STREAMFLOW VARIABILITY AND SEDIMENT YIELD IN NORTH-WEST UPPER TANA BASIN, KENYA

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THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INTEGRATED WATER RESOURCES MANAGEMENT IN THE SCHOOL OF ENVIRONMENT, WATER AND NATURAL RESOURCES, SOUTH EASTERN KENYA UNIVERSITY

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2019

DECLARATION

CANDIDATE

This thesis is my original work and has not been submitted for examination in any other university

…………………………………………

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(W502/KTI/20677/2015)

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This thesis has been submitted with our approval as the university supervisors

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DEDICATION

This study is dedicated to God who has helped me all the way. I would also like to dedicate this work to my parents, Mr. Everton Njogu Njoroge and Mrs. Veronica Njoki Njogu and my brothers, Peter Ngugi and Ken Mwangi who tirelessly have been a pillar of strength and encouragement.

ABSTRACT

The main objective of the study was to determine how river discharge and sediment yield in the basin is influenced by variations in rainfall and land use land cover change. The study was based on the analysis of hydrological and meteorological data archived by the Water Resources Authority (WRA) and the Kenya Meteorological Department (KMD), respectively. The river discharge, Total Suspended Sediment Concentration (TSSC) and sediment yield data was collected from established river gauging stations in the basin, namely Sagana (4AC03), Maragua (4BE01), Saba Saba (4BF01), Mathioya (4BD01), North Mathioya (4BD07), Irati (4BE03), Thiba (4DD01), Thika (4CC05) and Gikigie (4BE08),for the period 2010-2012. Rainfall data was for the period 1980-2012, river discharge data was for the period 1980-2012 while sediment yield data was from the period 2010-2012.The study used Landsat 5 and 7 satellite data for Land Use Land Cover (LULC) change detection analysis and Geographical Information System (GIS). The statistical methods of data analyses applied in this study included regression analysis, correlation analysis, measures of central tendency, coefficient of determination (R^2), and the analysis of variance (ANOVA). The study also applied Soil Water Assessment Tool (SWAT) Model to simulate the relationship between sediment yield, river discharge and rainfall in NWUT catchment. Nash Sutcliffe Efficiency (NSE) was used to test the efficiency of the SWAT model in predicting these parameters.This study found a positive relationship between river discharge and sediment yield in the NWUT catchment with (r) of 0.74 and (R^2) of 0.55. The maximum Total Suspended Sediment Concentration (TSSC) was 1,433 mg/l at Saba Saba (4BF01) and the peak river discharge was 170.4 m^3/s at Sagana (4AC03). Water yield and sediment yield from NWUT basin was 327,638,974 m^3/month and 590,637.4 tons/month respectively. Sediment production rate from the basin was 59.55 tons/km^2/month in the period O2010-2012. Land Use Land Cover Change (LULCC) detections analysis for the period 2000- 2014 found out there was increase on bare-land (from 6.5 to 9.7%), increase in build-up areas (from 0.2% to 0.8%), decrease in forest cover (from 32.3% to 21.7%), decrease in rangeland (from 17.0% to 12.7%), increase in plantation (from 12.7% to 15.0%), increase in silted water bodies (from 0.1% to 0.7%) and reduced waterbody (1.5% to 0.5%). SWAT modelling application in the simulation of river discharge and sediment yield was good with NSE above 95%. The study puts forward various recommendations for soil and water management in the basin. Some of the recommendations for land management include application of soil and water conservation measures, Payment for Ecosystem Services (PES), Integrated Water Resources Management (IWRM), Eco-Hydrology and reforestation to improve high ediemnt yield from the basin.

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ADV:	Acoustic Doppler Velocimeter
ADCP:	Acoustic Doppler Current Profiler
AOI:	Area of Interest
ASAL:	Arid and Semi-Arid Lands
AVHRR:	Advanced Very High Resolution Radiometer
CCCPF:	County Climate Change Policy Framework
CIDP:	County Integrated Development Plans
CLASS:	Comprehensive Large Array-data Stewardship System
DEM:	Digital Elevation Model
DMCA:	Double Mass Curve Analysis
DMC:	Double Mass Curve
EOLi:	Earth Observation Link
ESA:	European Space Agency
FAO:	Food and Agriculture Organization
GCM:	Global Climate Model
GDP:	Gross Domestic Product
GEF:	Global Environment Facility
GERD:	Grand Ethiopian Renaissance Dam
GIS:	Geographical Information System
Glovis:	Global Visualization Viewer
GoK:	Government of Kenya
GWC:	Global Water Commission
GWC:	Green Water Credit
HEP:	Hydro-Electric Power
IFAD:	International Fund for Agriculture Development
ISRIC:	International Soil Reference Information Centre
ITCZ:	Inter-Tropical Convergence Zone
IWRM:	Integrated Water Resources Management
KENGEN:	Kenya Electricity Generating Company
KIFCON:	Kenya Indigenous Forest Conservation
KMD:	Kenya Meteorological Department
KNBS:	Kenya National Bureau of Statistics

KTDA:	Kenya Tea Development Authority
LANDSAT EMT:	Land Soil and Terrain Satellite Enhance Thematic Mapper
LANDSAT MSS:	Land Soil and Terrain Satellite Multispectral Scanner System
LANDSAT TM:	Land Soil and Terrain Satellite Thematic Mapper
LANDSAT:	Land Soil and Terrain Satellite
LULC:	Land Use Land Cover
MODIS:	Moderate Resolution Imaging Spectroradiometer
NASA:	National Aeronautics and Space Administration
NCCAS:	National Climate Change Action Strategy
NFP:	National Forest Policy
NIR:	Near Infra-Red
NOAA:	National Oceanic and Atmosphere Administration
NSE:	Nash Sutcliffe Efficiency
NWMP:	National Water Master Plan
NWP:	National Water Policy
NWUPC:	North-West Upper Tana Catchment
PES:	Payment for Ecosystem Services
RGS:	River Gauging Station
RUSLE:	Revised Universal soil Loss Equation
SDGs:	Sustainable Development Goals
SDR:	Sediment Delivery Ratio
SPR:	Sediment Production Rates
SWAT:	Soil and Water Assessment Tool
SWIR:	Short Wave Infra-Red
TARDA:	Tana and Athi Rivers Development Authority
TSSC:	Total Suspended Sediment Concentration
UNEP:	United Nations Environmental Programme
USDA:	United States Department of Agriculture
USGS:	Unites States Geological Society
USLE:	Universal Soil Loss Equation
VNIR:	Very Near Infra-Red
WRA:	Water Resources Authority
WRUA:	Water Resources Users Association
HRUs:	Hydrologic Response Units

CHAPTER ONE

INTRODUCTION

1.1 Introduction

The study focuses on assessing the influence of landuse change and rainfall variability on river discharge and sediment yield in NWUT catchment in Kenya. The background of the study, statement of the problem, conceptual model of the study, main and specific objetives of the study, hypothesis and justification for the study are provided.

1.2 Background of the Study

Land-use change has important implications on streamflow and sediment yield in tropical basins. This is due tothe fact that it changes the pattern and magnitude of peak flows and sediment yield which adversely affects the life span of reservoirs. The goal of the study was to generate information that can be used to promote sustainable land use practices and conservation in NWUT catchment. It was expected that provision of information on factors influencing high sediment yield and river discharge in NWUT catchment basin will lead to application of suitable soil and water conservation practices that would eventualy lead to the sustainable water flows and reduction in the discharge of sediments into Masinga dam. Past studies (Schneider, 2000; Brown *et al.*, 1996; Kitheka *et al.*, 2005; Jacobs *et al.*, 2004; Hirji and Ortolano, 1991) have shown that Masinga reservoir has been silting up rapidly and this has led to the reduction in the storage capacity hence reducing the life span of the dam. This has resulted in the reduction of the capacity of the dam to generate hydro-electric power (HEP) and control flooding downstream which were the primary roles of the dam when is was designed (Schneider, 2000). Effects of climate change have led to increased variability in rainfall and stream flow (Brown *et al.*, (1996); Batjes, (2014); Mogaka, (2006); Hunink *et al.*, (2013); Oludhe *et al.*, (2013). Previous studies have shown that climate change is also affecting vegetation and land cover in the study area (Hunink *et al.*, 2013). Rainfall variability in NWUT catchment increased the sediment yield loading in the basin (Hunink *et al.*, 2013). This coupled with unsustainable landuse in the basin has increased the ability of the rivers in the catchment to transportsediments due to increased sediment availability and increased capacity of river to transport sediments (Kitheka *et al.*, 2005; Brown *et al.*, 1996; Hunink *et al.*, 2013; Lal, 1985).

According to Bunyasi *et al.*, (2013), who examined the implications of construction of the Masinga dam in NWUT catchment, high input of sediments from Masinga reservoir resulted in the dam loosing design capacity of 215.26 m^3 which is approximately 13.6% of its storage capacity by 2011. These figures have increased over the years and there is a possibility that the capacity of the reservoir will be reduced considerably before 2050 (Bunyasi *et al*., 2013; Otieno and Maingi, 2000; Maingi, 2012; Mutua *et al*., 2005). This will mean that the benefits associated with the dam such as the provision of water, hydropower generation, flood control, recreation including also ecological and or environmental benefits will be affected (Bunyasi *et al*., 2013).

Several studies have been carried out on river discharge and sediment yield in theNorth-West Upper Tana catchment (Maingi and Marsh (2002), Mango *et al*., (2011), Dunne and Ogwenyi (1976), Ongwenyi (1978). However, these studies have not determined how key parameters such as rainfall variability and land use change overtime affects sediment yield and river discharge in the catchment. Studies by Maingi and Marsh (2002), quantified the hydrologic impacts following the construction of Masinga dam along the Tana River and Dunne and Ongweny (1976) came up with a new way of estimating the sedimentation along the Upper Tana catchment. Mango *et al*., (2011) used a calibrated model to explore the potential impacts of continued land use and future climate change in the Upper Tana catchment. Dunne 1979 carried a study in the southern part of Kenya and in his study he concluded that land use was the main factor that influenced sediment yield in the Upper Tana basin. Archer (1996) in his study on Nairobi area came up with a conclusion that the sediment rate in the reservoirs found in Nairobi area was high in areas with rainfall amounts ranging between 1000mm and 1600mm and runoff of between 350mm and 700mm. The NWUT catchment receives a maximum rainfall of 2700mm which makes the basin highly susceptible to soil erosion. Due to geographical differences, land use and economic differences, the conclusions of previous studies in the Upper Tana basin cannot be applied to the North-West Upper Tana catchment hence the need of this particular study.

1.3 Statement of the Problem

This study investigated the influence of rainfall variability and land use land cover change on sediment yield and stream flow in NWUT basin in Kenya. The main causes of stream flow variability are land use land cov er changes and rainfall variability. The influences of rainfall variability on stream flow are usually complicated by seasonal and inter-annual changes in land use and vegetation cover, (Hughes, (1990); Lal, (1985); Dunne, (1979); Hunink *et al*., (2013). As a result, the amount of sediment yield from NWUT catchment is highly variable (Maingi, 2012). High sediment input in Masinga reservoir has major direct or indirect implications. These include reduction of reservoirs storage capacity, reduced hydro-electric power production which is the reservoirs main function along the Tana River, the reduced control of downstream floods and reduced water supply to urban and rural areas (Oludhe, 2012). There is also possibility of increased eutrophication as a result of increased sediment-bound nutrient input that subsequently reduces the aesthetic value associated with the Masinga reservior (Mwaura, 2003). While the influence of land use and vegetation cover change has received a lot of attention in past studies in Upper Tana basin (Schneider, 2000; Ongwenyi, 1985; Jacobs *et al*., 2007; Jacobs *et al*., 2005), this is not the case with the influence of rainfall and river discharge variability. There is still lack of understanding on rainfall and land use land cover changes in the NWUT basin and how the changes affect water and sediment yield from the basin. In this regard, this study examined the influence of land use land cover change and rainfall variability on sediment yield and river discharge in details. This is important since these variables shows significant changes due to climate change whose future trends and implications on the Seven Folks reservoirs along the Tana basin have gained major attention in the recent past (Hunink *et al*., 2013). If the causes and impacts of rainfall variability and land use land cover change are not investigated in NWUT, the issues of siltation of the reservoirs along the Seven Folks will continue to be a major setback in terms of development in Kenya (Oludhe *et al*., 2013). There is a possibility that water development projects launched in the future will not be sustainable since the key hydrologic processes in the basin are not understood (Oludhe *et al*., 2013). The Tana River provides water resources to people living upstream and downstream and also it's an important ecosystems for a wide range of flora and fauna (Okello and Kiringe, 2004). If proper land use and land cover management practices are not adopted in the NWUT basin then the biodiversity will not thrive. Major socio-economic impacts such as increased expenses in health care, increased poverty, unemployment and conflicts over scarce water resources will be experienced if the resources deteriorates and not enough to cater for the rising demand in the study area (Terer *et al*., 2004).

There is lack of adequate information on how land use land cover change and rainfall variability impacts on sediment yield and stream flow in NWUT catchment. Therefore, to achieve a full sediment yield assessment, the examination of all the factors involved in the soil particle detachment and transportation is important and this study focuses on bridging this gap. This work compliments other studies on sediments yield in the Tana Basin (Kitheka *et al*., 2008; Dunne and Ongwenyi (1976), Maingi (1991), Maingi and Marsh (2002) etc), but provides more recent perspectives especially with regard to the influence of climate change and land use changes, which have not been adequately demonstrated in previous studies.

1.4 Main objective

The main objective of the study was to determine how stream flow and sediment yield are influenced by land use change and rainfall variability in the NWUT catchment in Central Kenya

1.5 Specific objectives

1. To establish the relationship between stream flow variability and sediment yield in NWUTcatchment in the period between 2010 and 2012
2. To determine the spatial temporal variability of stream flow and sediment yield in NWUTcatchment in the period between 2010 and 2012
3. To analyse land use land cover change and its impacts on stream flow and sediment yield in NWUT catchment in the period between 2000 and 2014
4. To evaluate the extent to which SWAT model can be used to predict stream flow and sediment yield in NWUTcatchment in the period between 1981 and 2012

1.6 Hypothesis

The following were hypothesesof the study;

Null hypothesis (H_0): There is no significant relationship between stream flow and rainfall in the NWUTbasin in the period between 2010 and 2012

Alternative hypothesis (H_1):

Null hypothesis (H_0): There is no significant relationship between sediment yield and rainfall in the NWUT basin in the period between 2010 and 2012

Alternative hypothesis (H_1):

Null hypothesis (H_0): There is no significant relationship between stream flow and sediment yield in the NWUTbasinin the period between 2010 and 2012

Alternative hypothesis (H_1):

Null hypothesis (H_0): There is no significant relationship between observed and simulated stream flow in the NWUTbasinin the period between 1981 and 2012

Alternative hypothesis (H_1):

Null hypothesis (H_0): There is no significant relationship between observed and simulated sediment yield in the NWUTbasin in the period between 1981 and 2012

Alternative hypothesis (H_1):

Null hypothesis (H_0): There is no significant LULC changes inNWUTbasin in the period between 2000, 2005 and 2014

Alternative hypothesis (H_1):

1.7 Justification of the Study

This study is justified on the basis of the following, most of the water draining into Kenya's largest river system, Tana, originates in mountainous regions of Central Kenya which experiences high rainfall variability and land use change. The NWUT basin provides most of the water that flows into Tana river and which is critical in sustaining various water uses associated with the Tana river basin. As a result, these regions are highly populated due to high potential in agriculture which greatly alters the land use practices in the region. The Vision 2030 Kenya (GoK, 2013) pillars, environment, water sanitation under the socio pillar advocates for protection and rehabilitation of water towers in Kenya to ensure sustainability in water resources in the future.

The National Water Master Plan (NWMP) (GoK, 2014) and Vision 2030 has put the objective of assessing and evaluating the quality and vulnerability of the Country's water resources up to year 2050. The Tana River serves a bigger population and is one of the most important water resources in Kenya and hence is prioritized. According to GoK (2013), it is expected by the year 2030 that all the catchments in Kenya will be experiencing water deficit due to the rise in demand and hence the need for robust management and planning for water resources. The NWMP (GoK, 2014) recognizes the change on land use practices in most of the water towers which has resulted in altered hydrology and morphology of water resources.

Previous studies (Bunyasi *et al*., 2013; Schneider, 2000; Jacobs *et al*., 2004; Oludhe *et al*., 2013; Kitheka *et al*., 2005; Otieno and Maingi 2000; Hunink *et al*., 2012; Hunink *et al*., 2013; Batjes, 2014) have not adequately addressed the influence of variability of rainfall and issues related to land use land cover change and the impacts on sediment yield and stream flow in the Upper Tana basin. There is a need to establish the extent of the relationships in which these variables influence sediment yields not forgetting the scaled influence of climate change to these variables. Understanding the linkages willallow the prediction of future trends including the designing of appropriate intervention measures (Begueria *et al*., 2003; Walling, 1999). The uncertainty in spatial temporal distribution in rainfall has resulted in variations in water availability (Marshall, 2011).

Most of the previous studies in the Upper Tana basin have concentrated on the relationship between land-use and sediment yield (Dunne, 1979; Hunink *et al*., 2013; Brown *et al*., 1996; Ongwenyi, 1985; Kitheka *et al*., 2005). The influence of land use change and rainfall variability on sediment yield and river discharge has not been conclusively established in most of the previous studies. There was no adequate information on the influence of land use change and rainfall variability on sediment yield and river discharge in NWUT basin. Hence, this study provides data and information that can be used for sustainable land and water management to enable the catchment meet the expected water needs (Ongwenyi, 1978). The information can also inform future processes of choosing sites for constructing dams in the catchment and other water supply projects with the same tropical climatic and geographic characteristics. Findings of this study will be valuable to major stakeholders in the NWUT basin particularly those requiring data and information for formulation of policies on sustainable water and land management.This study also contributes to the debate on the influence of land use change on river discharge and sediment yield in tropical river basins.

1.8 Scope of the study

The study examined the influence of rainfall variability and LULCC on stream flow and sediment yield in NWUT basin. Data for stream flow, TTSC and sediment yield was obtained from Water Resources Authority (WRA) Embu Regional Offices. Rainfall data was obtained from Kenya Meteorological Department (KMD) for the period of 1980-2012. LULC changes were obtained from satellite images for 2000, 2005 and 2014 and analysed using Erdas Imagine Version 2018. This study examined the relationship between stream flow and sediment yield by applying r and R2. The spatial temporal variability in sediment yield and TSSC was analysed with time-series for the year 2010 to 2012. The SWAT Model was adopted for this study for the relationship between observed and simulated stream flow and sediment yield in the basin. Future projections in rainfall, stream flow and sediment yield were done upto year 2030 for this basin. This study also puts forward recommendations on soil and water conservation in the basin.

CHAPTER TWO:

LITERATURE REVIEW

2.1 Introduction

The sediment yield in river basins has been a subject of many studies done at global, regional and national level. In this study, review of past studies was carried out to establish gaps on methodologies, findings and recommendations.

2.2 Studies Done at Global Level

2.2.1 Factors Influencing Sediment and Water Yield

The actual evapotranspiration represents an important feature and it is recognized as the main hydrologic loss (50-60 % of mean annual rainfall) (Walling and Fang, 2003). In the semi-arid areas for instance, they experience a spatial temporal climatic variability due to the high variability of rainfall patterns including the influence of topography and the spatial distribution of geology, soil and land-use. Sediment yields in most of the environments can be related to the interaction between erosive energy and vegetation density even if climatic seasonality, relief, basin lithology and the extent of human activity combine to influence the global pattern of erosion processes (Gentile *et al*, 2010). Several factors that influence Sediment Delivery Ratio (S_{DR}) include hydrological inputs (mainly rainfall), landscape properties (such as: vegetation, topography, and soil properties) and their complex interaction at the land surface (Jain, 2000). The components of the hydrological cycle are the main drivers and dynamics playing part in climate change and its effects on surface runoff, precipitation and evapotranspiration (Kundzewicz *et al*., 2008). There is duration variance in the rainfall in different years. By the year 2100, there will be an increase in temperature of between 1.4 ^{0}C and 5.8 ^{0}C which greatly affect rainfall variability and intensities (Pachauri and Meyer, 2014). Therefore, a rise in evaporation rates is expected which will affect the global water availability (Yilmaz, 2015). Batjes *et al*., (2008) conducted a study on climate change and water and found out that rainfall is greatly influenced by prevailing climatic patterns.

2.2.2 Relationship between Stream Flow and Sediment Yield

Stream channel erosion results from concentrated water which forms from rills and gullies, and contains sediment removal from streambed and stream banks (Foster and Meyer, 1977).Bank erosion in stream channels can lead to the formation of channel meandering which results in excessive erosion and deposition within the floodplain (Darby *et al*., 2002). It should be noted, if the amount of detached soil is more than the transport capacity, only the transportable amount will be carried downslope and the rest will be deposited on the segment (Foster and Meyer, 1977). Estimation of the sediment transport by assessment of river discharge during the events is necessary for the computation of long-term sediment yields from river basins, as one single event may represent the transport of several ‘normal’ years (Wolman and Gerson, 1978). The relationship between rainfall, runoff and soil loss are of complex in nature. Since runoff is the carrier of sediment particles, its seasonality and peak value affects the high sediment load in rivers (Shen *et al.,* 2003). Maximum sediment yield occurs at an annual rainfall of approximately 300 mm. When the precipitation exceeds 300 mm, increased vegetation growth protects the surface (Shen *et al*., 2003). Global Climate Model (GCM) in Apalachiola basin showed that peak stream flow in the basin results in peak sediment yield especially in rainy seasons (Hovenga, 2015).

2.2.3 Spatial Temporal Variation in Sediment Yield

Globally, reservoirs lose approximately 1% of the storage volume annually due to sedimentation (Mkhonta, 2016). River discharge from a catchment provides the means of conveyance of detached and delivered particles and may be limiting especially in semi-arid areas (Ludwig *et al*., 2005). These factors show complex interactions such that the weight which attaches to a factor in one area may not apply in another (Ludwig *et al*., 2005).Sediment yield from catchments are often about an order of magnitude lower than the soil erosion rates measured from hill-slope plots (Ludwig *et al*., (2005); Bisantino *et al*., (2011); Chanson *et al*., (2011); Campbell *et al*., (2005). This signifies that most of the sediments travel only a short distance and are deposited (Parsons and Stormberg, 1998).

Sediment yield is directly related to the Sediment Delivery Ratio (S_{DR}). Sediment Delivery Ratio (S_{DR}) can be defined as the ratio of the sediment yield at a given stream cross-section to the gross erosion from the watershed upstream of the measuring point (Julien, 2010). This is a dimensionless scalar and conventionally expressed as:

$S_{DR} = \frac{Y}{A_T}$……………………………………………………………..……. Equation 1

Where:

Y is average annual sediment yield per unit area

A_T is average annual erosion over that same area (Julien, 2010). Observations show that only a small fraction of the eroded sediment within a drainage basin will find its way to the basin outlet and it is represented as the sediment yield.

The equation is statistically derived from the regional data to transfer the results of gauged to ungauged basins in the same region (Julien, 2018). A widely used method to estimate S_{DR} is through the empirical S_{DR}-area power equation given below:

$S_{DR} = \alpha A^{\beta}$………………………………………………………………………. Equation 2

Where:

A is the catchment area (in km^2), αand β are empirical parameters.

The S_{DR} has the problem of temporal and spatial lumping and lack of physical bases (Julien, 2010). It did not take into account the local factors affecting the sediment delivery such as rainfall, topography, vegetation, and soil characteristics. Paute basin in Ecuador, there is improved land cover which has resulted in low sediment yield from the basin of 26 to 15,100 mg/km^2/year with lithology being the main contributor to sediment yield (Molina *et al*., 2008). Belgium on the other hand experiences high sediment yields ranging from 0.4 to 20.6 tons/ha/year (Verstraeten and Poesen, 2001).

2.2.4 Land Use Land Cover Changes and its Impacts on Stream Flow and Sediment Yield

The variability in land use have significant effect on sediment yield and erosion but emphasizes on disintegration of these factors and analysis of them as stand alones which is the goal of this study (Walling, 1999). Sediment yield increase with increase in human population and especially along river banks (Syvitski *et al*., (2005). An increase of 1-3% of carbon and 1.4 billion ton/year of sediments has been recorded in the past in man-made dams. Sediment production rates from various basins around the world ranges between 43-210 tons/km^2/year. However, some of the basins with altered land use land cover experiences figures above 10,000 tons/km^2/year (Gade and Raju (2000); Lal, (1985). Dali basin in China is ranked among the highest in terms of sediment production rates in the world with a sediment production rate of 25,600 tons/km^2/year and a surface area of 96.1 km^2 (Gade and Raju, 2000). Evaluation of Land Use and Land Cover changes and its impacts on stream flow and sediment yield in Peru significant loss in sediment yield of approximately 50% between 1988 and 2007 (Inca and Carlos, 2009). Sediment yield of 1,260.37 tons/km^2/year, 1201.48 tons/km^2/year and 1227.61 tons/km^2/year were established in 1988, 1997 and 2007 respectively (Inca and Carlos, 2009). Major influence on sediment yield and stream flow was established in high and mid-latitudes of the basin (Inca and Carlos, 2009). SWAT model simulation on Land Use Land Cover (LULC) shows that the impacts of climate change will highly be felt on Land Use Land Cover practices which will lead to serious impacts on stream flow and sediment yield in Apalachiola basin in Florida (Hovenga, 2015): Davis, (1996).

2.2.5 Modeling of Stream Flow and Sediment Yield

In the recent past, there have been a number of studies focusing on modeling of sediment yieldand river discharge (Batjes, 2014).In order to estimate soil erosion and the resultant sediment yield at any part on the earth surface, predictive tools are usually applied. Soil erosion models have been applied before to fulfill this function. The Universal Soil Loss Equation (USLE) is one of the major developments in soil and water conservation in the 20th century (Arnold *et al*., 2001). Prediction of yields through prior estimation of local erosion rates can be done using the Universal Soil Loss Equations (Wischmeier and Smith, 1965). The use of this equation outside its area of derivation would suffer from inadequate local information on delivery ratios (Walling, 1983). This empirical model has been applied around the world to estimate soil erosion by raindrop impact and surface runoff. USLE model is the result of decades of soil erosion experimentation conducted by university faculties and federal scientists across the U.S. It was initially proposed based on the concept of detachment and transportation of particles from rainfall in order to calculate soil erosion rates in agriculture areas (Wischmeier and Smith, 1965). The model was developed based on the data obtained from more than 10,000 test plot throughout U.S. in 20 years. The test plots were designed to accurately estimate soil erosion under different conditions (Wischmeier and Smith, 1978).

In 1997, the U.S. Department of Agriculture (USDA) developed a new model to predict long term, average annual soil loss erosion by water for a broader range of farming, conservation, mining, construction, and forestry. The Revised Universal Soil Loss Equation (RUSLE) is the upgraded version of USLE which incorporates improvements in factors based on new data but keeps the basis of USLE equation (Renard *et al*., 1997). The improvements were based on the revisions of USLE factors including development of a new procedure to calculate vegetation factor, introducing new algorithms to reflect rill to inter-rill erosion in slope length and steepness factors, and revision of climatic factors based on expanded database of rainfall-runoff. Application of Geographical Information System (GIS) in water management in Middle East showed high level of applicability in water resources management due to its ability in digital image classification (Isaac and Owewi, 2001). Gorganroud basin in Iran showed the potential increase in stream flow and sediment yield in future under scenario of climate change. The rate of sediment production will be high compared to water yield if proper soil and water conservation measures are not adopted. However, there is potential to reduce sediment yield by 7.2 % if proper soil and water conservation measures are implemented (Azari *et al*., 2017). Application of SWAT Model in Apalachiola basin showed that coupling of climate change and Land Use Land Cover changes results in major effects on stream flow and sediment yield (Hovenga, 2015). Different spatial resolution have relative effect on the out of SWAT model simulation on stream flow and sediment yield in a basin (El-Sadek and Irvem, (2014); Mosbahi *et al*., (2013).

2.3 Studies Done at Regional Level (Africa)

2.3.1 Factors Influencing Sediment and Water Yield

Variability in climatic factors, Land Use Land Cover changes, effects of climate change, physical characteristics of the basin like topography, soils and geology and anthropogenic activities are the main factors influencing sediment yield and stream flow in Africa (Walling, 1999). The effects of climate change exacerbates the water yield and sediment production rates from tropical river basins which are mainly found in Africa (Munthali *et al*., 2011). All the factors that are involved in production and transport of runoff and sediment yield govern the water yield and sediment yield of a basin (De vente and Poesen, 2005). Groundwater recharge is a key component that influences stream flow and sediment yield of a basin especially during the dry season. Water losses experienced in a catchment is mainly due to evaporation that results to over 60% water loss from the basin (Setegn *et al*., 2010). Tekeze basin in Northern Ethiopia is dominated by Eutric Cambisols soils which are highly vulnerable to erosion. This has resulted in sedimentation of Tekeze dam reducing the life span of the dam significantly (Ashagre, (2009); (Welde, (2016).

2.3.2 Relationship between Stream Flow and Sediment Yield

There is a positive relationship between stream flow and sediment yield in Africa. An increase in stream flow results to an increase in sediment yield in most tropical basins (Walling, 2017). The positive relationship between stream flow and sediment yield is mainly noticed during the rainy seasons (Picouet *et al*., (2001); (Setegn *et al*., 2010). A coefficient of determination (R^2) on the relationship between stream flow and sediment yield of above 0.5 in Ethiopia (Setegn *et al*., 2010).

2.3.3 Spatial Temporal Variation in Sediment Yield

Spatial temporal variation in sediment yield in Africa is greatly influenced by land use land cover practices, which is evident in Algeria, Morocco and Kenya (Walling, 1999). More than 75% of the continent has a sediment yield production rates well above 100 tons/km^2/year. The Total Suspended Sediment Concentration (TSSC) is a good indicator of sediment yield in a given basin. Sediment load in Africa is approximately 201 *10^6 tons/year (Walling, 1999). The spatial temporal variation in sediment yield is greatly influenced by climate change. Increase in rainfall in Sudan has not reduced the drought occurrence during the dry season, which the wet season is characterized by peak flows (Descroix *et al*., 2009). The spatial temporal variation in sediment yield in Southern Ghana ranging from 11 to 50 tons/km2/year with the annual production rates from the basin ranges from 15,000 to 1.2 *10^6 tons/year (Walling, (2017); Lal, (2001). There are two sources of sediments in tropical basin, those from the mountainous and land surrounding the basin and those that are generated by the river channel. The mountainous sediments are mainly influenced by rainfall and are only deposited into the channel in the rainy season while those generated by the river channel are present through the season (Picouet *et al*., 2001). Small steep catchments with considerable forest cover show low production rates in sediment yield compared to catchments with agricultural practices and bare lands that facilitate the detachment of sediments (Hecky *et al*., 2003). Sedimentation is major problem to most reservoirs in Africa which results in reduction of storage capacity (Borji, 2013). This problem has gained the attention of key researchers in Africa, most have tried to quantify the long term data on sediment yield, water yield and Total Suspended Sediment Yield (TSSC) to come up with solutions (Borji, 2013). The Grand Ethiopian Renaissance Dam (GERD) traps 245 million tons/year of sediments with 100% trap efficiency. This has greatly reduced the storage capacity of the dam and hence its ability to meet various water uses (Borji, 2013). In Africa, 19% of storage volume is lost to sedimentation in most reservoirs (Mkhonta, 2016). The Luborane reservoir in Swaziland had lost 1.36% of its storage capacity by 2016. During the design, the reservoir had a life span of 100 years which had reduced to 81 years due to sedimentation. The sediment yield in 2015 from the surrounding basin was 8.99 tons/ha/year and hence the need to adopt and implement soil and water conservation in the basin (Mkhonta, 2016).

2.3.4 Land Use-Land Cover Changes and its Impacts on Stream Flow and Sediment Yield

Land Use-Land Cover change and soils in West-Africa have major influence in sediment yield especially in Sahelian regions (Descroix *et al*., 2009). The effects of Land Use-Land Cover changes on stream flow and sediment yield are significant in Africa. Improved land use practices in South Africa resulted in reduced sediment yield production and increased water yield to cater for the rising demand (Hecky *et al*., 2003; Ncube and Taigbenu, 2007). There is increased stream flow generation and sediment yield by 16% due alteration of land use land cover in South Africa (Cape Town). Stream flow and sediment yield from a basin is greatly influenced by presence and type of vegetation over and soil structure (Scott, 1993). Basins with intensified agriculture greatly influence stream flow and sediment yield in tropical regions due altered soil structure (Hecky *et al*., 2003). Agriculture is the main contributor to sediment yield and increased runoff in many basins followed by stream bank and river bed erosion (Garde and Raju, 2000).

2.3.5 Modeling of Stream Flow and Sediment Yield

Pan-European Soil Erosion Risk Assessment (PERESA) Model was applied in Songwe basin in Malawi to assess the sediment yield from this basin. Sediment yield from Songwe basin is high and influenced by human activities by settlement and clearing of forest cover for agriculture production. The encroachment of head waters have resulted in peak flows in wet seasons upstream and flooding downstream. This has resulted in poor sustainability of reservoirs due to sedimentation (Munthali *et al*., 2011). SWAT Model was applied in West-Africa in simulation of stream flow and sediment yield and demonstrated good performance (Schuol and Abbaspour, 2007). The assessment of SWAT Model application in simulation of stream flow and sediment yield in mountainous basins was done in Uganda, the model showed good performance in the simulation of stream flow and sediment yield in tropical basins (Griensven *et al*., 2012). SWAT Model showed good performance in stream flow and sediment yield simulation in South Africa having NSE of 0.83 and hence the applicability of the model in other tropical catchments (Viviroli *et al*., 2011). SWAT model shows good performance in the simulation of stream flow and sediment yield in Tekeze basin in Northern Ethiopia. The maximum water yield and sediment yield of 137.74 m^3/s and 15.17 tons/ha/year were recorded respectively. Agriculture and bare lands are the most vulnerable land use to erosion recording the highest values in sediment yield in Northern Ethiopia (Ashagre, (2009); Welde, (2016); Tessema *et al*., (2015).

2.4 Studies Done at National Level (Kenya)

2.4.1 Factors Influencing Sediment and Water Yield

Climate change and rainfall are the main factors influencing stream flow and sediment yield in Kenya. These factors are further exacerbated by changes in land use and land cover in basins (Mango *et al*., 2011).

2.4.2 Relationship between Stream Flow and Sediment Yield

Stream flow is highly related to sediment yield in Kenya. An increase in stream flow in river increases the carrying capacity of sediments (Mango *et al*., (2011) ; Baker and Miller, 2013). Sediment Derivery Ratio (SDR) of 0.83 was obtained in Perkerra basin (Onyando *et al*., (2005); Mango *et al*., (2011). High water yiels from Perkerra basinhas resulted in high sediemnt yield which has resulted in siltation of Lake Baringo. The Lake had lost a depth of 6.5m in 2003 which calls for proper soil ans conservation measures to deal with this severe situation (Onyando *et al*., (2005); Mango *et al*., 2011).

