MODELLING IMPACT OF LAND USE CHANGE ON SEDIMENT YIELD OF RIVER YALA, KENYA

BY:

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Water Engineering of Moi University

DECLARATION BY THE CANDIDATE

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DEDICATION

To my Wife, Son and Daughter, the source of my effort:

> *For in much wisdom is much grief; and he that increaseth knowledge increaseth sorrow*

(Ecclesiates1:18)

ABSTRACT

Increase in human population and the subsequent need for economic activities has led to degradation of catchments in most Sub-Saharan countries. Unsustainable land use coupled with management practices are the main causes of soil erosion, which leads to land degradation. Transboundary basins occupy about 60% of world fresh water in 192 countries. Of these, 310 lakes and rivers are shared by 153 countries and they serve 2.8 billion people, about 42% of the world population. The main objective of this study use SWAT model in simulating sustainable land use management practices of river Yala catchment. The specific objectives were to: determine the spatial and temporal land-use change of river Yala catchment (1973-2000), Set up, calibrate and validate the Soil Water Assessment Tool (SWAT) model to predict streamflow, sediment quantity, and concentration in river Yala, and Apply the SWAT model to analyze various management scenarios that may reverse the impacts of the land use changes of the Yala catchment. Land use/cover database for a period of 27 years representing the beginning, mid and end of the period for the years 1973, 1986 and 2000 were analyzed to determine changes. SWAT model integrated with Geographic Information System (ArcGIS, version 10.3) was used to analyze the images, simulate discharge and sediment yield. Other data required for modelling included soil, elevation, drainage, climate, and land use. The model was calibrated and validated using the SWAT-CUP and flow at IF02 gauge station (Tindinyo) on monthly time step for the years 1979-1983 and 1984 -1988 respectively. Sediment predictions and streamflow of the watershed was carried out by spatial resolution through watershed subdivision. Three scenarios were used to represent different patterns of LULC. Scenario A represented baseline, i.e. the original watershed conditions. In scenario B, 30% of pastureland was converted to the forest and for C, strip farming was introduced into the watershed. The findings of this study indicated that in the base year (1973), the largest LULC was occupied by vegetation - covering 56% of the entire area and then reduced to 30% in 1986, and 21% in 2000. The settlement area increased from 20% in 1973 to 67.9% in 2000.Bare lands that were 25% reduced to 20% then 11% in 1986 and 2000 in the three scenarios respectively. The highest sediment concentration was 3,552.4 mg/l in 1991 while the lowest was 612.71mg/l in 1985. Model performance measures coefficient of determination (R^2) was 0.72 and the Nash–Sutcliffe simulation efficiency (*NSE*) of 0.79 for calibration. For validation, $R^2 = 0.80$ while *NSE* was found to be 0.94%. These indicated a good performance of the streamflow simulation on the monthly time step. Flow prediction and soil loss are key tools for determining suitable land use and conservation measures. SWAT model integrated with GIS effectively simulated sediment transfer and water phenomena. It is therefore recommended that spatio-temporal land cover images of higher resolution based on future scenarios be analyzed to mitigate the negative effects and recommend appropriate management practices.

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LIST OF ABBREVIATIONSAND ACCRONYMS

AMC	Antecedent Moisture Condition
AVHRR	Advanced Very High Resolution Radiometer
DEM	Digital Elevation Model
DH	Danish Hydrological Institute
DMC	Double Mass Curve
ECA	Economic Commission for Africa
EOS	Earth Observation Systems
Eq	Equation
ERTS	Earth Resource Technology Satellite
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GIS	Geographic Information System(s)
GLCN	Global Land Cover Network
GPS	Geographical Positioning System
GWP	Global Water Partnership
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
ITCZ	Inter-Tropical Convergence Zone
KSS	Kenya Soil Survey
LCC	Land Cover Change
LCCS	Land Cover Classifications System
MEA	Millennium Ecosystem Assessment
Mm^3	Million Cubic Meter
MSS	Multispectral Scanner

NASA	National Aeronautics and Space Administration-
NGO	Non-Governmental Organization
NRCM	National Resource Conservation Service
PA	Producer Accuracy
RCMRD	Regional Centre for Mapping and Resource for Development
ROI	Regions of interest
SCS	Soil Conservation Service
SDR	Sediment Delivery Ratio
SFM	The Geospatial Stream Flow Model
SHE	Systeme Hydrologique European
SPOT	Satellite Probatoired' Observation De La Terre
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
SWIR	Shortwave Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
UA	User Accuracy
UK	United Kingdom
USGS	United States Geological Survey
WEAP	Water Evaluation and Planning
WRA	Water Resource Authority
WRM	Water Resource Management

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

About 71% of the Earth's surface is covered by water. Out of this, ninety seven percent (97%) is salty. Only 3% is freshwater. Out of this fresh water, 30% is ground water, 68% is in the form of frozen glaziers, polar ice caps and 0.3% is surface water in rivers, Lakes and swamps (NASA, 2016). Transboundary basins occupy about 60% of world fresh water in 192 countries. Of these, 310 lakes and rivers are shared by 153 countries and they serve 2.8 billion people (GWP, 2016). About 42% of the world's population reside in the sub-catchment basins (MEA, 2005). Catchments are units that function on a common landscape like soil, plants, water and animals, hence any activity within which affects the whole. Urbanization, deforestation and agricultural activities generally modify land surface characteristics (White, 2006). Deforestation, which has opposite effects to afforestation, affects the characteristics of the stream flow in a significant manner (Calder, 1992).

(Anderson JR, 1976) developed a system that combines land use/land Cover and placed all land into nine (9) level one categories: Agricultural land, Urban built land, Rangeland, Water, Tundra, Forestland, Barren land, Wetland and Perennial snow ice. The second can be divided into level two: High-density, Medium density and Low density Residential, Industrial, Institutional, Commercial, Extractive and Open urban land.

Vegetation Changes often result into hydro-ecological fluxes (Grist, 1997; Poveda, 2001). Increased agricultural activities, human settlement, industrial and urban development in previously forestlands affects the ecological hygiene of ecosystems and water quality (Johnson *et al.*, 2001). Population increase in tropical countries in the last decades has caused acute land use changes and this has combined with the increased demand for food resources (Lambin, *et al.*, 2001).

Water bodies have the favorable conditions for the existence of different bio diversities (Cardinale, 2011; Ward JV, 2001). Adjustments to this ecosystem composition therefore result into threats to biota (Dallas H, 2004).

Surface water pollution by anthropogenic activities is mainly in two ways. One is through point sources like discharge from sewage treatment plants and non-point sources like overland runoff from agricultural and urban areas (buffer zones) (Sliva, 2001).

The main land use change in East Africa is through the clearing of forest to create room for agriculture, settle population and urbanization. These are the major stressors of streams and rivers (Kobingi, 2009). Grazing and row crop in Agriculture are considered important sources of sediment pollution to stream ecosystems (Waters, 1995).

Kenya with an estimated population of 47.6 million in 2019 will face a crisis in water resources because of its deforestation in water catchment areas, rainfall variability and distribution, water pollution and dynamic national land-use policies (GOK, 2008). The different types of land use practices within the Lake Victoria catchment contributes to water quality deterioration causing enormous pollution to major water towers in the region (Anyona, 2014; Matano, 2015). The rivers discharging their waters into the lake from the Kenyan side of the catchment contribute over 37.5% of the lake surface inflows (COWI, 2002).

The Yala River whose basin covers about 3,351km^2 is also one of the main Kenyan rivers flowing into Lake Victoria. Its long-term annual average discharge (based on data from

1950 to 2000) is 37.6m^3/s, which accounts for 4.8% of the surface inflow into Lake Victoria (Otiende, 2009).

1.2 Problem Statement

Population growth leads to expansion of agriculture, urbanization, and the demand for fuel and encroachment, which leads to destruction of ecosystems biodiversity. About 75 Million Hactares of forestland in Africa was converted to agriculture between 1990 and 2010 (FAO, 2010). The different types of land use practices within the Lake Victoria catchment contributes to water quality deterioration causing enormous pollution to major water towers (Anyona, 2014; Matano, 2015). Unsustainable land use coupled with management practices are the main causes of soil erosion, which leads to land degradation. Sediment in river systems is essential.

Sediment quantity assessment and SSC assists to evaluate the extent of damage to watersheds. The stream flow in the Yala River causes flooding downstream (UNEP, 2004). Okungu (2002) did a study that estimated the pollution loadings transferred to the Lake Victoria from the catchments in Kenya. He looked at how nutrients runoff and sedimentation, industrial and urban point sources pollution including burning of biomass had induced the rapid eutrophication of the Lake. The methodology used was through samples collection at the river mouths as they flowed into the Lake Victoria. The study observed that river Yala with its catchment area of 3,357km^2 and a discharge of 27.4m^3/s had a phosphorus contribution of 130tons per year taking position four out of ten Kenyan rivers after Nzoia 1,365tons/year, Kuja 298 tons/year and Nyando 156 tons/year. This study estimated the loads to the lake using data from samples taken from the last sampling stations to the mouth of each river. The study looked at the types of parent rocks sediment originated but failed to quantify the loadings. The likely cause of nutrient transfer was not studied hence scenario analysis to advise on management was not possible. Although Yala watershed is endowed with natural resources like water and forests, population increase is exerting pressure to them. If the trend is not managed, it will lead to flooding, disease, and degradation of natural resources, especially land.

This study therefore attempts to model the Impact of Land use change on sediment load of the River Yala and propose the best management practices to reverse the impacts.

1.3 Study Justification

Increase in human population and the subsequent need for economic development have placed water resources under extreme pressure in many sub-Saharan countries. Land cover change directly affects ecological landscape functions and processes with far-reaching consequences on biodiversity and natural resources. The soil erosion effects are not just the loss of fertile land, but includes sedimentation and pollution of rivers and streams. This clogs waterways causing suffocation of all organisms that depend on the ecosystem. The lands that have been degraded cannot also store water accelerating flooding risk. “Accelerated erosion” is a natural process that are human induced and may increase the rate of erosion by 10-40% (Pleguezuelo and Zuazo, 2009). Lake Victoria basin is shared and affected by over 30 million people in five countries. There is therefore need to avoid harmful activities that affect the lake for sake of the livelihoods of the inhabitants of this basin which is shared by five countries as shown in Table 1.1. Yala is the second largest of all Kenyan basins flowing to Lake Victoria at 11.4% after Nzoia 35% and the second largest Lake Victoria basin at 4.8% after Nzoia at 14.8 % that is shared by five countries. (Cheruyiot, 2015). The economy of the region is still largely rural, and more than 90 percent of the population earns its living from agriculture and livestock. The absence of other economic activities except agriculture in the basin points at the need for prudent management of the catchment.

Table 1.1: Lake Victoria Catchment Distribution

County	Catchment Area (Km^2)	Catchment Area (%)
Burundi	13510	7
Rwanda	21230	11
Uganda	30880	16
Kenya	42460	22
Tanzania	84920	44
Total	**193,000**	**100**

Okungu, 2002*: An introduction to Lake Victoria catchment, water quality, physical limnology and ecosystem status (Kenyan Sector)*

1.4 Research Objectives

1.4.1 Main Objectives

The main objective of this study is to use SWAT model in simulating sustainable land use management practices of river Yala catchment.

1.4.2 Specific Objectives

The specific objectives of this study were to:

i. Determine the spatial and temporal land-use change of river Yala catchment (1973-2000).

ii. Set up, calibrate and validate the Soil Water Assessment Tool (SWAT) model to predict streamflow, sediment quantity, and concentration in river Yala,

iii. Apply the SWAT model to analyze various management scenarios that may reverse the impacts of the land use changes of the Yala catchment.

1.4.3 Scope of the Study

This study is limited to suspended sediment load of the river water quality. Other forms like bed load and saltation loads are out of the scope of this research.

1.4.4 Study Area

River Yala, located at latitude 0°-30′N – 0°-10′S and longitude 34°-00′E – 35°-40′E, is one of the main rivers of Lake Victoria catchment (see Figure 1.2). The catchment area is about 3,350km^2 and is approximately 220km long. The river originates from the Nandi escarpment and traverses Vihiga, Kakamega, Bondo, and Siaya counties as it flows to Lake Victoria. Its long-term average annual discharge (based on data from 1950 to 2000) is about 38m^3/s, which accounts for 4.8% of the surface inflow into Lake Victoria (Otiende, 2009).

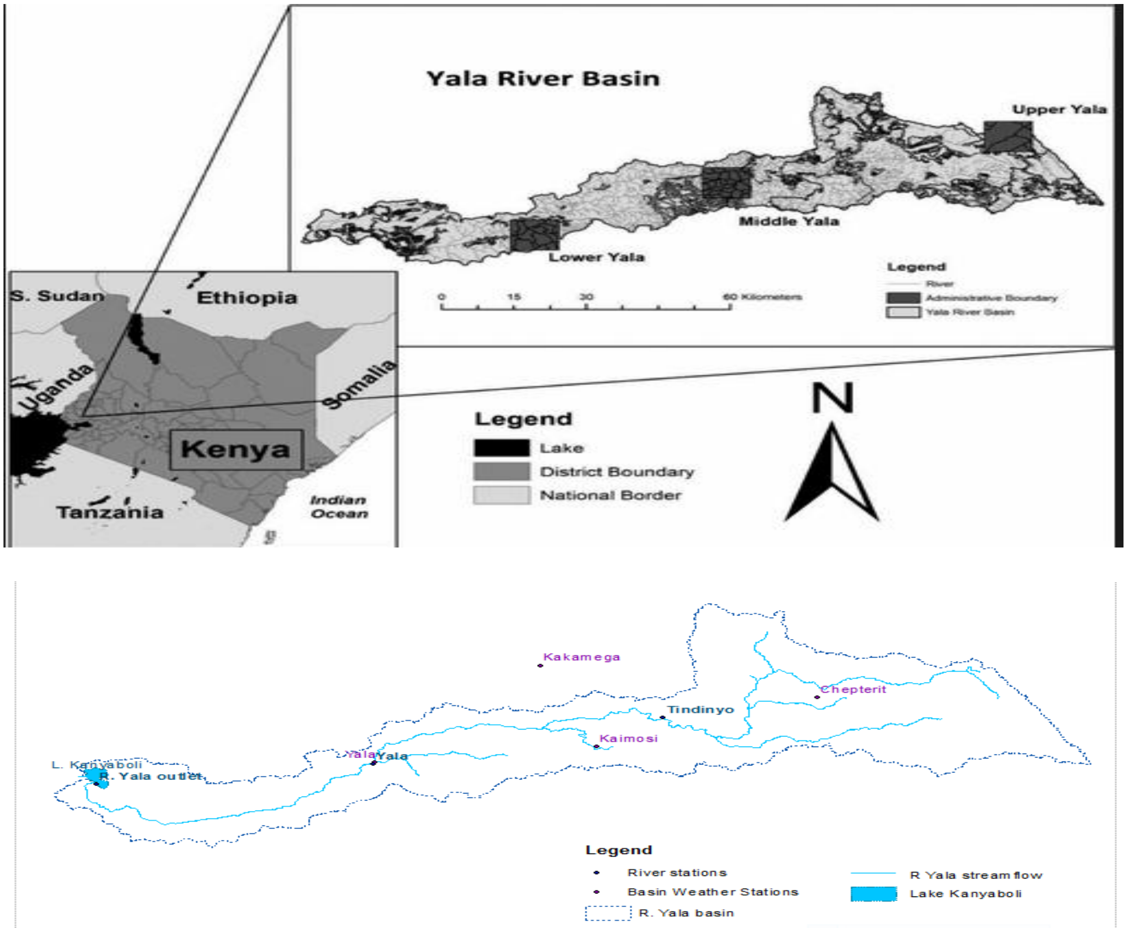

Figure 1.1: River Yala Catchment

The main land uses adjacent to the river in this area are livestock grazing, tea and coffee plantations and human settlements. The activities are mainly rain fed; hence, they increase with onset of rains increasing erosion. The lower elevation of Yala region to upper elevation ranges from 1,200m on the lower region to 2,200m on upper region. The mean annual rainfall is 1,589mm.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Sediment load is the total amount of erodible debris delivered to and transported by a stream. This is different from sediment yield which is such material exported from a drainage basin expressed as a volume or weight per unit area over a given time. Sediment load can be measured by collecting water samples and measuring sediment contained in if the volume of water in known. The greatest part of sediment load is usually in form of suspended.

