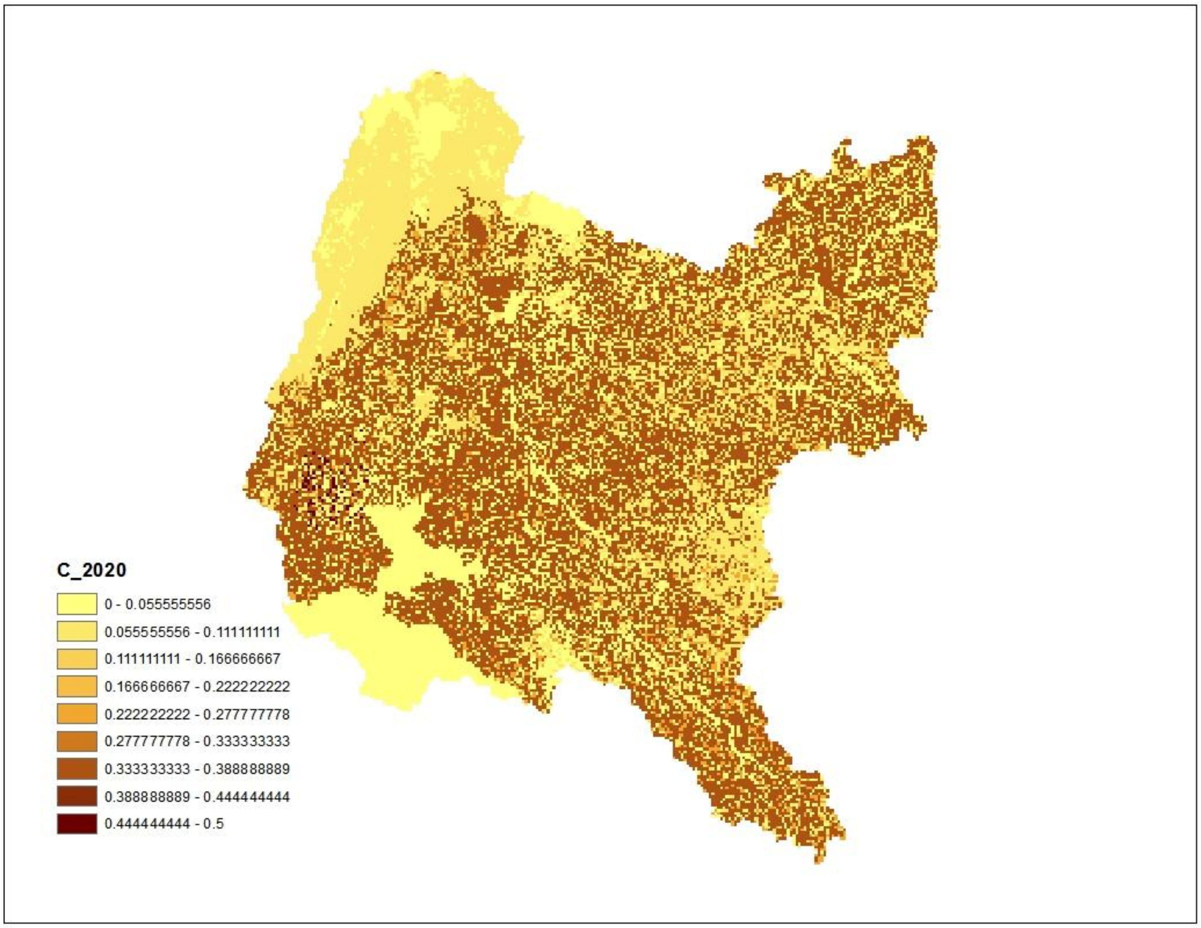
R_2020
R_2020M
Value
High : 256.724
Low : 163.115