2.4.3 Spatial Temporal Variation in Sediment Yield

In his study, Archer (1996) assessed the sedimentation rates of the potential reservoirs in the Upper Tana and Athi river basins. It was noted from this study that the zone of highest sediment yield occurred where annual rainfall ranged from 1000 to 1600 mm and runoff between 350 and 700 mm. It was also noticed from Archer (1996) that at higher elevations with higher rainfall, sediment yield is of an order of magnitude lower, both in the indigenous forest and in the zones of smallholder cultivations, where soils have high structural permeability and generate little surface runoff. On the lower dry plateau, mean sediment concentration is high but sediment yields are comparatively low since annual river discharge is limiting.Thus prediction of sediment yields using multivariate equations relating sediment yield to climatic and catchment characteristics may give misleading estimates when applied outside their area of derivation (Joseph, 2016; Archer 1996). Some of the major basins in Kenya like Perkerra basin experiences highest sediment yield production rates of 19,520 tons/km^2/year with a surface area of 1,310 km^2 (Garde and Raju, 2000).

2.4.4 Land Use-Land Cover Changes and its Impacts on Stream Flow and Sediment Yield

In a previous study over a broader area of southern Kenya on sediment yields, it is concluded that land use was the dominant control, although the influence of runoff, river discharge and topography could also be recognized (Dunne, 1979). Equations to determine yield for four land use categories: (a) forested; (b) forest > 50%; remainder cultivated; (c) agricultural land > 50%, remainder forested; (d) rangeland (Dunne, 1979). Sediment yield from the agricultural land and grazed land was significantly greater than from partially or completely forested basins. However, there was great variability within each land use type and especially in cultivated catchments (Dunne, 1979). Altered Land Use Land Cover changes in Kenya headwaters have resulted in peak water flows and high sediment yield in the basins during the wet seasons (Defersha and Malesse, (2012); Baldyga *et al*., 2004). Modelling of Land Use Land Cover Changes (LULCC) and the effects on stream flow and sediment yield in Njoro River basin showed that LULCC have major implications on stream flow and sediment yield (Baker and Miller, 2013). There is need to promote sustainable soil and water conservation measures in Kenya (Mango *et al*., 2011). The adoption of soil and water conservation measures (contouring) in Sasumua basin resulted in reduction of sediment yield from 32,620 tons/year to 16,600 tons/year which is approximately 49% decrease. Water yield was reduced by 16% and base flow was increased by 7.5% (Mwangi, 2013). Adoption of permanent vegetative strips reduced sediment yield from 32, 620 tons/year to 8,720 tons/year while bench terracing reduced sediment yield to 4,730 tons/year. The reduction in sediment yield of 41% resulted in increased ground water recharge of 23.5% (Mwangi, 2013). Agricultural land and bare lands are the most vulnerable to erosion having 53.6% sediment load production, 44% water yield and reduced groundwater recharge of 10%. The most effective soil and water conservation measure is terracing in tropical basins (Mwangi, 2013).

2.4.5 Modeling of Stream Flow and Sediment Yield

Several studies have applied SWAT Model in the simulation of stream flow and sediment yield in Kenya (Jayakrishnan *et al*., (2005); Baldyga *et al*., (2003); Baker and Miller (2013); Mango *et al*., (2011). SWAT Model showed good performance in the depiction on spatial temporal variation in stream flow and sediment yield in Njoro river basin (Baldyga *et al*., 2003). SWAT Model have been used in water resources research and decision making and has shown remarkable performance in prediction of future rainfall (Jayakrishnan *et al*., 2005). The positive relationship between rainfall and stream flow is greatly influenced by climate change. If some of the factors were to be held constant like land use land cover changes and population growth, there is a projected increase in stream flow and rainfall in Western Kenya (Githui *et al*., 2009).

2.5 Studies Done in the Upper Tana Basin

The Upper Tana Basin is located in Central part of Kenya with Mt. Kenya and Abadare ranges forming the major water towers for the region. This basin is an important water resource in Kenya since the seven folks are constructed along the Tana River. Together these reservoir generate hydro-electric power which supplement other sources of power in Kenya. Flood control, recreation, water supply are among other primary roles of the reservoirs.

2.5.1 Factors Influencing Sediment and Water Yield

Climatic factors affecting sediment yield are temperature, humidity, solar radiation, wind and rainfall (Hunink *et al*., 2013; Dunne, 1979). Climate is characterized by extreme variability in rainfall and is subject to droughts and infrequent rainfall periods and subsequent flooding (Easterling *et al*., 2000).Precipitation is believed to be the fundamental factor that initiates the sediment transport from the source points (Muchena and Onduru, 2011). The amount of rainfall is associated with the amount sediments that can be transported by the resulting runoff (Dunne, 1979).Rates of sediment removal from a drainage basin depend on those factors which promote or inhibit the detachment of particles (land-use) and their transport (river discharge) to and within the river channel (Jacobs *et al*., 2007; Njogu and Kitheka, 2017). These factors are not limited to the following; rainfall amount and intensity, slope steepness, a range of many soil properties which influence infiltration capacity and resistance to particle detachment, vegetation and land use, and runoff.Water resources of the NWUTcatchment provided water for rain-fed agriculture and irrigation, which accounts for a large percentage in the total water demand according to the studies done (Hoff and Noel, 2007).

2.5.2 Relationship between Stream Flow and Sediment Yield

Sediment transport in water courses is an indicator of soil eroded from agricultural land, and the intensity of the phenomenon provides a measure of land degradation and the associated reduction in the global soil resource (Hunink *et al*., 2013). Sediment load is a useful parameter which has been applied in several studies as an indicator for assessing the effects of land-use changes and engineering practices in watercourses (Hunink *et al*., 2013; Batjes, 2014). The measurement of sediment yield is an integral part of studies designed to manage water resources (Kitheka *et al*., 2005; Hunink *et al*., 2012). There have been a number of advances associated with techniques for measuring sediment after Hadley (1985). Photoelectric turbidity meters, ultrasonic and nuclear sediment gauges, automatic particle size analyzer, etc. are the latest advances.Regulation of flow as result of the NWUTcatchment reservoirs constructed along is very minimal (Kitheka *et al*., (2005). This was explained by the small size of the reservoirs and the adequacy in the release of water downstream of the river. The origin of the sediments in the channel being connected to poor land use practices (Kitheka *et al*., 2005); Schneider, (2000); Otieno and Maingi, (2000) and Maingi and Marsh (2002).

2.5.3 Spatial Temporal Variation in Sediment Yield

Most of the prior studies of the Tana Rivers system, and in particular the NWUT catchment above the Masinga Dam, have focused on the potential erodibility of soils (Schneider, (1993). Some investigatory studies attempted to explain several impacts of the increased sediment yield in other catchment areas in Kenya (Archer, 1996).The analysis of the impacts of sedimentation of Masinga reservoir and its implication on the dam’s hydropower generation capacity showed that Masinga dam had lost about 215.26 m^3 (13.59 %) of its design storage capacity due to sedimentation by 2011 (Bunyasi *et al*., 2013).The average annual sediment yield for the Upper Tana catchment generally decreased with added forest cover by the year 2000 (Jacobs *et al*., (2000).The amount of sediment increased with total sediment load of $8*10^6$ ton/yr and $2*10^6$ ton/yr in 1993 and 2004 respectively (Ongwenyi, (1983). This background generally shows a significant impact of the sedimentation on various economic activities and reservoir management in the catchment areas. In general, the previous studies have dealt with a wide range of factors that determine the final estimation of the sediment yield (Kitheka *et al*., 2005; Hunink *et al*., 2013; Hunink *et al*., 2012); Kitheka, (2013); Maingi, (1991).The damming of the Tana River has resulted to reduced sediment load compared to the case when the channel had not been dammed (Kitheka *et al*., 2005). This is result of trapping of the sediments by the reservoirs in the North West Upper Tana catchment (Kitheka *et al*., 2005).

2.5.4 Land Use Land Cover Changes and its Impacts on Stream Flow and Sediment Yield

There is an increasing demand for irrigation water on the slopes of Mount Kenya, particularly to support horticulture production (Droogers *et al*., 2006). Water usage in the upstream areas affects water availability in the lower drier areas, where a big portion of water is used for hydro-electric power generation by KenGen, and some is used for irrigation and livestock (Mogaka *et al*., 2006).The seven folks along the North West Upper Tana catchment produces more than half of the power supply in the country Kenya (Droogers *et al*., (2006). Effects of LULCC on stream flow and sediment yield have been experienced in Thika river sub-basin where 36% forest cover have been converted to agriculture and settlement. Horticulture and settlement have taken 32% and 141% forest land respectively (Kigira, 2016). SWAT model simulations shows that increased forest cover will reduce sediment yield and moderate stream flow in the sub-basin which can be by adoption of climate smart agriculture and reforestation (Kigira, 2016); Tamooh *et al*., (2014).

2.5.5 Modeling of Stream Flow and Sediment Yield

SWAT Model have been applied in Upper Tana by various researchers in the examination of various parameters in the basin (Batjes, (2014); Kauffman *et al*., (2014); Jacobs *et al*., (2007); Hunink *et al*., (2014); Hunink *et al*., (2012). Water Evaluation and Planning Tool (WEAP) have also been used in the basin (Hoff and Noel, (2007); Droogers *et al*., (2006); Kiptum, (2017). Sustainable management of water resources especially at head water by proper land use practices results to low sediment yield production and improved groundwater resources in Upper Tana basin (Hunink *et al*., 2012). Application of Green Water Credits (GWC) in the Upper Tana have resulted to promotion of Carbon (iv) oxide sequestration. Anthropogenic activities like overgrazing, lumbering and intense agriculture have completely altered the hydrological balance in the area (Batjes, (2014). The integration of WEAP Model and Green Water Credits (GWC) In Upper Tana to estimate the cost of proper land use practices to promote the sustainable land and water management showed that farmers play key role in these activities (Droogers *et al*., (2007); Hoff *et al*., (2007). The examination of reforestation scenarios in Upper Tana was conducted and results showed that proper tree species and land use especially in the head waters is important (Jacobs *et al*., (2007). The integration of climate change simulation and hydrological characteristics of Thika River basin showed that temperature will rise in 2050-2100 resulting to increased stream flow during the same period (Kiptum, 2017).

2.6 Conclusions and Research Gaps

Whereas there has been a lot of work done on sediment yield and stream flow in other parts of the world, this is not applicable to Kenya and in particular the NWUT catchment. Few studies in Kenya have addressed the issue of variability in rainfall, sediment yield and factors accompanying and influencing the detachment and transport processes, stream flow, spatial characters and land use change and the influence they have on sediment yield and stream flow at catchment level. Rainfall, river discharge and land use change are important factors that need to be considered in a study of sediment yield in a river basin to come up with decisive conclusions about factors affecting sediment yield in typical tropical river basins.

Previous studies have focused on single factors to address the issue of sediment yield which is not enough to form conclusions on sediment yield and stream flow. This study aims to bridge the gap by integrating all the key parameters that influence sediment yield that include variability in rainfall, river discharge, land use change and other important spatial characters like population, vegetation, land cover, soils, geology and slope in the study area. This study will apply the SWAT Model which incorporates all this factors and climatic variables to predict sediment yield and stream flow in a given catchment. This study therefore will provide sediment yield and stream flow simulated data which can be used to examine further issues related to sediment yield in the basin.This study focussed on the influence of land-use change and rainfall variability on sediment yield and river discharge in the NWUTcatchment to add knowledge in the best land management practices and reservoir management based on assessment of rainfall, land-use and other spatial characters and their effect on river discharge and sediment yield.

2.6 The Conceptual Framework of the Study

The study adopted the following conceptual framework of the study. The causes and effects of Land Use Land Cover changes, rainfall variability and their influence on stream flow and sediment yield in NWUT basin were identified. The associated inpacts both environmental and socio-economic were idenfied and outlined in figure 2.1 for this study. The overall goal is to achieve Integrated Water Resources Management in NWUT basin as outlined in figure 2.1.

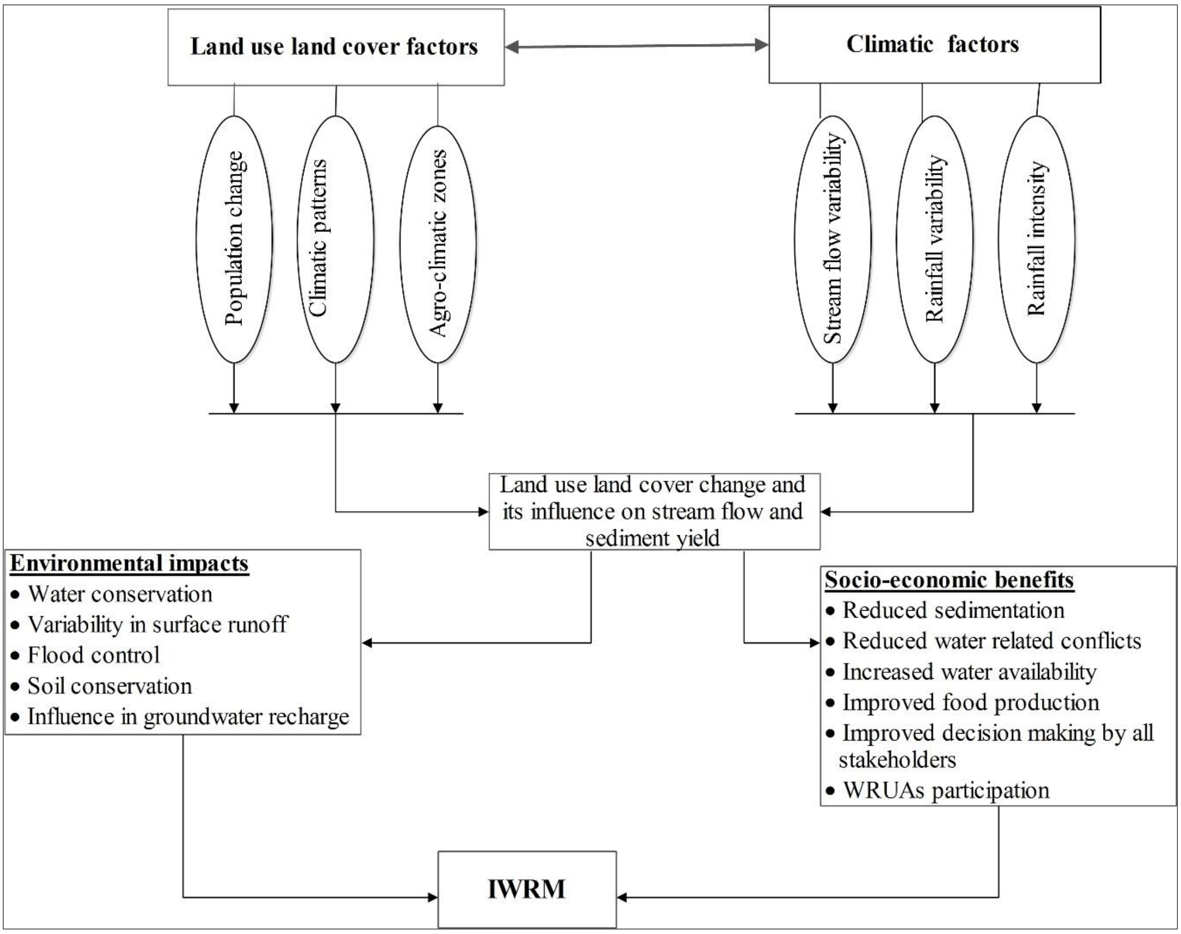

Figure 2. 1: The Conceptual framework of the study (Njogu, 2018)

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1 Introduction

NWUT basin is located in the central part of Kenya (Figure 3.1). The basin is part of the larger Tana River Basin that has its headwaters on Mt. Kenya and Abadare regions. The basin has diverse climatic and hydrological characteristics and also various land-use and socio-economic features that are described in this chapter. The chapter therefore presents a description of the basin including the underlying geographic characteristics.

3.2 The Location of the Study Area

The study area is located between longitudes $36^{0}30'0''$ E and $37^{0}40'0''$ E and latitudes $1^{0}10'0''$ S and $0^{0}10'0''$S (Figure 3.1). The basin covers a surface area of approximately 9,918.42 km^2 with elevation ranging from 3,844m to 881min the Mt. Kenya region and lower regions, respectively (KNBS, 2009).

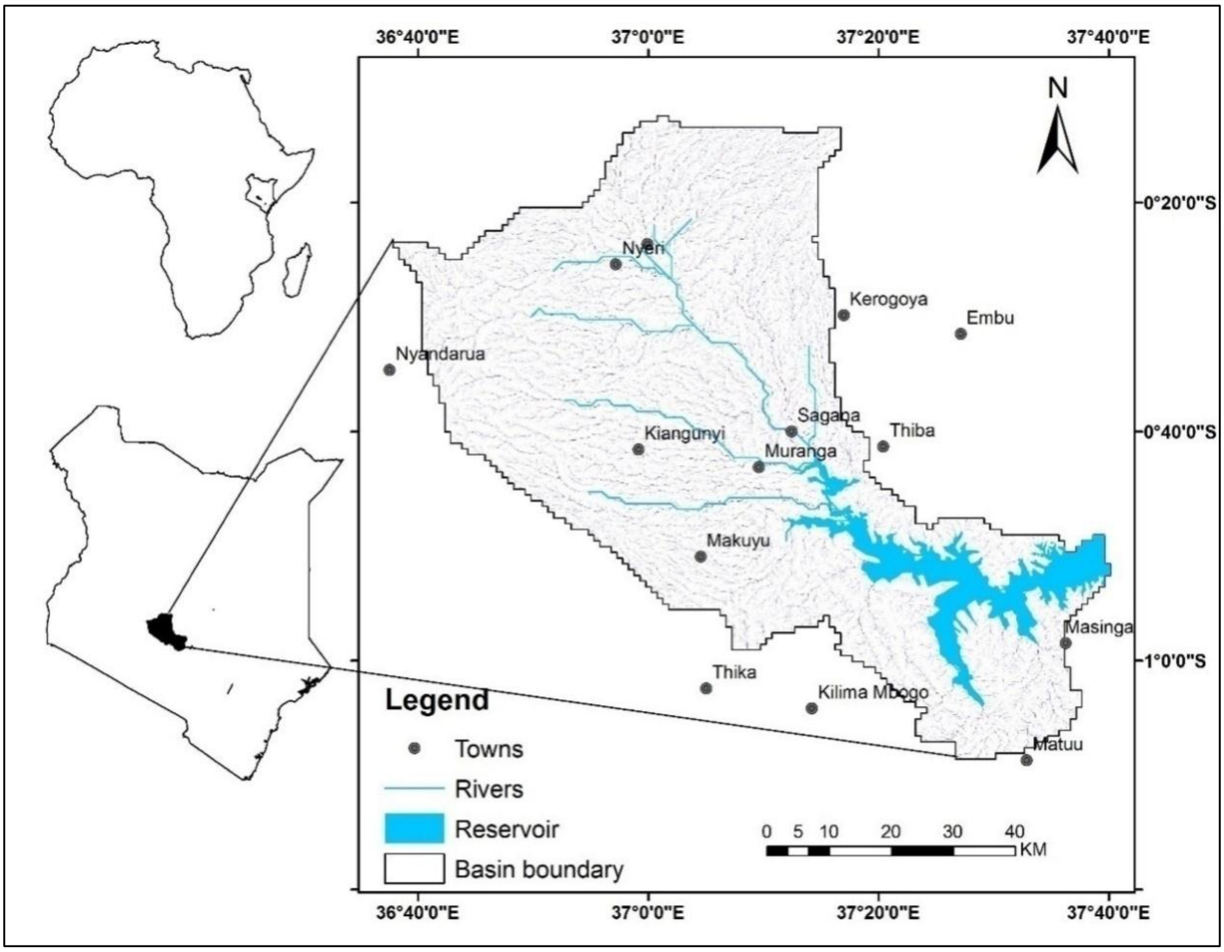

Figure 3. 1: The location of North-West Upper Tana basin in Kenya (Njogu, 2018)

The main rivers in the catchment include the Sagana, Tana Sagana, Mathioya, Maragua and Saba Saba (Jacobs *et al*., 2007). There also exist several protected areas in the study area such as Mount Kenya National Park and the Abardares National Park.

NWUT catchment is the source of water used by KenGen Company to generate electricity in the seven folks HEP dams. Five major HEP dams that have been built in the lower reaches of the basin are Masinga, Kamburu, Kindaruma, Gitaru, and Kiambere. Together, these reservoirs provide approximately three quarters of electricity in Kenya and regulate the flow of the river (Bunyasi *et al*., 2013). The study area covers Nyeri, Murang'a and Kiambu Counties of Kenya. The main contributing water towers are the Abadare ranges and Mt. Kenya which together form the headwaters to majority of the rivers in this region.

3.3 Climatic Conditions

NWUT basin experiences bimodal rainfall regime due to the inter-tropical convergence zone (ITCZ). The long rain season is from March to June, the short rain season is from September to December (Kiptum, 2017). There is a great variation in the rainfall patterns in the NWUT basin (Jacobs *et al*., 2004). The average annual rainfall ranges between 400mm and 2300mm in the windward side south of Mount Kenya and drops to 800mm in the summit region (Notter *et al*., 2007). In North-West part of the catchment, rainfall increases with increase in altitude with dry seasons being well defined in the Southern and Eastern part of the basin (Kiptum, 2017). Light showers are experienced in July and October in parts of Murang'a and Nyeri despite the bimodal regime due to the influence of Mt. Kenya and Abadare ranges (Kitheka *et al*., 2005). It is evident that NWUT Catchment experiences variations in potential evapo-transpiration with regions around Mt. Kenya and Abadare ranges having 1200mm per year and the lower reaches experiencing as high as 2300mm per year (Notter *et al*., 2007). Temperatures in the mountainous regions range from 14^0C and 18^0C while the lower regions of the basin records considerably higher temperatures ranging between 26^0C and 30^0C (Jacobs *et al*., 2004). In most part of the basin, July and August are the coldest months while March and October are the hottest months. In the entire NWUT basin, the average annual relative humidity ranges from between 70% and 45% in morning and afternoon respectively (Kitheka *et al.*, 2005).

3.4 Hydrology and Drainage

The hydrology and drainage of the NWUT basin is greatly influenced by climatic patterns associated with the basin. Rainfall variability and temperature differences are the main determiners of the prevailing drainage and hydrology at a given time. According to Jacobs *et al*., (2007), Tana River basin is the largest and most important basin in Kenya. Its catchment has a surface area of 95,950 km^{2}which is equivalent to 17% of Kenya's land mass, and the flow of the Tana River basin constitute 27% of the total mean discharge measured along rivers in the country's major drainage basins. Tana River supplies water to approximately 17 million people in Kenya which is an equivalent of 50% of the country's population (Mogaka *et al.*, 2006; Notter *et al*, 2007).

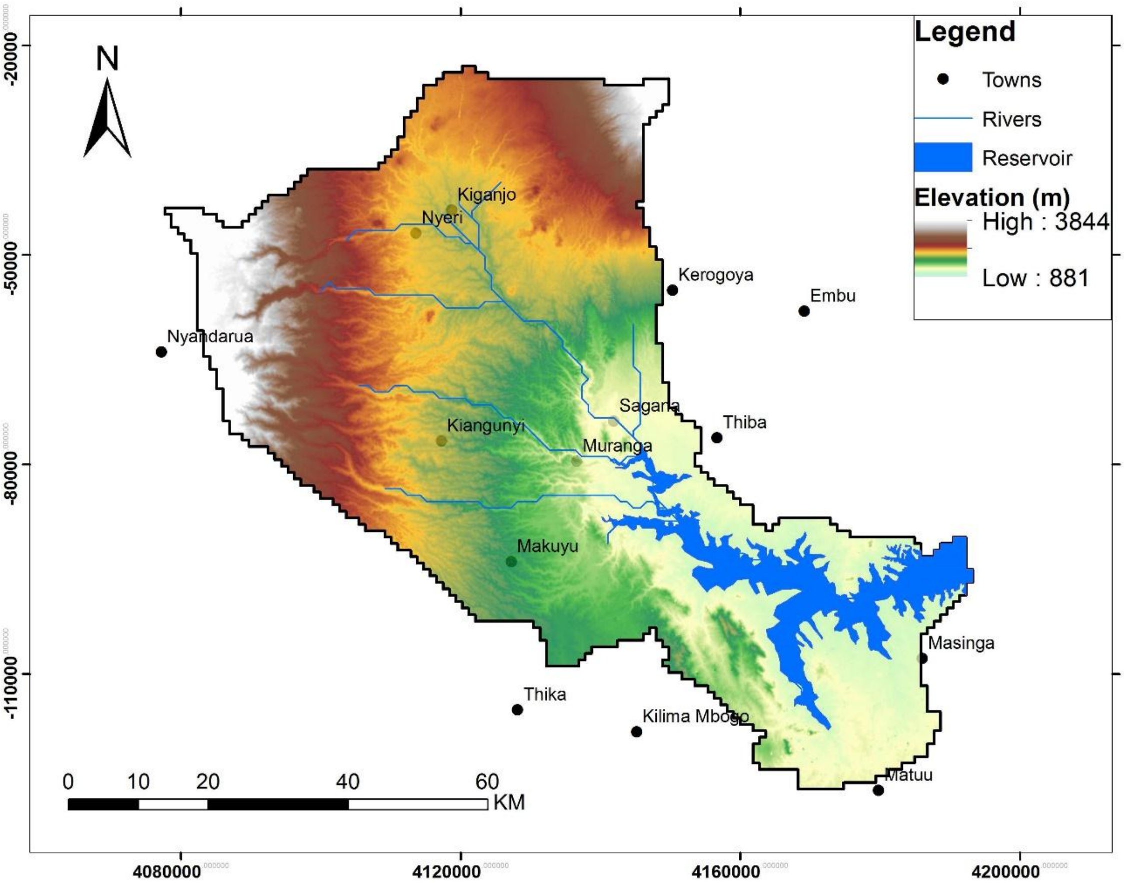

Figure 3. 2: The drainage of North-West Upper Tana basin, elevations above 2000 m asl cover approximately 45% of the study area while those below cover the remaining 55% (Njogu, 2018)

NWUT basin receives its water from the higher elevation regions (Figure 3.4), in particular from the Aberdares range and Mount Kenya (Droogers *et al*., 2006). Rivers originating from Mount Kenya are: The Thingithu, Rutugi, Ena, Rupingazi, Nyamindi and Thiba. Mathioya, Maragua and Sagana drain from the Aberdares. The NWUT basin drainage pattern is dendritic which shows homogeneous geologic material which shows that the geologic material is resistant to weathering and hence no major influence on the direction of the tributaries. NWUT basin experiences severe water shortages due to increased population which has increased water demand for various purposes. During the dry season the rivers in the catchment have low discharge and hence do not provide adequate water for the different uses (Notter *et al*., 2007). NWUT basin experiences a great variability in stream flow, Tana Sagana having the peak discharge of 128 m^3/s (Njogu and Kitheka, 2017). The major contributors to the flow of the NWUT are the Sagana, Gura, Tana Sagana, Maragua and Saba Saba. NWUT catchment supplies water to Nairobi city through the Nairobi water company which extracts approximately 75% from Thika river (Place and Way, 2012).

3.5 Vegetation Cover

Vegetation cover in the NWUT(Figure 3.3) is categorized as Alpine belt (above 3600m), ericaceous belt (3400-3600m) on the southern slopes and 2900m Northern slopes) and montane forest belt (below 3400m) (Mizuno, 2005). Vegetation cover in thebasin is divided into two broader categories; the Aberdares and Mt. Kenya sub-catchments (Muriuki and Macharia, 2011). Vegetation in the Aberdares sub-catchment can be divided into three categories, namely:

i. The Aberdares conservation area including the National Park;
ii. The middle zones consisting of farming areas; and
iii. The lower drier ASAL zones

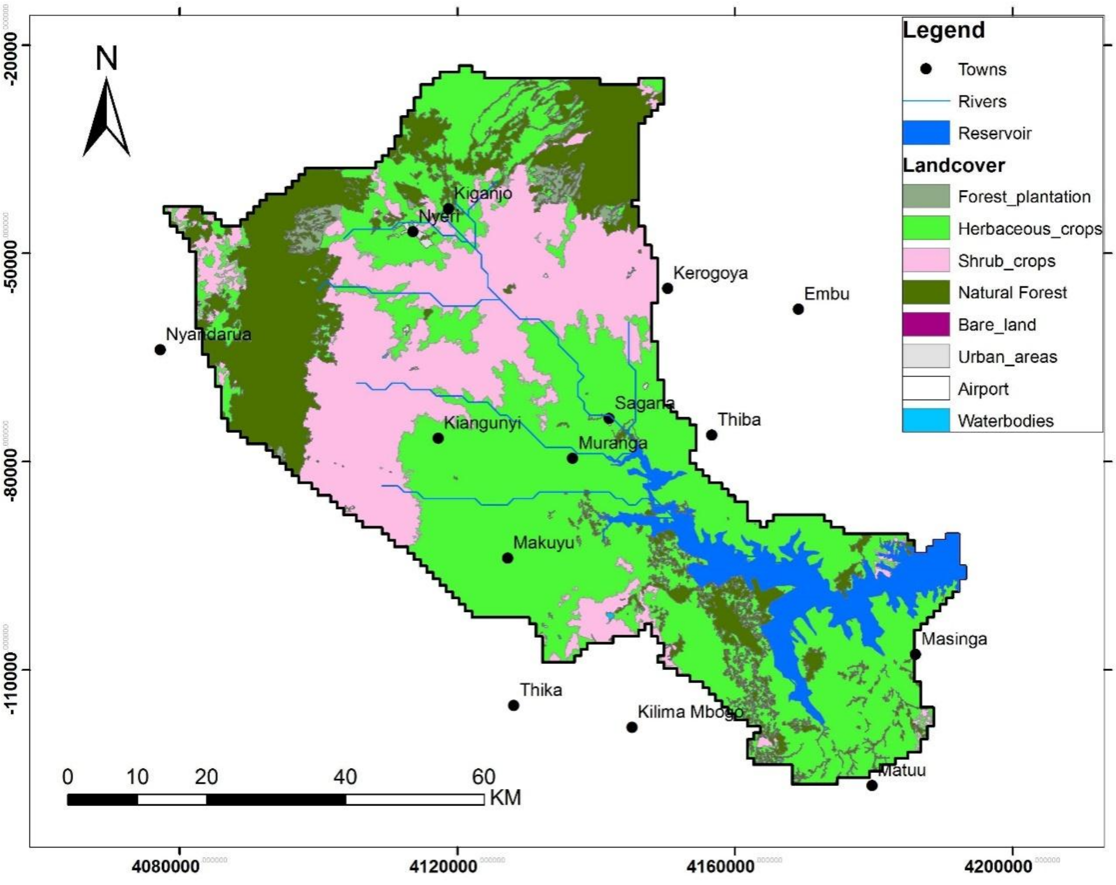

Figure 3. 3: Vegetation cover in North-West Upper Tana basin in 2014 (Njogu, 2018)

In the Abadares conservation area, vegetation is determined by rainfall distribution and temperature. The vegetation had been divided into four categories as one ascends, namely: - wetter evergreen forests; drier evergreen forests; Juniperus Podocarpus/Olive forests; and low altitude shrubs (Jacobs *et al*., 2007; Batjes, 2014; Brown *et al*., 1996).The ten (10) most common species of trees in the three forest reserves of the Aberdares Conservation area has been determined by Lambrechts *et al*., (2003). The five most abundant species of trees are *Nuxia congesta, Juniperus procera, Olea europaea, Podocarpus latifolius*, and *Neboutonia macrocalyx*. The middle zones of the basin consisted of agro forestry areas mainly planted with Grevillea, Eucalyptus, and fruit trees especially mangoes, pawpaw and avocado (Muriuki and Macharia, 2011). The lower drier zones consists of fruit trees, mainly mangoes, and some of the indigenous trees like *Ficus sycomorra* (mikuyu), and *Cordial africana* which had been left intact or which had regenerated. Other trees included; Commiphora spp., *Combretummolle*, Acacia spp., and Cassia spp.

Vegetation cover in the Mt. Kenya Sub-catchment is divided into four zones: (i) The Forest Zone; (ii) The Tea Zones; (iii) The Coffee Zone; and (iv) The Lower Zones. The Forest zone consisted of the Mt. Kenya National Park and Reserve, which was a protected area. The Mount Kenya ecosystem constituted an important reservoir for biodiversity. 880 plant species, subspecies and varieties belonging to 479 genera in 146 families have been identified below the 3200m altitude (Notter *et al*., 2007). There were at least 11 strictly endemic species of higher plants and more than 150 species that were near endemic. Vegetation zones and species distribution were distinguished according to the different climatic zones and altitudes, most obviously through variation in vegetation structure, cover and composition (Okello *et al*., 2016). In the lower regions of the basin, where the rainfall ranges between 900mm and 1200mm, with a prolonged dry season, the characteristic vegetation is Combretum woodland, *Terminalia brownii* interspersed with cultivated areas with *Themeda triandra* grass (Muriuki and Macharia, 2011). Anthropogenic activities have been rampant in the basin for timber logging, agriculture and settlement.

3.6 Land Use

The land use in NWUT catchment can be divided into three main classes, namely (i) Natural vegetation (forest, grassland and wetlands), (ii) Rain- fed and irrigated agriculture (tea, coffee, maize and cereals) and (iii) Range land (Jaetzold and Schmidt, 1983). Tea, coffee and forests are found in the high latitudes in the study area. The mid-latitudes are characterized by both rain fed and irrigated agriculture, while the lower latitudes are comprised of low livestock keeping and subsistence agricultural practices (Cadol *et al*., 2012; Rwigi, (2014); Wilschut, (2010).