Land Use Land Cover (LULC) seriously affect resources of water in terms of quality, quantity and increases changes in hydrological components like runoff (Ahearn et al 2005). Changes in land use varies stream flows, runoff patterns and increases flooding likelihood. In a watershed land –use changes alters hydrological processes like base flow, infiltration, runoff ground water recharge hence affecting water supply(Hickler et al 2005).

2.2 Water Resources

Beyond water supply, a well-functioning and biologically complex ecosystem of fresh water will give a valuable economic and commodities to a given society (Flint, 2004); (GWP, 2006). Water is a scarce but an integral part of the ecosystem resource and is an economic and social good (Shisanya, 2005).

Kenya has had a history of bad land management of mainly destroying natural vegetation in the catchment areas through human activities like illegal logging of forests, encroachment and farming. The net effect is the degradation of water resources (GOK, 2007a); (GOK, 2007b). Conversion of forests to settlements and illegal tree felling for timber and fuel have previously been the main causes of vegetation removal and deforestation. This escalated highly in the years 2000 and 2001, (Akotsi, 2006). There is hence increased flash flooding, runoff, and reduced infiltration and soil erosion. Dams and other reservoirs are experiencing increased siltation and this negatively affect the recharge level and quality (Terer, 2004).

2.3 Analysis of Land Use Land Cover

Land use is a series of activities, which are undertaken to produce services and goods, and is based on purpose of use. Cover is the physical as observed through remote sensing (FAO, 1997). Changes in vegetation are usually associated with hydro-ecological fluxes (Grist, 1997); (Poveda, 2001). Erosion has three-phase process. First is where individual soil particle detaches from the initial soil mass. Second, the detached soil is then transported using agents of erosion like water and wind, then finally deposited into lands of depression as dictated by human (accelerated soil erosion) or natural (geologic soil erosion) activities (Hundson, 1981). The need for more scientifically sound analysis of these fluxes has contributed to the need for developing hydrologic models. Models provide a basis of investigating and conceptualizing the relationships between water resources, human activities (e.g. Change in land use) and climate (Legesse. B., 2003). Sediments occur naturally and are broken down by weathering process. They then enter rivers as eroded fragments either in dissolved form or from rocky channels (McDowell, 1989). Models therefore assist engineers predict reliably the rate of sediment transported and quantity of transport to rivers, streams and other water. They also assist in identifying the problems associated with erosion within a given watershed and propose ways of reducing the impact (Yesuf, 2015).

2.4 Hydrological Modelling of Land Use Change

2.4.1 Water Quality Modelling

The water quality-modeling tool is important to planners, researchers, and other agencies to optimize practices that enable them manage and improve the quality of water. A number of models use the Natural Resources Conservation Services equations (previously Curve number) to predict watershed runoff. Such models include the Generalized Watershed Loading Function (GWLF) model (Haith and Shoemaker, 1987) and the Soil Water Assessment Tool (SWAT) model (Arnold, 1998). Vicente *et al.* (2016) in a case study of the influence of Land use change on sediment yield on the Sub-middle part of Sao Francisco River Basin simulated three land use scenarios using the SWAT model. Bare soil, corn growing and vegetation. Calibration was done using stream flows for the years 1993 to 1994 while validation was for 1995 to 2004. The study successfully identified specific areas where erosion was prevalent. Bare soil corresponded to an increase of 93.7% above the existing land use.

Faiza *et al.* (2018) modelled discharge and sediment transport in the Harraza Basin, North West Algeria using the SWAT Model. This is part of the Wadi Cheliff's basin whose area is 568 square kilometers and its altitude is 500m. The study simulated sediment concentration and discharge for the years 2004 up to 2009. They used metrological data from two stations covering a period of 13 years. Two sub-basins were generated resulting in two HRUs. Sequential Uncertainty Fitting 2 (SUFI-2, version 2) was used for calibration and validation using the years 2004-2007 and 2008-2009 respectively on a monthly time step. Calibration compared to simulated flows of the said period with D and P factors being 0.88 and 0.55. Additionally, the NASH criterion was 0.82 indicating that the observed and the simulated discharges compare by 82% hence model is able to represent various climatic conditions. The average total annual sediment was estimated as 54.24t $ha^{-1}year^{-1}$.

Kiluva V.M. (2018) modelled the rainfall runoff of Yala watershed in Western Kenya. The study was aimed at the development of an early warning system for floods to protect downstream households. The study made use of the Geological Stream flow Model (GeoSFM) and the Muskingum Cunge (M-C) models to determine the hydrologic processes. Historical hydrometric datasets used were for the years 1975-2005 for stream flow routing, calibration and verification. To get the hydrologic connectivity, the study made use of a 30m x 30m DEM from International Centre for Research in Agro-Forestry (ICRAF) and the Global Land Cover data of the United States Geological Survey (USGS). For the soil, it made use of the Digital Soil Map of the World from the Food and Agricultural Organization (FAO) website. The observed stream flow data on daily series was compared with the model's generation. The goodness of fit (R^2) value obtained for the model and calibration phases were 87.3% and 80.6% respectively. It was assumed that there was no inflow from areas that surround the channel.

Changes in land use are complicated processes that occur due to adjustments in land-cover to land conversion process (Aboud, 2002). There is limited data that can indicate how human factors and environment interact and operate to affect hydrological processes and the land use patterns (Olang' L., 2009; Lambin, *et al.*, 2001) suggested that the driver of land-use change the interaction of time and space between human and biophysical dimensions. Impacts on social and physical dimensions may also exist. Humanity has utilized land resources throughout his existence and this has caused significant changes in land use land cover (Gereta E., 2001).

Sediments occur naturally from materials broken down by weathering and erosion processes. They then enter into rivers either in the form of eroded fragments from rocky channels or as suspended in water McDowell (1989). When such sediments are deposited in waterways, they ruin the aquatic habitat and lower the quality of water. Such sediment makes water turbid with the resulting effect of blocking light penetration. Aquatic plants rely on this light to produce their food through photosynthesis. Sediments in suspension block gills of organisms that live in this environment. Furthermore, suspended sediments in the water have the potential of covering the stream bottom and clogging the gills of aquatic organisms. Deposited sediment leads to suffocation of benthic macro invertebrates, destroys natural spawning substrate and suffocates fish eggs. An increase of the quantity of particles in water lowers the amount of dissolved oxygen (MCWG, 2012).

N'geno (2016) studied Impact of Land Use and Land Cover Change on Stream Flow of Nyangores Sub-Catchment on the Mara River, Kenya. This study was based on the Mara Basin, Nyangores sub-catchment shared by Tanzania and Kenya. The study addressed the effects of land use changes on the sub-catchment's water resources by making use of the WEAP hydrological model. A DEM from the USGS website was used to analyze the terrain and surface water movement of the study area. Discrimination of changes in land cover for the study period was done using Landsat satellite data. The datasets that were projected to UTM-WGS 1984 coordinate system were found on zone 35°S. The study found that the changes in LULC change to Farmland increased to 38.9% from 30.1% between the years 1995 to 2010. There was also a decrease in forestland from 28.0% in

1995 to 26.8% in 2010. Tree plantation area showed a decrease of 9.4% from 21.3% to 11.9% during the years 1995 to 2010 respectively. He observed that using non-statistical and performance criteria required further evaluation.

Mulei *et al.* (2006) did a study that analyzed how land-use changes has affected the water quality and sediment yields and within the Nairobi River sub-basins, Kenya. The study was on the Nairobi River and its three distributaries: Nairobi, Mathare and Ngong located in Nairobi County Kenya. Six sites were sampled points in total on Nairobi, Mathare and Ngong Rivers. About 100 samples were collected for the period. A total of 15-water quality parameters were analyzed. The results indicated that for an increase in discharge, there was a corresponding increase in sediment concentration. Suspended sediments loads for the Rivers, Mathare, Ngong and Nairobi were 1733, 2987 and 6317t/km^{-2} year respectively. Riverine vegetation root system absorbed higher values of heavy metals and were therefore important in river system hygiene. This theory required further investigation.

Shivoga *et al.* (2007) researched on how land use/cover had affected the water quality of the upper and middle reaches of River Njoro in Kenya. Its objective was to investigate the cause of human induced disturbances to the degradation of the River Njoro's watersheds. He used GIS to determine the sub watersheds that contributed to the run-off to the sampling sites in the River and the distribution of spatial land-cover. A 50- m DEM was made from Topographical contour maps (GoK, 1974) which were digitized using ARCINFO model. Five Landsat images were selected for the study. Three Landsat TM+ scenes and one Landsat TM. Also topographical contour maps were digitized, which was acquired from GOK, (Government of Kenya, 1974) to create a 50-m DEM. The study used the ARCINFO model and found that there was marked differences in the concentration of phosphates, organic matter (total organic carbon) and Nitrates.

Kithiia (2006) conducted a study on the Upper-Athi River Basin, Kenya that looked at how the different types of Land Uses had affected the Water Quality and Hydrology of the Basin. It was conducted on the Athi River Basin Kenya drained by Ngong, Mathare and Nairobi rivers. Samples of water were collected fortnightly (two weeks) and analyzed in the Ministry of Water Resources Laboratories for water quality parameters. The study used the method of velocity x-sectional area to get discharges. Water samples for suspended sediment analysis were collected at the middle and both sides of the riverbanks using USDH48 sampler. The study observed that runoff increased, hence increase in discharge to the river as land use activities changed. There was increase in total suspended sediments with increase in river volume (discharge) and consequently water turbidity. The findings suggested the need to harmonize research in water quality degradation in rivers in the whole country and data acquisition and storage to help address emerging water quality issues in the country.

Odira, P.M.A. (2010) case studied of Nzoia catchment on River Nzoia in Kenya by making use of the SWAT model. The study researched on how Land Use/Cover affects dynamics of the stream flow: The study aimed to address perennial flooding downstream caused by watershed degradation. He started by acquiring the database for LULC for three years: 1973, 1986 and 2000. They were then analyzed using SWAT model. Sensitivity analysis was then done using a set of input variables. Other data used were Topography, climatic, Soil, and land use data. He obtained a 30m×30m DEM from the World Agroforestry Centre (ICRAF). This study found that the aerial coverage of the land for agriculture between the years 1970 and 1986 had an increase of 6.7%. In the year 2000 however, agriculture related activities declined by 4.6%. Between 1980 and the 2000, forest cover increased by 41.3%. The area under riverine agriculture land/bush land/shrub land increased by 23.4% in the years 1970, 1986 and then 11.10% in 2000. Forest cover area however reduced from the year 1970 and 1986 by 6.4%.

Njogu *et al.* (2018) did a study on the North -West part of the Tana Basin on sediment yield and variability. They aimed to establish how sediment yield the stream flow are influenced by variability in rainfall and LULC change and rainfall variability in the Northwestern part of Upper Tana catchment in Central Kenya. Sagana is the main river leaving upper Tana and its flow rates were simulated using the SWAT model. Water Resource Management Authority (WRA) provided data on the total Suspended Sediment Concentrations (TSSC). It was observed that the sediment yield is directly proportional to rainfall. An example was when the rainfall was 150mm; the sediment yield was 82,166.4tons/month. The study limitation was however the lack of long-term data. Geologists and Hydraulic engineers have been studying sediment movement in rivers to try to understand river hydraulics, morphology and other hydraulic characteristics of the rivers for a very long time. This is a complex subject only solved using semi-empirical and empirical formulae. A number of equations have been published but have very little laboratory data and, sometimes, data from the field. Solutions to these calculations do differ with field data.

Okungu (2002) researched on Pollution loads entering the Lake Victoria from the Kenyan catchments. He found that the problem was that nutrients runoff and sedimentation, urban and point sources, biomass burning and industrial pollution were the main inducers of increased eutrophication of Lake Victoria. The adopted method was mainly from collection of samples. The research observed that River Yala with its catchment area of 3,357km^2 and a discharge of 8.17km^2/s had a phosphorus contribution of 130tons per year taking position four out of ten Kenyan rivers after Nzoia 1,365tons/year, Kuja 298tons/year and Nyando 156tons/year. To get the estimated loads to the lake, the last stations at the mouth of the lake were sampled for all rivers in the study. It was then recommended that efforts of the various components of LVEMP be supported by further research on the Lakes pollution.

2.4.2 Impact of Sediment Concentration

The sediment cycle starts from erosion; hence, any material that can be dislodged is usually ready to be transported. The final stage is deposition when the energy for transport is depleted. In agricultural areas, toxic chemicals used as pesticides can be adsorbed or attached to sediment then deposited in other areas. The effects are on aquatic life and this may encourage plant growth leading to eutrophication.

Sediment in streams decrease light penetration in water, affecting marine animals schooling and feeding. Deposited sediment at beds also cover their eggs. Sediment particles absorb warmth from the sun, increasing water temperature, altering the normal environment for survival of fauna and flora.

2.5 Hydrologic Models

The following is a list and review of some of the major hydrological models reported in literature.

2.5.1 MIKE-SHE 1990

Developed by the Institute of Hydrology UK, Danish Hydrological Institute (DHI) and a French consulting firm SOGREAH developed SYSTEME HYDROLOGIQUE EUROPEAN (SHE). This model is physically based. MIKE SHE simulates components of hydrology that include saturated groundwater, evapotranspiration, surface water movement, unsaturated subsurface water, overland channel flow, and exchanges between groundwater and surface water. The model can simulate watersheds of all sizes. The existence of in-built digital post processor and are used for model evaluation and calibration of both management alternatives and current conditions. Model scenarios can be animated during results presentation. Being distributed, MIKE SHE data requirements are very high and such data is not easy to find. Getting a watershed with all input data is a challenge.

2.5.2 ARCINFO

ARCINFO Coverage is a geo relational data model developed by ESRI and it stores vector data; i.e., both the attribute (descriptive), the spatial (location) and data of geographic features. ARCINFO can also store attributes in tables in an RDBMS or INFO tables, which are then joined to a relationship class or a feature with a layer. It also has a topology that is used to determine the relationship between features. ARCINFO tools can work with Arc GIS. ESRI has however stopped supporting it.