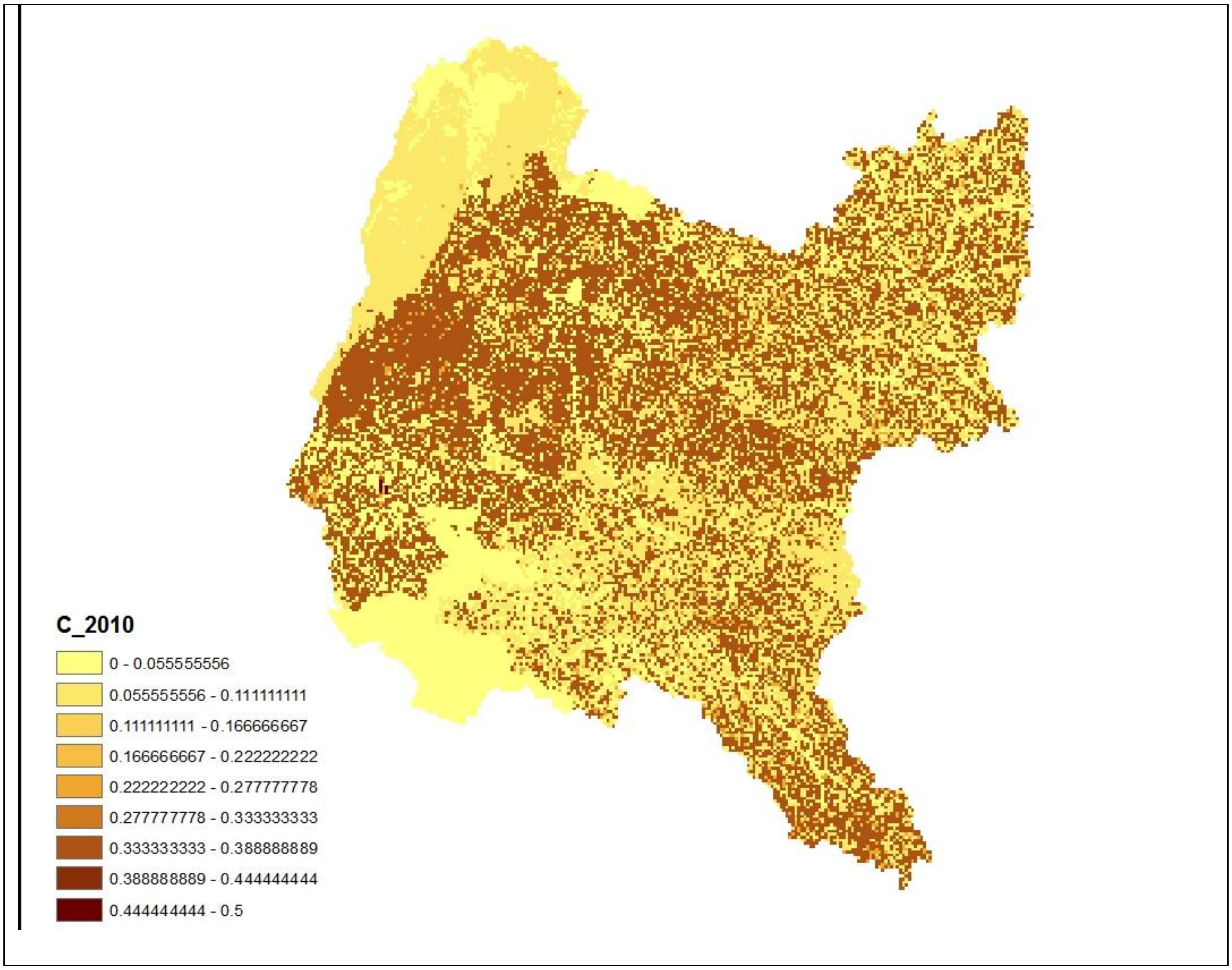
Appendix 2: Soil Erodibility (K-factor)



Appendix 3:C-Factor




C_2020
0 - 0.055555556
0.055555556 - 0.111111111
0.111111111 - 0.166666667
0.166666667 - 0.222222222
0.222222222 - 0.277777778
0.277777778 - 0.333333333
0.333333333 - 0.388888889
0.388888889 - 0.444444444
0.444444444 - 0.5


C_2010
0 - 0.055555556
0.055555556 - 0.111111111
0.111111111 - 0.166666667
0.166666667 - 0.222222222
0.222222222 - 0.277777778
0.277777778 - 0.333333333
0.333333333 - 0.388888889
0.388888889 - 0.444444444
0.444444444 - 0.5

Appendix 3: LS Factor