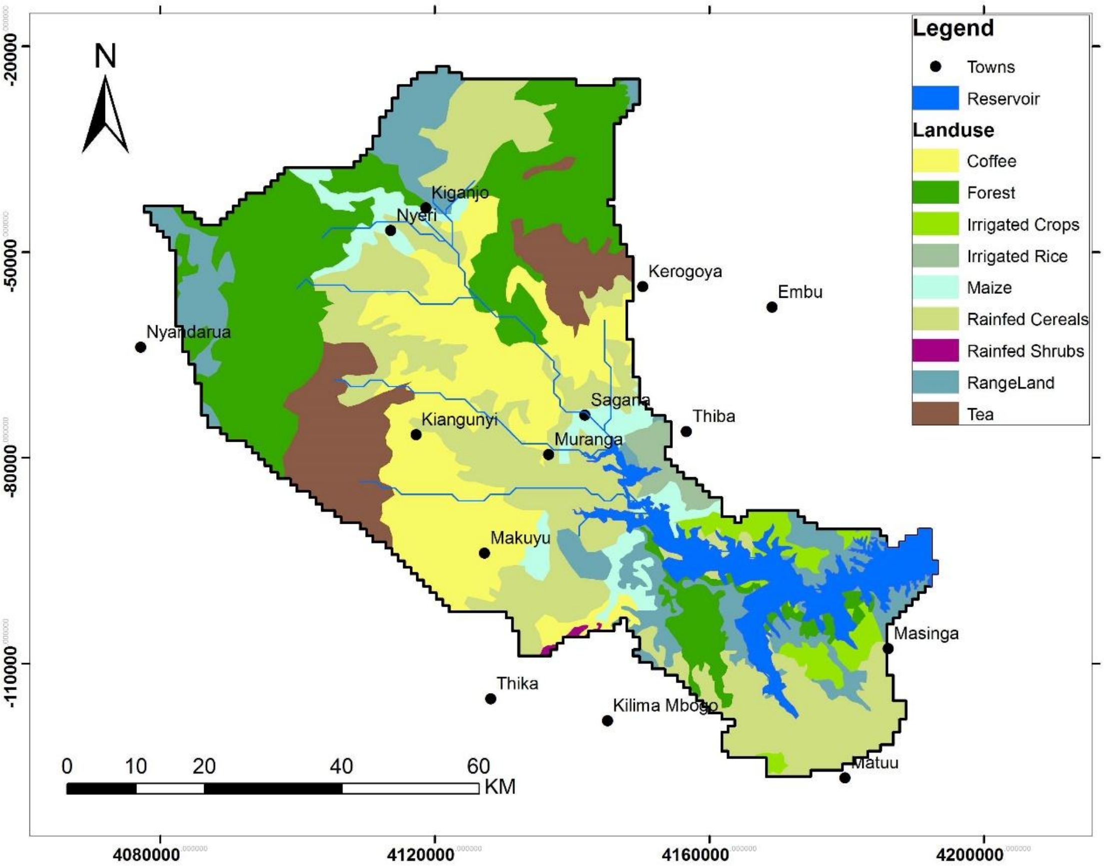

Figure 3. 4: Land Use map for North-West Upper Tana basin based on survey done in 2014 (Njogu, 2018)

NWUT catchment is divided into different agro-ecological zones which corresponded to the different land use types (Jaetzold and Schmidt, 1983) (Figure 3.4). The major crop production in NWUTcatchment is mainly coffee production, followed by forest cover and tea production being the least (Geertsma *et al*., 2010). There has been changes in land use land cover from 1974 to 2004 which has negatively impacted on stream flow and rainfall in the Upper Tana region (Batjes, 2014). Coffee trees were first introduced in 1939 by the settlers but the Kenyan farmers were first allowed to grow then in their farms in early 1960s (Cowen, 1981). Tea was introduced in 1960 following the introduction of the first tea factory in 1970 (Dorsey, 1999). Tea and coffee are grown in high elevation areas which resulted in forest clearing to create land for growth (Brown and Brown, 2006). Most of the farmers integrates coffee trees with other fruit trees like the macadamia to obtain maximum profit from agriculture (Karanja and Nyoro, 2002; Lamond *et al*., 2016). Land use change has been experienced in the catchment from 1960-1980 resulting to water quality deterioration due to the decline in coffee production and conversion of land for other agricultural purposes by tillage (Ovuka, 2000). Majority of the farmers in the catchment have adopted irrigation agriculture since income generated from horticulture can supplement benefits from tea, coffee and dairy farming (Ovuka, 2000).

3.7 Geology

The geology of the NWUT basin is comprised of the Mozambique belt, tertiary and quaternary volcanic and basement rocks. NWUT catchment is mainly dominated by two main geological structures: in the highlands volcanic rocks of the Cenozoic are found and in the lowlands the bedrock consists of metamorphic rocks of the Mozambique belt (Veldkamp *et al*., (2012), Mathu and Davies (1996). Mount Kenya, an extinct volcano formed between 100-4000 million years ago (Street-Perrott *et al*., 2004), is located in the west most part of the catchment. The Mt. Kenya volcano erupted for the last time between 1.6 and 3.1 million years ago. Patches of Precambrian intrusive rocks can be found around Masinga reservoir (Veldkamp *et al*., (2007); Baker (1967). Tertiary and quaternary volcanic have been accompanied by faulting which resulted to the formation of volcanic piles. The most dominant rock type is Pyrocrastic which covers nearly half of the basin, the andesite, trachyte and phonolite are the second most dominant and fund in areas of Mt. Kenya and Far East of the basin. The basement rock complex is found in Murang'a and in the Masinga reservoir. The Acidic metarmorphic rocks, eolean, basalt, gneiss and the quaternary deposits form a small portion of the rock system in the basin.

3.8 Soils

Soils in the NWUT catchment can be broadly categorized as either clay, sandy or loamy. Soils in the NWUT catchment are dominated by the Humic Nitisols which were formed as result of the volcanic deposits on the high altitude zones (Batjes, 2011). The Nitisol soils have proved useful in the cultivation of tea and coffee since they are highly resistant to erosion (Kauffman *et al*., (2014); Schluter, (2006). These soils are however highly vulnerable to erosion where soil conservation measures are not applied (Schluter, (2006). The other soil types in NWUT catchment include vertisols, cambisols, andosols ferralsols and leptisols.Gelisols are characterized as frozen, Litisols are organic and wet, spodosols are sandy and acidic, andisols are volcanic and ash, oxisols are very weathered, vertisols shrink and swell, aridisols are very dry, ultisols are weathered, mollisols are deep and fertile, alfisols are moderately weathered, inceptisols are slightly developed while entisols are newly formed (Isbell, 2016).

3.9 Population Size and Distribution

The population in the NWUT catchment is highly influenced by elevation and availability in agricultural land. The NWUT catchment hosts approximately 3, 787,475 people (KNBS, 2009). The largest towns are Thika and Nyeri with about 90, 000 and100, 000 inhabitants, respectively.

Population density declines with elevation partly due to decreasing rainfall and soil fertility. Growth rates in the regions has been documented to be 2.7%, with population distribution being influenced by infrastructure, employment, and potential of the land for agriculture (KNBS, 2009). The high population growth rates are as result of poverty, high fertility in people and availability of food in the region. Population growth in the future is expected to decline due to pressure on existing resources (KNBS, 2009). The high population growth has serious impacts to the environment due to pollution on land and water resources, clearing of forest cover for agricultural land.

3.10 Socio-Economic Activities

The socio-economic activities in the NWUT catchment are highly governed by trends in crops production and contributing activities like industries, trade and commerce in the region (Omiti *et al*., 2009). There are several coffee, tea and macadamia estates, cooperatives and factories that are found in the study area that deals in processing, manufacturing and packaging of these products. Most of the factories are found in proximity to major towns in the region i.e. Nyeri, Thika, Murang'a, Kirinyaga and Juja. Together these companies provide both skilled and unskilled source of employment to residents (Cowen, 1981). Other food crops are grown in the region that includes beans, maize, horticulture and high value crops like tomatoes. In high altitude areas, growth in crops like maize is slowed down due to cool climatic conditions resulting to poor household food supply. In mid and low latitude areas, most of the farmers have adopted irrigated agriculture due variability in rainfall (Leauthaud *et al*., 2013). The stability of the Kenyan shilling in stock market, good diplomatic representation and marketing have made is easy to export coffee, tea, macadamia and other products in most parts of the world. Other considerations like the high grade of coffee, tea and macadamia have boosted the global market (Kirui *et al*., 2014). Most of the people in the NWUT catchment relied heavily on agriculture output as well as the associated agro-industries where most of the people are employed (Batjes, 2014). In NWUT catchment, the main socio-economic activity was focused on agriculture (Hunink *et al*., 2012). The type of agriculture practiced and the yield in these regions are mainly dependent on the altitude the height above sea level which influences rainfall and temperature which are key factors in the crops production (Leauthaud *et al*., 2012). On the southern slopes of Mount Kenya, agriculture ispracticed on the arid lands (Batjes, 2014). In the upper reaches of the NWUT basin, potatoes, pyrethrum and tea are grown. In the mid altitude zones coffee, maize, rice and bananas are grownin the lower reaches, tobacco, cotton, sorghum, millet and peas are grown (Batjes, 2014). The income in the farming practices varied with the tea farmers having the greatest income with those in the cotton and tobacco practice receiving the least (Brown and Brown, 2006).

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

The chapter on the methodology of the study provides details on the approaches that were adopted in the collection and analysis of data. The study employed standard procedures for data processing and analysis. The methodology used in this study is based on similar methods that have been applied in previous studies conducted in the study area and elsewhere. In this chapter, details are presented on methods used on data collection, analysis and presentation.

4.2 River Gauging Stations and Streamflow Data

Secondary data on the rainfall, river discharge and sediment yield were obtained from WRA Embu regional offices and KMD headquarters. Stream flow (discharge) data for this study was obtained from 9 different River Gauging Stations (RGS) (Table 4.1) from where data on sediment yield and TSSC was available in the basin. Inter-annual variability in discharge was analyzed for all the stations. Data from river gauging stations having no major gaps was used in hydrological modeling using SWAT model.

Table 4.1: Location of the River Gauging Stations (RGS) in NWUTcatchment

RGS_Name	RGS_Code	X- Coordinate	Y-Coordinate
Sagana	4AC03	37.043	-0.449
Mathioya	4BD01	37.178	-0.714
North mathioya	4BD07	36.95	-0.617
Maragua	4BE01	37.153	-0.75
Irati	4BE03	37.017	-0.783
Gikigie	4BE08	36.842	-0.722
Saba saba	4BF01	37.264	-0.864
Thika	4CC05	37.456	-1.031
Thiba	4DD01	37.642	-0.821

(Source: Njogu, 2018)

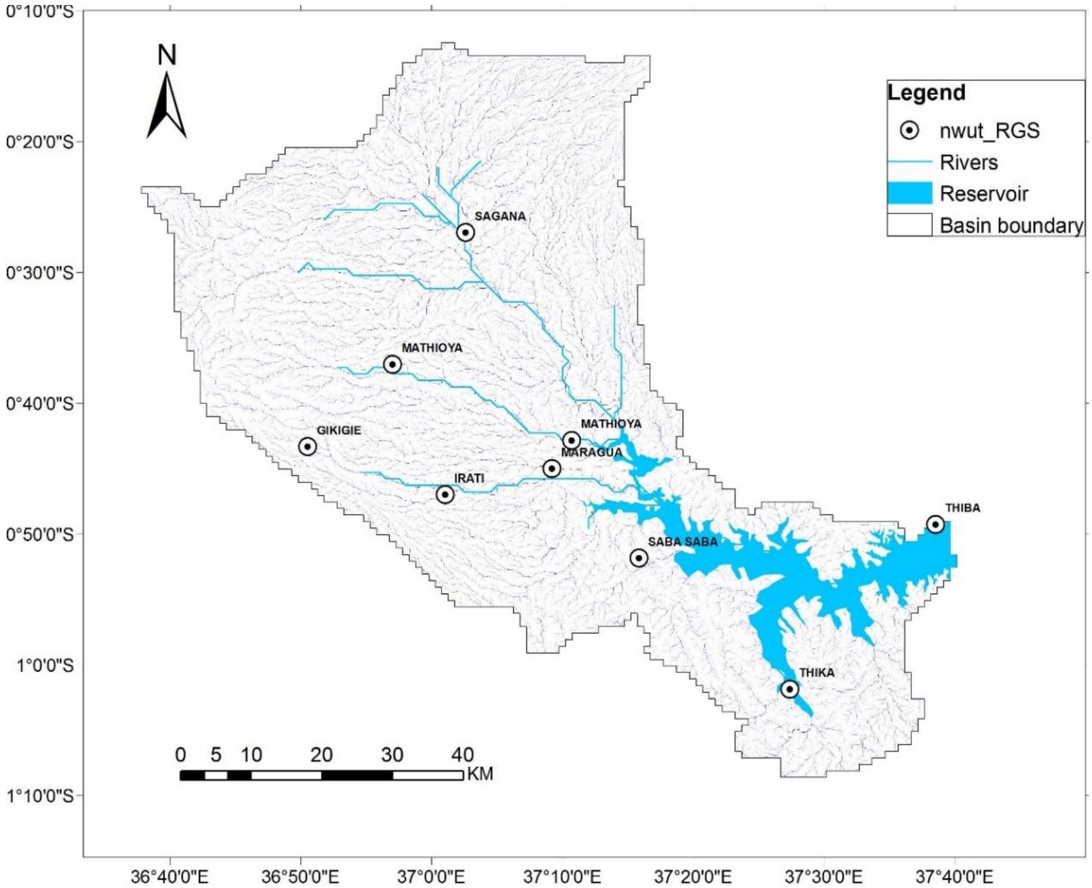

Figure 4. 1: The location of River Gauging Stations (RGS) in NWUT basin (Njogu, 2018)

4.3 Rainfall Stations and Rainfall Data

The available meteorological stations in NWUT Catchment includes; Nyeri ministry of works (9036017), Nyeri met station (9036223) and Sagana fish culture farm (9037096) (Kerandi *et al*., 2017).The meteorological station that was used for the purposes of rainfall data included the Sagana Fish Farm Station and Nyeri ministry of works because of their strategic location and consistency in their records (Dijkshoorm *et al*., 2011). The details of the station ID, station name, location, length of data available and percentage of missing data are provided in table 4.2.

Table 4.2: Rainfall stations and data available in NWUT Catchment

Station ID	Station Name	Longitude	Latitude	Length of Data	% of missing data
9036017	Nyeri Ministry of Works	36.9500	-0.4167	1957-2012	0
9036223	Nyeri Met Station	36.9667	-0.6	1981-2013	0
9037096	Sagana Fish Farm	37.2000	-0.6667	1966-2016	24

(Source: Njogu, 2018)

4.4 Total Suspended Sediment Concentrations Determination

The Total Suspended Sediment Concentrations data were obtained from Water Resources Authority (WRA) for the following River Gauging Stations (RGS); Sagana (RGS 4AC03), Maragua (RGS 4BE01), Saba Saba (RGS 4BF01), Mathioya (RGS 4BD01), North Mathioya (RGS 4BD07), Irati (RGS 4BE03), Thiba (RGS 4DD01), Thika (RGS 4CC05) and Gikigie (RGS 4BE08). The location of the RGS is shown in figure 4.1. TSSC data was also obtained from other published sources that have previously dealt with these parameter (Kitheka and Mavuti 2016).

4.5 Computation of Suspended Sediment Load

The Total Suspended Sediment Concentration (TSSC) and instanteneous river discharge (Q) data from Sagana (4AC03) RGS were obtained (Table 4.3). The intanteneous sediment fluxes in kg/s were obtained by the use of equation 4 (Simons *et al*., 2017; Gaeraert *et al*., 2015)

$Q_s = C* Q$..Equation 3

Where

C is the Total Suspended Sediment Concentration (kg/m^3), Q_s is the sediment flux (kg/month) and Q is the river discharge (m^3/month).

The annual sediment load was computed by summing the monthly sediment loads using equation 4.

$Q_L = \sum_{n}^{i=1} Q_i \, . \, C_i$..Equation 4

WhereQ_L= Annual Sediment load (tons/year), Q_i Monthly instantaneous river discharge (m^3/month), and C_i monthly TSSC (kg/m^3)

The basin Sediment Production Rate was computed as follows

$(SPR) = \sum_{n}^{i=1} \frac{Q_i * C_i}{A}$..Equation 5

Where A is the basin area (km^2), C_i is the instantaneous monthly sediment load (kg/m^3) and Q_i is the instantaneous river discharge (m^3/month).

4.6 Hydrological Data Analysis

This study adopted hydrograph analysis to analyze the stream flow variability and the influence on input and output in reservoirs located in the catchment. This study also adopted the use of

Double Mass Curve analysis (DMCA) which is a plot of cumulated river discharge against mean discharge from surrounding RGS and time series analysis in NWUT basin.

4.6.1 Time-Series Analysis

The data obtained for this study was analyzed in time series to show the trend on river discharge, sediment yield and Total Suspended Sediment Concentration (TSSC) for the period of 2010-2012 when data for this parameters under examination was available in NWUT Catchment. This study adopted the analysis of hydrographs in the NWUT catchment to determine the trends, variations and means in rainfall, river discharge and sediment yield (Wei, 2006 and Tong, 2012).

4.6.2 Double Mass Curves Analysis

The use of double mass curve has widely been used in checking consistency in hydrological data of many kinds, this include precipitation, stream flow, sediment data and precipitation-runoff relations (Siriwardena *et al*., 2006). This exercise involves comparison of data from one station which shows considerable consistency with another set of data from different stations in the surrounding area (Chang and Lee, 1974). Breaks on a double mass curve are caused by changes in relationship between variables under examination (Simmons and Reynolds, 1982). These changes may be attributed by changes in the method employed in data collection or physical changes that affect the relationship between the two variables.

4.7 Determination of Land Use Change in the Basin

4.7.1 Satellite Data Acquisition

The Landsat archive was utilized in the land cover land use change analysis. Historical data is available since 1972 when Landsat program was launched by the National Aeronautics and Space Administration (NASA). The historic imagery data on land use land cover changes makes it easy for different users to make various earth observations on the earth processes and phenomena. A series of Landsat sensor technologies have been utilized since 1972 with the use of Landsat MSS for Landsat 1 to 3 (1972 to 1992), Landsat Thematic Mapper (TM) for Landsat 4 and 5 (since 1982) and Landsat ETM+ for Landsat 7 (1999 to present). Governance, maintenance, and calibration of the data is done by the United States Geological Society (USGS). The satellite images were acquired from the Global Visualization Viewer (Glovis) archive which is managed by the United States Geological Society (USGS) (https://earthexplorer.usgs.gov/). Glovis offers a platform where the user can evaluate images from different series of Landsat program since 1972. Glovis is also user friendly to browse through and access data. Glovis is an archive of several satellite data including Landsat has the longest continuous free satellite data source for scientific uses.

One Landsat scene covers an area of 185 x 185km and the images have a spatial resolution of 30m captured from an altitude of about 170km above sea level (Table 4.4). This means that the objects less than 30m may not be clearly observed on Landsat imagery. However, image pan sharpening was the procedure used to resample the Landsat images from 30m to a higher spatial resolution of 15m. The images are taken after every 16days in different rows and columns therefore changes within this period can easily be determined. This interval also determines the observable characteristics of the data captured.

Table 4.3: Characteristics of the Landsat satellite imagery used in this study

	Landsat dataset acquisition date	**Landsat program**	**Cloud cover (%)**	**Multi-Spectral spatial resolution (m)**
1.	21 February 2000	5	0.00	30
2.	18 February 2005	7	1.00	30
3.	03 February 2014	8	1.41	30

(Source: Njogu, 2018)

Landsat is a sun synchronous satellite since it crosses the equator at a specific time of the day when the data is captured. This allows the users of the data to make comparable observations between two days. It is from this fact that temporal series of events and other processes on the earth can be done. This makes Landsat the most reliable source of charge free imagery data for land use and land cover mapping. The location and boundary of the study area lie on path 168 and row 060 and 061. This is covered by two Landsat scenes.

4.7.2 Image Preprocessing

The downloaded data comes with a metadata showing all the processes undertaken at level 1 (1T) before the images were uploaded on the Landsat Glovis archive. These included mirror scan correction, geometric correction, projection, sensor line of sight generation, grid generation, image resampling, and terrain correction. However, all the images acquired from Landsat 7 archive since 2003 have a scan line failure hence images are acquired with data gap. This means all the images acquired for 2005 have a scan line data gaps due to malfunctioning of Landsat 7 scanner. These images show an increase of the data gaps (approximately 25% loss) towards both sides of the images from the center. The scan line data gaps were filled by applying a special spatial tool (focal analysis) in Erdas Imagine.Clouds are common hindrances in satellite data acquisition thus minimizing the observations that can be made on the images. The images acquired for this study had some cloud cover ranging between 0.34 to 5%. This leaves 95% of the satellite images usable for further procedures since most of the features on the land can easily be observed.

4.7.3 Possible Source of Error and Omission

Landsat ETM+ records reflectance from the earth surface. Each object on the earth surface has a reflectance value that is recorded and stored as a raster data. In case of Landsat the records are stored in grid cells which represent an area of 30m by 30m for each band. Each cell shows an average of the ground reflectance value for the object(s) in a $30m^2$ pixel. This challenge of omission was minimized by creating a subset area defined by the NWUT catchment map. This was done by introducing an area of interest (AOI) by manually digitizing the boundary of the study area at minimal snapping error of 0.4%. This AOI was used as the masking boundary in all the subsequent processes.

4.7.4 Digital Image Classification

Image classification was done in order to assign different spectral signatures from the Landsat datasets based on the appropriate color composite. Landsat images are recorded in 7 spectral bands. Making Red, Green, and Blue color combination of certain bands leads to images with different information content. Different color composites were utilized to improve visualization of different features on the imagery. Infrared color composite NIR (4), SWIR (5) and Red (3) was applied in the identification of varied levels of vegetation growth and separating different shades of vegetation. Soils rich in iron and silica reflect more in this combination. Clean water absorbs more of the infrared rays hence appearing black while silted water would appear blue in color as shown in the left side image in. Green color dominates in this combination when the vegetation reflects more in the SWIR and lower in NIR implying lower moisture content. Non-vegetated soils and built-up areas will appear in blue towards gray colors. The other color composite such as Short Wave Infra-red (7), Near Infra-red (4) and Red (2) combination is sensitive to variations in moisture content. This combination was applicable in the identification of the built-up areas and bare soils which appear cyan-pink and shades of blue in the image. The bright green shades indicate vegetation while clear water appears dark blue or black as shown in the top right-hand side of the image where the reservoir for the seven folk dams is located.

4.7.5 Land Use Land Cover Change (LULCC)Detection Analysis

Table 4.5 below was used in this study in the classification of various land use land cover changes in the North-West Upper Tana basin.

Table 4.4: The key land use land cover classes identified and described in the NWUT catchment

Land Cover	Description
Forest	This describes the areas with trees mainly growing naturally in the reserved land, along the rivers and on Mountains and ranges
Rain-fed Cropland	The land used for growing food crops such as maize, rice, beans. Crops grown in this land are either irrigated or rain-fed
Plantation	Land covered with mango plantation, coffee, shrubs, and banana trees
Water bodies	The land cover that describes the areas covered with water for example along the river bed or reservoirs, dam, lakes and water ponds
Sedimented waterbody	Turbid Waterbody due to presence of sediments
Bare-land	This describes the land left with minimal vegetation cover. This is as a result abandoned cropland, land degradation, cleared land for construction and weathered road surfaces
Rangeland	This class of land cover defines the area where short grass, bush and shrubs are the main vegetation cover.
Built-up area	This class describes the land covered with buildings or settlements in rural and urban areas. The tarmac roads, airport and large concrete structures are also put in this class
Evergreen vegetation	Tea, young and healthy broad-leafed trees

(Source: Njogu, 2018)

4.7.7 Ground Truthing and Validation

The ground truthing and validation were undertaken in the study area in the period between September and December 2017. The objective of this activity was to make sure that all the different land cover classes were noted and their coordinates recorded for validation of the supervised image classification. The visited sites were evenly distributed in the study area and were projected on a map to evaluate the distribution of the various land cover and land use. A total of 100 points were used for ground truthing and validation of the image classification in September to December 2017. Google Earth was also used for confirmation and ground truthing the classified images. All the points that were visited during the fieldwork were recorded with their coordinates then utilized in ground checking in supervised image classification.

4.8 Hydrologic Modeling

The hydrologic modelling for stream flow and sediment yield in the NWUT basin was undertaken by the use of SWAT Model. The SWAT Model mainly deals with soil and water parameters, with primary data inputs which included the Digital Elevation Model (DEM), land use and soils shape files (Jacobs *et al*., (2007); Neitsch *et al*., (2002). The Model was calibrated using data of 13 years' time series from Sagana fish farm meteorological stationwhich had consistent data. Model validation was done using the remaining data for 13 years followed with comparison between simulated and observed discharge and sediment yield in the period between July and May (2010-2012).

SWAT was developed primarily by the United States Department of Agriculture (USDA) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Wang *et al*., (2014); Jacobs *et al*., (2007); Hunink *et al*., (2013). For modeling purposes, the North-West of Upper Tana watershed was partitioned into a number of sub-basins. Input information for each sub-basin was then grouped or organized into climatic hydrologic response units (HRUs) categories.

4.8.1 SWAT Model Setup and Selection

The SWAT Model was used to simulate the erosion processes for all combinations of soil types and land uses available in the NWUT basin (Hunink *et al*., 2013). The Soil Water Assessment Tool (SWAT) incorporates aspects of water and soil assessment which is the key target for this study (Tripathi *et al.*, 2003 and Arnold *et al*., (2012).The model primarily focused on the interaction between land management versus water- and erosion processes (Hunink *et al*., 2013). Several hydrological studies have been carried out in Tana Basin using SWAT model as the main assessment tool (Hunink *et al*., 2013; Jacobs *et al*., 2007; Kauffman *et al*., 2014; Veldkamp *et al*., 2012).The SWAT model used for this study will be built using the Arc-Map interface called the Arc SWAT which provides the suitable means to enter data into the SWAT code.

4.8.2 SWAT Model Specifications

SWAT model is a process based, continuous physically based distributed parameter river basin model that simulates water, sediment and pollutant yields that was developed in the 90's to assist water resources managers assess the impact of different land use practices on water, and diffuse pollution for large ungauged catchments with different soil types, land use and management practices (Levesque *et al*., 2008; Arnold *et al*., (2012). The SWAT model components include weather, soil, hydrology, erosion, temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing (Rostamian *et al*., 2008). The first step in creating a SWAT model involved the delineation of the sub-watersheds in the basin for which each of them is treated as individual units. The sub- basins were further divided into hydrologic response units (HRUs) for which they have a homogenous land use practices, soil type and management practices. The most important hydrologic components like surface runoff, base flow and sediment yield are estimated from each HRU and the basin hydrologic components are calculated from each HRU.

4.8.3 SWAT Model Data Requirements

The SWAT model data requirements were as follows, an overview of the different steps to perform the hydrological and erosion modeling assessment using SWAT is provided in figure 4.4 which also reveals the relation with the datasets that were used and generated using the tool. Data was collected and analyzed from WRMA and KMD. SWAT model data requirements have been enabled on the GIS platform which acted as the interface for the model (Jayakrishnan *et al*., (2005); Oberg and Mueller, (2007). The following sections describe the stepsthat were used in the model. The following datasets are described consecutively:

i. Climate

The climatic data that was used to run the model was daily rainfall, minimum and maximum temperature, solar radiation, wind speed and relative humidity (Arnold *et al*., 2012. The climatic data was obtained from WRA Embu regional offices which was in daily time step as required by the model.

ii. Digital elevation model

The Digital Elevation Model (DEM) for the purposes of this research was developed using Arc-GIS. Digital Elevation Model for this study was downloaded from United States Geological Society (USGS) website.

iii. Soils, Land use and slope

Soils, land use and slopes data were fed into the SWAT model in each box at the hydrologic response unit (HRUs). The soils and land use data were converted into shape files which were created using Arc GIS platform. The slope was set according to the area of the watershed/catchment.

iv. Stream flow datasets

The stream flow data sets were used as input for Sagana (4AC03) RGS in the period between July to May (2010-2012) in the watershed delineation table. Stream flow datasets to run the model was obtained from WRA Embu regional offices.

v. Sediment yield datasets

Sediment and erosion datasets were SWAT Model generated. Sediment yield datasets were obtained from WRA Embu regional offices for Sagana (RGS 4AC03), Maragua (RGS 4BE01), Saba Saba (RGS 4BF01), Mathioya (RGS 4BD01), North Mathioya (RGS 4BD07), Irati (RGS 4BE03), Thiba (RGS 4DD01), Thika (RGS 4CC05) and Gikigie (RGS 4BE08) and used in the comparison between observed and simulated sediments yield in the period between July (2010) to May (2012)

4.8.4 Model Calibration and Validation

The SWAT Model calibration and validation was done using rainfall data from Sagana fish farm from 1/1/1983 to 31/12/1996 (calibration period) and 1/1/1999 to 31/12/2012 (validation) with 2 years warm up in each process. The model calibration was undertaken in order to come up with a model that could simulate past and future conditions in an adequate way (Moriasi *et al*., 2007). To calibrate the model for this study, the following rainfall datasets from Sagana fish farm were used (Arnold *et al*., (2012); Santhi *et al*., (2001).

The long-term calibration was done for 32-year time span for which the basin was thought to have changed considerably in terms of land use and in terms of infrastructure roads, small-scale hydraulic works and diversions (Arnold *et al*., 2012). The calibration procedure assumed that all these factors are stationary and do not change over time (Douglas *et al*., (2010); White and Chaubey, (2005).

4.8.5 Model Evaluation Using Nash Sutcliffe Efficiency

The Nash-Sutcliffe efficiency (NSE) was used to determine the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”) (Nash and

Sutcliffe, 1970). NSE indicated how well the plot of observed versus simulated data for sediment yield and stream flow fits the 1:1 line (McCuen *et al*., 2006). The NSE is computed using the equation 6 (Criss and Winston, 2008):

$$NSE = 1 - \left[\sum_{i=1}^{n} \frac{(Y_i^{obs} - Y_i^{sim})^2}{(Y_i^{obs} - Y^{mean})2}\right] \text{...Equation6}$$

Where: $\mathbf{Y_i^{obs}}$– $i^{th}$is observation for the constituent being evaluated, $\mathbf{Y_i^{sim}}$– i^{th} simulated value for the constituent being evaluated, $\mathbf{Y^{mean}}$ –mean of the observed datafor the constituent being evaluated, **n-**Total number of observations

The Nash Sutcliffe Efficiency ranges from - ∞ to +1, where the acceptable levels of performance are the values greater or equal to 0.0 to 1 (Jain and Sudheer, 2008). If the NSE number is less than 0.0 it indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance of the model (Mathevet *et al*., 2006). NSE is very commonly used, which provides extensive information on reported values (Krause *et al*., 2005). Sevat and Dezetter (1991) also found NSE to be the best objective function for reflecting the overall fit of a hydrograph.

4.9 Statistical Methods of Data Analysis

The statistical methods of data analysis that were used for this study were measures of central tendency, measures of dispersion, regression analysis, correlation analysis and analysis of variance. These methods are presented in details in the following sections.

4.9.1 Measures of Central Tendency

Measures of central tendency were used in the analysis of data. In this study, the arithmetic mean were applied. The arithmetic mean of a series of values was determined by summing up the values and then dividing by the number of values (Gupta and Gupta, 2009) using equation 7.

$$\bar{X} = \frac{\sum X}{N} \text{...Equation 7}$$

Where: $\bar{X}$ = Arithmetic mean

$\sum X$ = Sum of values in the series

N = Number of values in the series

The arithmetic mean wasused in quantifying different quantitative indicators such as the mean annual rainfall in different years, river discharge, land use change and average sediment yield (Richter *et al*., 1996). Some averages were expressed in terms of percentage. Mode was used to calculate the range of the rainfall in which most values lie. The Median was used to compute the amount of rainfall in which the rainfall data collected falls between. The mode was computed using equation 8 according to Gholba, (2012).

$$Z = L_i + \frac{f_i - f_o}{2f_i - f_o - f_2} * i \text{ .... Equation 8}$$

Where: Z= value of mode L_i= lower of modal classf_o= frequency of the preceding modal class f_2= frequency of the subsequent modal class and post modal classi= class interval of the modal class

The median was computed using equation 9 according to Gholba, (2012).

$$Median = Bm + I * \left[\frac{\frac{n}{2} - (\sum f_i)o}{f_m}\right] \text{ ....Equation 9}$$

Where: B_m= lower boundary of the median class, $(\sum f_i)_o$ = the sum of the frequencies from the classes, fm= frequency of the median class, n= number of the observations, I= interval of the median class.

4.9.2 Measure of Dispersion

The measure of dispersion that were used in this study is the range. Range was used to show the difference between the highest and the lowest values in the series (Boos and Brownie, 2004). It is found by subtracting the lowest from the highest value. Range between rainfall amounts in the area of study, river discharge as well as the sediment yield was computed by subtracting the lowest values from the highest values in the period covered by the data obtained. Range was computed by the use of equation 10.

Range= maximum value- minimum value……………………….……………………Equation 10

4.9.3 Ratio Mean

Ratio mean will be used to detect variability in the available data. The greater the computed value the more variable or dispersed the data (Morrison, 2005). It can be computed using equation 11;

Vr = 1-fm/N……………………………………………………………………Equation 11

Where fm- frequency of the mode, N- Total number of items/data

4.9.4 Regression Analysis

The regression analysis was based on the application of linear and multiple regression analysis methods which are explained in details in the following sections.

4.9.4.1 Simple Linear Regression Analysis

The simple regression analysis was used to examine the relationship between rainfall and either stream flow, sediment yield or land use land cover change (Seber and Lee, 2012). The simple regression analysis allowed the dependent variable to be computed once the independent variable was known (Montgomery *et al*., 2012). A simple linear regression equation of the following form was generated for the relationship between rainfall and river discharge or sediment yield. Simple linear regression was computed using equation 12.

$$Y=a+bx+e \qquad \text{Equation 12}$$

Where: X- Independent variable (rainfall), Y- Dependent variable (river discharge, sediment yield or land-use change), b – Slope of the line, a- Intercept and e- error term.

4.9.4.2 Multiple Linear Regression Analysis

The multiple linear regression analysis was to estimate the association between rainfall and or stream flow and sediment yield (Yevjevich, 1972). The dependent variable (rainfall) was assumed to depend or be systematically predicted by the independent variables (Seber and Lee, 2012). In this study, the rainfall measurement was the independent variable (Y) and the dependent variables are the discharge (X_1), land use change (X_2) and sediment yield (X_3). The *p*-value was determined to show the significance of the relationship between independent and dependent variables in the regression equation (Katz *et al*., 2002). The smaller the p-value the more significant was the relationship and the regression equation (Katz *et al*., 2002). The regression equation is significant if the p-value is less or equal to 0.05 (Katz *et al*., 2002). This study adopted the following multiple regression model equation 13

$$Y= ax_1^2+bx_2+c \qquad \text{Equation 13}$$

Where

Y= Sediment Yield (tons/month), a and b = the coefficients value of X variables, X_1= River discharge (m^3/month), X_2= Rainfall (mm/month) and c= Constant.

4.9.5 Correlation Analysis

The correlation analysis was used to determine the relationship between observed and simulated data in stream flow and sediment yield in North-West Upper Tana basin. The correlation coefficient (r) describes the degree of collinearity between simulated and measured data. The correlation coefficient (r), which ranges from −1 to 1, was used as index of the degree of linear relationship between observed and simulated stream flow and sediment yield data (Lee and Nicewander, 1988). If r = 0, no linear relationship exists. If r = 1 or −1, a perfect positive or negative linear relationship exists (Taylor, 1990). The correlation analysis was undertaken using equation 14.

$$r=\frac{n=(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \text{………………………...……………. Equation 14}$$

Where R is the correlation coefficient, x- Dependent variable (e.g. sediment yield), y- Independent variable (e.g. river discharge) and n -Total number of values/variables.

4.9.6 Coefficient of Determination (R^2)

The coefficient of determination (R^2) was used to describe the proportion of the variance in data obtained from WRA Embu regional offices.Coefficient of determination (R^2) refers to the amount of variation explained by the independent variable/variables (Legates and McCabe, 1999). Coefficient of determination (R^2) ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 were considered acceptable (Santhi *et al*., 2001; Van Liew *et al*., 2003). The R^2 was computed using equation 15.

$r=\sqrt{R^2}$…………………………………………………………...……………. Equation 15

Where R^2= coefficient of determination, r= the correlation coefficient

4.10 Analysis of Variance (ANOVA) and Hypothesis Testing

The Analysis of Variance (ANOVA) was used to determine the significant differences between two or more variables at a selected probability level (Park, 2009). The one-way ANOVA was used in this study (Armstrong *et al*., 2002). For the purposes of this study, the independent variable was the rainfall which was compared with the sediment yield and river discharge the dependent variables under a 95% level of significance. The hypothesis was tested at a 95% level of confidence and the results obtained were tested as follows; if the significant/critical F is > F-value, the Ho (null hypothesis) was rejected OR If the p-value (x) is > 0.05, reject the Ho.