2.5.3 Geo SFM

Geo SFM (The Geospatial Stream Flow Model) was developed to establish a common visual environment to monitor hydrologic conditions over wide areas (Artan *et al.,* 2001). To achieve this, this model carries out topographic analysis; assimilate data, process time series and present results. The Model is designed to use remotely sensed meteorological data in parts of the world with sparse data (Artan and others, 2007).

2.5.4 WEAP

The Stockholm Environment Institute (SEI) developed Water Evaluation and Planning (WEAP) model. It is mainly a water evaluation and planning system that enables engineers evaluate and plan water resource development issues, (Sieber *et al.*, 2004). This model can best be applied to agricultural and municipal systems. Issues it can address include water rights and allocation priorities, sectoral demand analyses, reservoir operation, water conservation, stream flow simulation, ecosystem requirements and project cost-benefit analyses.

2.5.5 SWAT MODEL

The Soil and Water Assessment Tool (SWAT) is a small watershed to river basin scale model. It was developed mainly to quantify how management practices affect chemical, agricultural and sediment yields and water in complex large watersheds with different land uses, soils, and the resultant conditions of management over long periods. The models original developers intended to use it to predict how land management influences sediment, agricultural chemical yields and water in basins that are large and un-gauged (Arnold *et al.*, 1995). Being physically based, it makes use of surface properties like soil, topographic, land use among others are its main inputs. It estimates precipitation (runoff) in two ways. One is the Ampt and Green method and two, the SCS curve number that has now been renamed National Resource Conservation Service (NRCM) method.

This study selected SWAT model because it is capable of simulating management practices that occur in a watershed (Arnold, 1998). Information required by SWAT include weather, topography, soil properties, and ground cover and the practices of land management in the watershed. Data requirement is minimum and such data is available in well-functioning agencies of the government. The model partitions watersheds into sub-units called sub-watersheds or hydrologic response units (HRU). Other processes that include the watershed delineation, identification of stream networks, and finally partitioning the study area to smaller units. The process is usually automated and performed using the GIS.

SWAT simulates using the water balance equation (Equation 2.1) of the hydrological cycle:

$$SW_t = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Wseep - Ea - Qgw) \quad \textit{Equation 2.1}$$

Where SW_o and SWt, are the initial and final soil water (mm) contents on day *i* respectively.

R_{day} stands for quantity of precipitation (mm) on the day *i* while Q_{surf} represents the runoff on the surface on the same day. W_{seep} and E_a are the quantities of water that enters the unsaturated zone and evapotranspiration on day *i* in mm respectively. Q_{gw} represents the return flow in mm.

The Soil Conservation Service (SCS) curve number procedure (USDA-SCS, 1972) was selected for use to estimate surface runoff from daily precipitation. For each HRU, SWAT simulates peak runoff rates and surface runoff volumes. The SCS Equation (Equation 2.2) is:

$$Q_{surf} = \frac{(Rday - 02S)^2}{(Rday + 0.8S)} \qquad \textit{Equation 2.2}$$

Where, Q_{surf} represents the total excess rainfall or runoff (mm). R_{day} and S are the precipitation depth per day and the retention parameter, both in mm respectively.

The moisture of the watershed before precipitation is antecedent moisture condition (AMC). SCS defines three antecedent moisture conditions; dry (AMC-1), average, (AMC-2) and wet, (AMC-3). Dry is a wilting point while wet is the field capacity. The accuracy of runoff estimation depends largely on the accuracy of the lumped parameter CN. (Hawkins and Ponse, 1996). Moisture condition 1-curve number is calculated using Equation 2.3 and Moisture condition 3is found using Equation 2.4:

$$CN_1 = CN_2 - \frac{20*(100-CN2)}{100-CN2+exp[2.533-0.0636*(100-CN2)]} \qquad \textit{Equation 2-3}$$

$$CN_3 = CN_2 \; x \; exp\; [0.00673(100-CN_2)] \qquad \textit{Equation 2.4}$$

Where CN_1, CN_2 and CN_3 are the moisture conditions (wet, normal and dry) on curve numbers I, II and III respectively.

Equation 2.5 usually defines the soils retention parameter

$$S = 25.4\,(\frac{100}{CN} - 10) \qquad \textit{Equation 2.5}$$

Where S is in mm and CN is dimensionless.

The USDA Agricultural Research Service actively supports SWAT and has allowed it to be in public domain. SWAT is used to predict sediment yield because it makes consideration of temporal and spatial catchment variations basing on potential variables that are physical. SWAT is split into two namely the stream and land phases. It solves the stream phase at sub-basin (reach), and land at HRU (Neitsch, 2011). Sediment yields and the water balance of the HRU are calculated on daily time step. Sediment yields from the HRU moved by rill and sheet erosion from land uses that are not urban are based on the MUSLE equation. (Williams, 1985). Sediment yield is a function of rainfall and runoff. It can be estimated using mathematical models based on fundamental or causal concepts (Morgan *et al.*,1998), unit sediment graph (Williams, 1978), Stochastic concepts (Moore, 1984) or Empirical concepts like the universal soil loss equation (Santos, 1997) which is inbuilt in the SWAT model. The basin was 567km^2 with the highest altitude of 1200m. Available data was rainfall for four stations in 27 years (1966-1992) among other weather data. Sediment transport capacity was found to be identical in the three models. There was a small deviation of the average annual erosion and sediment yield. Time series models have been adopted to simulate sediment transport due the absence of long-term sediment concentration data (Box, 1994; Hafzullah, 2019) looked at the modelling practice of erosion and sediment. In this study, erosion and sediment is modelled using the Buys ballot and the least squares methods. SWAT is modelled on a daily time step hence a time series model.

The main factor that controls sediment yield is the runoff's transport capacity (Mutchler *et al.* 1988).This makes it suitable for this study.

2.5.6 SWAT-CUP Model

Since hydrological modeling has numerous uncertainties, defining and quantifying them has developed the interest of researchers. There are a number of uncertainty techniques for analyzing watersheds that have been developed. Bayesian procedure methods include Mark chain Monte Carlo "MCMC" (Foerch and Kassa, 2007); Generalized Likelihood Uncertainty Estimation "GLUE" (Beven, 1992), Sequential Uncertainty Fitting "SUFI-2" (Abbaspour, 2007; Abbaspour, 2004) and Particle Swarm Optimization "PSO" (Eberhartand Kennedy, 1995). No single calibration program meets the objectives of the varying needs in modeling. PSO, Parasol Glue, MCMC, and SUFI-2 all interfaced with SWAT to a single package known as SWAT Calibration Uncertainty Programs (SWAT-CUP) (Abbaspour, 2007).

SWAT-CUP programme is independent and was developed specifically to calibrate the SWAT model. It has five calibration procedures that are different. They include functions for validation and sensitivity analysis and visualizing the areas of interest.

2.5.7 Remote Sensing and GIS

These are procedures of acquiring information of various objects on the planet without coming into physical contact with them. Geographical Information Systems (GIS) enables the acquisition, storage, processing and mapping spatial datasets (Fiorentino and Singh, 1996). There are various tools that assist manage this data. GIS and remote sensing have become very useful in Hydrology and LULC analysis. This is mainly because the data required can easily be gotten from the remotely sensed images.

Remote sensing acquires spectral signatures in real time to expansive areas. They are then used to extract information about emissivity, energy flux and LULC surface temperature (Gumindoga, 2010). Changes in LULC are analyzed over a time by Landsat Thematic Mapper (TM) and Landsat Multi Scanner (MSS) plus using image-classifying procedures (Gumindoga, 2010).

A summary of the techniques used in remote sensing are as shown in Table 2.1:

Table 2.1: Summary of Remote Sensing Techniques

Methods	Examples	Characteristics
Non-Parametric	Classification for Nearest neighbor, Fussy, support vector machines and Neutral networks etc.	Made no assumptions
Supervised	Classifies using Maximum likelihood and minimum distance Parallel-piped, etc.	Classes represented in training sites identified to represent in classes and each pixel is classified after statistical analysis.
Unsupervised	K-means and ISODATA etc.	Unknown prior ground information. Similar spectral characteristic of pixels grouped to their statistical criteria

Parametric	Maximum likelihood classification and Un-supervised classification	Assumes normal distribution of data. Advance information of class density functions
Non-metric	Classification is by decision tree	Operates on both nominal and real values
Hard (Parametric)	Classifies using Unsupervised and supervised methods	Classifies by individual categories
Soft (Non-Parametric)	Makes use of the Fussy Set Classification logic	Considers the world as heterogeneous. Each pixel assigned an inland cover that is within it.
Pre-Pixel		Pixel by pixel image classification
Object oriented		Image regenerated into homogeneous objects
Hybrid		Includes artificial intelligence and expert systems.

(Source: Jensen, 2005: pp 337-338)

2.6 Land Use Land Cover Change

2.6.1 LULC Change

Land-cover is modified to land conversion through complex land - use processes (Aboud, 2002). How exactly environmental and human factors interact and operate to affect hydrological processes land-use patterns is not known (Olang' L., 2009). Increased population and Industrialization and accelerated the land-use change phenomena in several regions. These human induced changes are the major influencers to hydrological (Akotsi, 2006). To feed the increasing population, agriculture had to expand into savannas, forests, and grasslands globally. Their management was therefore ignored both in current and in the future. This study tries to examine LULC changes that occurred in the Yala sub-catchment between 1973 and 2000.

2.6.2 Image Classification

Different, features of the earth vary in how they remit and reflect light from the sun. Classification process recognize and categorize data that can be extracted (Jensen et al, 1983). Classification categorizes pixels raw remotely sensed satellite data or raw and assigned a set of land cover themes or labels (Lillesand, 1994). This is achieved using FAO scheme (LCCS), UNESCO and the Geological survey Land use /Land Cover of the US (Anderson, 1976). The USGS was adopted for this study.

2.6.3 Detecting Change

Four aspects used in monitoring of natural resources can detect change (MacLeod and Congalton; 1998).

i. Detection: Establish the occurrence of change,
ii. Identify: identify the nature of the change,
iii. Measuring: quantify the change extent, and
iv. Evaluate change's spatial pattern.

Alternatively, land cover change is influenced by four categories of causes (Lambin and Strahler; 1994b).

i. Changes in conditions of climate over a long period,
ii. Ecological Geomorphological and processes such as vegetation succession and soil erosion,
iii. Vegetation cover alteration induced by human like, deforestation, land degradation, and

iv. Inter-annual climate changes.

LULC change may be contributing to global changes more than climate change. To get the extend of change, the region of interest (ROI) must be identified carefully and held constant throughout the change detection period. The change detection remotely sensed data should hold the following resolutions constant: spatial (and look angle), temporal, spectral, and radiometric. The data should be acquired on anniversary dates like March 1st 1975 and March 1st 2000. This reduces the changes induced by planting seasons. Such data should be rectified. The soil moisture conditions must be similar throughout the imaging dates of the study period.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

The study aimed to investigate how the land use changes have affected the water quality of river Yala catchment. The land use changes during the study period were analyzed from Landsat image in ArcMap. Images were classified by conversion of the multi-band raster imagery to a one-band raster, which contain various categorical classes that were relating to different types of land cover type. Figure 3.1 is the framework adopted in this study.

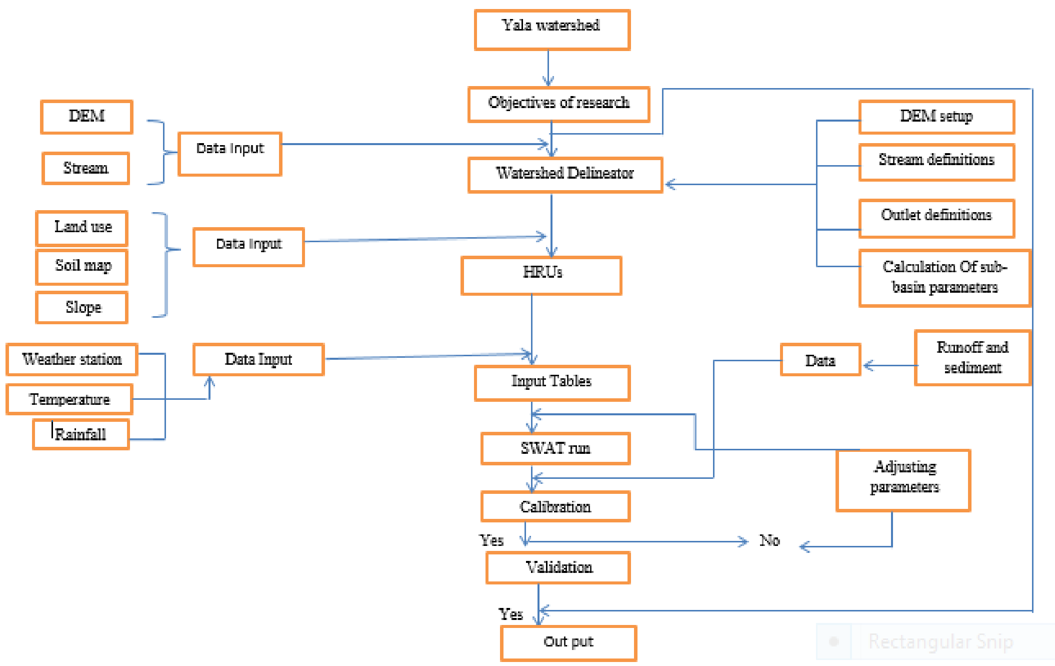

Figure 3.1: Conceptual Framework (Getachew and Melesse 2012)

3.2 Data Requirements

The data required for SWAT simulation is as shown in Table 3.1.

Table 3.1: SWAT Data

Secondary Data	Period	Sources
DEM	2009	A resolution of 30 meters Global Land Cover data of the United States Geological Survey Regional Centre For Mapping of Resources for Development. (RCMRD)
Water quality	2009	Water Resources Authority
The Digital Soil Map Data	1997	Food and Agricultural Organization (FAO) and the Global Land Cover data of the United States Geological Survey
Rainfall, Evaporation	1978-2008	Kenya Metrological Department
Stream flow	1978-2008	Water Resources Authority
Land Use Map Data	1973, 1986, 2000	USGS
Primary Data	**Period**	**Sources**
Water Quality	March 2021	WRMA

3.2.1 GIS Data: Digital Elevation Models

Digital Elevation Model (DEM) gives the slope, elevation and streams network definition in a basin. This is available with environmental bodies like the Department of Resource survey and Remote Sensing, International center for Research in Agroforestry (ICRAF), USGS website, etc.

3.2.2 Soils Data

For stream flow prediction, SWAT needs data on soils. Such data must contain hydraulic conductivity properties like the saturated conductivity, the soil bulk density, and the capacity of water available in the soil. FAO has made its digital version of the world soil to the scale of 1:5 million. This map has 4,931 units of mapping of soil associations. Different soils and mixtures are classified to FAO-UNESCO legend. This legend consists of 106 soil units classed basing on their properties and four non-soil units. Chemical properties given for the soil units. These include base saturation, $CaCO_3$ content, CEC, pH, C/N ratio and organic carbon. The sub-soil and top soil textures given include bulk density, percentages of clay, silt and sand. The soils in the study area are as shown in Figure 3.3.