CHAPTER FIVE

RESULTS

5.1 Introduction

This chapter presents the results of the study. The results are discussed in more detail in the later sections of the chapter. The chapter presents the results of the data analysis on the hydrologic characteristics of the basin, the spatial temporal variation in sediment yield, Land Use Land Cover Changes (LULCC) and SWAT Model results. In presenting the results, special attention was paid on the need to address the key objectives of the study.

5.2 Hydrological Characteristics

5.2.1 Inter-Seasonal and Inter-Annual Variation in Stream Flow

There is a significant inter-seasonal and inter-annual variation in streamflow in North-West Upper Tana Basin. These variations are related mainly to variations in climatic conditions particularly rainfall in the basin. Figure 5.1 shows variation in streamflow for the period between July 2010 and May 2012. There is a significant difference between flows that were measured in the year 2010 and those that were measured in 2011 and 2012. The year 2010 experienced relatively higher streamflows for all the rivers found in the NWTB with river discharge reaching 170m^3/s for the main Sagana river. The flows were generally higher in the period between September and December 2010 and 2011. On the other hand, the stream flows were low in the period between January and August 2011.

As can be observed in Figure 5.1, the streamflows were generally higher during the short rainy seasons in both years. There is evidence of extension of the short rainy season with the streamflows beginning to rise much earlier than the usually period of commencement of short rains in October. Data shows the streamflows increasing rapidly from the month of August to attain the peak in October. From the month of October, there is a rapid decline in streamflow up to February-March period. It is important to note that during the long rainy season, the streamflows were unusually low. During this period, river discharges in most of the rivers were of the order 0.10-0.19 m^3/s. Saba Saba river (RGS 4BF01), Mathioya river (RGS 4BD01) and Gikigie river (RGS 4BE08) in particular, experienced the minimal flows during the long rainy season. It is important to note that the results presented in Figure 5.1 shows significant shifts in the patterns of stream flow in the North-West Upper Tana Basin. These shifts can be attributed to climate change that is probably leading to significantly low rainfall during the traditional long rainy season. It seems that relatively higher rainfall now occurs during the traditional short rainy season. Even then, the short rainy season seems to be beginning much earlier (in August-

September) than in the past when the month of the normal commencement of short rains was October. The short rainy season seems to extent up to the months of February and March in the basin. It is also clear from Figure 5.1 that the traditional long rainy season (March-April-May) seems to be losing its dominance and short rainy season (October-November-December) seems to be becoming more dominant season in the basin.

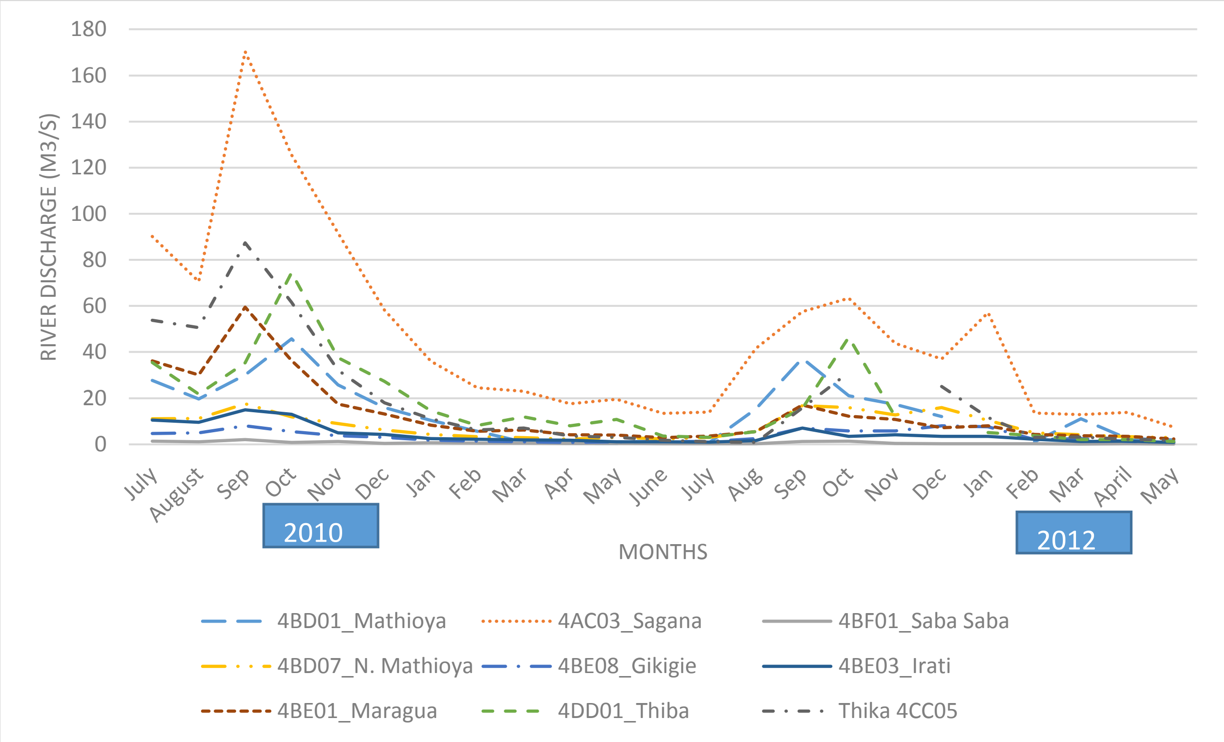

Figure 5. 1: The variability in river discharge (m^3/s) at different RGS in the period between July 2010 and May 2012 (Njogu, 2018)

5.2.2 Spatial Temporal Variability in River Discharge

Stream flow of rivers found in the North-West Upper Tana shows significant differences and no two rivers have the same level of discharges. Rivers that experienced relatively higher streamflows are Sagana, Thiba, Thika, North Mathioya and Mathioya, where the river discharges reached a maximum of 170 m^3/s. Within a given river system in the NWUT Basin, there are also significant changes in the maximum river discharges from one season to the other and from one year to the other. For instance, streamflow at Sagana river (RGS 4AC03) attained the maximum values of 170 m^3/s in the period between 2010 and 2012. For Mathioya river (RGS 4BD01), the dry season river discharge ranged from 36 to 57 m^3/s. The maximum river discharges for the river ranged from 12 to 46 m^3/s. The typical flows during the rainy season for Mathioya river ranged from 37 to 46 m^3/s, and the typical dry season flows were of the order of 10 m^3/s.

The maximum river discharges for Maragua River (RGS 4BE01) was 59 m^3/s during the period of this study.The river discharge ranged from 17 to 59 m^3/s during rainy season and during the dry season, the flow was nearly constant being of the order 8 m^3/s. The maximum river discharge for Thika river (RGS 4CC05) was 87m^3/s and the higher flows for this river generally ranged from 11 m^3/s to 87 m^3/s during rainy seasons. The maximum river discharges for Thiba river (RGS 4DD01) was of the order 74 m^3/s. The dry seasons flow for the river was of the order 5 m^3/s.

Significantly low river discharges in the North West Upper Tana basin were observed in Irati, Gikigie, North Mathioya and Saba Saba rivers where the flows were generally low. For instance, the river discharge for Saba Saba river (RGS 4BF01) attained the highest river discharge ranging from 0.27 to of 2.1 m^3/s during the rainy seasons. The results presented in preceding sections shows evidence of significant interseasonal variations in both the maximum and minimum streamflows in the basin. While rainfall is considered to be a key factor influencing streamflow variability, other factors such as land use/land cover change and water abstraction seems to be important.

5.2.3 Relationship between Stream Flow and Rainfall

There is a significant relationship between stream flow and rainfall in NWUT basin. Figure 5.2 shows the relationship bewteen stream flow and rainfall in the NWUT basin. Stream flow used in this excercise was obtained fron Sagana (4AC03) while rainfall data was obtained fron Sagana Fish Farm.

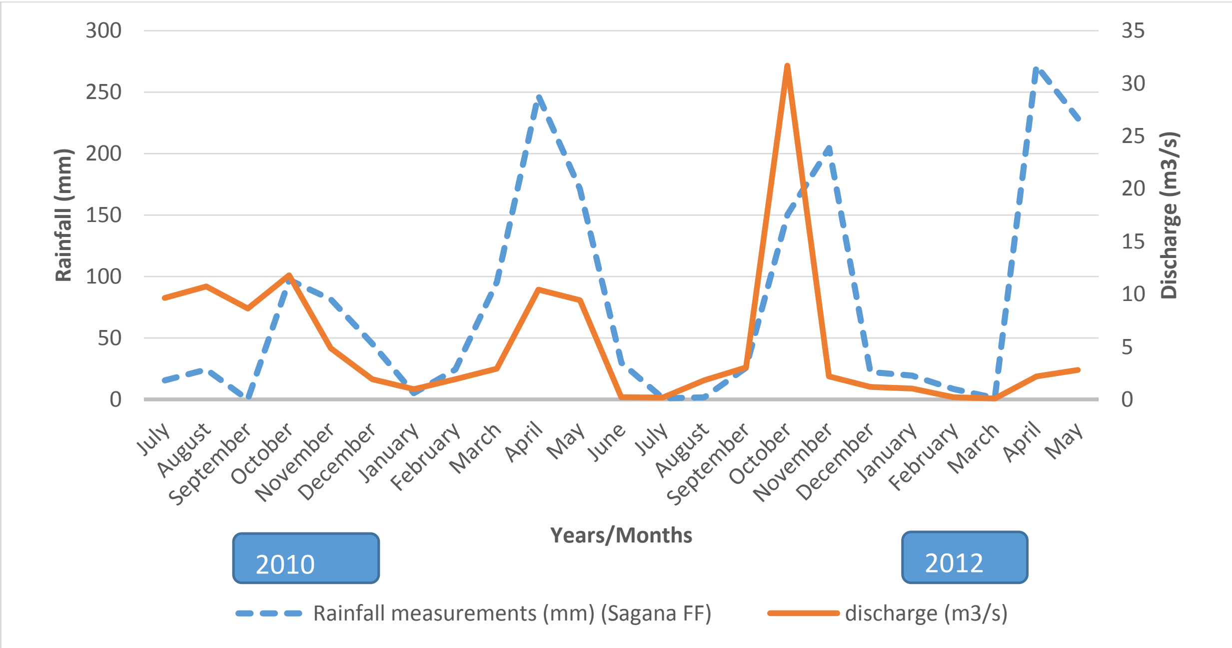

Figure 5. 2: Relationship between rainfall (mm) and stream flow (m^3/s) in the period of July to May (2010-2012) (Njogu, 2018)

Majority of stream flow were measured when rainfall was below 300mm. High stream flows corresponded to high rainfall measurements in the basin. Stream flow measurements ranged from 0.09 m^3/s to 11.78 m^3/s in the period of July to May (2010-2012). There is a significant relationship between stream and rainfall in NWUT basin. A correlation coefficient (r) of 0.81 and coefficient of determination (R^2) of 0.65 was obtained for this relationship. This shows that rainfall has 65% influence on stream flow in NWUT basin.

5.2.4 Double Mass Curve Analysis

This study adopted the use of double mass curve to check the consistency of data provided by WRA Embu regional offices on river discharge (Figure 5.3). The cumulated river discharge from Sagana (4AC03) RGS was plotted against the cumulated monthly average from other stations in the study area. A coefficient of determination (R^2) of 0.99 and correlation coefficient of (r) of 0.99 was achieved from this exercise. This means that the river discharge data archived by WRA Embu regional offices was consistent from all the stations during the period of this study.

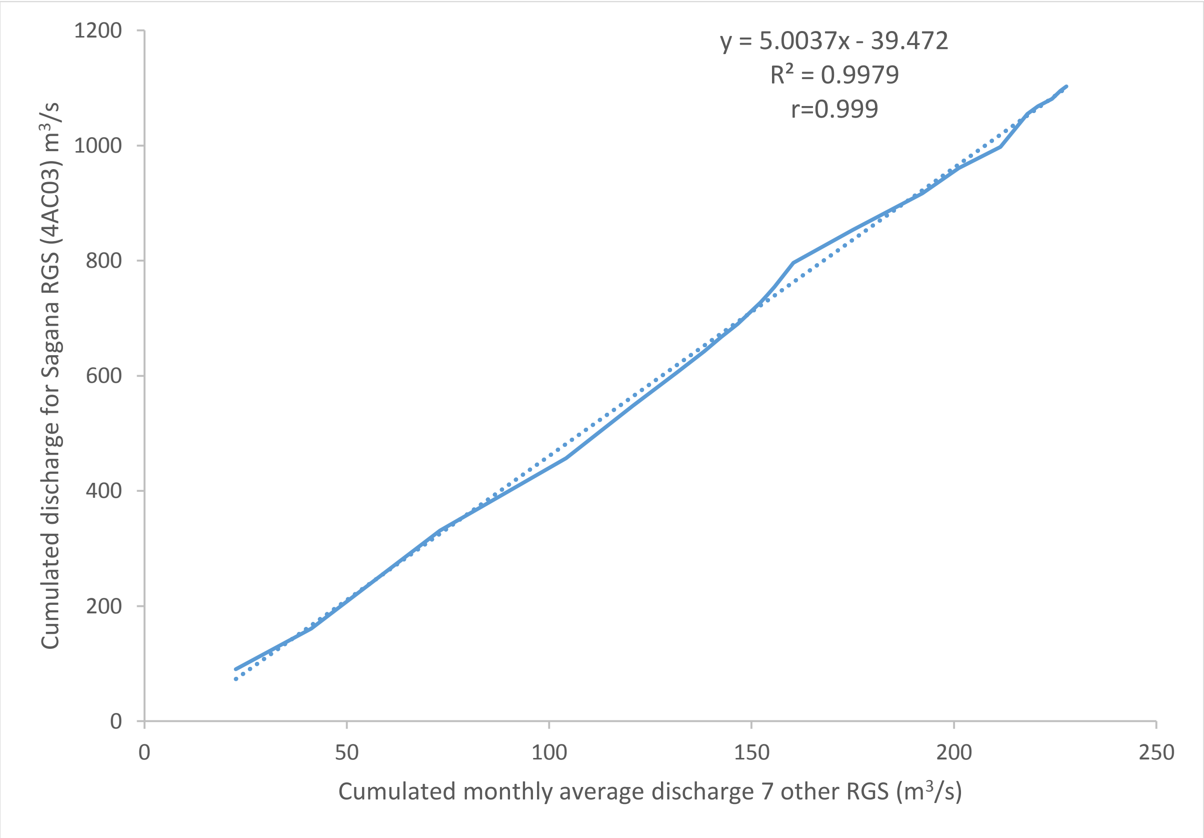

Figure 5. 3: Double Mass Curve (DMC) analysis for the cumulated discharge from Sagana and other RGS for data consistency check in NWUTcatchment (Njogu, 2018)

5.3 Analysis of Sediment Yield Data

5.3.1 Seasonal and Inter-Seasonal Variation of Total Suspended Sediment Concentration (TSSC)

The rivers draining the NWUT basin show great variability in Total Suspended Sediment Concentration (TSSC). The TSSC data covered the period of 2010 to 2012, with the results showing significant spatial temporal variability (Figure 5.4). Saba Saba river (4BF01) recorded the highest values for Total Suspended Sediment Concentration (TSSC) of 1433 (mg/l). The results of the study showed that the river discharge has been decreasing with time in the NWUT basin during the period of study. During the two rainy seasons the stream flow is much higher but highest during the long rains.Saba Saba river (4BF01) recorded the highest values of 800 mg/l and 1433mg/l during the wet (July-December) and dry (January-June) seasons respectively. This shows that the basin has a high potential for TSSC especially in the wet seasons. Thika River (4CC05) recorded values of 120mg/l during the dry season (January-June). Gikigie River (4BE08) had the lowest values of 14 mg/l and 19 mg/l during wet season and 5 mg/l during the dry season. During the second dry season (January-May 2012), Gikigie river (4BE08) and North Mathioya river (4BD07) had low value of TSSC of 10 mg/l.

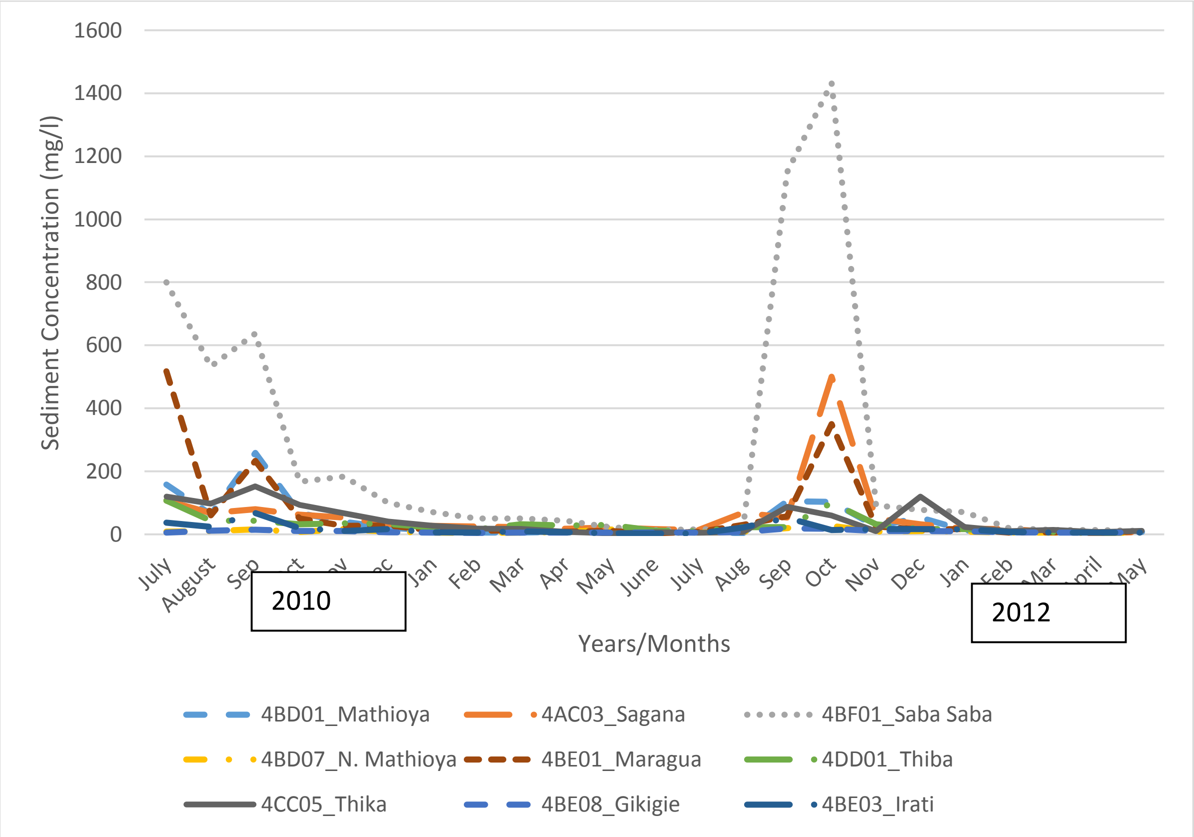

Figure 5. 4: The variability in Total Suspended Sediment Concentration (TSSC) (mg/l) in the period between July-May (2010-2012) (Njogu, 2018).

5.3.2 Seasonal and Inter-Annual Variation of Sediment Yield

Sediment yield in rivers in NWUT shows significant seasonal variation in the period of 2010 to 2012 (Figure 5.5). Sediment yield was highest during the wet seasons with some station like Sagana river (4AC03) recording the highest values of 82,166 tons/month and 2,519.4 tons/month during the dry season. Maragua river (4BE01), had the highest values of sediment yield of 48,418.6 tons/month and 10,987.5 tons/month in both wet seasons (July-December). However, it is important to note that during the onset of the second wet season in 2012 there was a major decrease in the values of sediment yield from this particular RGS. Thika river (4CC05) recorded high value of 7,804.5 tons/ month in the dry season (January-June). Gikigie river (4BE08) and Irati river (4BE03) recorded the lowest values of sediment yield of 290.3 tons/month and 349.9 tons/month (wet season) and 23.3 tons/month 155.5 tons/month (dry season) respectively.

5.3.3 Relationship Between Sediment Yield and Rainfall

A monthly average was computed for rainfall and sediment yield in the NWUTcatchment to come up with a monthly time series on the same parameters (Figure 5.6).

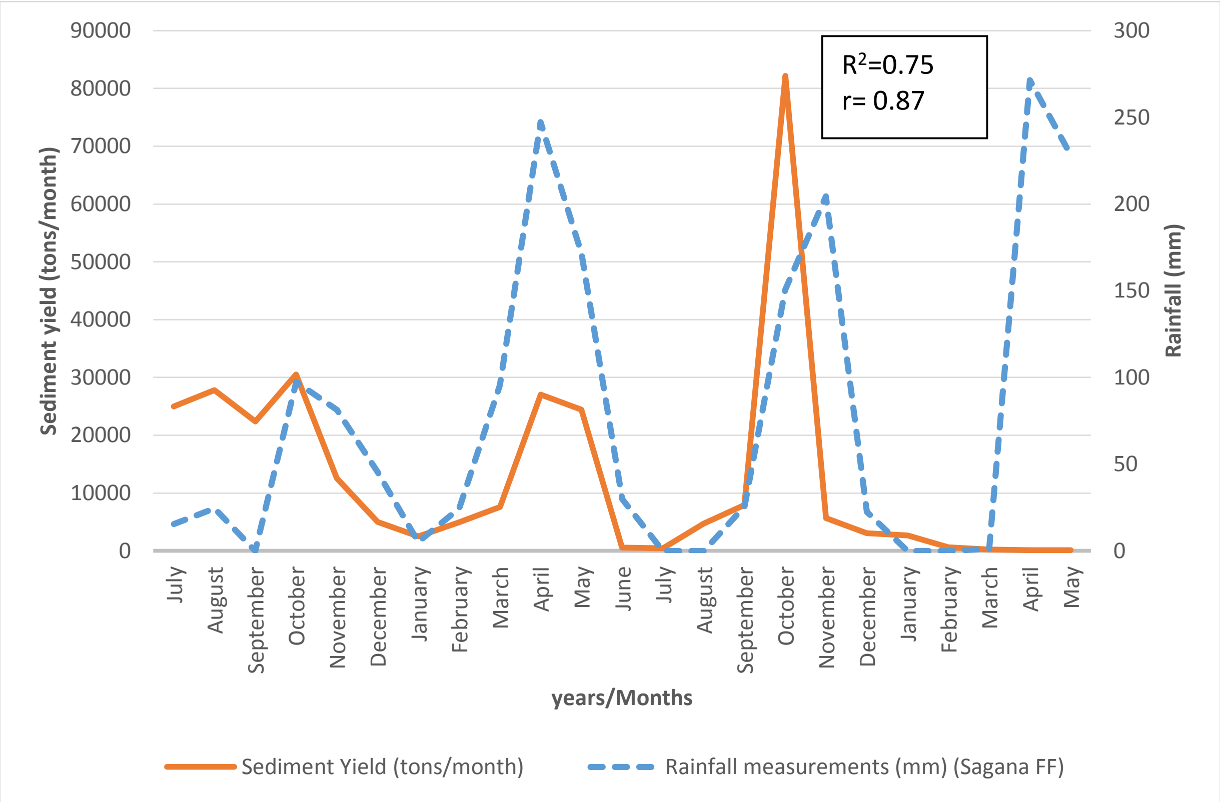

Figure 5. 5: Relationship between rainfall (mm) and Sediment yield (tons/month) in the NWUTcatchment in the period between July-May (2010-2012) (Njogu, 2018).

The relationship between rainfall and sediment yield in NWUT basin is quite significant with rainfall having 75% influence in sediment yield in the basin. The sediment yield peaks with rise in rainfall in the period of July to October since it's the beginning of the rainy season and there is low vegetation cover to protect the ground from rain drop impact. Sediment yield decreases as rainfall increases in the period of November to March, this is because there is improved vegetation cover that dissipates runoff and protects sediments detachment.

5.3.4 Relationship Between Sediment Yield and Stream Flow

There is significant relationship between sediment yield and stream flow for rivers draining the NWUT basin. Figure 5.7 shows the relationship between stream flow and TSSC for the river draining NWUT basin.

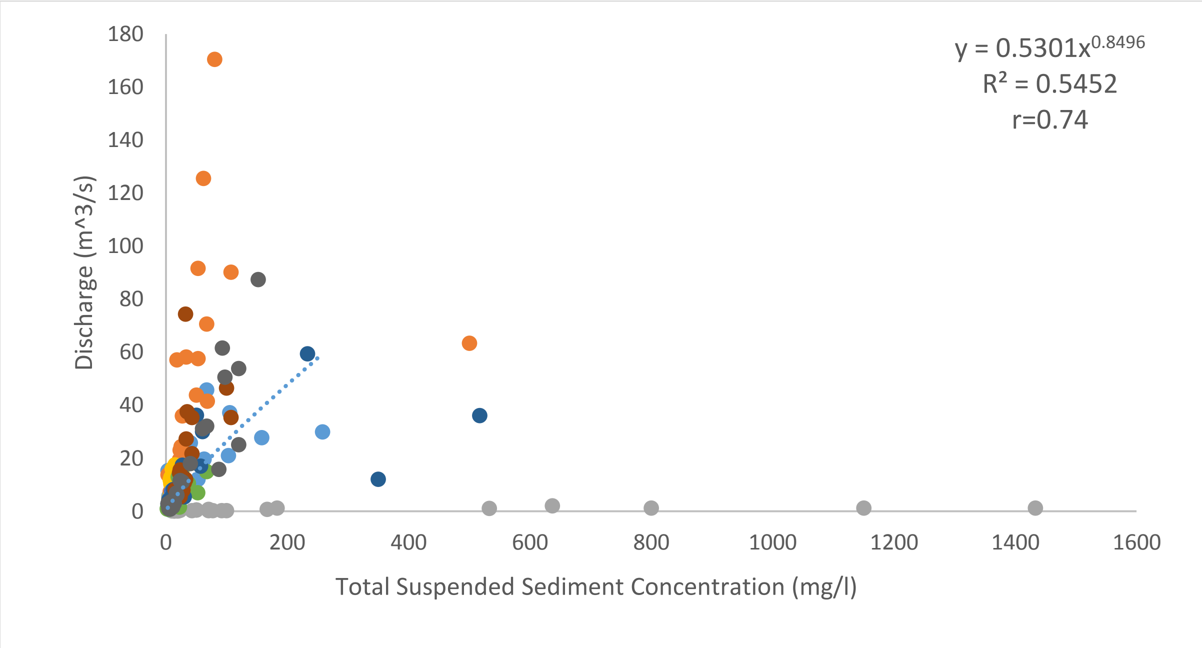

Figure 5. 6: The relationship between river discharge (m^3/s) and Total Suspended Sediment Concentration (TSSC) (mg/l) in different RGS in the period of July 2010 to May 2012 (Njogu, 2018)

Majority of the TSSC were measured when stream flow was below 100 m^3/s. The TSSC were relatively higher for lower flow compared to high flows. This is attributed to changes in the basin characteristics as low flows are associated with bare land susceptible erosion. The TSSC ranged from 2mg/l to 1433mg/l. The relationship is non-linear implying that stream flow is not the main driver in TSSC generation. The correlation coefficient (r) was 0.74 for the relationship between stream flow and TSSC. The coefficient of determination (R^2) was 0.55 implying that 55% of TSSC is influenced by stream flow.Figure 5.8 shows the relationship between stream flow and sediment yield for river draining NWUT basin in the period between 2010 and 2012 (July-May). The results are based on combined sediment yield and stream flow data for the main rivers in the study area namely Sagana, Thika, Thiba, Irati, Gikigie, Maragua, Mathoiya, North-Mathioya and Saba Saba. There is significant relationship between stream flow and sediment yield.

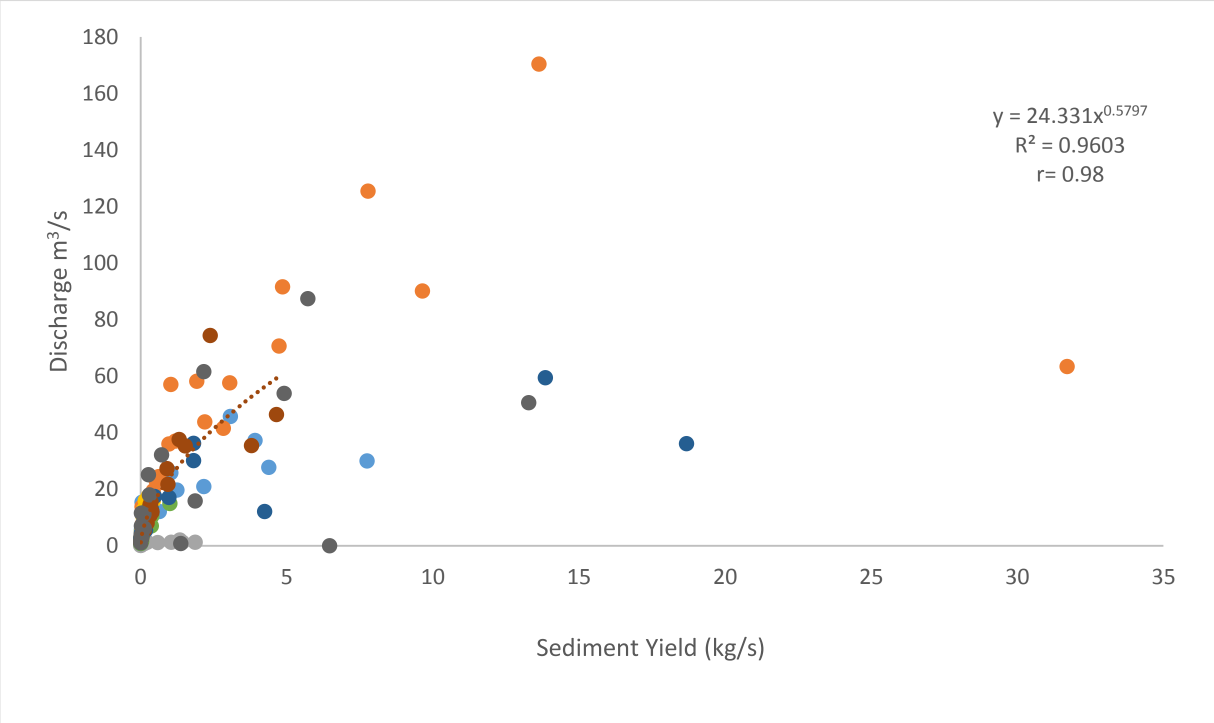

Figure 5. 7: Relationship between river discharge (m^3/s) and sediment yield (kg/s) in different RGS in the period of July 2010 to May 2012 (Njogu, 2018)

The sediment yield increases as stream flow increases. This is because at high flows, the river greater capacity to transport suspended sediments. The relationship was best presented by a power function of the form $y= a\ x^b$. High sediment yield of 35,334.14 tons/month occurred during high stream flow of 170.4 m^3/s. The lowest sediment yield of 2.6 tons/month occurred during low flows of 0.12 m^3/s. The relationship were confirmed through determination of correlation coefficient (r) and coefficient of determination (R^2) which were 0.98 and 0.96 respectively. These figures of the coefficients shows that sediment yield is highly related to stream flow.

5.3.4.1 Relationship betweenStream Flow and Sediment Yield in River Sagana

There is significant relationship between stream flow and sediment yield in river Sagana.Figure 5.9 during the period of July to May (2010 to 2012) in NWUT basin.

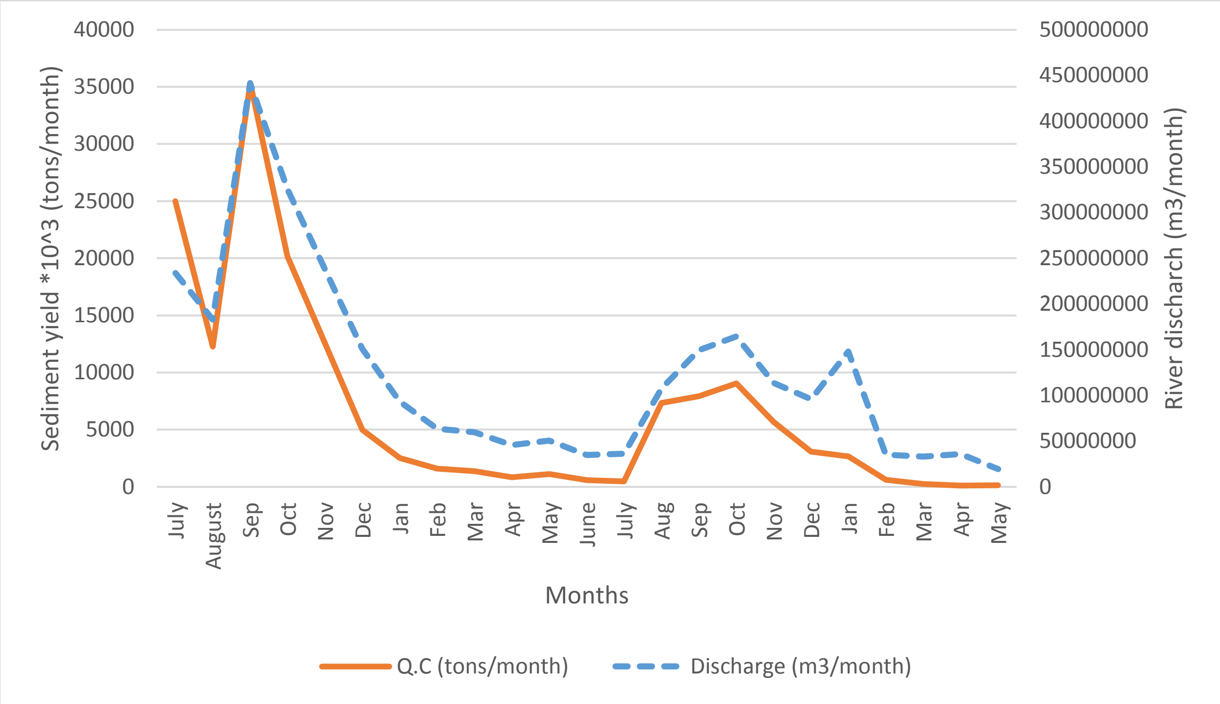

Figure 5.8: Relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Sagana in the period of July to May (2010 to 2012) (Njogu, 2018).