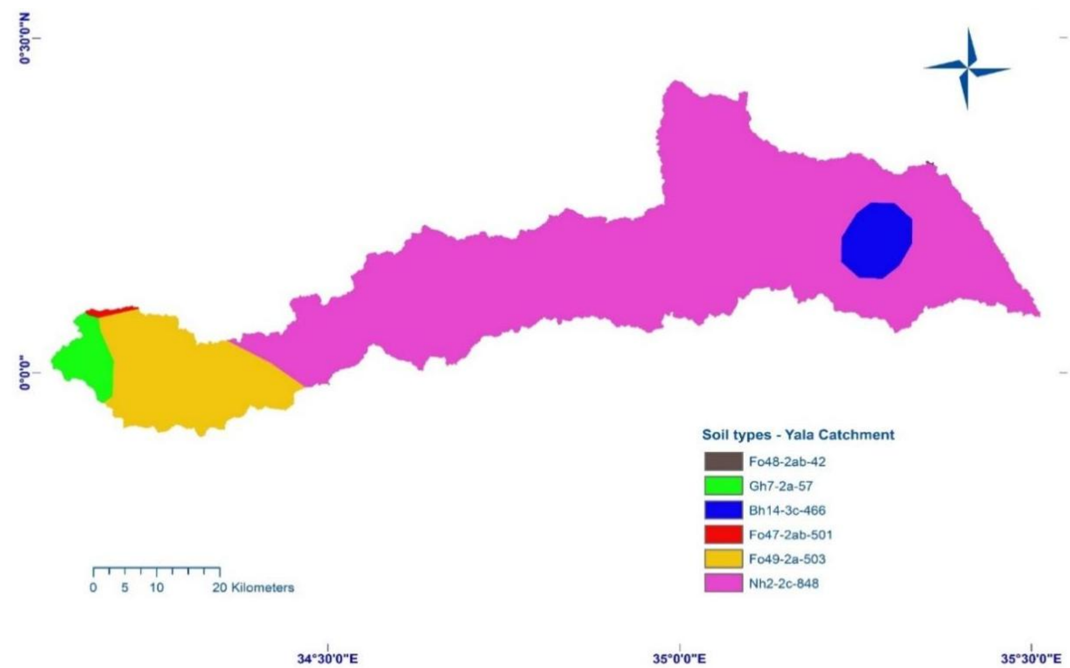

Figure 3.2: Soils at the Yala Catchment

3.2.3 Land Use Land Cover Data

Natural climate cycles vary with human influence and they occur at multiple scales from years, decades, centauries and millennia. Millennia are changes arise from the Earth's orbit changes and occur slowly in time of 10,000 to 100,000 years. This affects the amount of solar radiation reaching the earth at varying seasons (NASA 2000). Centaury scales, which take 200 to 1500 years, are not properly understood but they are assumed to result from the change in sun and ocean circulation patterns (Bond, 2001). Inter-annual takes two or more while decadal is divided into 10 years or longer. Decadal duration is preferred to study climate change (Mantua, 1997)

Land use and land cover data for years 1973, 1986 and 2000, which represent the initial, middle and last phases of the simulation were downloaded from Landsat 1, 5 and 7 respectively. The Landsat 1-5 Multispectral Scanner (MSS) has an approximate scene size 185km west east, 170km north south. Its images have four spectral bands and the resolution is 60 meters.

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) has a scene size of 170km north south by 183km east west with eight bands, seven of which have a resolution of 30m. The eighth one has a higher resolution of 15 meters and it is panchromatic.

For the years 1973, 1986 and 2000 Landsat images were obtained from different satellites. Images for the year 2000 were obtained from Landsat 7, while for 1986, Landsat 5 and 1973 Landsat 1. Based on the satellite, the bands to download were selected. Natural colour images bands 4-3-2 from Landsat 7 were downloaded and composited. The resultant images for the three years are as shown in Figures 3.4, 3.5 and 3-6 respectively. The raster was then copied to remove the black spot. The figures show the land uses for the three years with the main land-uses being mixed forest, water, medium density residential and summer pastures.

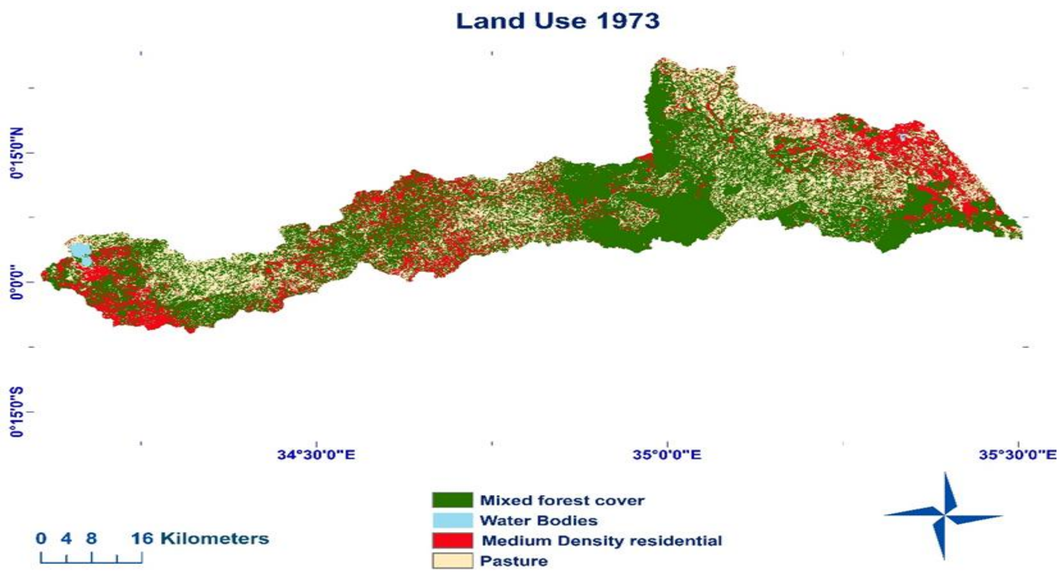

Figure 3.3: Land Use for the Year 1973

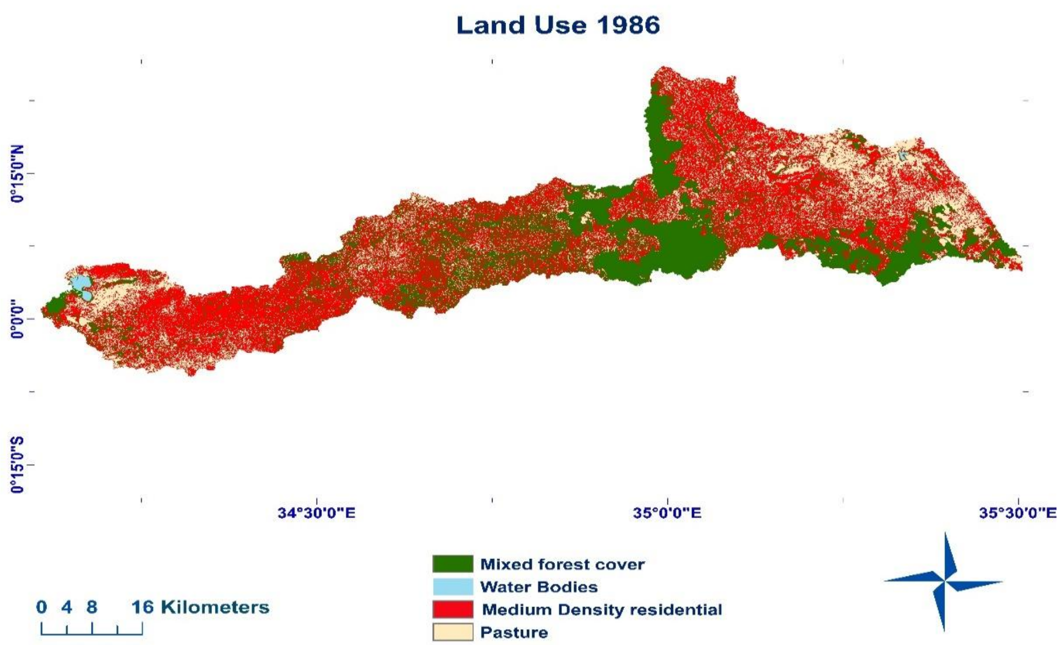

Figure 3.4: Land Use for the Year 1986

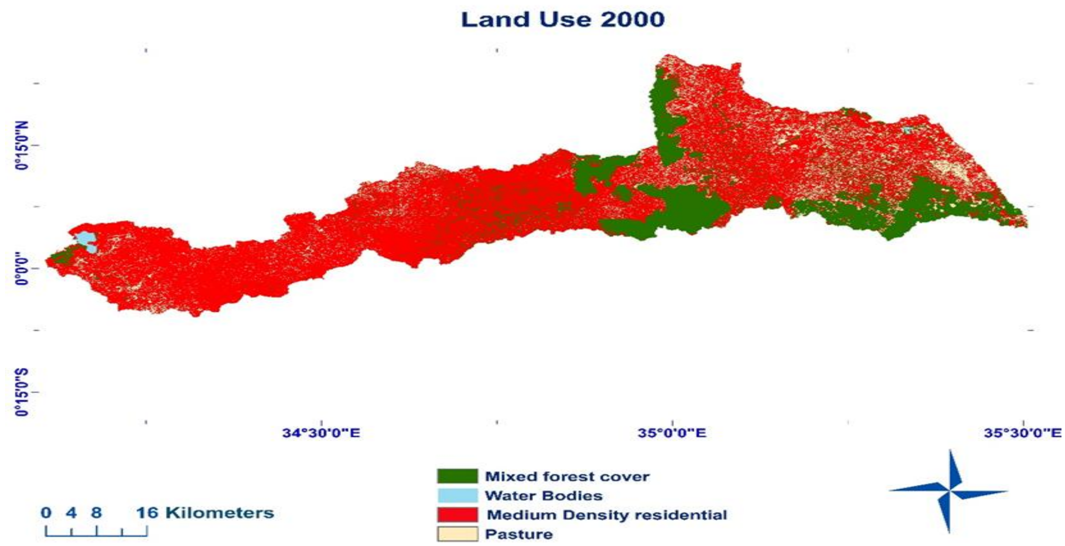

Figure 3.5: Land Use for the Year 2000

3.2.4 Metrological Data

Daily meteorological dataset as observed such as wind speed, rainfall, maximum and minimum temperature, sunshine hour and relative humidity, of four representative stations within Yala watershed mainly Kakamega meteorogical station Sichirai station number 8934273 lies on latitude 00°30' North and 34°08' East. It has an elevation of 1535m above sea level. Additional data was taken from Chepterit, Yala and Kaimosi gauge stations for a period of 27 years (1973-2000) were collected from Kenya Meteorology Department. The location of these stations are as indicated on Figure 1.1.

3.2.5 Streamflow Data

This was found from WRA for two gauge stations along the river. Yala market station IFE01 located at N 00 05.083, E 34 50.169 on elevation 1416m and Tindinyo station IFG02 at N 00 10.875, E 34 32.544 elevation 1724m. Available data was taken from the hydrographs shown on Annex 4.

3.3 Sediment Component

Sediment yield is a function of the available water to transport it and this too affects the concentration. This can be determined using empirical or process based models. Models that are process based consider energy and mass conservation laws. Traditionally, yield is estimated from direct computation of sediment delivery ratio (SDR) or parameters of the catchment. This can be from soil properties (Walling 1963), land cover (Willems 1977), runoff (Dendy, 1976). Getting accurate data for these formulae is however a challenge.

Sediment concentration on the other hand is a function of the material transported over time against the water volume. This can be obtained from Equation 3.1:

$$SC = \frac{Material\ transported\ annually\ (mg)}{Water\ volume\ \ that\ same\ year\ (l)} \qquad \text{Equation 3.1}$$

Sediment may readily be available in specific times of the year. High concentrations can be exhibited after long dry periods when most vegetation has wilted. Data collected using the second method was used to compare the efficacy of the model results for the study period.

Suspended Sediment is several time greater than bed load. Transport in suspension falls within 85% to 99%, while bedload accounts for 1%-15% depending on depth, velocity grain size cross section position and discharge (Yang, 1996).

For field analysis, two methods commonly used in determination of suspended material in samples of water:

a) Standard Method for determination of sediment concentration (Method D 3977-97 by the American Society for Testing and Materials, 2000), and

b) Method 2540 d TSS dried at 103°C to 105°C by the American Water Works Association, American Public Health Association, and Water Pollution Control Federation (1995).

SWAT adopts the Modified Universal Soil Loss Equation (MUSLE) to estimate sediment yields for each HRU. (Williams, 1995). Erosion and runoff are for a specific rainstorm is found from Equation 3.2. It uses the normal runoff, the peak runoff rate and volume; in conjunction of the area of the sub basin calculate the energy of erosive variable.

$$Q_{sed} = 11.8\ (Q_{Run} \times Q_{peak} \times area_{hru})^{0.56} \times C_{USLE} \times K_{USLE} \times LS_{USLE} \times P_{USLE} \times CRFG \qquad \textit{Equation 3.2}$$

Q_{sed} denotes Sediment yield in the time considered, Q_{Run} and Q_{peak} are runoff per unit of area (mm/ha) and the rate of peak runoff (m^3/s) respectively. The $area_{hru}$ is the size of the Hydrologic response unit in hectares. C_{USLE}, K_{USLE}, LS_{USLE} and P_{USLE} are the cover management, erodability of the soil, slope length and the particle transport factor respectively. CRFG is the course fragment factor. Sediment is routed into the channel using Bagnold's power equation (RA, 1977). For sediment to move, it must be first degraded and then deposited in reach at the same time (Neitsch, 2005). The maximum velocity of the channel determines the quantity of sediment. The results were compared with the scanty data from for the Tindinyo gauging station IF02 from WRA. Sediment was calculated from the Equation 3.3:

$$S = 0.0864 * TSS * Q \qquad \textit{Equation 3.3}$$

Where S is the sediment load in Tons per day, TSS is the Total suspended solids in mg/l and Q is the discharge in M^3/S.

3.4 SWAT Model Setup

This research work made use of ArcSWAT 2012, which is interfaced with in ArcGIS. The datasets used in the model are listed in Table 3.1. From the ArcGIS interface, a new SWAT project was set up.

3.4.1 Watershed Delineation

Delineation involves segmenting the watershed (sub-dividing the watershed into discrete channel and land segments) to enable their behavior be studied. The digital elevation model for the Yala Basin in a 30m x 30m resolution was downloaded from the US geological survey. The basin co-ordinates were used to locate the geographic position as shown in Figure 3.7:

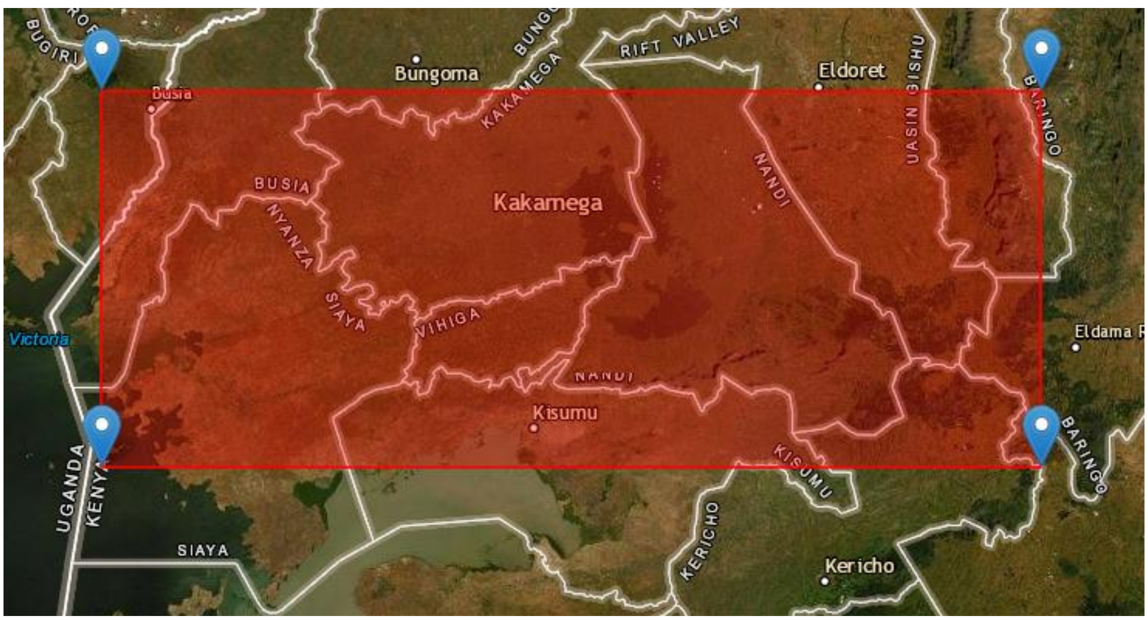

Figure 3.6: The Location of the Study Area

Data from the Shuttle Radar Topography Mission (STRM) was then selected and four images downloaded. They were then processed using ArcGIS. The images were then mosaiced to new raster in one band and the watershed extracted by mask as shown in Figure 3.8. Its UTM zone was determined as 36N.

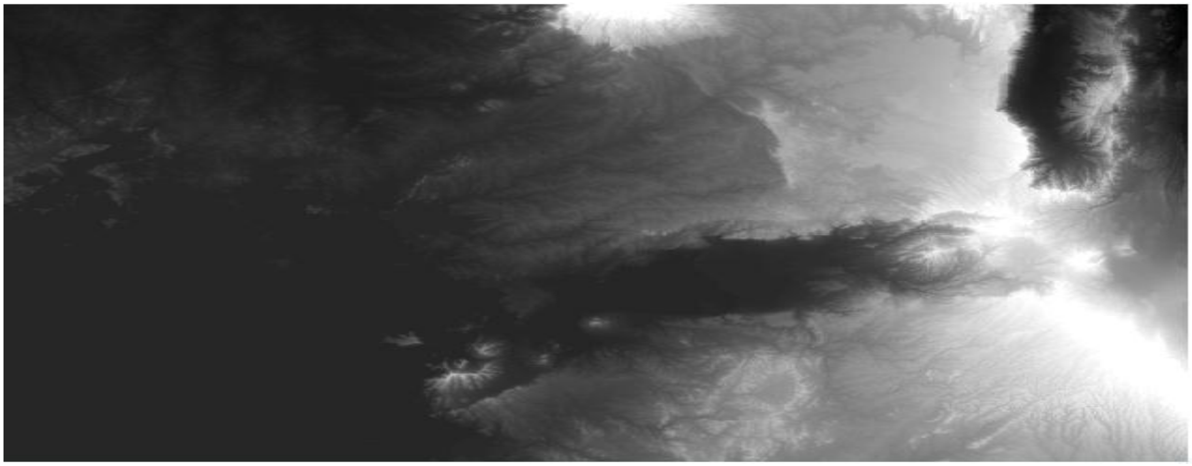

Figure 3.7: Shuttle Radar Topography Mission for Yala Catchment

Yala watershed was then extracted from the DEM using the basins shape file and the image colour enhanced as shown in Figure 3.9:

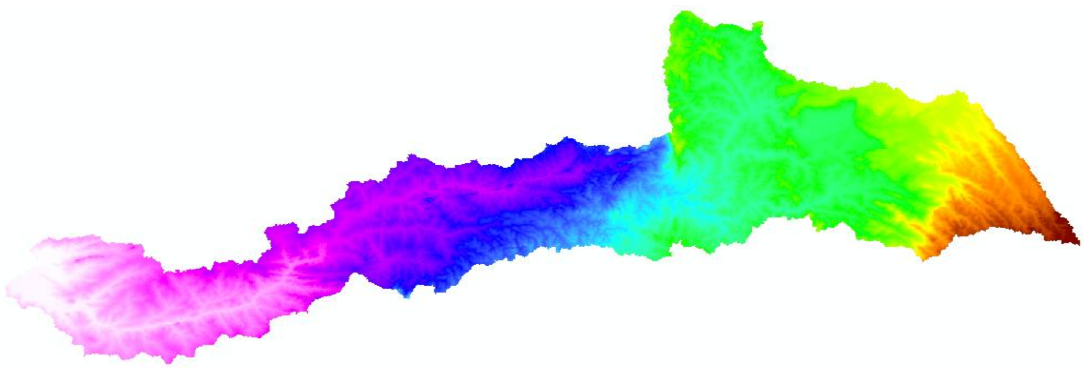

Figure 3.8: Extracted by Mask Yala Watershed

It was then used to extract physiographic characteristics of the River Yala catchment. ArcGIS tools were used for pre-processing terrain and the processing of the basin characteristics. The Sub-basin boundaries, stream network and other hydrologic elements were obtained.

3.4.2 Hydrological Response Unit

Land use, slope and soil were specified, and then used to determine the Hydrologic Response Unit (HRU). Land use data determines the land area to be simulated in each sub-basin while the hydrologic characteristics that existing in each sub-basin depends on the soil. The dataset files for Soil and Land use are loaded as themes. The catchment slope determines sediment, water, and nutrients movement.

3.4.3 Calibration

Calibration means adjusting model inputs (variables, parameters, structures, etc.) with the aim of achieving the best simulation to match the observation. Calibrating physically based models like SWAT require input parameters be kept within realistic uncertainty ranges. Such exercise cannot be automated.

The first step in this process is to determine the most sensitive parameters for a particular watershed. The model was run several times while parameters were varied and the behavior of the results observed. The rate model outputs were changed compared to input parameters and the most sensitive parameters selected. The sensitivity analysis was therefore complete. The parameters are adjusted to get the best fit. This optimizes the objective function for discharge by minimizing g

$$(B)= \sum_{n=1}^{n}(Q_o - Qs)^2 \qquad \textit{Equation 3.4}$$

Where Q_s stands for the value of the simulated discharge and Q_o the observed. Four years were selected for the calibration from 1979 to 1983. The excel report generated is as shown on Annex 18.

River flow data for calibration was prepared to be compatible to SWAT requirements for the same period. Sensitive parameters of a model vary with each data and watershed conditions. The most sensitive parameters for the Yala watershed were determined by manual calibration and their values are as indicated in Table 4.2. Sediment concentration is sometimes high with high flows due to availability of the material for erosion. On other occasions, it can be high in low flows due to the dilution effect. Generally, it follows a hysteric curve.

The results showed that SWAT model was efficient in simulating the water quality and sediment transport phenomena. Its interface is user friendly. Its joint use with ArcGIS makes it possible to account for special variability.

3.4.4 Validation

This is the process of demonstrating that the model produces accurate or acceptable simulations. The model is run using parameters that were arrived at during calibration process. For this study, validation was done for the years 1984 to 1988.

3.4.5 Performance Evaluation

The regression coefficient (R^2) is the proportion of the cumulative difference in the observed model data. The closer the regression value to one, the higher the similarity between observed and measured data. The value of this regression coefficient is found from the equation 3.5.

$$R^2 = \frac{\{\sum(X_i - X_{avg})(Y_i - Y_{avg})\}^2}{\sum(X_i - X_{avg})(Y_i - Y_{avg})^2}$$ *Equation 3.5*

X_i denotes measured value, X_{avg}, the average measured value, and Yi and Y_{avg} are the simulated and measured values respectively.

Nash and Sutcliff simulation efficiency (NSE) formula is a measure of the degree of fitness of both observed and simulated data. It is calculated from the Equation 3.6:

$$NSE = 1 - \frac{\sum_{t=1}^{T} (Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q}_o\right)^2}$$

Equation 3.6

Where Q_m is the modelled discharge, Q^t_o being the observed discharge at time t and $\bar{Q}_o$ is mean observed discharge. It is one minus the ratio of the variance error of modelled output divided by observed variance. When the variance error is zero, the Nash- Sutcliffe Efficiency equals one (NSE=1). Values of NSE near one means the model is more accurate.

The value of NSE ranges from one (best) to negative infinity. If the measured value is equal to predicted, NSE = one. If the value is negative, it means poor prediction hence; the average output value is a better estimate than the model prediction (Nash and Sutcliffe, 1970).

The percentage difference (D) is the mean difference between measured and simulated values of a given quantity over period. This function is found from Equation 3.7:

$$D = 100\left(\frac{\sum Yi - \sum Xi}{\sum Xi}\right) \qquad \textit{Equation 3.7}$$

A value closer to 0% signifies the best for D. Where accuracy of observed data is relatively poor, higher values of D are acceptable.

Percent Bias (PBIAS) simulated data tends to vary from the actual according to Gupta *et al.* (1999). The optimum value is 0.0. When the value is low, then the simulation is accurate and vice versa. When the PBIAS is negative or positive, the model has over-estimated or underestimated respectively. It is derived from Equation 3.8, where Y^{obs} and Y^{sim} are observed and simulated flows on day i respectively.

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

Equation 3.8

ASCE recommended it in 1993. Table 3.2 shows the performance of PBIAS in various models.

Table 3.2: Ratings for the Performance of PBIAS for SWAT Model

Value (%)	Rating	Phase	Reference
<25	Satisfactory	Nitrogen after flow and sediment calibration	Bracmorth et al (2006)
20	Satisfactory	Calibration and Validation	Van Liew et al (2007)
<10	Very good	Calibration and Validation	Van Liew et al (2007)
<10to <15	Good	Calibration and Validation	Van Liew et al (2007)
<15 to <25	Satisfactory	Calibration and Validation	Van Liew et al (2007)
>25	Unsatisfactory	Calibration and Validation	Van Liew et al (2007)

Adapted by Van Liew et al. (2003) and Singh et al. (2004)

3.5 Spatial/Temporal Land Use Change and Suspended Sediment Parameter

3.5.1 Landsat Data

Includes aerial photos or satellite images acquired from Geo-information organizations or satellite data. They include Regional Centre for Mapping and Resource for Development (RCMRD) and United States Geological Survey (USGS).

Data used for this project was acquired from USGS and it included Landsat Images from Landsat 1, Landsat 5 TM and Landsat 7 ETM on paths/rows 160_60 and 170_60 (which covered the area of interest) for periods 1973, 1986 and 2000. All the datasets used were acquired between January and March to have approximately the same annual weather properties for the three spans. The three data composites had the following band properties (see Table 3.3).

Table 3.3: Landsat Bands

	Landsat 1	**Landsat 5-TM**	**Landsat 7-ETM**
Blue		Band 1	Band 1
Green	Band 1	Band 2	Band 2
Red	Band 2	Band 3	Band 3
Near Infra-Red (NIR-1)	Band 3		
Near Infra-Red (NIR)	Band 4	Band 4	Band 4
Short Wave Infra-Red (SWIR-1)		Band 5	Band 5
Short Wave Infra-Red (SWIR-2)		Band 7	Band 7
Thermal		Band 6	Band 6
Pan Chromatic			Band 8

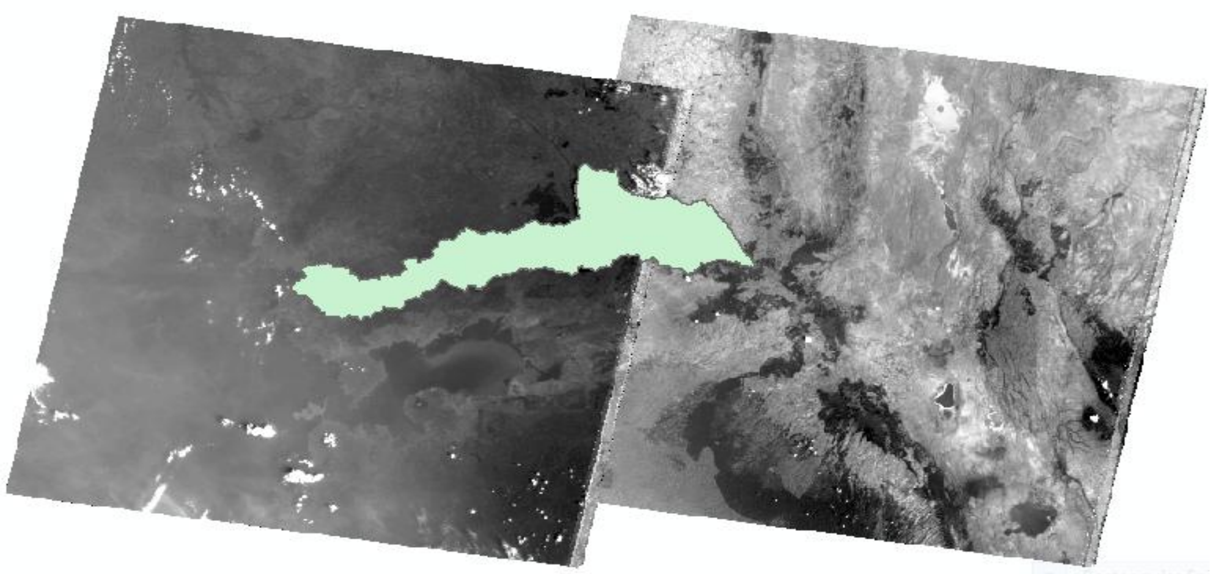

Figure 3.9: Mosaiced Tiles from TM and ETM+ Landsat Sensors

3.5.2 Land Use Classes Definition

There are a number of systems in use worldwide. There is no single land cover system that is accepted internationally (FAO, 1997). Each organization therefore sets its own different classification depending on the aspect of land use land cover it is interested in CARA (2006). General principles for Land use/cover classification can be found in FAO (1997) and Duhamel (2012).

Level of classification dependents on images spatial resolution. Maximum resolution for four levels is say:

1. 80 meter Level I
2. 2.5 meters for Level II
3. 0.90 meters for Level III
4. 0.45 meters for Level IV

Anderson (1976) classified a combination of land use/cover placing all uses and cover into nine level -1 categories, which are as outlined hereunder:

1) Built up or Urban land
2) Water
3) Range land
4) Forested land
5) Agricultural land
6) Wet land
7) Barren land
8) Human activity land (Tundra)
9) Perennial snow or ice

Level II would be Biome/Region. For Agricultural land, it would be 51 Cropland and pasture, 52 confined feeding operation 53 Orchards, Groves, Vineyard, and 54 Other Agricultural Land. For Water, it would be 21 Streams, 22 Lakes, 23 Reservoirs and 24 Bays and Estuaries.