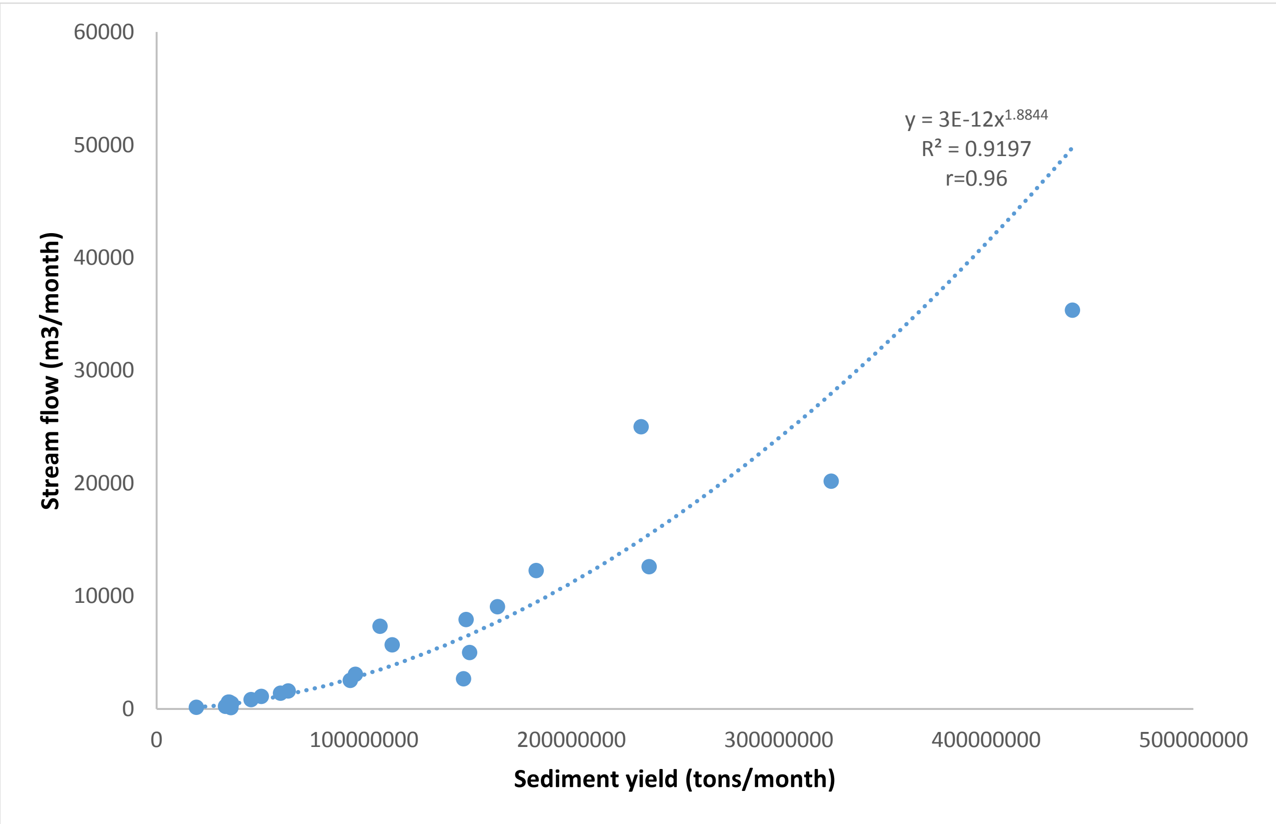

Figure 5. 9: Scatter plot on the relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Sagana in the period of July to May (2010-2012) (Njogu, 2018).

Majority of sediments were transported during high flows while in low flow the river transport low sediments. The relationship between stream flow and sediment yield in river Sagana had a correlation coefficient (r) of 0.96 and coefficient of determination (R^2) of 0.92. This shows that stream flow has 92% influence on sediment yield in the basin.

5.3.4.2 Relationship between Stream Flow and Sediment Yield in River Maragua

There is significant relationship between stream flow and sediment yield in river Maragua. Figure 5.11 shows the relationship between stream flow and sediment yield in river Maragua during the period of July to May (2010 to 2012) in NWUT basin. Majority of sediments were transported during high flows while in low flow the river transported low sediments. The relationship between stream flow and sediment yield in river Maragua had a correlation coefficient (r) of 0.97 and coefficient of determination (R^2) of 0.94. This shows that stream flow has 94% influence on sediment yield in the basin.

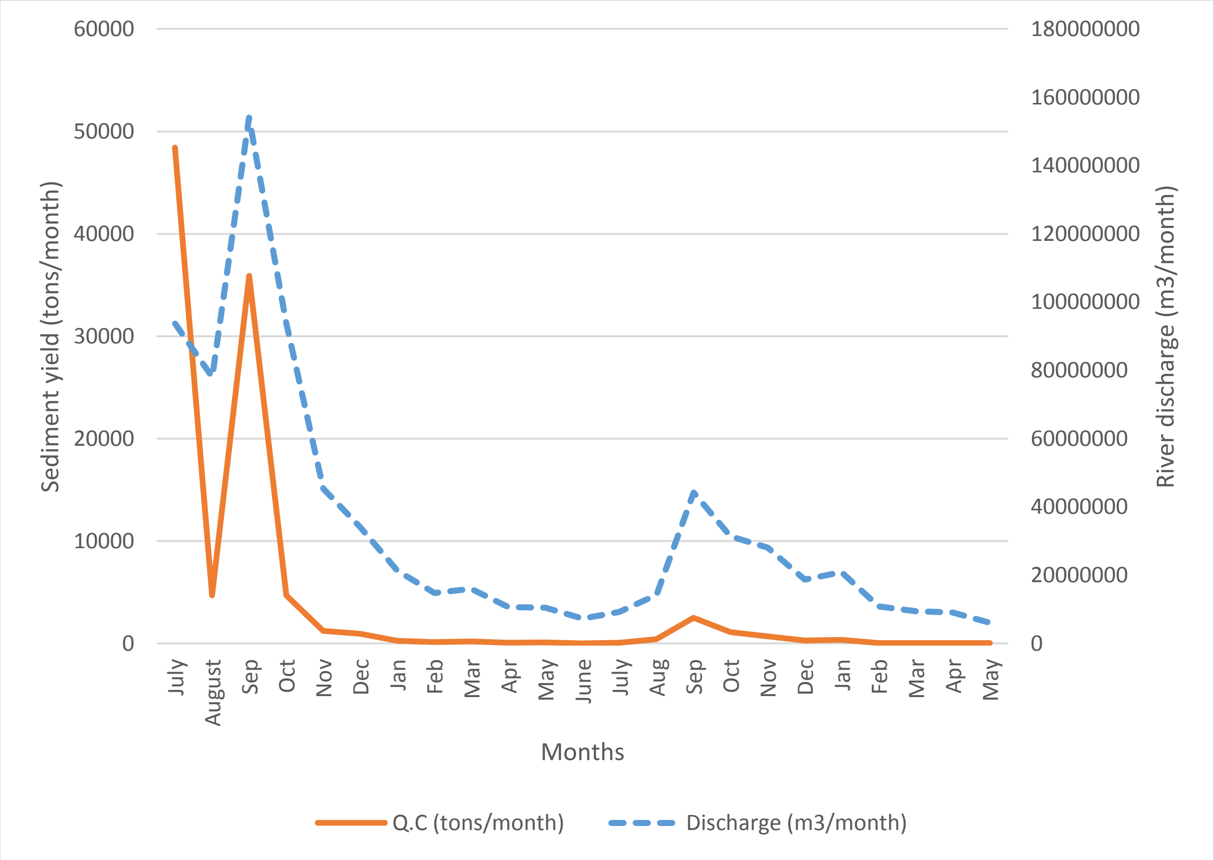

Figure 5. 10: Relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Maragua in the period of July to May (2010 to 2012) (Njogu, 2018).

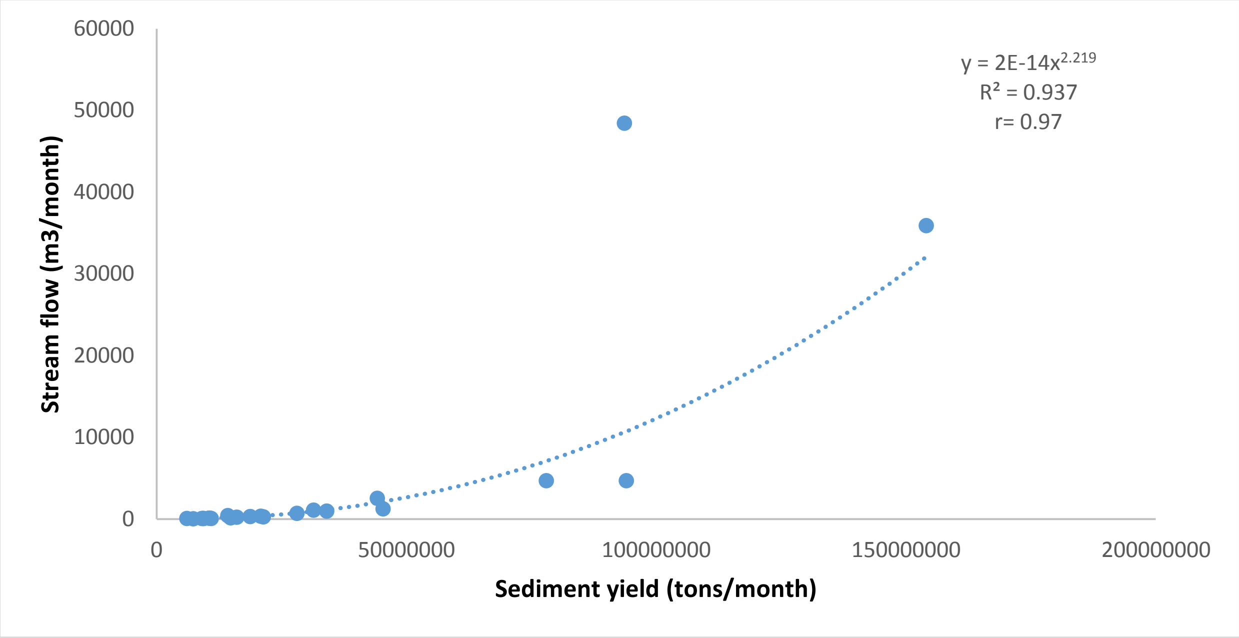

Figure 5. 11: Scatter plot on the relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Maragua in the period of July to May (2010-2012) (Njogu, 2018).

5.3.4.3 Relationship between Stream Flow and Sediment Yield in River Mathioya

There is significant relationship between stream flow and sediment yield in river Mathioya. Figure 5.13 shows the relationship between stream flow and sediment yield in river Mathioya during the period of July to May (2010 to 2012) in NWUT basin.

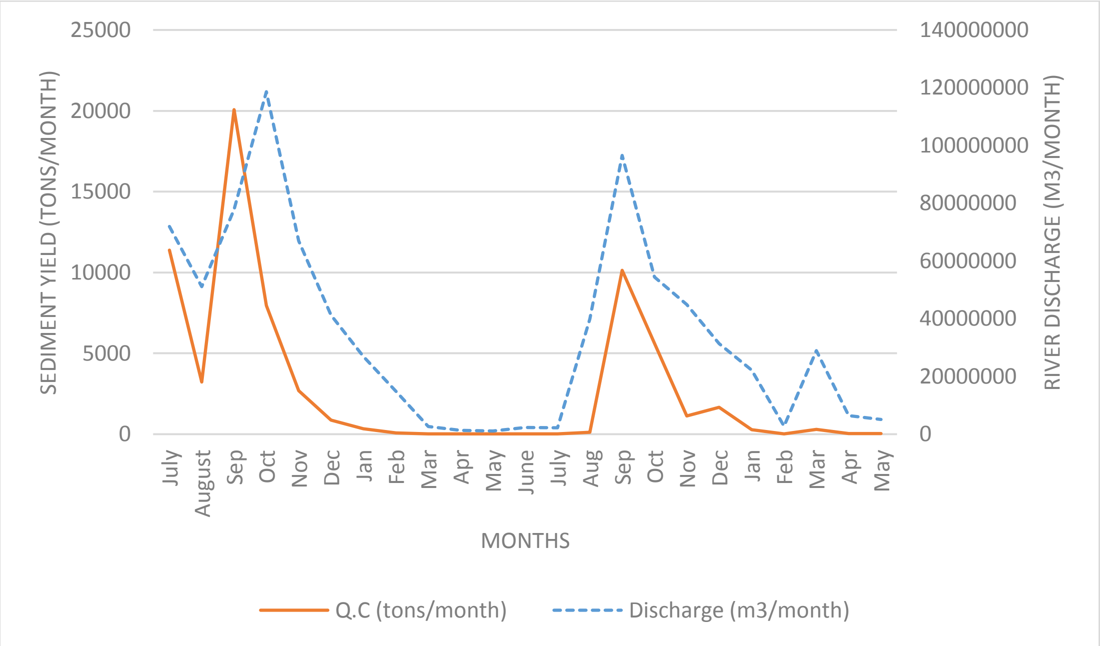

Figure 5. 12: Relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Mathioya in the period of July to May (2010 to 2012) (Njogu, 2018).

Majority of sediments were transported during high flows while in low flow the river transported low sediments. The relationship between stream flow and sediment yield river Mathioya had a correlation coefficient (r) of 0.94 and coefficient of determination (R^2) of 0.88. This shows that stream flow has 88% influence on sediment yield in the basin.

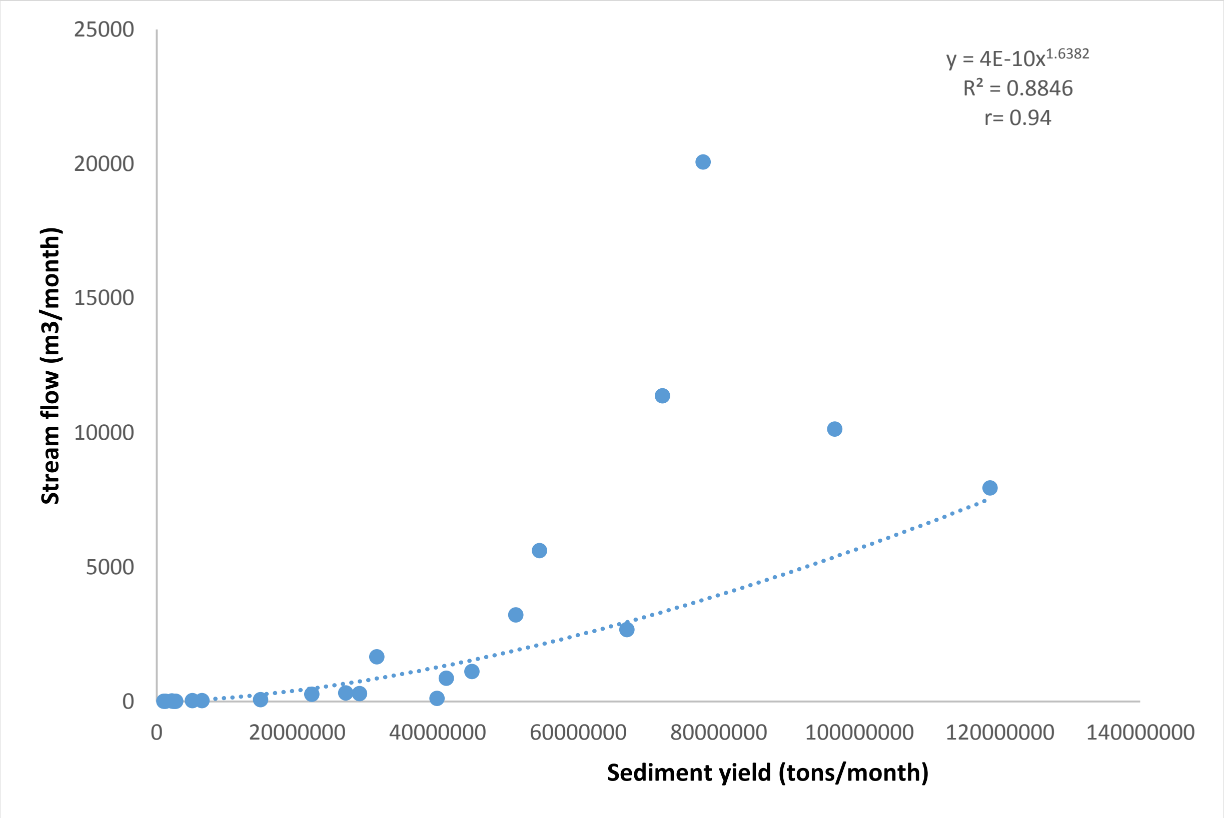

Figure 5. 13: Scatter plot on the relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Mathioya in the period of July to May (2010-2012) (Njogu, 2018).

5.3.4.4 Relationship between Stream Flow and Sediment Yield in Thika River

There is significant relationship between stream flow and sediment yieldin Thika river.Figure 5.15 shows the relationship between stream flow and sediment yield in Thika river during the period of July to May (2010 to 2012) in NWUT basin. Majority of sediments were transported during high flows while in low flow the river transported low sediments. The relationship between stream flow and sediment yield in Thika river had a correlation coefficient (r) of 0.96 and coefficient of determination (R^2) of 0.92. This shows that stream flow has 92% influence on sediment yield in the basin.

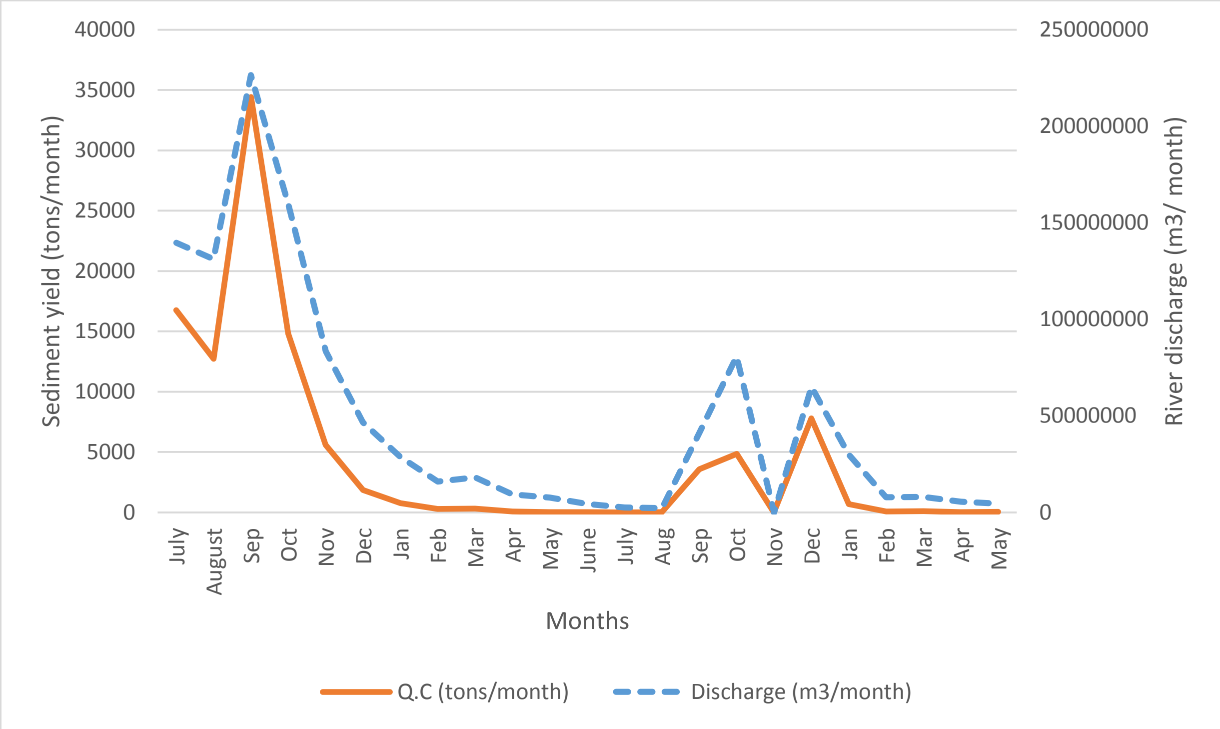

Figure 5. 14: Relationship between stream flow (m^3/month) and sediment yield (tons/month) for Thika river in the period of July to May (2010 to 2012) (Njogu, 2018)

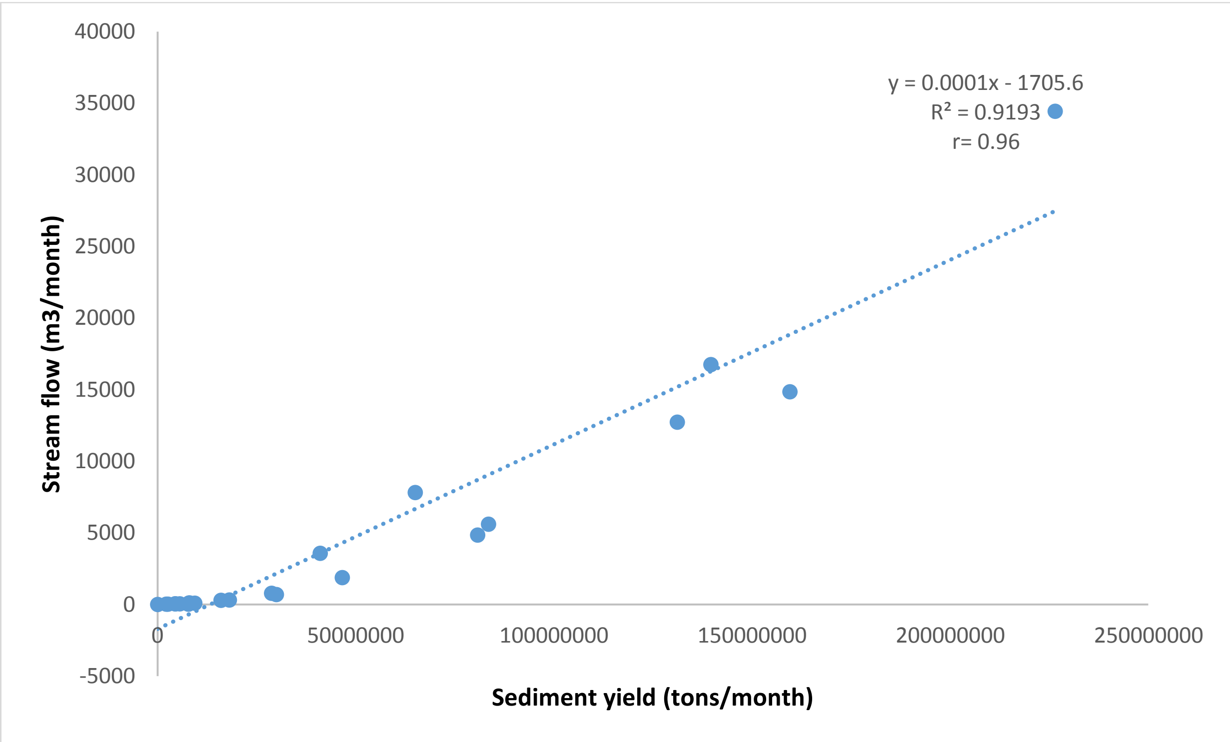

Figure 5. 15: Scatter plot on the relationship between stream flow (m^3/month) and sediment yield (tons/month) for river Mathioya in the period of July to May (2010-2012) (Njogu, 2018).

5.3.5 Estimation of Sediment Production Rates and Yield in the Sub-Basins

Estimation of sediment production rates and water yield from Sagana, Maragua, Mathioya and Thika sub-basins was carried out. This sub-basins were preferred because they form the main rivers in the NWUT basin.

5.3.5.1 Estimation of Sediment Yield and Water Yield in Sagana River

Figure 5.17 shows the comparison between annual river discharge and annual sediment flux in river Sagana in the NWUT basin. There is a significant relationship between annual river discharge and annual sediment flux in the basin. The annual sediment flux for river Sagana was 146,626.5 tons/year while annual river discharge was 1.072 E+12 m^3/year in the year 2011. Sagana sub-basin have a surface area of 1,501.26 km^2 and a sediment production rate of 152.34 tons/km^2/month.

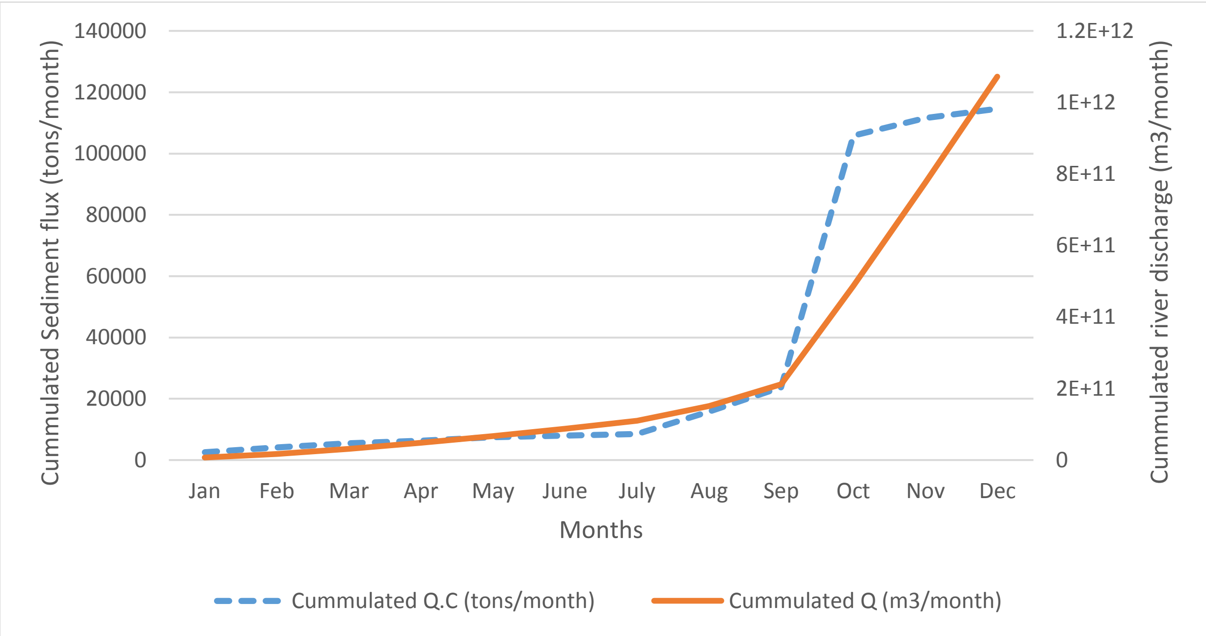

Figure 5. 16: Comparison between annual sediment flux (tons/year) and annual river discharge (m^3/year) for river Sagana in year 2011 (Njogu, 2018)

5.3.5.2 Estimation of Sediment Yield and Water Yield in River Maragua

Figure 5.18 shows the comparison between annual river discharge and annual sediment flux in river Maragua in the NWUT basin. There is a significant relationship between annual river discharge and annual sediment flux in the basin. The annual sediment flux for river Maragua was 15,805.3 tons/year while annual river discharge was 1.45 E+11 m^3/year in the year 2011.

Maragua sub-basin have a surface area of 1,307.21 km^2 and a sediment production rate of 85.86 tons/km^2/month.

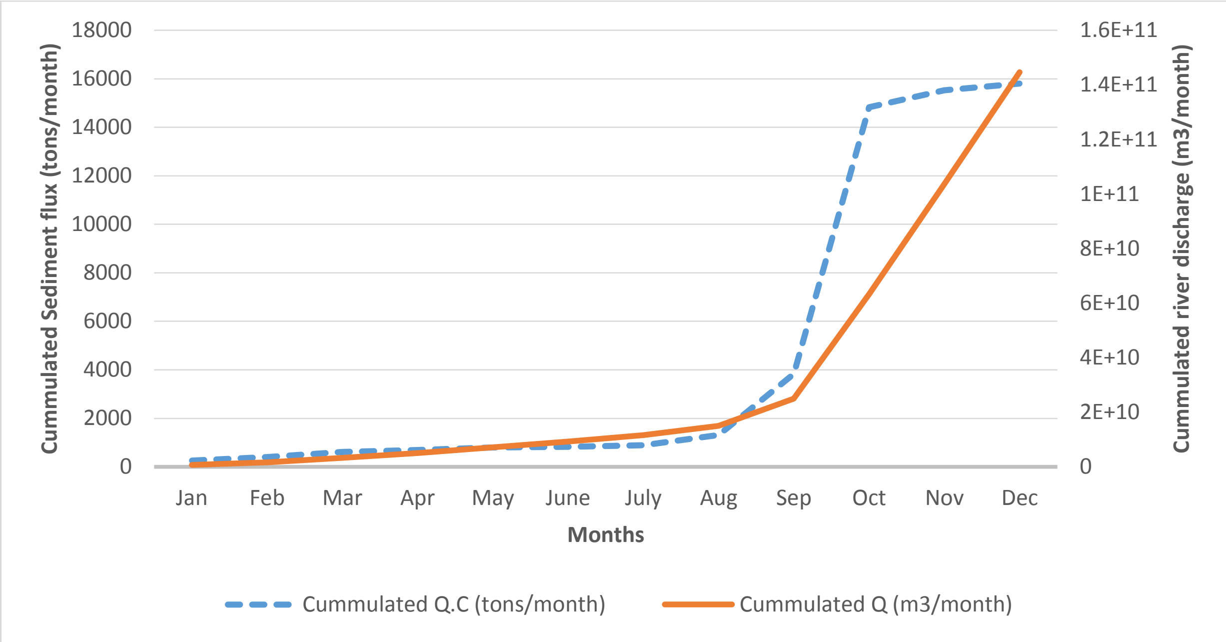

Figure 5. 17: Comparison between annual river discharge (m^3/year) annual sediment flux (tons/year) and for Maragua river in year 2011 (Njogu, 2018).

5.3.5.3 Estimation of Sediment Yield and Water Yield in River Mathioya

Figure 5.19 shows the comparison between annual river discharge and annual sediment flux in river Mathioya in the NWUT basin.

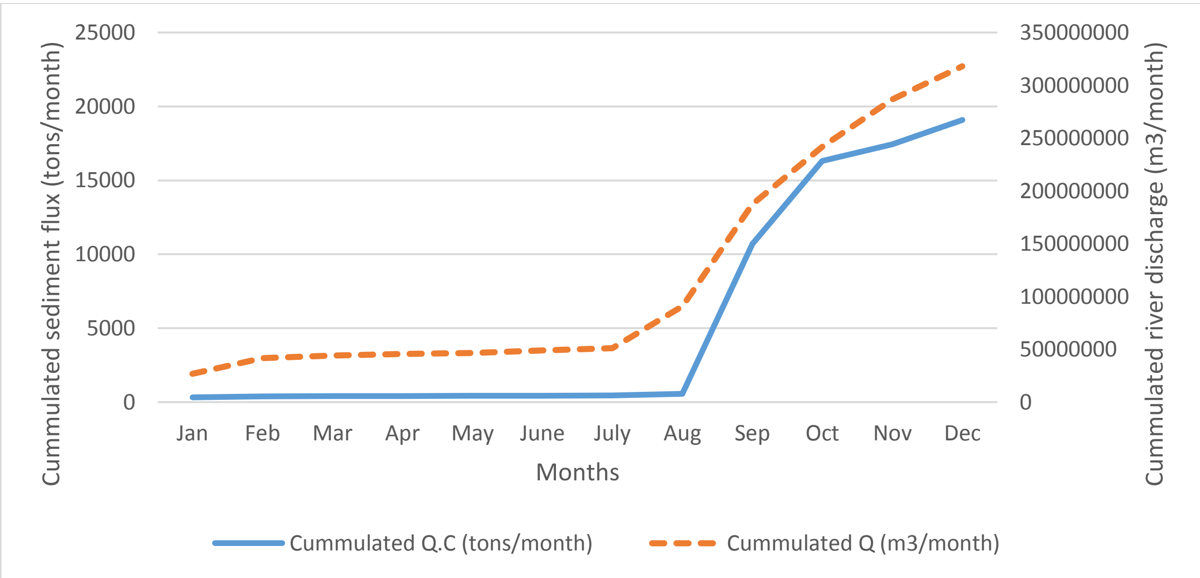

Figure 5. 18: Comparison between annual sediment flux (tons/month) and annual river discharge (m^3/month) for Mathioya river in year 2011 (Njogu, 2018)

There is a significant relationship between annual river discharge and annual sediment flux in the basin. The annual sediment flux for river Mathioya was 19,096.59 tons/year while annual river discharge was 318,064,320 m^3/year in the year 2011. Mathioya sub-basin have a surface area of 1,318.32 km^2 and a sediment production rate of 49.97 tons/km^2/month.

5.3.5.4 Estimation of Sediment Yield and Water Yield in Thika River

Figure 5.20 show the comparison between annual river discharge and annual sediment flux in Thika river in the NWUT basin. There is a significant relationship between annual river discharge and annual sediment flux in the basin. The annual sediment flux for Thika river was 17,754.84 tons/year while annual river discharge was 276,229,440 m^3/year in the year 2011. Thika sub-basin have a surface area of 1,186.68 km^2 and a sediment production rate of 88.41 tons/km^2/month.

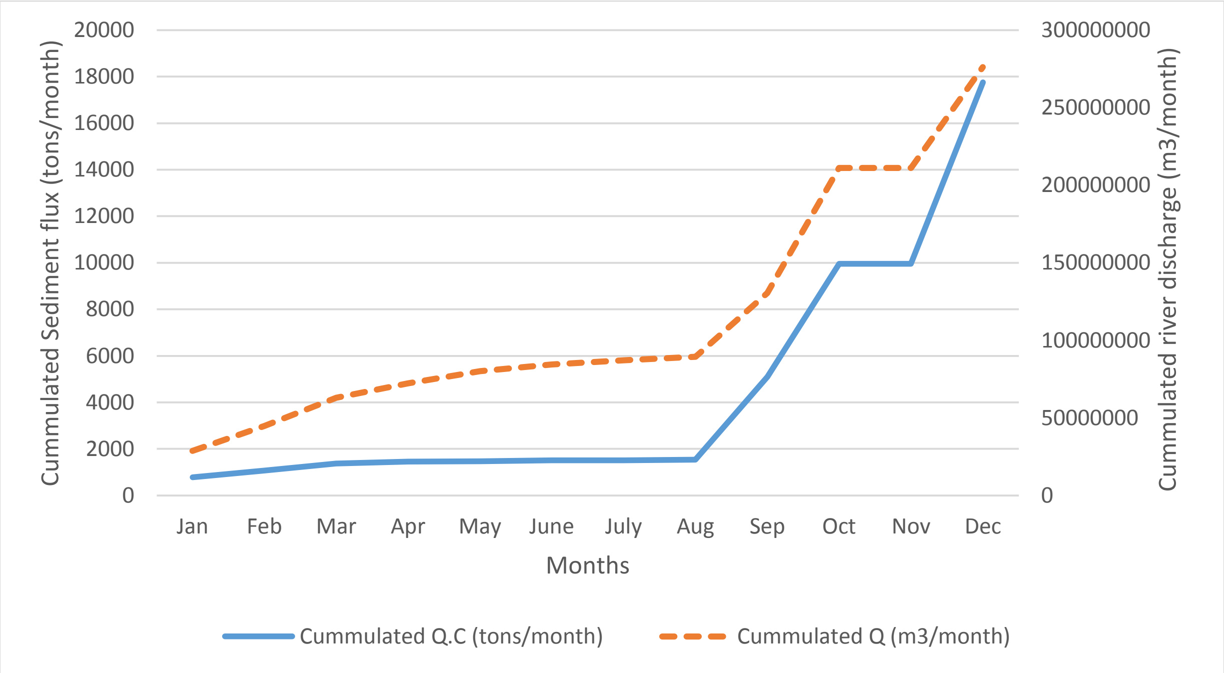

Figure 5. 19: Comparison between annual sediment flux (tons/year) and annual river discharge (m^3/year) for Thika river in year 2011 (Njogu, 2018)

Table 5.1: Water yield, sediment yield and sediment production rates in NWUT basin

Sub-basin	**Water Yield (m^3/month)**	**Sediment Yield (tons/month)**	**Sub-basin area (km^2)**	**Sediment production rate (tons/km^2/month)**
Sagana (4AC03)	124,262,734	228,702.6	1,501.26	**152.34**
Mathioya (4BD01)	35,253,454	65,881.49	1,318.32	**49.97**

N.Mathioya (4BD07)	20,342,692	5,444.055	957.58	**5.69**
Maragua (4BE01)	33,998,024	112,241.1	1,307.21	**85.86**
Irati (4BE03)	10,965,287	7,035.388	889.19	**7.91**
Gikigie (4BE08)	9,174,553	2,166.186	1,021.69	**2.12**
Saba Saba (4BF01)	1,578,866	17,742.11	1,011.43	**17.54**
Thika (4CC05)	48,654,094	104,914.1	1,186.68	**88.41**
Thiba (4DD01)	43,427,270	46,510.41	725.06	**64.15**
Total for NWUT basin	**327,638,974**	**590,637.4**	**9,918.42**	**59.55**

(Source: Njogu, 2018)

5.3.6 Spatial Temporal Variation in Sediment Yield

This study examined the spatial temporal variability in sediment yield in NWUT catchment which catered for all the factors leading to sedimentation of reservoirs in the study area. This exercise further examined the spatial temporal variability in TSSC and river discharge which are the parameters in sediment yield assessment.

5.3.6.1 Variability in Total Suspended Sediment Concentration (TSSC)

Spatial temporal variability in TSSC was conducted in NWUT catchment in the period between July-May (2010-2012). Significant changes were observed during the rainy and dry seasons, while RGS in the mountainous regions having the low amounts of TSSC and downstream RGS recording the highest amounts in TSSC. Data on Total Suspended Sediment Concentration (TSSC) was available for two wet seasons and two dry seasons. The spatial temporal variability in TSSC was done for nine RGS spatially distributed in the NWUT catchment. The distribution of the data available was done for every RGS showing the maximum values per station for the four seasons. Sagana (4AC03) had maximum values of 107 mg/l, 27 mg/l, 500mg/l and 32 mg/l during the July-December, January-June two seasons in the period of 2010-2012 respectively. It is important to note the gradual increase in TSSC for Sagana (4AC03) during both seasons from 107 mg/l to 500mg/l (wet season) and from 27 mg/l to 32 mg/l (dry season). Mathioya (4BD01) had maximum values of 258 mg/l, 12 mg/l, 105 mg/l and 53mg/l for the four seasons. For this particular RGS, there was a major decrease from 258mg/l to 105 mg/l (wet season) while in dry season there was significant increase form 12 mg/l to 53 mg/l. Maragua (4BE01) had maximum values of 517 mg/l, 13 mg/l, 350 mg/l and 17 mg/l for the four seasons. There was also a gradual increase in TSSC from 2010-2012 during the dry period while a decrease was recorded in the wet season. Saba Saba (4BF01) had the maximum values as 800 mg/l, 70 mg/l, 1433 mg/l and 77 mg/l. This station had the highest values during the period of 2010-2012. There is a nearly double increase in TSSC during the wet season (July-December) from 800 mg/l to 1433 mg/l while in dry season there is a gradual increment of 7 mg/l. Other stations like Gikigie (4BE08), Irati (4BE03), Thika (4CC05), Thiba (4DD01) and North Mathioya (4BD07) had low values of TSSC close to flat bars during the period of 2010-2012. Overall, North Mathioya (4BD07) and Gikigie (4BE08) had the lowest values of TSSC in North-West Upper Tana catchment. It however important to note the increase in wet season for North Mathioya from 16 mg/l to 27 mg/l and decrease in dry season from 15 mg/l to 10 mg/l. Gikigie RGS had an increase in both wet and dry season from 14 mg/l to 19 mg/l and 5 mg/l to 10 mg/l respectively.

5.3.6.2 Variability in Sediment Yield

Sediment in the NWUTcatchment were highly variable in terms of space with Sagana, Mathioya, Maragua, Thika and Thiba RGS showing the highest values. Maximum values for sediment yield during the two wet seasons (July-December) and two dry seasons (January-June) in 2010 to 2012. Sagana (4AC03) showed a significant increase in both wet (July-December) and dry (January-June) seasons from 13.63 kg/s to 31. 7 kg/s and 0.972 kg/s to 1.184 kg/s respectively. Mathioya (4BD01) on the other recorded a decrease in the wet season (July-December) from 7.743 kg/s to 3.909 kg/s and an increase in the dry season (January-June) from 0.125 kg/s to 0.64 kg/s in the period between 2010 and 2012. Maragua (4BE01) on the other hand recorded the highest values in sediment yield during the onset on the first wet season (July-December) 2011 of 18.68 kg/s. However, this value decreases significantly during the onset on the second wet season (July- December) 2012 to 4.24 kg/s. There is a notable increase in sediment yield value in the dry season (January-June) from 2010 to 2012 from 0.099 kg/s to 0.137 kg/s. Thika (4CC05) had high values of sediment yield of 13.282 kg/s during the first wet season in 2010. However, this value decreased significantly during the second wet season in 2011 to 1.87 kg/s. During the dry season (January- June), values of sediment yield increase from 0.3 kg/s to 3.011 kg/s in the period between 2010 and 2012. Thiba (4DD01) also had relatively high values of sediment yield from this catchment.

During the wet season (July-December), there was an increase from 3.791 kg/s to 4.647 kg/s while in the dry season (January-June) there was decrease from 0.382 kg/s to 0.086 kg/s. Overall, there was high values of sediment yield in the onset of first wet season (July-December) in 2010 which decreased in most RGS with Sagana (4AC03) showing the only increase during the period of 2010-2012. It is important to note that North Mathioya and Gikigie RGS had the lowest values in sediment yield during the period of 2010-2012. Despite North

Mathioya (4BD07) having recorded the lowest values in sediment yield in NWUTcatchment, it is important to note the increase in both wet and dry seasons from 0.264 kg/s to 0.428 kg/s and 0.044 kg/s to 0.159 kg/s respectively. There is also a gradual increase in Gikigie (4BE08) in both wet and dry season from 0.112 kg/s to 0.135 kg/s and 0.009 kg/s to 0.079 kg/s respectively. It was noted during the period of study that the major contributing rivers to sedimentation of Masinga reservoir were the Sagana (4AC03), Maragua (4BE01), Thika (4CC05) and Mathioya (4BD01) having a total of 47.49 kg/s, 23.15 kg/s, 18.46 kg/s and 12.42 kg/s respectively. The following values translated from the yearly computation on sediment load from these stations Sagana (4ACO3), Maragua (4BE01), Mathioya (4BD01) and Thika (4CC05) having 1, 4497, 581.568 tons/yr, 730, 184.544 tons/yr, 391, 582.512 tons/yr and 582, 249.168 tons/yr. Computation of the values of sediment load in tons per year into the reservoir were done during the period of 2010-2012 and a total of 3.67 million tons/year were deposited in the dam during this period.

5.4 Land Use Land CoverChange in NWUTBasin

This study examined the land use land cover changes that have taken place in NWUTcatchment from 2005 to 2014. Land use changes were categorized as into nice classes which were easily identified from the satellite images.

5.4.1 Determination of Land Use Land Cover Change

Determination of land use and land cover changes in the North Western parts of the Upper Tana was done for the year 2000, 2005 and 2014 between the month of January and February. The northern parts of the NWUT is well covered with green vegetation and forest especially on Mount Kenya and the Aberdare Ranges. The water bodies cover about 1.5% of the study area. The main waterbody in the study area is the Masinga reservoir which ispart of the seven folk dams. The built-up areas are not well visible in the rural areas but some towns and settlements were observed with most people occupying highlands and towns.

5.4.2 Land Use and Land Cover in 2000

The study area was classified into nine land use land cover categories, which were: Water Bodies, sedimented water, plantation, rangeland, forest, evergreen vegetation, rain-fed cropland, built-up area and bare land.

Table 5.2: Land use Land cover in 2000 in North-West Upper Tana catchment

LULC	Area (km^2)	% Area
Bare land	350.36	6.5%
Built-up land	10.95	0.2%
Cropland	1271.92	23.6%

Evergreen Vegetation	327.16	6.1%
Forest	1739.92	32.3%
Rangeland	916.83	17.0%
Plantation	681.50	12.7%
Sedimented waterbody	5.28	0.098%
Waterbody	81.80	1.5%
Total	**5385.72**	**100.0%**

(Source: Njogu, 2018)

Figure 5.21 shows the land use and land cover map in the year 2000 generated from Landsat 5 satellite image while table 5.2 below provides details on individual changes per class.In the year 2000, a huge land in the NWUTregion was still covered with forest (32.3%) which was largely observed at the northern parts of the area while the evergreen vegetation covered only 6.1% of the land.

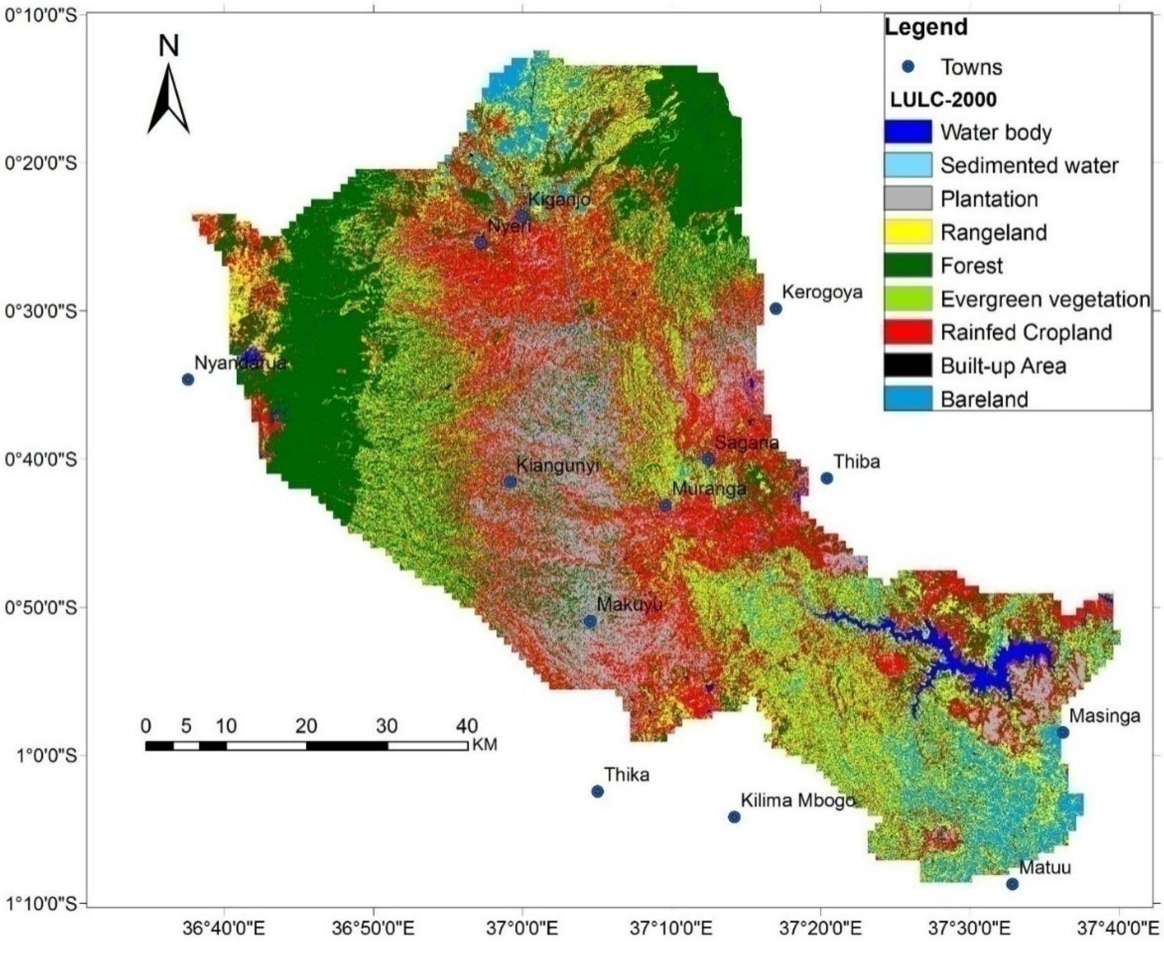

Figure 5. 20: Land use Land cover in 2000 map in the NWUTcatchment (Njogu, 2018)

The cropland was also relatively large (23.6%) mainly observed around the reservoir.The land category defined here as plantation covered 12.7% of the land area in 2000 where the common vegetation were banana plantations, mango plantations, shrubs and maize plantations. The bareland and the built-up area covered 6.5% and 0.2%, respectively. During the year 2000, the water body covered 1.5% while the sedimented section of the waterbodies was 0.098%.

5.4.3 Land Use and Land Cover in 2005

Land Use Land Cover in 2005 was very significant for this study because it showed the changes that took place in between 2000 and 2014. During the year 2005, the land used as cropland was increased to 38.9%. The cropland is represented in red shades in the map shown in Figure 5.25 which the plantation which occupied 13.4% of the land was represented in gray shades in the map. The bareland increased from 6.5% in 2000 to 7.3% in 2005 as indicated in Table 5.3. The waterbody coverage was slightly higher at 1.6% in 2005 compared to the year 2000. Forest cover was 21.3% with an area coverage of 1,149.43 km^2. Sedimented waterbody covered 0.052% which was asurface area of 2.78 km^2. The surface area of waterbody was 86.04 km^2 covering 1.6% of the total surface area of the study area. Rangeland and plantation covered a surface of 55.42 km^2 and 720.97 km^2 respectively representing 10.3% and 13.4% respectively in 2005. Built-up land decreased by 3.5 km^2 from 2000 to 2005 resulting to a total built-up area of 7.45 km^2 in 2005. This means some of the buildings that existed in 2000 were demolished hence the decrease in the area by 2005. The evergreen vegetation increased by 52 km^2 which is approximately 1% of the total surface area from 2000 to 20005. This shows that some of the trees which were cut down in 2000 had regenerated resulting to the increase in broad leafed forest cover by 2005.

Table 5. 3: Land use Land cover in 2005 in NWUT catchment

LULC	Area(km^2)	%Area
Bareland	391.47	7.3%
Built-up land	7.45	0.1%
Cropland	2096.02	38.9%
Evergreen Veg	379.13	7.0%
Forest	1149.43	21.3%
Rangeland	552.42	10.3%
Plantation	720.97	13.4%
Sedimented waterbody	2.78	0.052%
Waterbody	86.04	1.6%
Grand Total	**5385.72**	**100.0%**

(Source: Njogu, 2018)

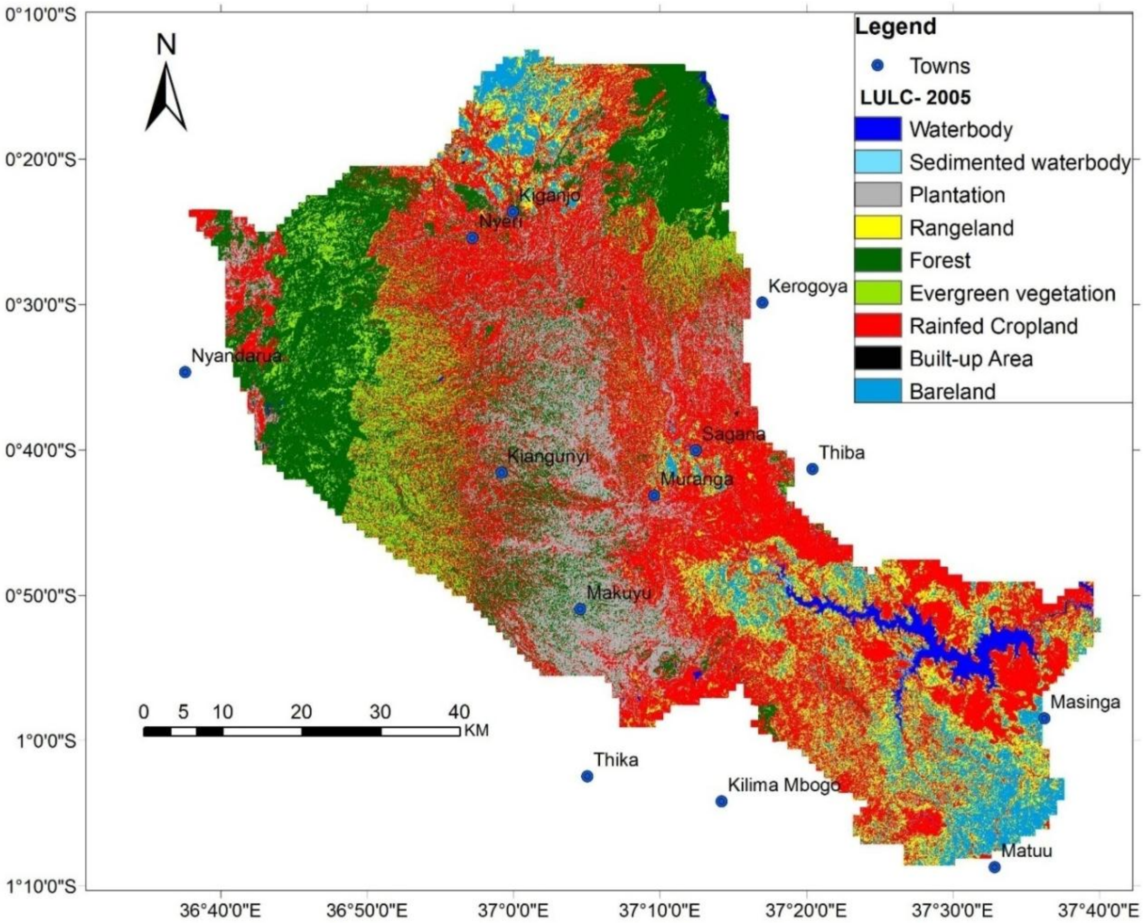

Figure 5. 21: Land Use Land Cover 2005 map for NWUTcatchment (Njogu, 2018)

5.4.4 Land Use and Land Cover in 2014

Land use land cover change in the 2014 shows major changes in many of the classes adopted for this study in NWUTcatchment. Waterbody decreased by more than half between the year 2005 and 2014. More waterbodies were significantly sedimented in 2014 showing 26.3km^2 (0.5%) of land coverage. The cropland was reduced while the plantation was increased and this accounted to 1623.2km^2 (30.1%), and 809.8km^2 (15%), respectively.

Table 5.4: Land use Land cover 2014 in NWUTcatchment

LULC	Area(km^2)	%Area
Bareland	524.43	9.7%
Built-up land	41.40	0.8%
Cropland	1623.17	30.1%
Evergreen Veg	465.33	9.0%
Forest	1170.42	21.7%
Rangeland	685.53	12.7%
Plantation	809.76	15.0%
Sedimented waterbody	39.38	0.7%
Waterbody	26.30	0.5%
Grand Total	**5385.72**	**100.4%**

(Source: Njogu, 2018)

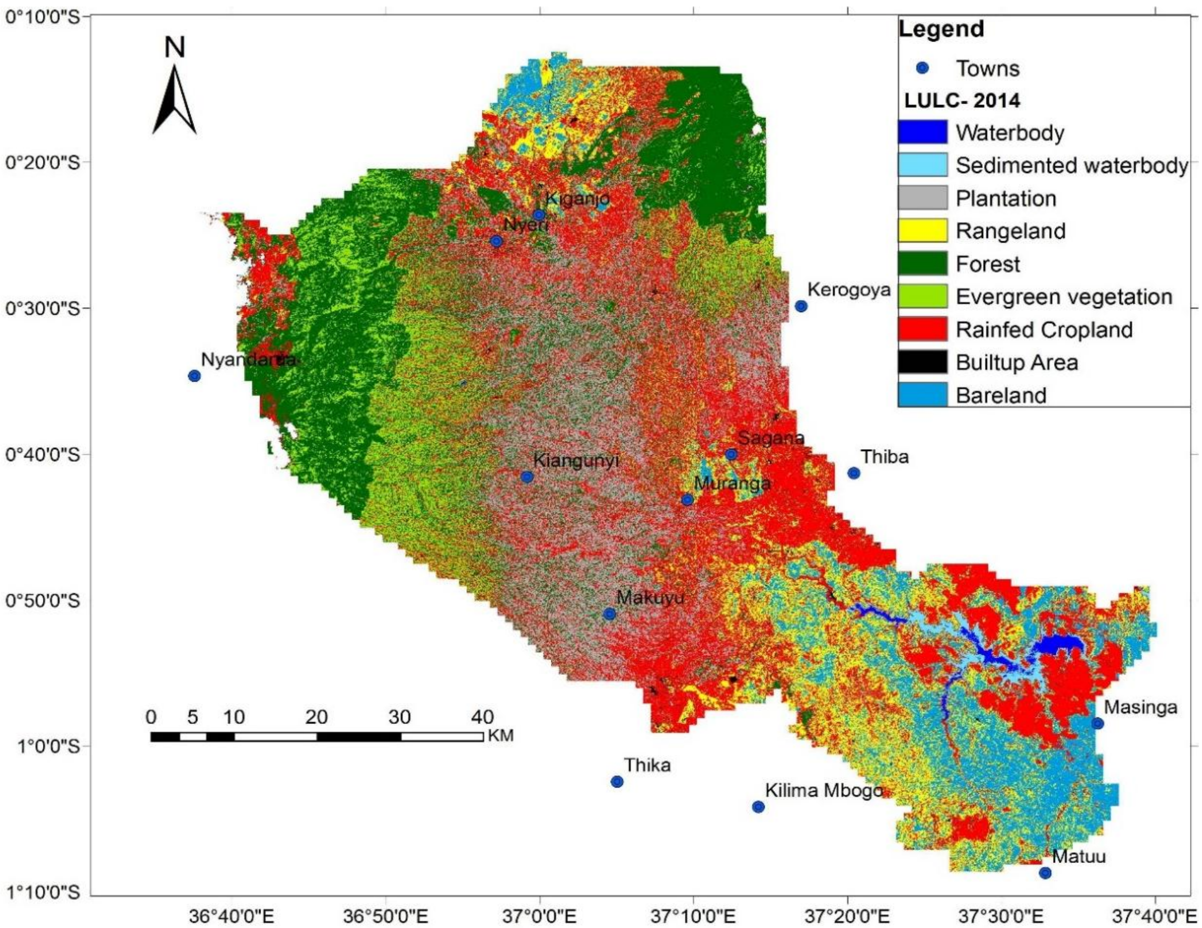

Figure 5. 22: Land Use Land Cover 2014 map for NWUTcatchment (Njogu, 2018)

The built-up land was 41.4km^2 (0.8%) which was an increase by more than six times since 2000. The bareland increased consistently as shown in the map (Figure 5.23). The forest cover showed a slight increase by 0.4% from 2005 to 2014. Figure 5.26 shows the land cover and land use map of the NWUT catchment in 2014.

5.4.5 Land Use and Land Cover Changes between the year 2000 and 2014

This study analyzed the land use land cover that has occurred in the period between 2000 and 2014. Table 5.5 shows the transitioning area coverage in square kilometers of the classified LULC categories from the year 2000 through to 2014. The changes in land cover and land use was indicated with negative (decreased) and positive (increased) changes.

Table 5.5: Land use Land cover changes between the year 2000 and 2014 in NWUT catchment

	2000-2005		2005-2014		2000-2014	
	Area(km^2)	**change**	**Area(km^2)**	**change**	**Area(km^2)**	**change**
Bareland	41.1	0.8%	133.0	2.5%	174.1	3.2%
Built-up	-3.5	-0.1%	33.9	0.6%	30.4	0.6%
Crop land	824.1	15.3%	-472.9	-8.8%	351.2	6.5%
Evergreen	52.0	1.0%	86.2	1.6%	138.2	2.6%
Forest	-590.5	-11.0%	21.0	0.4%	-569.5	-10.6%
Rangeland	-364.4	-6.8%	133.1	2.5%	-231.3	-4.3%
Plantation	39.5	0.7%	88.8	1.6%	128.3	2.4%
Sedimented waterbody	-2.5	0.0%	36.6	0.7%	34.1	0.6%
Water body	4.2	0.1%	-59.7	-1.1%	-55.5	-1.0%
Grand Total	**5385.7**	**0.0%**	**5385.7**	**0.0%**	**5385.7**	**0.0%**

(Source: Njogu, 2018)

For example, the bareland positive change (increased) all throughout the years since 2000 to 2014 (0.8 to 3.2%). The built-up area also increased by 30.4km^2 (0.6%) between the year 2000 and 2014. The forest and rangeland also decreased significantly by 569.5km^2 (10.6%) and 231.3km^2 (4.3%), respectively in a span of 15 years. The water bodies were reducing in the same period by 55.5km^2 (1%) while the sedimented water bodied increased by 34.1 km^2 (0.6%). The land used as cropland decreased by 472.9km^2(8.8%) between 2005 and 2014 but showed some increase by 6.5% between 2000 and 2014. The plantations increased consistently by 128.3km^2 (2.4%) between the year 2000 and 2014.Generally, the forest cover, rangeland, and water bodies reduced significantly while the bare-land, built-up areas, cropland, plantations, evergreen, and the sedimented water increased between the year 2000 and 2014.

5.4.6 Land Use Change Detection between the year 2000 and 2014

The highlighted are the area for the land cover that never changed from 2000 to 2014. For example, the land area that remained as bareland since the year 2000 was 251.5km^2, the built-up area was 3.3km^2, the cropland was 691.78km^2, evergreen vegetation was 112.73km^2, forest was 816.78 km^2, rangeland remained 307.8 km^2, plantation remained 338.84 km^2, sedimented waterbody was 0.25 km^2 while water body was 25.37 km^2. Significant transformation of land from one land cover to the other was also observed. The results show that 103km^2 of land that was covered with evergreen vegetation in 2000 was converted to cropland in 2014. The forest cover was also cleared and 58.22km^2 was left bare in 2014 while 11km^2 was used as built-up area, 274.24km^2 was used as cropland, 193.14km^2 was left as a rangeland, and 121.1km^2 was used as a plantation land. The water body decreased between the year 2000 and 2014 because part of it dried up and used as crop land (11.06km^2) in 2014, 0.75km^2 was left as rangeland, 1.98km^2 used for plantation and 33.62km^2 got sedimented. The total area of the waterbody that was sedimented in 2014 was 39.38km^2 compared to the same in 2000 (5.28km^2).

5.4.7 Land use change detection between the year 2005 and 2014

The landuse change detection in the period between 2005 and 2014 showed that there has been significant changes in land use in the NWUT basin. The highlighted are the area for the land cover that never changed from 2005 to 2014. For example, the land area that remained as bareland since the year 2005 was 279.2 km^2, the built-up area was 2.18 km^2, the cropland was 1177.46 km^2, evergreen vegetation was 271.93 km^2, forest was 843.01 km^2, rangeland remained 256.90 km^2, plantation remained 371.10 km^2, sedimented waterbody was 1.35 km^2 while water body was 25.63 km^2. Significant transformation of land from one land cover to the other was also observed. The results show that 38.41km^2 of land that was covered with evergreen vegetation in 2005 was converted to cropland in 2014. The forest cover was also cleared and 138.03km^2 was cleared and converted into plantation in 2014 while 187.83km^{2}of rangeland was left bare in 2014. Plantation land of 230.74 km^2 and 101.48 km^2 in 2005 was converted into cropland and forest in 2014 respectively. Cropland of 156.46 km^2, 322.46 km^2 and 293.36 km^{2}in 2005 was converted into forest, rangeland and plantation in 2014 respectively. The water body decreased between the year 2005 and 2014 because part of it dried up and used as crop land (14.03km^2) in 2014, 0.35km^2 was left as rangeland, 0.09km^2 used for plantation and 37.66km^2 got sedimented. The total area of the waterbody that was sedimented in 2014 was 39.38km^2 compared to the same in 2005 (2.78km^2).

Table 5.6: Comparison ofLand Use Land Cover for 2000 and 2014 in the NWUT Basin

		2014									
	LULCC	**Bare land**	**Built-up**	**Crop land**	**Evergreen**	**Forest**	**Rangeland**	**Plantation**	**Sed-wtrbody**	**Water body**	**Grand Total**
2000	Bareland	251.45	2.07	14.59	0.78	0.37	80.50	0.31	0.27	0.04	**350.36**
	Built-up	2.07	3.30	3.07	0.12	0.02	1.88	0.07	0.38	0.04	**10.95**
	Crop land	8.49	12.46	691.78	31.72	149.89	75.12	300.74	1.53	0.18	**1271.92**
	Evergreen	3.23	0.87	103.62	112.73	64.04	23.08	19.57	0.00	0.02	**327.16**
	Forest	58.22	11.00	274.24	264.03	816.78	193.14	121.10	1.31	0.09	**1739.92**
	Rangeland	200.60	8.72	279.57	52.72	39.34	307.80	27.14	0.87	0.07	**916.83**
	Plantation	0.32	2.15	240.57	2.27	92.71	3.24	338.84	1.14	0.26	**681.50**
	Sedimented waterbody	0.00	0.08	4.66	0.02	0.00	0.01	0.01	0.25	0.24	**5.28**
	Water body	0.06	0.76	11.06	0.93	7.28	0.75	1.98	33.62	25.37	**81.80**
	Grand Total	**524.43**	**41.40**	**1623.17**	**465.33**	**1170.43**	**685.53**	**809.76**	**39.38**	**26.30**	**5385.72**

(Source: Njogu, 2018)

Table 5.7: Comparison of Land Use land Cover change from 2005 to 2014 for the NWUT Basin

		2014									
	LULCC	**Bareland**	**Built-up**	**Crop land**	**Evergreen**	**Forest**	**Rangeland**	**Plantation**	**Sedimented waterbody**	**Water body**	**Grand Total**
2005	**Bareland**	279.20	2.71	15.60	0.61	0.31	92.70	0.33	0.01	0.00	391.47
	Built-up	0.53	2.18	2.71	0.33	0.62	0.64	0.28	0.13	0.02	7.45
	Crop land	54.68	24.33	1177.46	67.07	156.46	322.46	293.36	0.18	0.01	2096.02
	Evergreen	0.31	0.42	38.41	271.93	61.49	2.92	3.64	0.00	0.00	379.13
	Forest	0.80	2.16	49.18	112.24	843.01	4.01	138.03	0.01	0.00	1149.43
	Rangeland	187.83	5.26	94.37	2.68	2.44	256.90	2.93	0.01	0.00	552.42
	Plantation	0.69	2.72	230.74	8.67	101.48	5.54	371.10	0.02	0.00	720.97
	Sedimented waterbody	0.01	0.07	0.66	0.04	0.00	0.00	0.00	1.35	0.65	2.78
	Water body	0.37	1.54	14.03	1.77	4.61	0.35	0.09	37.66	25.63	86.04
	Grand Total	**524.43**	**41.40**	**1623.17**	**465.33**	**1170.42**	**685.53**	**809.76**	**39.38**	**26.30**	**5385.72**

(Source:Njogu,2018)

5.5 Modelling of Stream Flow and Sediment Yield

The SWAT Model gives the results in statistical format and hence this data had to be further analyzed using the excel spreadsheet which had the capacity to draw graphs to show the various simulation on river discharge and sediment yield as per the objective 4 of this study. During the modelling process, a warm up time of 2 years was allowed during the calibration and validation processes. The model was calibrated with rainfall data from Sagana Fish Farm from 1981-1996 and validation from 1997-2012. After the validation process, the model was run and the output from 2000 to 2030 for river discharge and sediment yield in the NWUTcatchment was obtained. The starting date for the Model was from 1/1/1998 to 31/12/2030. Below are the outputs of the Model based on this period.

5.5.1 Modelling of Stream Flow (Calibration Period)

Model calibration for stream flow data in the period of 1980 to 1996. Separation of parameters under examination was done in order to compare the observed verses simulated data on each of them.

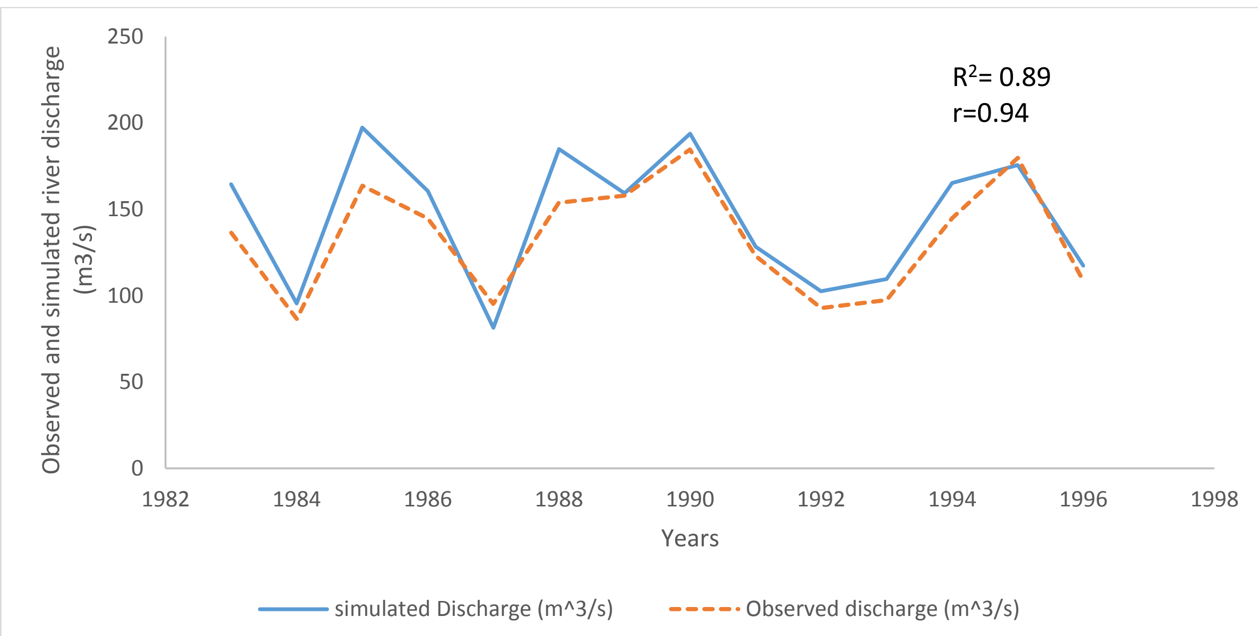

Figure 5. 23: Comparison between observed and simulated river discharge in the period of 1983-1997 during the calibration process in the NWUT catchment (Njogu, 2018)

There was a near fit on observed and simulated river discharge measurements during the period of 1983-1996. There was minor variation between the datasets in 1983, 1984, and 1985. However, the model showed good simulation in river discharge in the study area during the calibration process period (Figure 5.24). The relationship between observed and simulated river discharge data showed a Pearson's correlation coefficient (r) of 0.94 which shows that the Model is a good predictor of river discharge in NWU Tcatchment. This also ascertains the positive relationship between the observed and simulated river discharge in the basin. A coefficient of determination (R^2) of 0.89 showed a high relationship between simulated and observed river discharge during the calibration process in the NWUT catchment.

5.5.2 Modelling of Stream Flow (Validation Period)

Model validation was done using stream flow data to validate the results obtained for stream flow and sediment yield. Comparison between observed and simulated values in river discharge was done in the period of 1999-2012 during the validation process (Figure 5.25).