The Yala catchment land uses were classed into four categories:

i. Mixed forest
ii. Medium density urban
iii. Water
iv. Summer pastures

3.5.3 Analysis of the Remotely Sensed Data and Importing to ArcGIS

For image processing, radiometric and geometric correction was done using ENVI software from Harris Geospatial. Radiometric calibration was done to solar effects by converting solar radiance to Top-of Atmosphere reflectance. While calibrating, ENVI makes use of the date and time of data acquisition and the sun azimuth normally supplied together with satellite images. Radiometric correction using ENVI was done on Landsat 7 ETM by pan-sharpening process using the panchromatic band (band 8) supplied to it. For Landsat 5TM and 1, were the band is missing, high resolution images for both Landsat 5TM and 1 courtesy of RCMRD for the years were used, and a comparison was done too on Google earth images for the period (under historical images). From the images, a contrast stretched mosaic was created on ArcMap, then geo-referenced and projected to match the projection for the other bands. Each image generated acted as a panchromatic image for the respective periods.

Compositing included combining bands from the same group of images to have different varieties of combinations that make different features dominant. Band combinations can include visible composites (combination of blue, green and red bands) to form natural colour or invisible composites or invisible composites (Infrared, short wave infrared bands). Band rationing included arithmetically dividing pixels on one band by corresponding pixels on the second band. The following band ratio computations were determined in this exercise.

A contrast stretched ratio image shows spatial region with highest contrast values as most vegetative and vice versa. The fourth band both Landsat 7 ETM and Landsat 5 TM are Near Infra-Red bands responsible for representing chlorophyll regions with high contrast in an image. Band 3 is visible red bands. In most false color composites involving Infrared or Near Infra-Red composites, vegetation is represented in red. It is computed from Equation 3.9 for Landsat 5TM and 7 ETM while for Landsat 1 is found from Equation 3.10 as shown:

For Landsat 5 TM & Landsat 7 ETM,

$$NDVI = \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3} \qquad \textit{Equation 3.9}$$

For Landsat 1

$$NDVI = \frac{Band\ 4 - Band\ 2}{Band\ 4 + Band\ 2} \qquad \textit{Equation 3.10}$$

Dry bare soil index represents bare soil and rocky areas with high spectral index than non-built up regions. It makes use of Short Wave Infra-Red band (SWIR-1) or the fifth band in both Landsat's 7 ETM and 5 TM. It is calculated from Equation 3.10:

For Landsat 5 TM & Landsat 7 ETM,

$$DBSI = \frac{Band\ 5 - Band\ 2}{Band\ 5 + Band\ 2} \qquad \textit{Equation 3.11}$$

Normalized Difference Bare Soil and Urban Index

This Index represents with high index the bare lands and soil (bare soil) data. Bands used include SWIR-2, NIR and Red band (i.e. Bands 7, Bands 5 and Bands 3).

Equation 3.11 is used for its computation for both Landsat 7 ETM and Landsat 5 TM;

$$NDBSUI = \frac{\left[(Band\ 7 + \sqrt{(Band\ 3 + Band 5)}\right] - ((Band\ 3 + Band 5))}{\left[(Band\ 7 + \sqrt{(Band\ 3 + Band 5)}\right] + ((Band\ 3 + Band 5))} \qquad \textit{Equation 3.12}$$

After computation of the three rations, they were then composited into an image to be used to classify features of interest to this study.

Image enhancement contrast enhancement and image transformation. Enhancement was done to improve feature visibility and match composites or ratio computations intended to be mosaicked. Operations done on all images used included adjustment or stretching of contrast, opacity levels and color enhancement.

Regions of interest (ROI) was then extracted. This included masking out only the region that covers Yala basin for all composites to be used. The extents of the basin used originated from a priory-computed delineation for the region by use of an Elevation Model from SRTM data in ArcSWAT. Extraction was important in that it excluded unnecessary computations of pixels outside the ROI.

Processing of Images

Image processing is the grouping features of interest into distinguished classes. Four classes were used in this study including mixed forest cover (forests with various species of trees clustered together), dominant water bodies, medium density residential regions and summer pasture/temporal vegetation cover including unclassified features. Supervised classification process was used.

It was suitable because sampled data (trained data) was created by sampling regions representing the four classes then called to the algorithm that relates them to each pixel in the composite (Signature files). Since the samples may most likely not have the same reflectance even within each group, and more so to the rest of the images, an option of classification of the nearest neighbors characteristics had to be adopted, hence adoption of the maximum likelihood classification option. In practical sense, classification is either repeated afresh severally on visual inspection and realization that pixels are not properly assigned.

Post Processing of a Classified Image

Post processing of classified images is done for several reasons including reassigning pixels that had been miss-assigned to wrong classes, assigning ideal colors to the classes, removal of no data areas, and post classification. Finally, the classified images were computed of accuracy assessment. This was done to determine the quality of data resulting from the whole process. Qualitative assessment method was employed. Ground truth data used were acquired directly on the ground using a GPS data collector and high-resolution aerial photos from RCMRD then comparing spatial placement of distinct features on classified image in relation to the ground.

3.5.4 Supervised Image Classification

Supervised classification takes the following three steps:

1. Select training areas
2. Generate signature file
3. Classify

This classifies an image based on a known land cover types. The procedure includes the identification and delineation of the regions from satellite image, which will eventually be used as training sites. Such sites should be having similar spectral information of the types of land covers for use in calculating classification algorithm. Multivariate statistics assigns a code to all pixels on the image. The brief procedure was:

1) Training Areas: Several polygons were drawn on areas to be created in ArcGIS using Image analysis tool bar. The polygons are then merged into a single class.
2) Signature file: Having training samples for each class, the samples were saved as signature files.
3) Classify: This can be done using:
    i. Maximum Likelihood
    ii. Minimum distance to mean
    iii. Parallel-piped method

3.5.5 Composting of the Images

The images are then imported to ArcGIS and composited. Where key features occur, their co-ordinates are confirmed using a hand held GPS.

3.5.6 Change Detection

Change detection algorithms commonly used include:

a) Multi-date composite image

b) Image algebra (e.g., band differencing, band rationing)

c) Performing post-classification comparison

d) Application of binary mask to second date

e) Using ancillary data as source for first date

f) Spectral change vector analysis

3.6 Setting Up, Calibration and Validation of SWAT Model

3.6.1 Delineate the Designated Watershed for Modelling

From the ArcGIS a new project was set up and the Yala raster as previously prepared DEM loaded from the disk for automatic delineation. The projection was set up and the Z-units adjusted to meters. The DEM was then analyzed for flow direction and stream networks (Figure 3.10). Nine outlets were found. The outlet for the whole watershed was selected and delineation was done (Figure 3.11). The resulting map was as shown in Figure 3.12 after clearing temporary grids. Sub-basin parameters were calculated with reduced report outlet skipping the stream geometry.

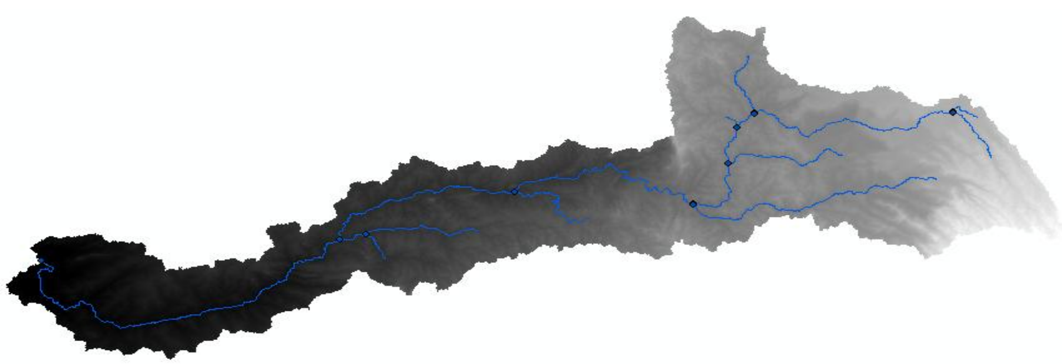

Figure 3.10: Yala Basin Stream Network

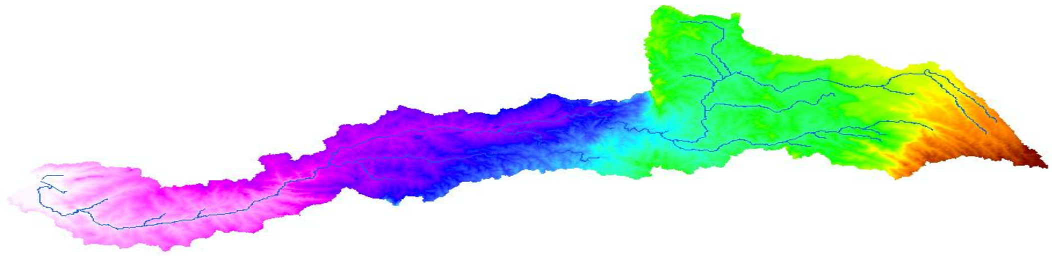

Figure 3.11: Watershed with Inlets/Outlets Removed

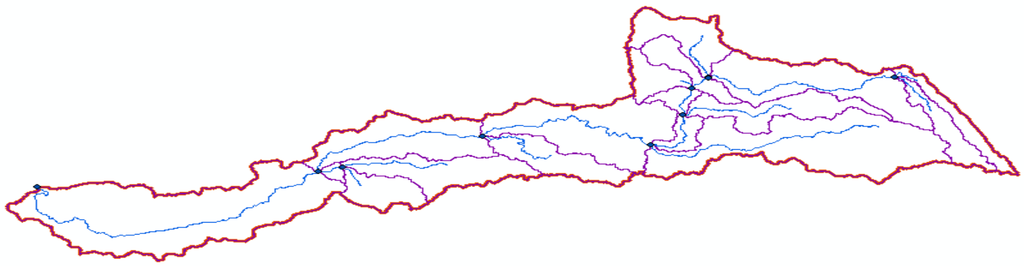

Figure 3.12: Delineated Yala Watershed

3.6.2 Land Use, Soil and Slope Definition

LULC data was imported and the grid changed to "VALUE". The four land use classes were identified from user table and overlaid (see Figure 3.17, then re-classified in Figure 3.18). Soil polygon shape file was added from user-soil (Figure 3.19) and the grid adjusted to soil numeric (SNM) and re-classified (Figure 3.20). A selection for "single slope" or "Multiple slope" is to be made. Five slopes were chosen, ranging from 0-15^o, 15°-30°, 30°-45°, 45^o-60° and 60°-999°. The resulting image was then reclassified (Figure 3.13).

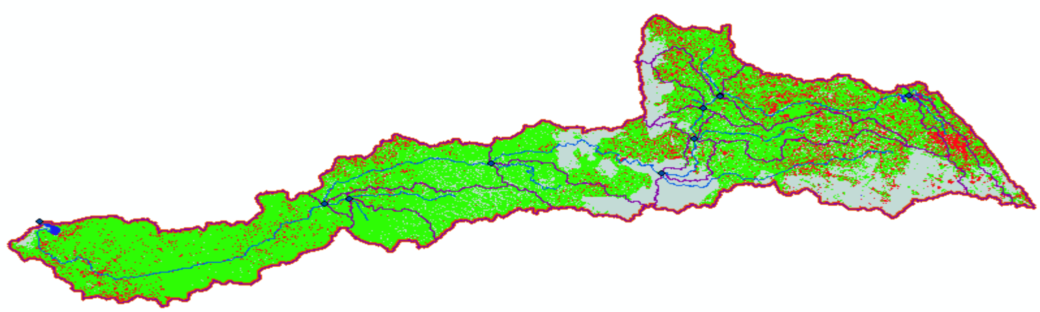

Figure 3.13: Land-Use Defined for the Yala Basin

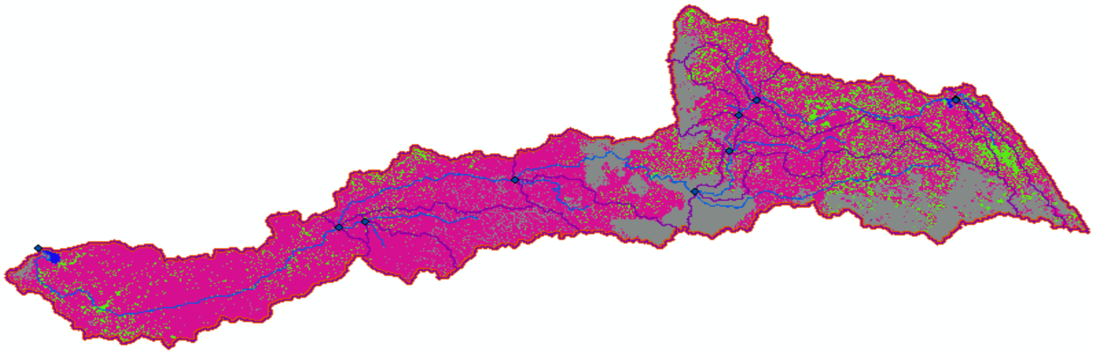

Figure 3.14: Re-Classified Land-Use for the Water-Shed

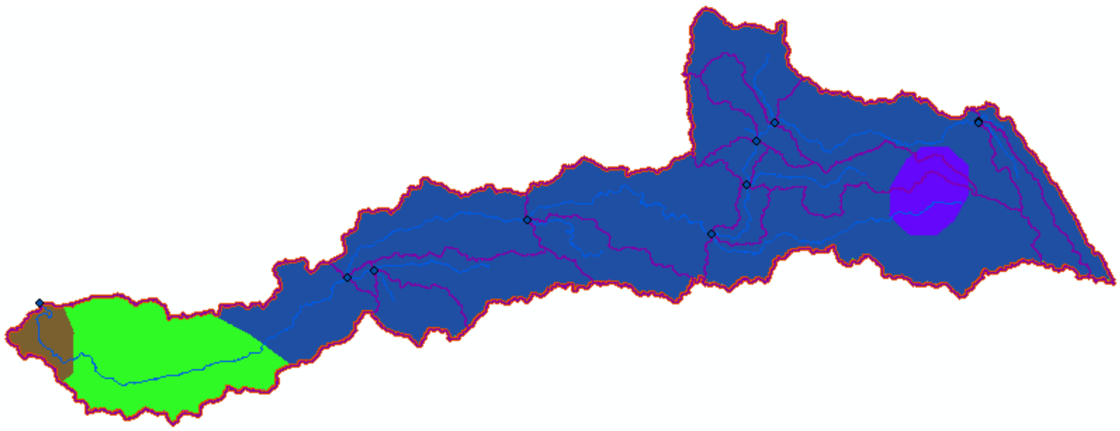

Figure 3.15: User Soil Map

The land-use was then re-classified (see Figure 3.14) and FAO soil data loaded (see Figure 3.15)

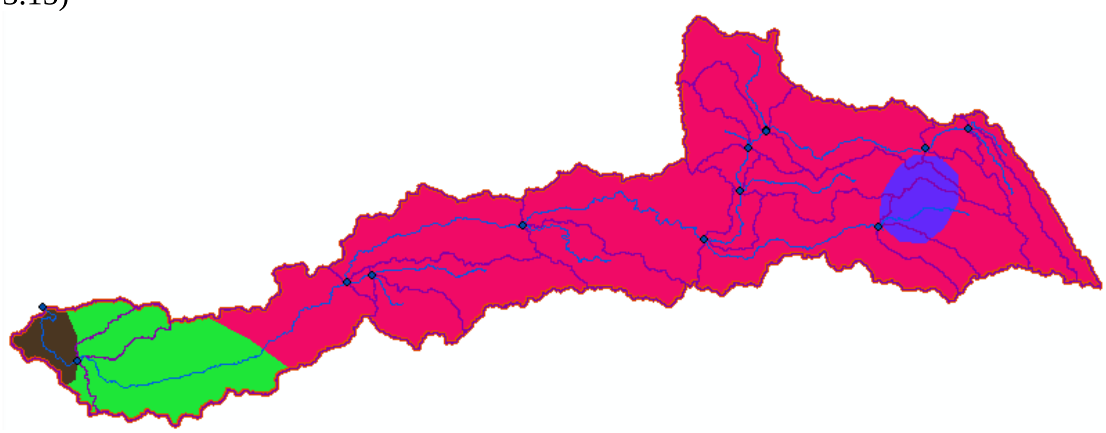

Figure 3.16: Re-Classified Soil

Soil and slope were then re-classified (see Figure 3.16 and Figure 3.17) respectively.