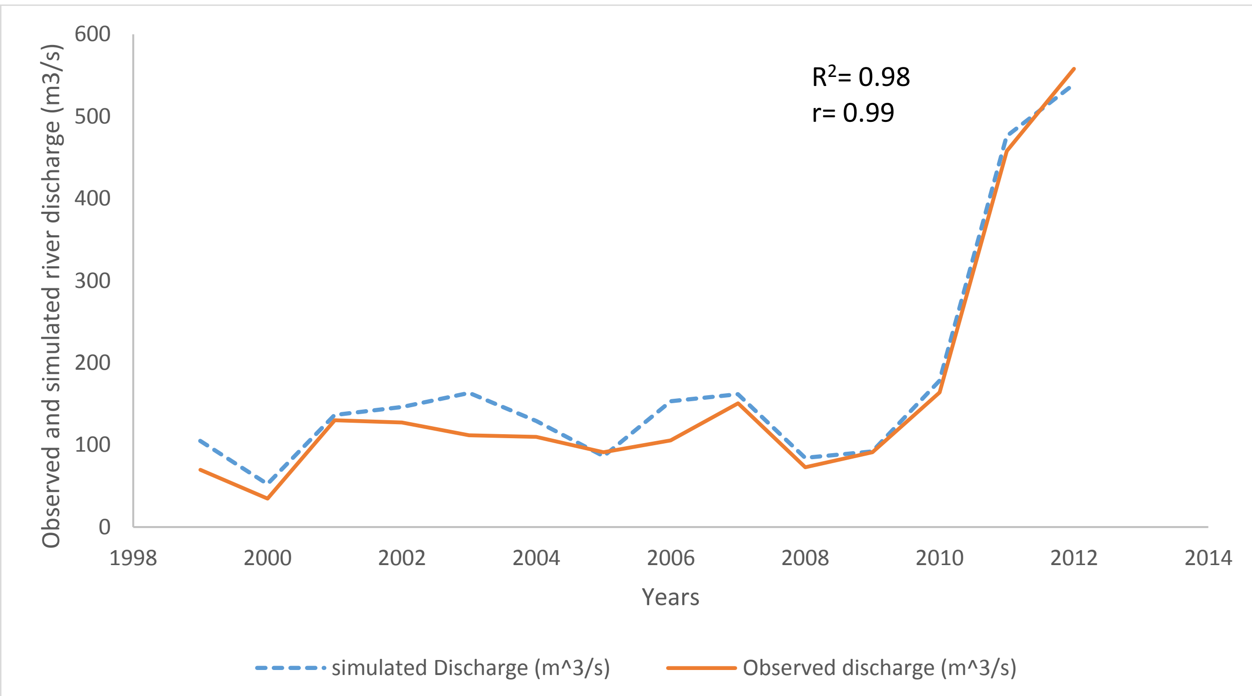

Figure 5. 24: Comparison between observed and simulated river discharge during validation process in the period of 1999-2012 in NWUT (Njogu, 2018)

The model showed good performance in the validation process in NWUTcatchment. There however were some years when the simulated values slightly differed with observed values like 1999, 2003 and 2006. The relationship between observed and simulated river discharge during the validation process in the NWUTbasin showed a Pearson's correlation coefficient (r) of 0.99 and a coefficient of determination (R^2) of 0.98. Pearson's correlation coefficient (r) of 0.99 was quite high showing a strong relationship between the observed and simulated river discharge in the catchment. This shows the success of the validation process. Coefficient of determination (R^2) of 0.94 showed less variation in observed and simulated river discharge values in the catchment (Figure 5.25).

5.5.3 Modelling of Sediment Yield

Comparison between observed and simulated sediment yield was done in the period between July-May (2010-2012) for the study area. The SWAT model showed good performance in the prediction of sediment yield in the basin with a near 1:1 fit on both graphs (Figure 5.26).

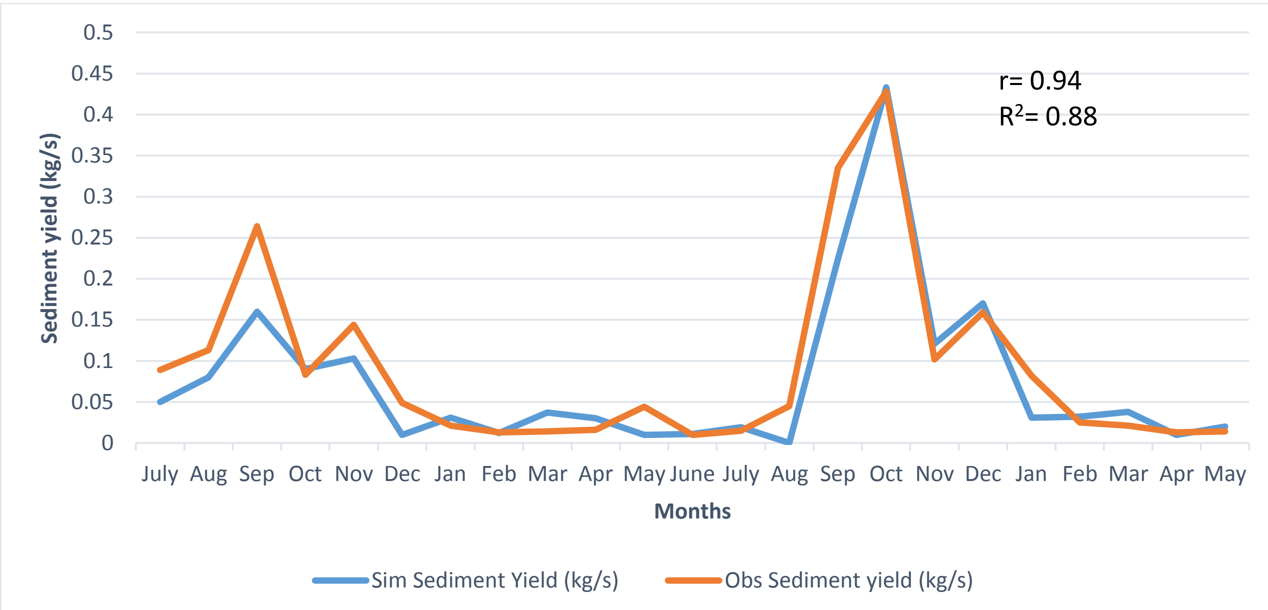

Figure 5. 25: Comparison between observed and simulated sediment yield in the period between July-May (2010-2012) in the NWUTcatchment (Njogu, 2018)

However, there were some months when the model gave a slightly larger or smaller figure compared to the observed value. These months included September and December (2010), March and August (2011) and January (2012).Existing relationship between observed and simulated data on sediment yield was carried out and results on correlation coefficient (r) of 0.94 and Coefficient of determination (R^2) 0.88 were obtained. Correlation coefficient (r) of 0.94 showed a positive relationship between observed and simulated data on sediment yield. A coefficient of determination (R^2) of 0.88 is higher than 0.5 which is the commendable value hence less variation between observed and simulated values of sediment yield in the basin.

5.5.4 Modelling on the Relationship between Rainfall, River Discharge and Sediment Yield

A monthly trends comparison of simulated data was carried out on rainfall, river discharge and sediment yield in the North-West Upper Tana catchment in the period of between July-May (2010-2012) (Figure 5.27).

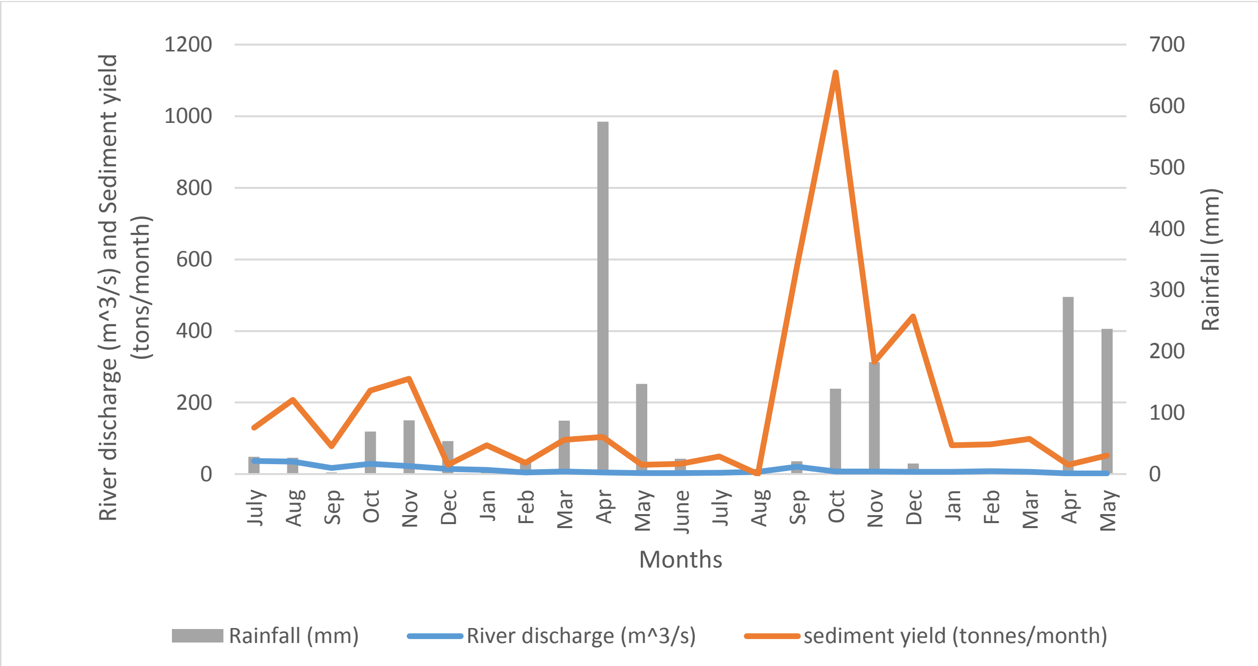

Figure 5. 26: Monthly trends on simulated rainfall, river discharge and sediment yield in NWUT catchment in the period of July-May (2010-2012) (Njogu, 2018)

River discharge showed a decreasing trend from July- May (2010-2012), sediment yield data showed significant rise in the period when river discharge was high while rainfall measurements simulation were highest in April for both years. Rainfall simulated data showed high values in April -May (short rains) and October-November of 2011 having 574.43 mm, 147.25 mm and 139.21 mm, 182.63 mm respectively. The year 2012 also had high values of rainfall in April-May having 289.12 mm and 236.8 mm respectively. The model simulated an increase in river discharge from July-November 2010 with these having 36.49 m^3/s, 35.36 m^3/s, 54.22 m^3/s, 28.95 m^3/s and 22.73 m^3/s respectively with September recording the highest values of 54.22 m^3/s during the whole period of study. It is important to note that during the period of high rainfall and river discharge did not result in high corresponding values in terms of sediment yield during the period of July-May (2010-2012). This scenario was only different in October 2011 which had the highest values of sediment yield of 1,122.34 tons/month and a corresponding high rainfall.

5.5.5 Prediction of Future Trends in Rainfall, Stream Flow andSediment Yield

SWAT simulation was done on rainfall, river discharge and sediment yield from 2000 to 2030 (Figure 5.28). In the year 2000, rainfall simulated was 1052.55mm which translated to river discharge and sediment yield values of 203.49 m^3/s and 2,540.16 tons/year respectively. In 2005 records of rainfall, river discharge and sediment yield were 1008.12mm, 396.83 m^3/s and 22,965.12 tons/year respectively. In 2014, there was high rainfall simulated (1024.18mm) which translated to river discharge and sediment yield values of 201.74 m^3/s and 8,087.04 tons/year respectively. This is an interesting result since high rainfall in 2014 did not directly result in high river discharge and sediment yield as expected. However, it is important to note the high values of sediment yield simulated in 2015, 2024 and 2027 of 40,616.64 tons/year, 54,872.64 tons/year and 39,942.72 tons/year respectively.

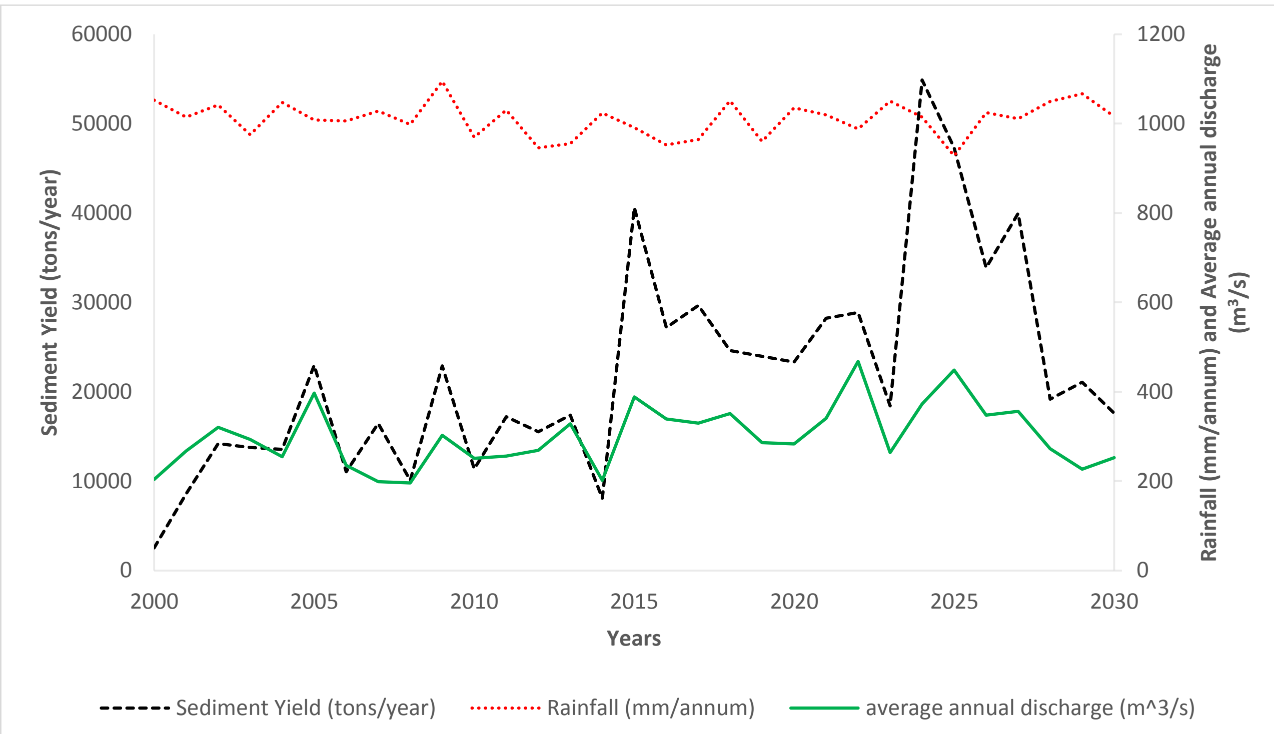

Figure 5. 27: Annual future trends on rainfall, river discharge and sediment yield in the NWUT catchment (Njogu, 2018)

During these years' rainfall measurements were as high compared to the values of sediment yield and river discharge experienced during this period; this is clear translation that there was change in land use practices during this year's making sediments available to high velocity flowing water. From the data generated from the model, the values of sediment yield will be on the rise with 2024-2027 recording the highest values of 21.17 kg/s, 18.25 kg/s, 13.07 kg/s and 15.41 kg/s respectively.

There is an interesting increase in rainfall from 2020-2030 with 2022 and 2025 having the lowest values of 960mm and 928 mm respectively. It is also important to pay attention to year 2025 with rainfall simulation of 928 mm and yet will have very high values of river discharge and sediment yield of 448.61 m^3/s and 18.25 kg/s respectively. This means if factors like land-use and land cover, soils, population and matters related to climate change are held constant, the simulated values will result. It is also important to note that an increase in river discharge results in a corresponding increase in sediment yield for this simulation. This is evident in years like 2005, 2009, 2015 and 2023 (Figure 5.28). There was also an interesting observation from 2027-2029 since when river discharge was decreasing, sediment yield increased during this simulation period. In 2022 and 2025 simulation years showed high levels of river discharge which was not as a result of high rainfall. This could be attributed to changes in land use during this period into bare, farming or paving resulting to these changes.

5.5.6 Nash Sutcliffe Efficiency (NSE)

Model evaluation was done to determine how well the simulated and observed data fits on a 1:1 plotting. This was carried out for all the datasets i.e. river discharge and sediment yield having NSE values of 98% and 99% respectively. This shows that the model is good predictor on the parameters under examination.

5.6 Hypothesis Testing

5.6.1 The Relationship between Stream Flow and Rainfall

Analysis of variance (ANOVA) was performed on stream flow and rainfall data in the period of July to May (2010-2012). There is a significant relationship between stream flow and rainfall in the NWUT basin. The Analysis of Variance showed a significant F of 1.859 which is greater than the F-value of 0.187, P-value of 0.081 was also obtained from the regression analysis which is greater than 0.05, hence we reject the Null hypothesis (H_0) and accept the alternate hypothesis (H_1) that there is significant relationship between stream flow and rainfall in NWUT basin (Table 5.8 and 5.9).

Table 5.8: Analysis of variance (ANOVA) on the river discharge and rainfall for NWUTcatchment

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.8686E+14	5.86E+14	0.187	1.859
Residual	21	6.61E+15	3.15E+14		
Total	22	7.2E+15			

(Source: Njogu, 2018)

Table 5.9: Regression analysis on stream flow and rainfall in NWUT catchment

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9062868	4935450	1.836	0.081
X Variable	57760.01	42358.65	1.364	0.187

(Source: Njogu, 2018)

5.6.2 The Relationship between Sediment Yield and Rainfall

Analysis of variance (ANOVA) was performed on sediment yield and rainfall data in the period of July to May (2010-2012). There is a significant relationship between sediment yield and rainfall in the NWUT basin (Table 5.10 and 5.11).

Table 5. 10: Analysis of variance (ANOVA) on the sediment yield and rainfall for NWUTcatchment

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15608.66	15608.66	0.167	2.049
Residual	21	159933	7615.857		
Total	22	175541.7			

(Source: Njogu, 2018)

Table 5.11: Regression analysis on sediment yield and rainfall NWUTcatchment

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	58.007	22.978	2.481	0.217
X Variable	0.0015	1.432	1.432	0.167

(Source: Njogu, 2018)

The Analysis of Variance showed a significant F of 2.049 which is greater than the F-value of 0.167, P-value of 0.217 was also obtained from the regression analysis which is greater than 0.05, hence we reject the Null hypothesis (H_0) and accept the alternate hypothesis (H_1) that there is significant relationship between sediment yield and rainfall in NWUT basin.

5.6.3 The relationship between Stream Flow and Sediment Yield

Analysis of Variance was performed on stream flow and sediment yield data in the period of July to May (2010-2012). There is a significant relationship between stream flow and sediment yield in the NWUT basin. The Analysis of Variance in Table 5.12 had significant F value of 12.02 which is greater than the F-value of 0.006. Regression analysis was performed to examine whether to accept or reject the Null hypothesis of the study. From this analysis, a p-value of 0.061 was obtained which is greater than 0.05 (Table 5.13), hence we reject the Null hypothesis (H_0) and accept the alternate hypothesis (H_1) that there is a significant relationship between stream flow and sediment yield in the NWUT basin.

Table 5.12: Analysis of variance (ANOVA) on the river discharge and sediment yield for NWUTcatchment

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	504.0386	504.0386	0.006056	12.01671
Residual	10	419.448	41.9448		
Total	11	923.4867			

(Source: Njogu, 2018)

Table 5.13: Regression analysis on stream flow and sediment yield in NWUT catchment

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	19.87194	2.379895	8.349922	0.06056
X Variable	7.206674	2.07894	3.466513	8.08E-06

(Source: Njogu, 2018)

The relationship between stream flow and sediment yield a correlation coefficient (r) of 0.74 and a coefficient of determination (R^2) of 0.55. The coefficient of determination (R^2) of 0.55 shows that there was less error variance in the relationship between river discharge and sediment yield.

5.6.4 Relationship between Observed and Simulated Stream Flow

There is a significant relationship between observed and simulated stream flow in the NWUT basin. Analysis of Variance was performed on observed and simulated stream flow data in the period of July to May (2010-2012).

Table 5.14: Analysis of variance (ANOVA) on the observed and simulated stream flow in NWUTcatchment

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4288.73	4288.73	385.489	5.43E+15
Residual	21	233.634	11.125		
Total	22	4522.364			

(Source: Njogu, 2018)

Hypothesis testing on the relationship between observed and simulated river discharge was done for the validation process and p-value of 0.67 was obtained which is greater than 0.05 (Table 5.15), significant F of 5.43 E+15 which is greater than F-value of 385.49 (Table 5.14).

Table 5.15: Regression analysis on observed and simulated stream flow in NWUTcatchment

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.423	0.9794	0.4318	0.6703
X Variable	1.022	0.0521	19.634	0.8414

(Source: Njogu, 2018)

In both cases of testing, we reject the Null hypothesis (H_0) and accept the Alternate hypothesis (H_1) that there is significant relationship between observed and simulated river discharge in the NWUTbasin.

5.6.5 Relationship between Observed and Simulated Sediment Yield

There is a significant relationship observed and simulated sediment yield in the NWUT basin.

Table 5.16: Analysis of variance (ANOVA) on observed and simulated sediment yield for NWUTcatchment

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.2441	0.2441	174.961	1.18E+11
Residual	21	0.0293	0.0014		
Total	22	0.2735			

(Source: Njogu, 2018)

Table 5.17: Regression analysis on observed and simulated sediment yield in NWUTcatchment

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.0111	0.0098	1.1346	0.2793
X Variable	1.0694	0.8085	13.2272	1.18E-11

(Source: Njogu, 2018)

Analysis of Variance was performed on observed and simulated sediment yield data in the period of July to May (2010-2012) to test the hypothesis of the study. P-value of 0.27 was obtained which is greater than 0.05, significant F of 1.18 E+11 which is greater than F-value of 174.96 (Table 5.16 and 5.17). In both cases, we reject the Null hypothesis (H_0) and accept the Alternate hypothesis (H_1) that there a significant relationship between observed and simulated sediment yield in theNWUT basin.

5.7 Soil and Water Conservation Measures and Interventions

The constitution of Kenya (GoK, 2010) is committed to protecting the environment under article 42, 60(c) and 69 (a-h). It also advocates for sustainable management of natural resources by increasing the forest cover from 2% to 10% of Kenya land mass under protected area system. In the National Forest Policy, there was massive clearing of forest cover for illegal logging, agricultural land and settlement in 2003. The policy has promoted re-afforestation programmes across the nation and have attained 1.24 million hectares. The Kenyan Government is deprived of Ksh. 6 billion every year as a result of unsustainable soil and water conservation in the country (National Forest Policy, 2014). There is increased demand for renewable fresh water resources for various uses, and the demand is projected to rise with time due to increased population in Kenya (NWP; GoK, 2014). The per capita water availability was 647 m^3 per capita in 1992, 534 m^3 per capita in 2011 and is projected to further drop to 235 m^3 per capita by 2025. This means if proper adaptation and mitigation measures are not put in place, Kenya will severely be water scarce (NWMP; GoK 2014). The total water demand in Kenya was 3,218 milliom m^3/year in 2010 and there is a projection of 21,468 million m^3/year by 2030 and 23,141 milliom m^3/year by 2050 (NWMP; GoK, 2014). The National Climate Change Action Strategy, 2013 (NCCAS) advocates for PES with the aim of reducing the amount of Carbon (iv) Oxide released into the atmosphere. The adoption of climate smart agriculture is emphasized as a way of adapting to issues related to climate change. The Environment Management and Coordination Act (EMCA, 1999) enforces the protection of catchment areas in Kenya and rehabilitation of destroyed catchments by planting of trees or woodlots. The protection of water catchments is the sole mandate of Water Resources Authority (WRA) with the application of Catchment Management Strategies (CMS) through Integrated Water Resources Management (IWRM). The County Integrated Development Plans (CIDP) for Nyeri, Murang’a and Kiambu has promoted the adoption of climate smart agriculture technologies to adapt and mitigate the effects of climate change in these Counties. The County Climate Change Policy Framework (CCCPF) has enabled stakeholders’ participation to reduce the carbon foot print through promotion of green economy.

CHAPTER SIX

DISCUSSION OF THE RESULTS

6.1 Introduction

This chapter involves a detailed explanation of the results obtained in this study. Explanations on the the hydrological characteristics, spatila temporal variability in stream flow and sediment yield, LULCC and SWAT Model in prediction of stream flow and sediment yield in the basin. A comparison of this study with other studies in the same basin or other basins examining the same parameters was done to identify agreement or disagreement in findings of these studies.

6.2 Relationship between Stream Flow and Rainfall

There is a significant relationship between stream and rainfall in NWUT basin. The results in the determination of the relationship between stream flow and rainfall showed correlation coefficient (r) of 0.81 and coefficient of determination (R^2) of 0.65. This shows that rainfall has 65% influence on stream flow in the basin. Other contributing factors to stream flow could be as a result of snow melting on Mt. Kenya due to effects of climate change in the basin. These results compare well with results of Njogu and Kitheka, (2018) who found a correlation coefficient (r) of 0.99 and coefficient of determination (R^2) of 0.98. Chandimala and Zubair (2007), found coefficient of determination (R^2) of 0.3 and correlation coefficient (r) of 0.5 in a study conducted in Sri Lanka. Githui *et al*., (2009), found a good relationship between rainfall and stream flow in Western Kenya.

6.3 Relationship between Sediment Yield and Rainfall

There is a significant relationship between sediment yield and rainfall in NWUT basin. The results on the determination of the relationship between sediment yield and rainfall showed a correlation coefficient (r) of 0.87 and coefficient of determination (R^2) of 0.75. Rainfall has 75% influence on sediment yield in the NWUTbasin. This means that other factors like land use and cover, topography, soils, geology and effects of climate change have 25% on sediment yield in the basin. Gholami *et al*., (2013), found a coefficient of determination (R^2) of 0.99 and a correlation coefficient (r) of 0.99.

6.4 Relationship between Stream Flow and Sediment Yield

There a significant relationship between stream flow and sediment yield in NWUT basin. The results on the determination of the relationship between stream flow and sediment yield showed a correlation coefficient (r) of 0.74 and coefficient of determination (R^2) of 0.55. This shows that stream flow has 55% influence on sediment yield in NWUT basin. These results compares well with those of Njogu and Kitheka, (2017) which found a correlation coefficient (r) of 0.85 and coefficient of determination (R^2) of 0.73 in the Upper tana catchment. Hunink *et al*., (2013) did a study in the Upper Tana catchment and in their findings, they support that there is a strong relationship between river discharge and sediment yield in the catchment. Omengo *et al*., (2016) in their study in sedimentation of tropical floodplains, they noted that the relationship between river discharge and sediment yield is complex and differ seasonally with peak TSSC being experienced during peak river discharge. These results compares well with those of Kigira (2016), who found a coefficient of determination (R^2) of 0.66 and correlation coefficient (r) of 0.81. Setegn *et al*., (2010), found coefficient of determination (R^2) of 0.5 and correlation coefficient (r) of 0.71.

6.5 Estimation of Water Yield and Sediment Yield from the NWUT Basin

The estimation of water yield and sediment yield was computed for the whole basin and from Sagana, Maragua, Mathioya and Thika rivers in the NWUT basin. The North-West Upper Tana basin had a water yield of 327,638,942 m^3/month and sediment flux of 590,637.4 tons/month (7.1 million tons/year) in the period of July to May (2010-2012). North-West Upper Tana basin has a surface area of 9,918 km^2 which resulted into a sediment production rate of 59.6 tons/km^2/month which is approximately 715 tons/km^2/year from the basin. Sagana river had water yield of 1.072E+12 m^3/year and sediment yield of 146,626.5 tons/year. Maragua river had water yield of 1.45E+11 m^3/year and sediment yield of 15,805.3 tons/year. Mathioya river had water yield of 318,064,320 m^3/year and sediment yield of 19,096.59 tons/month. Thika river had water yield of 276,229,440 m^3/year and sediment yield of 17,754.84 tons/year. These results compares well with results Dunne and Ongwenyi (1976), estimated the sediment production rates from Upper Tana to be between 883,000 tons/year and 2,302,000 tons/year. Kigira (2016), found a significant increase in sediment yield between 1984 and 2006. Verstraeten and Poesen (2001), found sediment yield of 0.4-20.6 tons/ha/year. Ashagre (2009), and Welde (2016), found sediment yield of 15.17 tons/ha/year in Ethiopia. Borji (2013), found a sediment load of 245 million tons/ year in Grand Ethiopian Renaissance Dam (GERD) in Ethiopia. Inca and Carlos (2009), found sediment yield of 1,227.61 tons/km^2/year in 2007 in Peru. Garde and Raju (2000), found sediment yield from Perkerra and Dali to be 19,500 tons/km^2/year and 25,600 tons/km^2/year respectively. Walling (2017) and Lal (2001), found sediment yield in Ghana to range between 15,000 tons/year to 1.2 *10^6 tons/year.

6.6 Impacts of Stream Flow and Sediment Yield on Masinga Reservoir

Reservoirs in the Upper Tana catchment are drastically affected by stream flow variability and sediment loading with Masinga dam being the most affected (Vanmaercke *et al*., (2011); Boroujeni, (2012); de Vente *et al*., (2004). Processes of dredging and de-siltation are expensive and beyond the financial budgets of most third world countries. Water supply, flood control and hydro-electric power generation will therefore be crumbled due to sedimentation and reduced storage capacity of reservoirs (Syvitski *et al*., 2005). In the recent past the dependence in reservoirs for various services has risen in most tropical countries due to the effects of climate change on existing water resources (Jager and Smith, 2008). The increase in population in many countries have increased the demand for water supply for various uses which cannot be catered for by the dwindling water resources available hence the need for water reservoirs to increase supply (Oludhe *et al*., 2013). The effects of climate change on existing resources and hydrological characteristics of basins has resulted in the shift from rain-fed to irrigated agriculture to cater for increased demand for food supply (Wisser *et al*., 2010). The design capacity for Masinga dam was 1.56 million m^3 with a depth of 1037 m (Postle and Erfani, 2017). However, by the year 2013 the dam had lost 215.26 m^3 which is approximately 13% of its total storage capacity (Bunyasi *et al*., (2013); Palmieri and Dinar, (2001). This study examined sediment loading into Masinga dam in the period of 2010-1012 and found out that 7.1 million tons/year were deposited into the dam during this period. This results are however from few contributing river system into the dam. Increase in water demand, climate change and altered land use and land cover is important for the Government of Kenya to collaborate all stakeholders in the Upper Tana Kenya to ensure the sustainability of the dam. Kenya through the Vision 2030 aims at achieving a universal electricity distribution in the country which can only be achieved if the Upper Tana (Seven folks) are sustainably dealt with. High levels of stream flow of 170 m^3/s were recorded from Sagana (4AC03) which is a key contributor of inflows in to the dam. These records of high discharge results in the detachment, transport and deposition of sediments into the dam. If proper land use practices and land cover enhancement are adopted, the issue of detachment, transport and deposition will have been reduced. Postle and Erfani conducted a study in 2017 on the robustness of Masinga reservoir and found that the dam's efficiency in providing essential services will be reduced by half by the year 2030. This serves as an alarm for Towns depending on water support from the dam to look for other alternatives sources of water in the future since the dam cannot meet their demands.

6.7 Spatial Temporal Variability in Sediment Yield in NWUT Basin

This study found significant spatial temporal variability in sediment yield in NWUT basin. Spatial temporal variability in sediment yield for this study was done by examining the spatial temporal variability in TSSC, river discharge and sediment yield in the basin. Maximum values on Total Suspended Sediment Concentration (TSSC) were computed per season with Saba Saba (4BF01) recording the highest values in September and October of 1150 mg/l and 1433 mg/l respectively during the second wet season (2011). Irati (4BE03) had the lowest minimum value in sediment yield of 2 mg/l while Saba Saba (4BF01), Mathioya (4BD01) and Maragua (4BE01) all had minimums of 3 mg/l. Spatial temporal variability in river discharge was also done with Sagana (4AC03) having the highest values of 170.4 m^3/s. Others RGS experienced high river discharges during the wet season (July-December) and low flows in the dry season (January-June). Spatial temporal variability in sediment yield in NWUT catchment showed Sagana (4AC03 had the highest values of 31.7 kg/s in October followed by Maragua (4BE01) having 18.7 kg/s in August both in the first wet season (July-December) 2010. Comparing the levels of river discharge in the catchment is important to note that stations like Sagana (4AC03) has the highest discharge and corresponding sediment but this is not translated to TSSC. High TSSC in Saba Saba (4BF01) is not a translation of high sediment yield in the basin. This study found a high level of spatial temporal variability in sediment yield in the NWUT catchment. During this period, sediment load of 7.1 million tons/year was computed. These results compares well with those of Kitheka *et al*., 2005 who found out that the sediment flux of Tana river to be 6.8 million ton/yr. Brown *et al*., 1996 found out that sediment load into the Masinga reservoir was 0.6 to 0.9 million ton/year, Hunink *et al*., 2013 did a Physiographic survey on the sedimentation of Masinga dam by examining the parameters in Upper Tana and found 6.7 million ton/yr deposition rates into the dam. They further concluded that the future life of the dam was mainly dependent on the future climatic patterns. Hunink *et al*., (2011), did a study on the Masinga dam and in their findings the dam had lost 10% of its storage capacity since 1981 when it was constructed. From their study, Thika and Tana rivers contributed 8.03 million ton/yr in the dam. Ongwenyi, (1979) and Ongwenyi, (1985) concluded that the high sediment load in the Upper Tana was as result of land degradation and soil erosion in the basin. Omengo *et al*., (2016) found sediment flux in the Tana river to be between 3.5 to 8.7 million ton/yr. Bunyasi *et al*., (2013) conducted a study and in their findings they found out that Masinga dam was 75% to 98% efficient in trapping sediments and hence low sediment fluxes immediately downstream of the dam. Saenyi, (2004) conducted a study on Masinga dam and found out that it had lost 6% of its storage capacity during the first 8 years of operation. Jacobs *et al*., (2007) examined the life expectancy of Masinga dam and in their findings they noted that life expectancy of the dam upon design was 500 years but with the rate of siltation the dam can only live up to 65 years unless intervention measures are undertaken.