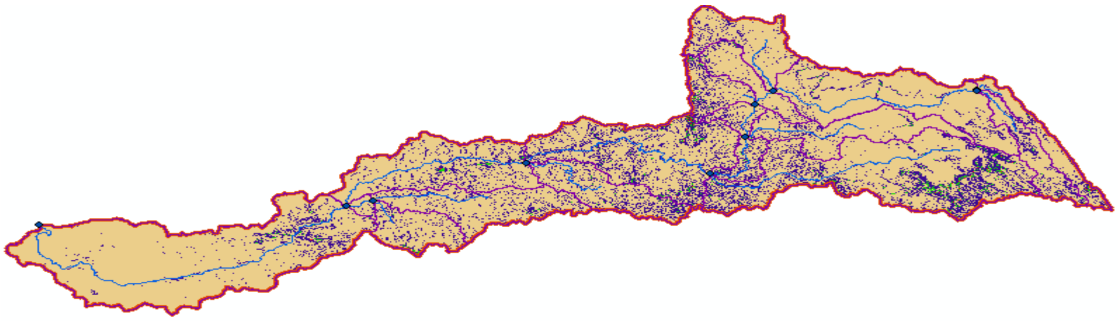

Figure 3.17: Re-Classified Slope

3.6.3 Determination of HRUs

Multiple HRU's were then defined and threshold percentages of land-use, soil class and slope to basin area set at 20%, 10% and 10% respectively. The three datasets were then over-laid to create HRU features and a final report generated (Annex 1). A total of 17 sub basins and outlets and 54 HRUs were found for this water shed. Figure 3.18 was the final overlaid Land-use, soil and slope.

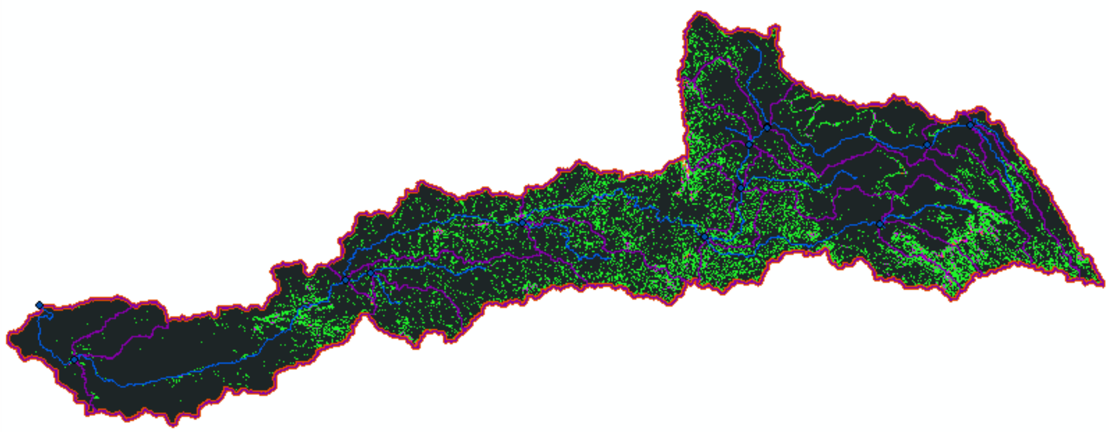

Figure 3.18: Final HRU Analyzed Image

3.6.4 Define Climate Data

SWAT requires spatial and temporal datasets to run. Spatial data are the DEM and soil in raster forms, Land use land cover as a shape file with attributes. Temporal data are the climate and hydrological. These are maximum and minimum temperatures, precipitation, humidity, solar radiation and wind. These data were then converted into text format and saved as coma - separated value (CSV) data. Since they are plain text, they are easier to import into a spreadsheet into SWAT database.

3.6.5 SWAT Sediment Transport

SWAT was used to simulate sediment yield and concentration of the Yala catchment. The area is being affected adversely from the growing population, which is leading to the increased demand for arable land. After simulation, SWAT generates a number of output files for the subbasin, HRU and the reach. This may be daily, monthly or annual. From the HRU, sediment yield in metric tons per hectare that is transported to the channel is simulated per time step. Also simulated is the monthly sediment yield (tons/km^2) from the subbasin. From the reach, SWAT simulated the total sediment transported into and out of reach in tons, sediment concentration in and out of reach in mg/l and the in and out flow to the reach in m^3/s all on a daily time step.

3.6.6 Write SWAT Input Files

First were the weather stations for 27 years of the period 1973 to 2000 for Kakamega, Kaimosi, Yala and Chepterit with their co-ordinates. Text files for precipitation, maximum and minimum temperature, relative humidity, solar radiation, were then defined. The prepared climate data was then loaded into the SWAT tool complete with their codes.

3.6.7 Scenario Analysis

To assist in determining the best management practice the Yala catchment, three scenarios were compared. The base, Conversion of 30% of land to forest and introduction of vegetative filter strip. The sediment movement was then compared.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Summary of the Study

During this study, qualitative and quantitative research techniques were employed. It made use of statistical, time series and change detection analysis. Remote sensing techniques and GIS classification were properly employed in the assessment of the change in land cover. The effects of land cover change on the hydrological components and sediment transport were simulated using the SWAT model. Sediment is transported by the reach, can effectively be calibrated, and validated using stream flow (Vicente P. R., 2016). With satisfactory streamflow data, suspended sediment can be simulated (Olga V., 2017).

4.2 Land Use Change for Study Period

Land use land cover change is a topic considered of supreme importance in researching sustainable development and the changes in environment. (Verburg *et al.*, 2000, Hu *et al.*, 2018). Deforestation is a key process of LULC (Batunacun, 2018), and it gives solutions to what drives the changes in land use (Sohoulande Djebou, 2017). Effects of land use land cover change is a threat to the world's economic development and its ability to feed the inhabitants (Ewers, 2006). This study defines deforestation as the conversion of forested areas to other types of land uses.

As shown in Figure 4.1 Land cover from1973, 1986 and 2000 obtained after classifying show significant deforestation over a period of 28 years. Farmland has however expanded over the same period. Classification shows the existence of dense forest.

The highest land use change of Yala watershed was from forest to urban built (Annex 4.1 and Figure 4.2) and it accounted for an average of 45% of the entire area (20%, 49%, and 67% for 1973, 1986 and 2000 respectively). Data shows that vegetation had occupied 56% of the watershed in the year 1973. This reduced to 30% then 21% in the years 1986 and 2000 respectively. In 1973, bare lands occupied 23% of the catchment. This reduced to 20% in 1986 then 11% in the year 2000. Settlements showed a marked increase from 20% to 50% then 68% of the watershed between 1973, 1986 and 2000 respectively (Table 4.1).

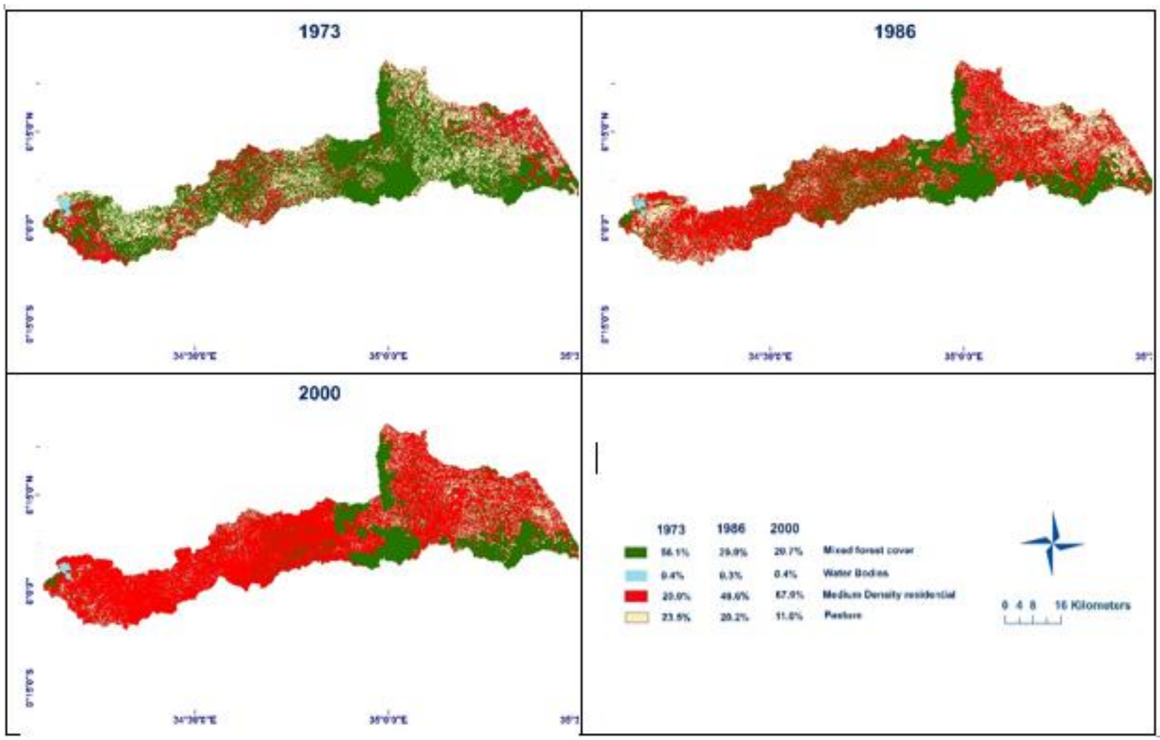

Figure 4.1: Land uses for 1973, 1985 and 2000

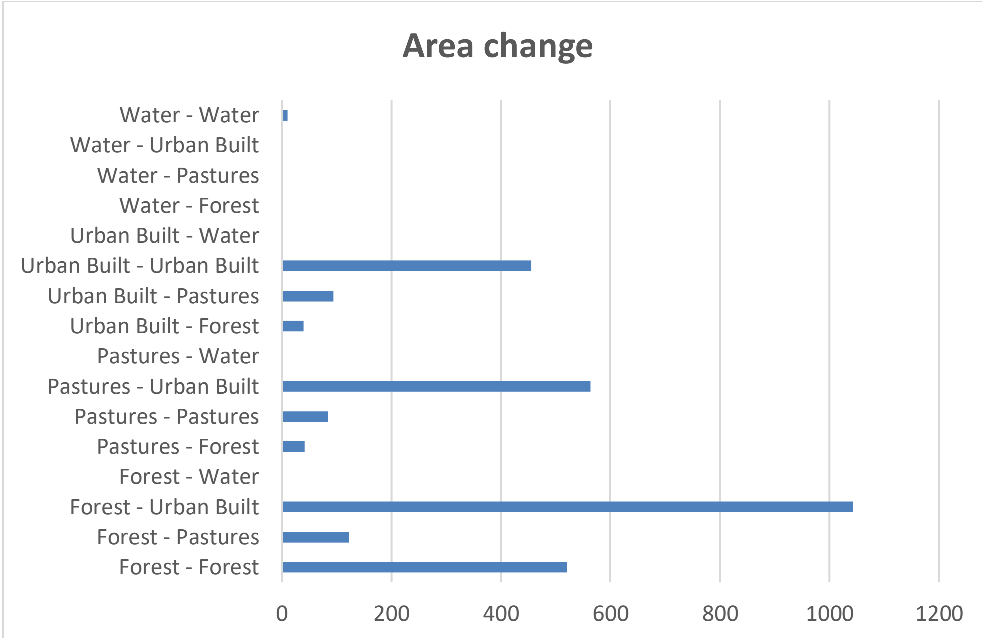

Figure 4.2: Area Change

The highest conversion was to settlements, which was 20% in 1973 to 67.9% in the year 2000 (see Table 4.1).

Table 4.1: Catchments Major Land Use Conversions from 1973 to the Year 2000

Year		1973			1986			2000	
Land use	**Counts**	**Area (Km^2)**	**% Area**	**Counts**	**Area (Km^2)**	**% Area**	**Counts**	**Area (Km^2)**	**% Area**
Vegetation	669053	1672.63	56.1	356983	892.46	29.90	247098	617.75	20.7
Water	4927	12.32	0.4	4172	10.43	0.35	4482	11.21	0.4
Bare lands	280358	700.90	23.5	241119	602.81	20.20	131304	328.26	11.0
Settlements	238489	596.22	20.0	591289	1478.22	49.54	810388	2025.97	67.9
Total	**1192827**	**2982.07**	**100.0**	**1193563**	**2983.91**	**100.00**	**1193272**	**2983.18**	**100.0**

At the scale of a specific region, multi-temporal NDVI is an important tool for land cover classification and detection of vegetation dynamics (Chu *et al.*, 2009). The two driving forces, LULC and climate change have an effect on climatic conditions. Separating the two is important for planning of their management. Policy makers, planners and researchers make use of LULC to quantify variations in natural resources and evaluate patterns of growth (Adeel, 2010). Detecting LULC change gives a better understanding of the land dynamics (Rawart, 2014). A number of studies have shown that space-borne imaging is effective in monitoring LULC change (Bakr *et al.*, 2010; Thakkar *et al.*, 2017).

The results of this study show that, in-stream water quality trends of the Yala catchment has been likely related to land use change. A number of other natural and human-induced driving factors involved add to the complexity of the river system and its attributes. Yala Watershed has in a period of 27 years (1976-2000) undergone a great change in land Use/cover with more land opened up for residential at the extent of the natural forest cover. Land cover maps assist managers with information on the catchments landscape, avails data on urban growth, forest depletion and hence develop priorities where to concentrate conservation. Worldwide, expansion of land uses to cropland is one single major driver to deforestation (Morton). The area under vegetation reduced from 1672.6km^2 in 1973 to 892.46km^2 then 617.75km^2 in 1986 to 2000 respectively. The areas under settlements however grew from 596.22km^2 to 1478.22km^2 then 2025.97km^2 within the same years.

Vegetation cover above the ground directly affects sediment yield and runoff by weakening the raindrops gravitational energy and capturing part of the precipitation (Dou, 1975). Litter on the surface increases its roughness and acts as rainfall intercept (Yu, 1997). The vegetation root system improve soil stability, reducing runoff while enhancing infiltration and porosity (Gyssels G., 2003; Sun 1989; Li *et al.*, 1998).

4.3 SWAT Modelling of Streamflow and Suspended Sediment Transport

4.3.1 Modelling of Streamflow

There are a number of studies that simulated suspended sediment using streamflow. (Olga V., 2017) evaluated sediment fluxes in Danube river basin using SWAT model. Model calibration and validation for 17 water basins were done using stream flows for 1987-2017. Runoff and sediment for Yala catchment, Kenya was modelled using SWAT. Calibration and validation was by daily and monthly time step for the years 1994 to 2002 and 2003 to 2006 respectively (Kaleab).