6.8 Land Use Land Cover Change (LULCC) from 2000-2014

There was significant Land Use Land Cover (LULC) in NWUT basin. Land use land cover for this study area was grouped into bare-land, build up, cropland (irrigated crops), and evergreen (tea and broad-leafed trees), forest, rangeland, plantation (bananas), sedimented waterbody and waterbody clear water. The results of this study showed that major changes had taken place in terms of LULC in the period of 2000 to 2014. This study found out that bare-land change from 6.5% to 7.3 % to 9.7% in 2000, 2005 and 2014 respectively. Built-up areas grew from 0.2% to 0.1% to 0.8, cropland increased from 23.6%, to 38.9% to 30.1%, Evergreen vegetation increased from 6.1% to 7.0% to 8.6%, forest decreased from 32.3%, to 21.3% to 21.7%, rangeland decreased from 17.0% to 10.3% to 12.7%, plantation increased from 12.7% to 13.4% to 15.0%, sedimented waterbody increased from 0.1% to 0.1% to 0.7% while waterbody decreased from 1.5% to 1.6% to 0.5% all from 2000 to 2005 to 2014 respectively. This results had major impacts on sediment yield and river discharge in the NWUTcatchment. The increase in bare land from 2000 to 2014 (6.5% to 9.7%) could have been as a result of decrease in cropland from 38.9% to 30.1% in 2005 to 2014 which translated into more bare-land hence increased sediment yield and runoff generation from these regions. Build-up areas increased from 0.2% to 0.8% in 2000 to 2014, this could have been as a result of towns' expansion, and population growth hence need for settlements or industrialization. Increase in build-up areas translated into increased compaction and paving which increased the magnitude of runoff generation. Cropland increased in 2000 to 2005 a decreased in 2014 (23.6% to 38.9% to 30.1%) respectively. These change may have been attributed to the increase in waterbody (more water for irrigation) in 2000 to 2005 (1.5% to 1.6%) and the decrease due to the decrease in waterbody in 2005 to 2014 (1.6% to 0.5%). Reduction in cropland resulted into an increase in bare-land hence an increase in sediment yield and river discharge. The evergreen vegetation increased from 2000 to 2014, this could have been attributed to increase in the tea farming or deforestation and regrowth of broad leafs from cut trees. An increase in evergreen reduces the raindrop impact on the soil surfaces and allows infiltration resulting to low runoff and sediment yield generation. Forest cover reduced in 2000 to 2005 (32.3% to 21.3%) and slightly increased in2014 to 21.7%. This major decrease in forest could have been as a result of high demand in timber for building, clearing to allow more cropland and plantation land or for settlement. Decrease in forest cover increased runoff generation and sediment loading. Rangeland decreased from 2000 to 2014 (17% to 12.7%), there was however an increase in 2005 to 2014 (10.3% to 12 7%). The decrease in rangeland from 2000 to 2005 (17% to 10.3%) could have been as a result of conversion to cropland, demand for settlement or for plantation. The sudden rise in rangeland in 2005 to 2014 could have been as a result of abandoned cropland or cleared forest cover. Increase in rangeland resulted in low sediment yield and runoff generation. Plantation showed an increase from 2000 to 2005 to 2014 (12.7% to 13.4% to 15.0%) respectively. Decreased forest cover could have been cleared to allow more expansion in plantation since the demand from these activities could have been fetching the farmers more money compared to other economic practices. Sedimented waterbody remained constant in 2000 to 2005 (0.1%) and then increased in 2014 to 0.7%. This constant could have been attributed to increase in cropland and hence less sediment deposition into the reservoir. Increase in sedimented waterbody in 2014 means that availability of sediments from the catchment this could have been as a result of abandoned cropland making sediments availability and deposition possible during that period possible. Water body increased in 2000 to 2005 (1.5% to 1.6%) this could have been as result of increase in runoff generation from increased bare-land during the same time. In 2005 to 2015 waterbody decreased to 0.5%, this could have been as result of sedimentation in the reservoir, decrease in forest cover or as a result of climate change. The results of this study compares well with those of Dunne, (1979) who examined sediment yield and land use in tropical catchment focusing on Upper Tana. In his findings, he concluded that sediment yield is highly affected by variation in land use changes in tropical catchments. Kigira (2016), found out that increased forest cover reduced sediment yield and increased ground water recharge. Coffee farming exposes soil to raindrops resulting to erosion and contribute sediment yield of 641.6 tons/ha (Kigira, 2016). Vogl *et al*., (2017) conducted a study in valuing sustainable land management in Tana river basin and emphasizes on all-inclusive stakeholders' approach in land management and education and outreach to farmers to ensure a holistic land and water management in the catchment. Garnett *et al*., (2013) and Nunes *et al*., (2011), conducted a study on sustainable intensification in agriculture and concluded that there is a direct link between land use changes on catchment slopes and changes in climate. Ongwenyi, (1979) and Ongwenyi *et al*., (1993) conducted a study in the Upper Tana and found that land degradation and soil erosion were the main contributors to high sediment flux in the catchment.

6.9 SWAT Modelling on Stream Flow and Sediment Yield

Modeling of stream flow and sediment yield was done in the period 1981 to 2012. The results of the modeling exercise showed good performance in the simulation of river discharge and sediment yield in NWUT catchment with correlations of 0.94 and 0.99 respectively between observed and simulated data.These results compares well those of Njogu and Kitheka, (2017) who found a correlation coefficient (r) of 0.99 and coefficient of determination (R^2) of 0.98.

6.10 Prediction of Future Trends in Rainfall, Stream Flow and Sediment Yield with SWAT Model

Future projections on rainfall, river discharge and sediment yield were done in the period of 2000-2030 for NWUT basin. If some parameters are held constant like land use, soils, population and climate change, then the model performance up to 2030 results will be applicable. The results of this study showed that in 2020 to 2022 river discharge will be increasing with a maximum value of 468.12 m^3/s while the increase will be experienced in 2023 to 2025 with a high value of 448.61 m^3/s. It was also noted from the model performance that in 2027 to 2029 there will be a major decline in river discharge while rainfall will be increasing in this period. In 2024, the model predicted rainfall, stream flow and sediment yield of 1014.6 mm, 372.8 m^3/s and 54,872.6 tons/month respectively. In 2030, the model predicted rainfall, stream flow and sediment yield of 1016 mm, 252.4 m^3/s and 17,573 tons/month. The results of this study compares well with those of Njogu and Kitheka, (2017) who conducted a study on the relationship between rainfall, river discharge and sediment yield in the Upper Tana. SWAT modelling was used for this study and the model showed good performance in the prediction of rainfall, river discharge and sediment yield in the Upper Tana catchment. These results are also in line with findings from studies done by Kitheka *et al*., (2005) who examined river discharge and sediment transport and exchange in Tana river concluded that maximum river discharge of 60 m^3/s to 750 m^3/s were experienced in Tana river.

6.11 SWAT Model Efficiency

SWAT Model efficiency and sensitivity analysis was done for the NWUT basin. The results showed an NSE above 95% in all the parameters. This showed that the model is a good predictor in rainfall, river discharge and sediment yield in NWUT catchment. Sensitivity analysis results showed 99% influence of rainfall on river discharge and sediment yield in the basin. These results compares well with those of Njogu and Kitheka, (2017) found an NSE of 89.4%. Kigira (2016), further clarifies model performance in simulation of stream flow and sediment yield in tropical basins. El-Sadek and Irvem (2014) found an NSE value of 0.76. Setegn *et al*., (2010), found NSE value of 0.5 in Ethiopia.

6.12 Hypothesis Testing

Hypothesis testing was done for the working hypothesis of the study in NWUT basin. Results in hypothesis testing rejected all the set Null hypothesis (H_0) resulting into acceptance of all Alternate hypothesis (H_1).

6.12.1 Relationship between Stream Flow and Rainfall

Hypothesis testing was done the existence of relationship between stream flow and rainfall in the NWUT basin. Results of this study showed a significant F-value of 1.859 was obtained which was greater than the F-value of 0.187, P- value of 0.081 was also obtained which was greater than 0.05. These results accepted the alternate hypothesis (H_1) that is a significant relationship between stream flow and rainfall in the NWUT basin and rejected the Null hypothesis (H_0).

6.12.2 Relationship between Sediment Yield and Rainfall

Hypothesis testing was done the existence of relationship between sediment yield and rainfall in the NWUT basin. Results of this study showed a significant F-value of 2.049 was obtained which was greater than the F-value of 0.167, P- value of 0.217 was also obtained which was greater than 0.05. These results accepted the alternate hypothesis (H_1) that is a significant relationship between sediment yield and rainfall in the NWUT basin and rejected the Null hypothesis (H_0).

6.12.3 Relationship between Stream Flow and Sediment Yield

Hypothesis testing was done the existence of relationship between sediment yield and stream flow in the NWUT basin. Results of this study showed a significant F-value of 12.02 was obtained which was greater than the F-value of 0.006, P- value of 0.061 was also obtained which was greater than 0.05. These results accepted the alternate hypothesis (H_1) that is a significant relationship between sediment yield and stream flow in the NWUT basin and rejected the Null hypothesis (H_0). Coefficient of determination (R^2) of 0.88 and correlation coefficient (r) of 0.94 were obtained in this study.

6.12.4 Relationship between Observed and Simulated Stream Flow

Hypothesis testing was done the existence of relationship observed and simulated stream flow in the NWUT basin. Results of this study showed a significant F-value of 5.43E+15 was obtained which was greater than the F-value of 385.49, P- value of 0.67 was also obtained which was greater than 0.05. These results accepted the alternate hypothesis (H_1) that is a significant relationship between observed and simulated stream flow in the NWUT basin and rejected the Null hypothesis (H_0). This study also found Coefficient of determination (R^2) of 0.98 and correlation coefficient (r) of 0.99 were obtained in this study. These results compares well with those of Njogu and Kitheka, (2017) which showed a correlation coefficient (r) of 0.67 and coefficient of determination (R^2) of 0.44. Kigira (2016), found a coefficient of determination (R^2) of 0.97 and correlation coefficient (r) of 0.98.

6.12.5 Relationship between Observed and Simulated Sediment Yield

Hypothesis testing was done the existence of relationship observed and simulated sediment yield in the NWUT basin. Results of this study showed a significant F-value of 1.18E+11 was obtained which was greater than the F-value of 174.76, P- value of 0.27 was also obtained which was greater than 0.05. These results accepted the alternate hypothesis (H_1) that is a significant relationship between observed and simulated sediment yield in the NWUT basin and rejected the Null hypothesis (H_0). This study also found a coefficient tof determination (R^2) of 0.98 and correlation coefficient (r) of 0.99. These results compares well with those of Njogu and Kitheka, (2017) which showed a correlation coefficient (r) of 0.86 and coefficient of determination (R^2) of 0.73. Gupta (2005), found a correlation coefficient (r) of 0.93 and coefficient of determination (R^2) of 0.86. Kigira (2016), found a coefficient of determination (R^2) of 0.9 and correlation coefficient (r) of 0.95.

6.13 Soil and Water Conservation Framework in NWUT Basin

The results on Soil and Water Conservation measures in the Upper Tana basin showed that there the National Government, International Agencies and the County Governments of Kiambu, Murang'a and Nyeri have tried to promote sustainable land use practices in the area. Despite these efforts, there has been increasing water yield and sediment load during the rainy seasons and reduced flow in dry seasons (Kitheka *et al*., 2008). The encroachment of riparian lands for agriculture is alarming resulting to overexploitation of surface and groundwater resources. Wetlands in the basin have been drained for agriculture or settlement purposes hence the hydrological instability in stream flow and sediment yield. Further, wetlands augment groundwater resources which recharge rivers during the dry season. This has rose the number the number of ephemeral and seasonal rivers in the basin (Haregeweyn *et al*., 2013).

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The conclusions and recommendations are based on results obtained in the examination of the set specific objectives of the study.

7.2 Key Findings of the Study

7.2.1 Inter-Seasonal and Inter-Annual Stream Flow Variation

The findings on the inter-seasonal and inter-annual variation in stream flow in NWUT basin were very significant. High flows were experienced in wet season (July-December) in 2010 and 2011. Sagana River had the highest flows of 170 m^3/s, followed by Maragua River with flows of 59 m^3/s and Mathioya River with a flow of 45 m^3/s.

7.2.2 Influence of Rainfall on Stream Flow

The findings on the relationship between rainfall and stream flow for study were significant. This study found a positive relationship between the two parameters. Correlation coefficient (r) of 0.81 and coefficient of determination (R^2) of 0.65 was obtained. These results shows that rainfall has 65% influence on stream flow in the NWUT basin. Other influences could be as a result of snow melting on Mt. Kenya and groundwater recharge into the streams.

7.2.3 Spatial Temporal Variation on Stream Flow

Findings on the spatial temporal variation in stream flow were done for rivers in NWUT basin. Major rivers included Sagana, Mathioya, Thika and Maragua. The spatial temporal variation findings in the wet seasons (July to December) and two dry seasons (January to June) in 2010 to 2012. Sagana river had 170.4 m^3/s and 63.4 m^3/s (wet season), 36.01 m^3/s and 57 m^3/s (dry season). Mathoiya river had 45.8 m^3/s and 37.23 m^3/s (wet season), 10.38 m^3/s and 12.08 m^3/s (dry season). Maragua river had 59.42 m^3/s and 17.05 m^3/s (wet season), 8.24 m^3/s and 8.05 m^3/s (dry season). Thika river had 87.38 m^3/s and 31.17 m^3/s (wet season), 11.1 m^3/s and 25.09 m^3/s (wet season).

7.2.4 Inter-Seasonal and Inter-Annual TSSC Variation

Inter-seasonal and inter-annual variation in TSSC was significant for NWUT basin. The spatial temporal variation on TSSC showed that Sagana, Maragua, Saba Saba and Mathioya rivers had the highest values in TSSC of 500 mg/l, 517 mg/l, 800 mg/l and 258 mg/l respectively.

7.2.5 Inter-Seasonal and Inter-Annual Variation in Sediment Yield

This study found a major inter-seasonal and inter-annual variability in sediment yield in NWUT basin. High sediment yield were experienced in wet season (July to December) when stream flow was high in respective rivers. Sagana, Maragua and Mathioya rivers showed the highest inter-seasonal and inter-annual variation. Sagana river had 82,166 tons/month (wet season) and 2,519 tons/month (dry season). Maragua river had 48,418.6 tons/month (wet season) and 10,987.5 tons/month (dry season). Mathioya river had 20,069.86 tons/month (wet season) and 10,004.3 tons/month (dry season).

7.2.6 Relationship between Sediment Yield and Rainfall

This study found animportant relationship between sediment yield and rainfall in the NWUT basin. The results of this study found a correlation coefficient (r) of 0.87 and coefficient of determination (R^2) of 0.75. This study found that rainfall has 75% influence on sediment yield in the basin.

7.2.7 Spatial Temporal Variation of Sediment Yield

This study found out that there is a high spatial variability in sediment yield in NWUT catchment with wet season. Sagana, Maragua, Mathioya and Thika rivers showed the highest spatial temporal variation in sediment yield in the basin. Sagana showed spatial temporal variation in sediment yield of 13.63 kg/s and 31.7 kg/s (wet season), 0.97 kg/s and 1.18 kg/s (dry season). Maragua River showed spatial temporal variation in sediment yield of 18.68 kg /s and 4.24 kg /s (season), 0.99 kg/s and 0.137 kg/s (dry season). Mathioya river showed spatial temporal in sediment yield of 7.7 kg/s and 3.91 kg/s (wet season), 0.125 kg/s and 0.64 kg/s (dry season). Thika River showed spatial temporal variation in sediment yield of 13.28 kg/s and 1.87 kg/s (wet season), 0.3 kg/s and 3.01 kg/s (dry season).

7.3.8 Relationship between Sediment Yield and Stream Flow

This study found that a positive relationship between river discharge and sediment yield in the NWUT catchment. **C**orrelation coefficient (r) of 0.74 and a coefficient of determination (R^2) of 0.55. This shows that there is a very high positive relationship between the two parameters under examination.

7.2.9 Relationship between Rainfall, Stream Flow and Sediment Yield

This study found a positive relationship between rainfall, stream flow and sediment yield in the NWUT basin. An increase in rainfall resulted to an increase in stream flow which increased the transport capacity of sediments in the basin. The results of this study found peak stream flow from river Sagana to be 170 m^3/s and sediment yield of 31.7 kg/s.

7.2.10 Water Yield and Sediment Production Rates in the NWUT Basin and Sub-Basins

The findings of this study on water yield and sediment production rates in the NWUT basin found significant results. The NWUT basin had a water yield of 327,638,942 m^3/month and sediment flux of 590,637.4 tons/month (7.1 million tons/year) in the period of July to May (2010-2012). North-West Upper Tana basin has a surface area of 9,918 km^2 which resulted into a sediment production rate of 59.6 tons/km^2/month which is approximately 715 tons/km^2/year from the basin. Sagana River had water yield of 1.072E+12 m^3/year and sediment yield of 146,626.5 tons/year. Maragua River ha water yield of 1.45E+11 m^3/year and sediment yield of 15,805.3 tons/year. Mathioya River had water yield of 318,064,320 m^3/year and sediment yield of 19,096.59 tons/month. Thika River ha water yield of 276,229,440 m^3/year and sediment yield of 17,754.84 tons/year.

7.2.11 Land Use Land Cover in the Period of 2000 to 2014

Land Use Land Cover (LULC) detections analysis from 2000 to 2014 found out there was increase on bare-land (6.5% to 9.7%), increase in build-up areas (0.2% to 0.8%), decrease in forest cover (32.3% to 21.7%), decrease in rangeland (17.0% to 12.7%), increase in plantation (12.7% to 15.0%), and increase in sedimented waterbody (0.1% to 0.7%) and reduced waterbody (1.5% to 0.5%).

7.2.12 SWAT Modeling on Stream Flow and Sediment Yield

Modeling of stream flow and sediment yield was done in the period 1981 to 2012. The results of the modeling exercise showed good performance in the simulation of river discharge and sediment yield in NWUT catchment with correlations of 0.94 and 0.99 respectively between observed and simulated data. These results compares well with those of Kigira (2016), who found a coefficient of determination (R^2) of 0.9 and correlation coefficient (r) of 0.95.

7.2.13 Future Trends in Rainfall, Stream Flow and Sediment Yield

Future projections on rainfall, river discharge and sediment yield were done in the period of 2000-2030 for NWUT basin. The results of this study showed were significant in the prediction of future trends in rainfall, stream flow and sediment yield in NWUT basin. In 2024, the model predicted rainfall, stream flow and sediment yield of 1014.6 mm, 372.8 m^3/s and 54,872.6 tons/month respectively. In 2030, the model predicted rainfall, stream flow and sediment yield of 1016 mm, 252.4 m^3/s and 17,573 tons/month. A decrease in stream flow was noted in the period of 2020 to 2022 (468.12 m^3/s) while the increase will be experienced in the period of 2023 to 2025 (48.61 m^3/s).

7.2.14 Hypothesis Testing

This study found substantial results on hypothesis testing in the NWUT basin. All the Null hypothesis (H_0) set for this study were rejected and alternate hypothesis of the study accepted (H_1). The relation between stream flow and rainfall had significant F-value of 1.859 which is greater than F-value of 0.187 and P-value of 0.08 which is greater than 0.05. The relationship sediment yield and rainfall had significant F-value of 2.049 which is greater than F-value of 0.167 and P-value of 0.217 which is greater than 0.05. The relationship between stream flow and sediment yield had a significant F-value of 12.0 which is greater than F- value of 0.006 and P-value of 0.061 which is greater than 0.05. The relationship between observed and simulated stream flow had a significant F-value of 5.43E+15 which is greater than F-value of 385.49 and P-value of 0.67 which is greater than 0.05. The relationship between observed and simulated sediment yield had a significant F-value of 1.18E+11 which is greater than F-value of 174.96 and P-value of 0.27 which is greater than 0.05.

7.2.15 Soil and Water Conservation Policy Framework in NWUT Basin

The results of this study from desktop review showed that National Government, County Governments and donors have tried to promote soil and water conservation measures in Upper Tana basin which are not adequate to deal with the issue of water yield and sediment load.

7.3 The Main Conclusions of the Study

The conclusions of the study are as follows;

i. There is a significant relationship between stream flow and rainfall in NWUT basin
i. There is a significant relationship between sediment yield and rainfall in NWUT basin
ii. There is a significant relationship between stream flow and sediment yield in NWUT basin

iii. The variations in rainfall determines the variations in stream flow and sediment yield in NWUT basin
iv. There is high sediment yield production in NWUT basin resulting in sedimentation of the Masinga reservoir
v. There is significant Land Use Land Cover changes in the NWUT basin
vi. SWAT model is suitable in stream flow and sediment yield simulation in NWUT basin
vii. SWAT Model is suitable in prediction of stream flow, rainfall and sediment yield in NWUT basin
viii. The soil and water conservation interventions measures are not adequate in NWUT basin.

7.4 Recommendations

This study provides recommendations to various stakeholders in the North-West upper Tana catchment. These stakeholders include the National Government, County Governments, Water Resources Authority (WRA), Water Users Associations (WUAs), Water Resources Users Associations (WRUAs), Development Authorities, local community, and SWAT Model developers to achieve a complete sediment yield assessment in the catchment.

7.4.1 Application of SWAT Model

The model should be developed in such a way that the interface is user friendly. The model data handling format is quite tedious where the data preparatoin to fit the requirement is quite time consuming, the format that the data had to be comma delimited making it very difficult especially when dealing with large amount of data. An occurence in error results in repeating the whole process which is time consuming. The Model should be modified to take the data format in the daily instead of annual to diversify on the output obtained. Based on the swiftness of the model in the NWUT catchment in simulation of rainfall, river discharge and sedimnet yield, the model can be used in other tropical basins.

7.4.2 Management of Hydrological Data

The Water Resources Authority (WRA) Embu Regional offices should ensure consistecy and completeness of the data collected and stored in their databases so that researchers in the Upper Tana catchment will not experience data gaps which makes it difficult to run models. Data inadequacy in sediment yield and TSSC was noted during this study which the office should ensure consistency in collection. Data sharing should be encouraged among major stakeholders in NWUT catchment thatwill help in the dissemination of information and research results to every stakeholder and hence an integrated catchment management strategy.

7.4.3 Land Use Land Cover Practices

Land Use Land Cover in the NWUT basin has major implications on stream flow and sediment yield. Major organizations and stakeholders in the region should take action on the land-use practices in the area to ensure that these practices ensure protection of the reservoirs in the catchment. Stakeholders' participation and education and outreach should be applied to ensure sustainable land and water management in the catchment (Ervin and Ervin, 1982).Adoption of sustainable land use practices and improvement of land cover should be enforced by the government and the local community (Bekele and Drake, 2003). The following land use measures are therefore recommended by this study in the North-West Upper Tana catchment.

7.4.3.1 Permanent Vegetative Contour Strips

Strip cropping is a practice in which contoured strips of soil are alternated with equal width strips of row crop or small grain. Strips of grass or other permanent vegetation in a contoured field help trap sediment and nutrients. Because the buffer strips are established on the contour, runoff flows slower and evenly across the grass strip, reducing sheet and rill erosion. The vegetation can also provide habitat for small birds and animals. Permanent vegetative contour strips are in fact an inexpensive substitute for terraces (Paudel and Thapa, 2004).

7.4.3.2 Soil and Water Conservation Measures

Soil and water conservation measures should be adopted in NWUT basin to promote the sustainability of these resources. Some the measures put forward by this study include the use of mulching, contouring and construction of check dams in hilly terrains to control the velocity of runoff (Soule *et al*., (2000); Hunink *et al*., (2012); Amsalu and Graaff, (2007).

7.4.3.3 Reforestation

This is the process of planting trees where they had previously been cut down in order to restore the vegetation cover of an area. Since major tree cut down has taken place along the Upper Tana catchment, tree planting can be done in the high altitude areas like the Mt. Kenya region, the Aberdares and the Nyambene Hills with an altitude above 1200m. This sections can further be put under conservation agencies which can foresee that the forests are conserved to the latter (Franzel *et* *al*., 2001); Muchena, (2008). A multi-stakeholders approach will be appropriate for this basin to ensure that not only planting of trees in taking palce but rather growing of trees.

7.4.3.4 Eco-Hydrology

This is an interdisciplinary field studying the interactions between water and eco-systems. These interactions may take place within water bodies, such as rivers and lakes, or on land, in forests, deserts, and other terrestrial ecosystems. Areas of research in eco-hydrology include transpiration and plant water use, adaption of organisms to their water environment, influence of vegetation on stream flow and function, and feedbacks between ecological processes and the hydrological cycle (Shisanya *et al*., 2014). This will also involve the taking care of the ecosystem along the Tana river to ensure safe and quality water, this will be done by planting trees along the river and other vegetation cover that attenuate the force of raindrops to cause erosion.

7.4.4 Payment for Ecosystem Services (PES)

Most Land Use Land Cover (LULC) practices in the NWUT basin do not promote soil and water conservation. There is need to promote Payment for Ecosystem Services (PES) in the basin to reduce sediment yield and increase ground water recharge (Lal, (2004) and Powlson *et al*., (2011). Green Water Credits (GWC) proposes payment of 1US $ per tonne of Carbon (iv) Oxide (CO_2) produced bythe farmer (Batjes, (2014); Hunink *et al*., (2012); Porras *et al*., (2007); Place and Way, (2012).

7.4.5 Integrated Water Resources Management (IWRM)

The Catchment Management Strategies (CMS) should be integrated with County Integrated Development Plans (CIDP) for Nyeri, Kiambu and Murang'a Counties.

An incentive based catchment management strategy should be implemented to promote soil and water conservation in NWUT basin. Mainstreaming of climate change and disaster mitigation for monitoring in Nyeri, Kiambu and Murang'a counties. The adoption of the IWRM principles in the basin is key for the success in maintaining a sustainable approach to soil and water conservation in the basin.

7.4.6 Further Research Areas

Recommendations on further reserch areas include the following;

i. Climate change impacts on sediment yield and river discharge

ii. Use autogenic process based model to cater for anthropogenic activities and climate change to avoid coupling of catchment characteristics and sediment yield
iii. Impacts of education and outreach and stakeholders participation in sustainable land and water management

The findings/ results of this study to be used by other researchers, National government, land owners, the community, Water Resources Associations (WRAs), Water Users Association (WUAs), Kenya energy Generating Company (KenGen), Tanathi Water Service Board (TAWSB) and Tana River Development Authority (TARDA) to facilitate a joint catchment management practice in this area.There should be continous monitoring and evalution by major stakeholders, facilitation of capacity building activities to the farmers to ensure proper land use practices are adhered to.

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APPENDICES

Appendix 1: Stream flow data from different River Gauging Stations (RGS) in NWUT basin (m^3/s)

Months	Mathioya (4BD01)	Sagana (4AC03)	Saba Saba (4BF01)	N. Mathioya (4BD07)	Gikigie (4BE08)	Irati (4BE03)	Maragua(4BE01)	Thiba (4DD01)	Thika (4CC05)
July	27.77	90.13	1.3	11.09	4.65	10.5	36.13	35.43	53.85
August	19.72	70.65	1.09	11.25	4.91	9.48	30.1	21.73	50.59
Sep	30.01	170.4	2.1	17.59	7.99	14.96	59.42	35.37	87.38
Oct	45.76	125.5	0.77	11.83	5.5	12.94	36.27	74.43	61.55
Nov	25.81	91.63	1.21	9	3.73	4.97	17.48	37.59	32.2
Dec	15.9	58.25	0.33	6.18	3.04	4.23	13.14	27.28	17.99
Jan	10.38	36.01	0.72	4.25	1.72	2.48	8.24	14.51	11.1
Feb	5.71	24.46	0.5	3.25	1.31	2.2	5.72	8.08	6.19
Mar	0.99	23.06	0.55	2.87	1.09	1.95	6.19	11.95	6.98
Apr	0.48	17.61	0.34	2.23	0.78	1.73	4.11	8	3.62
May	0.4	19.47	0.36	2.95	1.1	1.14	4.03	10.78	3
June	0.9	13.37	0.26	2.39	1.2	1.11	2.83	3.58	1.72
July	0.84	13.94	0.22	3.03	1.27	0.92	3.57	3.07	1.01
Aug	15.39	41.57	0.19	5.57	2.42	1.59	5.49	5.47	0.85
Sep	37.23	57.59	1.24	16.77	7.08	7.02	17.05	15.56	15.84
Oct	21.01	63.4	1.3	15.86	5.76	3.5	12.11	46.47	31.17
Nov	17.3	43.85	0.33	12.79	5.73	4.09	10.84	12.07	
Dec	12.08	36.99	0.25	15.94	7.95	3.5	7.23		25.09
Jan		57.13	0.27	10.31	7.53	3.46	8.05	5.06	11.58
Feb	1.05	13.54	0.21	5	2.06	2.18	4.2	3.67	3.02
Mar	11.13	12.81	0.16	4.17	2.4	1.25	3.64	2.04	3.09
April	2.48	13.85	0.19	3.34	1.19	1.31	3.5	2.04	2.17
May	1.96	7.43	0.12	2.85	1	0.79	2.34	1.17	1.74

Appendix 2: Total Suspended Sediment Concentration data (TSSC) from different River Gauging Stations (RGS) in NWUT basin (mg/l)

Months	Mathioya (4BD01)	Sagana (4AC03)	Saba Saba (4BF01)	N. Mathioya (4BD07)	Gikigie (4BE08)	Irati (4BE03)	Maragua (4BE01)	Thiba (4DD01)	Thika (4CC05)
July	158	107	800	8	5	37	517	107	120
August	63	67	533	10	11	24	60	43	97
Sep	258	80	637	15	14	67	233	43	152
Oct	67	62	167	7	10	20	50	32	93
Nov	40	53	183	16	10	10	27	35	67
Dec	21	33	100	8	6	16	28	33	40
Jan	12	27	70	5	5	6	12	22	27
Feb	5	25	50	4	4	5	10	15	18
Mar	5	23	50	5	5	9	13	32	17
Apr	8	18	43	7	5	6	8	28	8
May	8	22	23	15	5	3	10	30	3
June	4	17	13	4	5	2	3	11	7
July	8	13	15	5	5	2	7	9	5
Aug	3	68	18	8	7	22	30	23	7
Sep	105	53	1150	20	19	52	57	23	87
Oct	103	500	1433	27	18	13	350	100	60
Nov	25	50	92	8	10	17	25	32	10
Dec	53	32	77	10	10	17	15	17	120
Jan	12	18	70	8	9	15	17	17	23
Feb	5	17	20	5	6	7	5	8	10
Mar	10	7	13	5	5	5	6	7	14
April	5	3	13	4	5	5	6	5	7
May	7	7	10	5	5	5	9	5	11

Appendix 3: Sediment yield data from different River Gauging Stations (RGS) in NWUT basin (kg/s)

Months	Mathioya (4BD01)	Sagana (4AC03)	Saba Saba (4BF01)	N. Mathioya (4BD07)	Gikigie (4BE08)	Irati (4BE03)	Maragua (4BE01)	Thiba (4DD01)	Thika (4CC05)
July	4.388	9.644	1.043	0.089	0.023	0.389	18.679	3.791	6.462
August	1.242	4.734	0.581	0.113	0.054	0.228	1.806	0.934	4.907
Sep	7.743	13.632	1.338	0.264	0.112	1.002	13.845	1.521	13.282
Oct	3.066	7.781	0.129	0.083	0.055	0.259	1.814	2.382	5.724
Nov	1.032	4.856	0.221	0.144	0.037	0.05	0.472	1.316	2.157
Dec	0.334	1.922	0.033	0.049	0.018	0.068	0.368	0.9	0.72
Jan	0.125	0.972	0.05	0.021	0.009	0.015	0.099	0.319	0.3
Feb	0.029	0.612	0.025	0.013	0.005	0.011	0.057	0.121	0.111
Mar	0.005	0.53	0.028	0.014	0.005	0.018	0.08	0.382	0.119
Apr	0.004	0.317	0.014	0.016	0.004	0.01	0.033	0.224	0.029
May	0.003	0.428	0.008	0.044	0.006	0.003	0.04	0.323	0.009
June	0.004	0.227	0.003	0.01	0.006	0.002	0.008	0.039	0.012
July	0.007	0.181	0.003	0.015	0.006	0.002	0.025	0.028	0.005
Aug	0.046	2.827	0.003	0.045	0.017	0.035	0.165	0.126	0.006
Sep	3.909	3.052	1.431	0.335	0.135	0.365	0.972	0.358	1.378
Oct	2.164	31.7	1.869	0.428	0.104	0.046	4.239	4.647	1.87
Nov	0.433	2.193	0.03	0.102	0.057	0.07	0.271	0.386	
Dec	0.64	1.184	0.019	0.159	0.079	0.06	0.108		3.011
Jan		1.028	0.019	0.082	0.068	0.052	0.137	0.086	0.266
Feb	0.005	0.23	0.004	0.025	0.012	0.015	0.021	0.029	0.03
Mar	0.111	0.09	0.002	0.021	0.012	0.006	0.022	0.014	0.043
April	0.012	0.042	0.002	0.013	0.006	0.007	0.021	0.01	0.015
May	0.014	0.052	0.001	0.014	0.005	0.004	0.021	0.006	0.019

Appendix 4: SWAT Model simulated data on rainfall, stream flow and sediment yield in the period of 2000-2030 NWUT basin

Years	Rainfall (mm)	River Discharge (m^3/s)	Sediment Yield (kg/s)
2000	1052.55	203.49	0.98
2001	1014.89	267.49	3.3
2002	1041.88	320.05	5.47
2003	975.12	292.93	5.31
2004	1047.57	254.77	5.22
2005	1008.12	396.83	8.86
2006	1005.97	235.03	4.26
2007	1027.98	198.57	6.35
2008	997.91	195.61	3.89
2009	1094.85	302.08	8.83
2010	969.48	250.55	4.38
2011	1030.28	255.98	6.64
2012	945.79	268.42	5.98
2013	955.15	327.83	6.7
2014	1024.18	201.74	3.12
2015	990.66	388.21	15.67
2016	952.27	338.69	10.49
2017	964.61	329.47	11.44
2018	1051.3	351.02	9.49
2019	960.44	286.04	9.24
2020	1035.42	282.89	8.99
2021	1019.68	340.06	10.89
2022	988.06	468.02	11.14
2023	1050.57	263.99	7.1
2024	1014.59	372.75	21.17
2025	928.06	448.61	18.25
2026	1024.89	347.84	13.07
2027	1010.74	355.91	15.41
2028	1049.85	272.07	7.4
2029	1067.13	226.28	8.13
2030	1016.09	252.42	6.78

Appendix 5: Observed and simulated data on stream flow and sediment yield in the period of 1980-2012 for NWUT basin

Years	Simulated Rainfall (mm)	Simulated sed yied (ton/yr)	Simulated Discharge (m^3/s)	Observed discharge Sagana (4AC03) (m^3/s)-	Observed total rainfall Sagana FF (mm)
1981	1176.53	737.9	626.32	157.4283	1360.2
1982	1236.07	151.6	517.1	196.473	1287
1983	978.47	55.9	353.51	136.2596	1007
1984	716.78	67.2	200.48	86.40478	740
1985	1246.55	397.3	641.26	163.7069	1292
1986	1037.8	94.7	360.63	144.6474	0
1987	891.48	154.5	281.42	95.16281	950
1988	1642.37	150.7	840.9	153.7617	1756
1989	1319.27	142.9	591.28	157.9355	1411
1990	1488.66	480.6	832.85	184.5494	1593
1991	876.02	103.4	283.37	122.903	880
1992	1196.08	121.6	518.48	92.78058	1319
1993	942.79	100.8	405.63	97.33462	986
1994	1382.03	189.1	665.23	144.8565	1460
1995	1366.77	430	751.67	179.7413	1459
1996	669.66	80.5	170.27	108.3201	669
1997	1547.13	275.9	757.87	173.5303	1575
1998	1107.24	228.4	519.96	197.3613	985
1999	622.17	38.4	105.03	69.95678	454
2000	376.08	21.4	52.4	34.72148	357
2001	980.78	260.7	386.52	130.075	765
2002	1486.91	221	689.2	127.4909	1610
2003	861.89	106.8	463.57	111.8027	839
2004	961.85	84	248.98	110.0163	377
2005	656.26	23.2	156.5	91.0861	0
2006	1753.07	283.3	883.31	105.6007	1839
2007	911.74	52.9	261.78	150.7389	906.7
2008	767.35	61.3	184.27	72.75897	788.7
2009	695.19	48.5	169.3	91.1027	731.1
2010	982.49	138.5	378.09	163.9443	1022.9
2011	1014.24	179.3	476.06	458.0067	1247.3
2012	1263.31	204.9	539.6	557.9872	831.7