Setup and Run SWAT

There are three PET methods inbuilt in the SWAT model with varying input requirements. Hargreaves simulates using only air temperature. Penman-Monteith requires air temperature, solar radiation, wind speed and relative humidity. Priestley-Taylor method requires solar radiation, air temperature and relative humidity. For Yala, Potential evapotranspiration formula adopted in the model is Penman- Monteith equation and database were updated. A warm up period was set at two years then outputs selected. SWAT was run then output files read.

Calibrate Using SWAT-CUP Tool

This was achieved by using the SWAT-CUP 2019 software. Flow monthly records were used to refine the calibration of the river basin and its sub-basins. Calibrating of the SWAT model in the Yala basin using the SUFI-2 method was done for the period of 5 years (1979-1983) without any warm up period. By comparing the simulated against the observed and simulated discharges for global and one at a time respectively (Figure 4.4 and Figure 4.5). The Tindinyo gauging station coded IFE02 was used for this task. It lies on 35°55’18” longitude and latitude 00°10’38” as shown in the Figure 4.4.

Table 4.2: Adjusted Sensitive Parameters for Calibration

Variable	Description	Adjusted Value
r__CN2.mgt	SCS curve number for moisture condition II	-0.216439
v__ALPHA_BF.gw	Base flow alpha factor (1/days)	0.569751

v__GW_DELAY.gw	Ground water delay time (days)	-0.16903
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.557886
r__ESCO.bsn	Soil evaporation compensation factor	630.747742
r__ESCO.hru		0.014087
r__SOL_ALB().sol	Soil conductivity (mm/hr.)	0.552847
r__SOL_AWC().sol	Available water capacity of soil mm/hr)	-0.717200

The most sensitive parameter was CN2, the SCS-CN for antecedent moisture condition type II for whole catchment, followed by the base flow alpha factor ALPHA_ BF.gw (days). The least was SOL_AWC that represents the available water capacity in the soil in mm/mm.

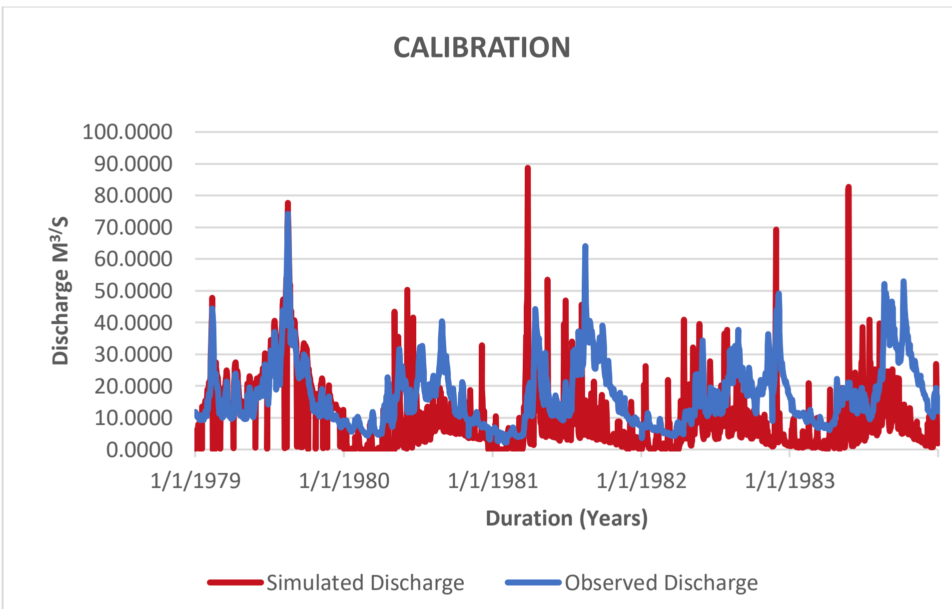

Figure 4.3: Observed Discharge Vs Simulated Flow

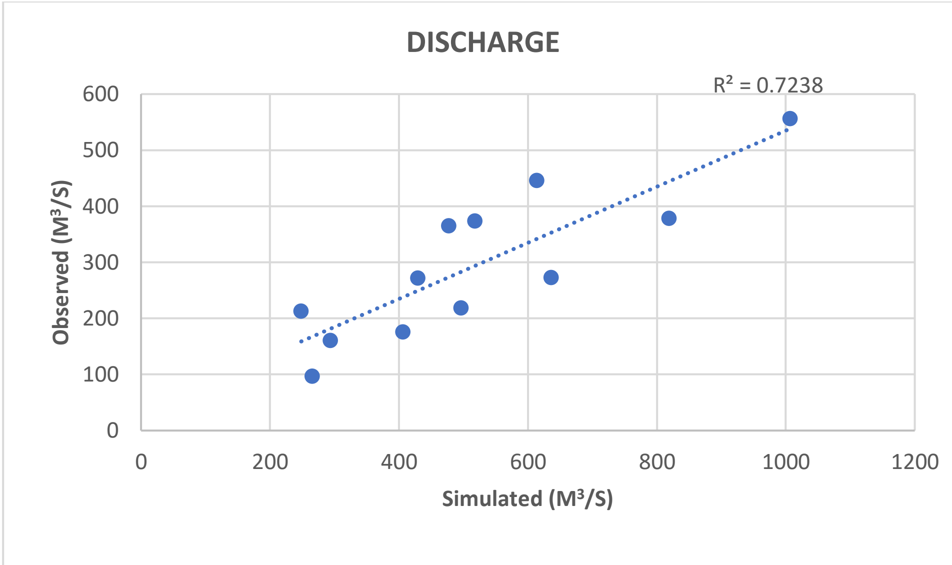

Figure 4.4: Scatter Plot of the Observed and Simulated Flow of the Calibrated Model

Validate the Model

There were flow measurements for the period 1987 to 2017. For the purpose of validation, flow for the years 1984 to 1988 were selected due to their closeness to the period satellite images were collected. This is also four years before calibration and results are presented in Figure 4.5 and Figure 4.6.

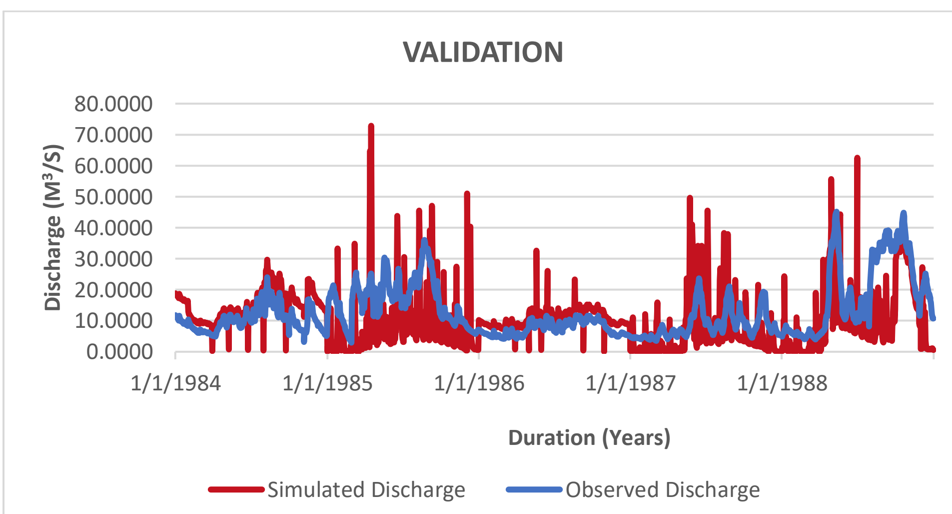

Figure 4.5: Observed and Simulated Flow of the Validated Model

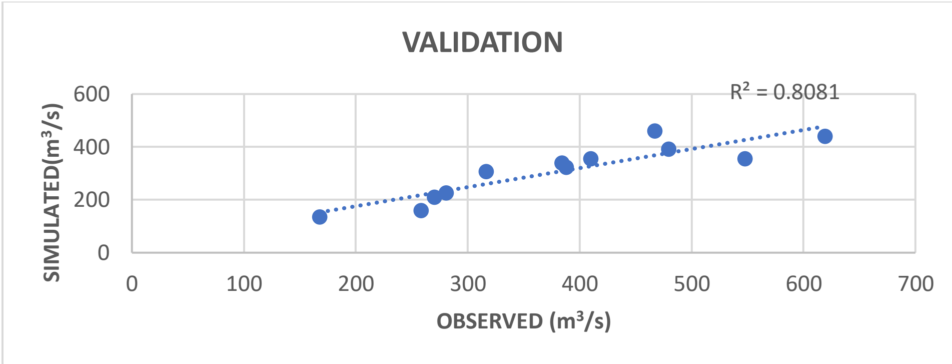

Figure 4.6: Scatter Plot of the Observed and Simulated Flow of the Model

Seven sediment concentration data were availed by the WRA as shown in Annex 16. They were for 15/1/1980, 1/1/1981, 23/2/1982, 3/3/1984, 19/2/1985, 10/27/1987 and 3/2/1988.The data was compared to the model output for the same dates and had an R^2 of 0.73 as shown in Figure 4.7.

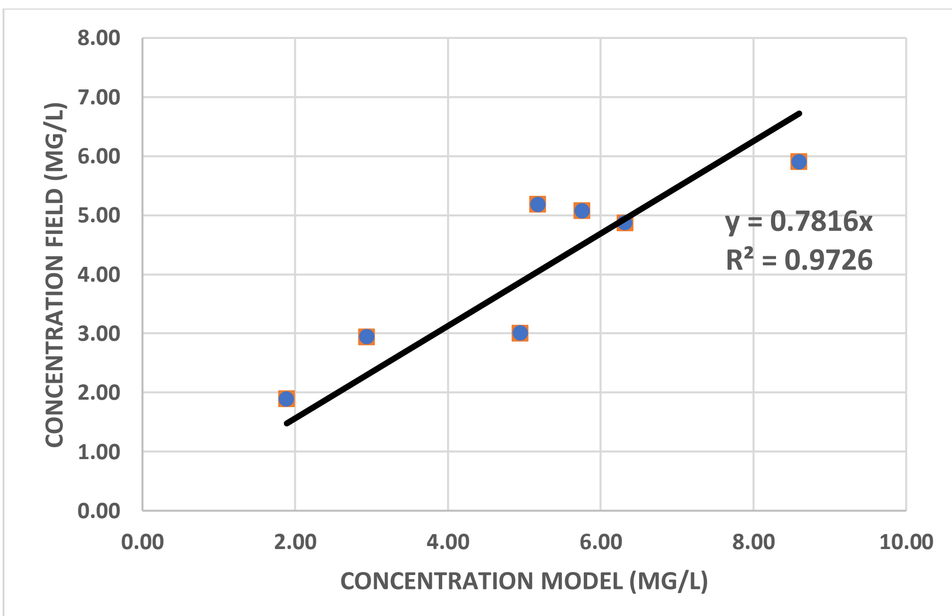

Figure 4.7: Scatter Plot of the Observed and Simulated Sediment Concentration

Evaluation of Performance

Table 4.4 shows the results obtained from the evaluation performance of the model. They fall in the acceptable ranges hence a true representation of hydrological processes except for the PBIAS for calibration, which was 0.43.

PBIAS values for streamflow tend to vary more, among different auto calibration methods, during dry years than during wet years (Gupta *et al.*, 1999). Calibration and validation were done at different periods

Table 4.3: Calibration and Validation

Parameter	Calibration Value	Validation Value	Optimum Value
R^2	0.72	0.81	1.0
PBIAS	0.43	0.20	15%-25%
NSE	0.79	0.94	1.0

4.3.2 Simulation of Suspended Sediment Transport

The impact of soil conservation measures can best be assessed by comparing simulations in the absence and presence of conservation measures on similar HRUs (Vigiak *et al.*, 2016). At different river scales, the relation between water quality and the type of Land use may not be the same (Tian YM, 2006). Prediction of flow and soil loss are two important factors for risk assessment of soil erosion hence coming up with appropriate soil conservation and land uses for a specific watershed.

When the SWAT model is well calibrated and validated to represent the actual river flow, three files were generated on successful running of the model. The HRU general file, HRU output file and the Reach output file. The HRU output gives the results of all the simulated parameters per HRU for each sub-basin for the entire period of simulation.

Sediment In and Out of Reach

The highest volume of sediment that was transported into and out of reach were 1,462,950 tons and 1,818,650 tons respectively, both in the year 1981.These values are as shown in Annex 7 and Figure 4.8. This year had the highest inflow and outflow of 368.333m^3/s and 366.619 m^3/s respectively after having two consecutive dry years of 1979 and 1980, with both an inflow and outflow of about 200m^3/s.

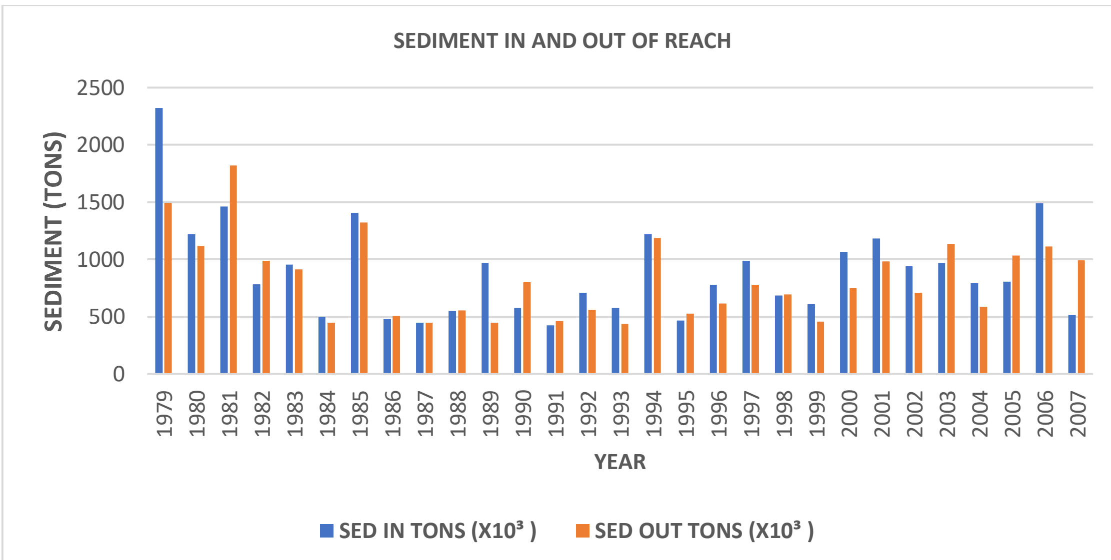

Figure 4.8: Sediment In and Out of Reach

Sediment Yield

The yield of the sediment responds to the streamflow with a lag as shown in on Annex 8. This could possibly be caused by weather variability within the catchment. Precipitation tends to vary within counties or even various watersheds within the same county. The highest yield was 3.95 Tons/Ha in 1979. Figure 4.9 shows the relationship between the catchments annual precipitation against sediment load. SWAT generates data on sediment in tons per square kilometer. Due to the need for a scale to make comparison with precipitation, 500 has been multiplied to values of the sediment yield. The catchment responds to precipitation with a lag.

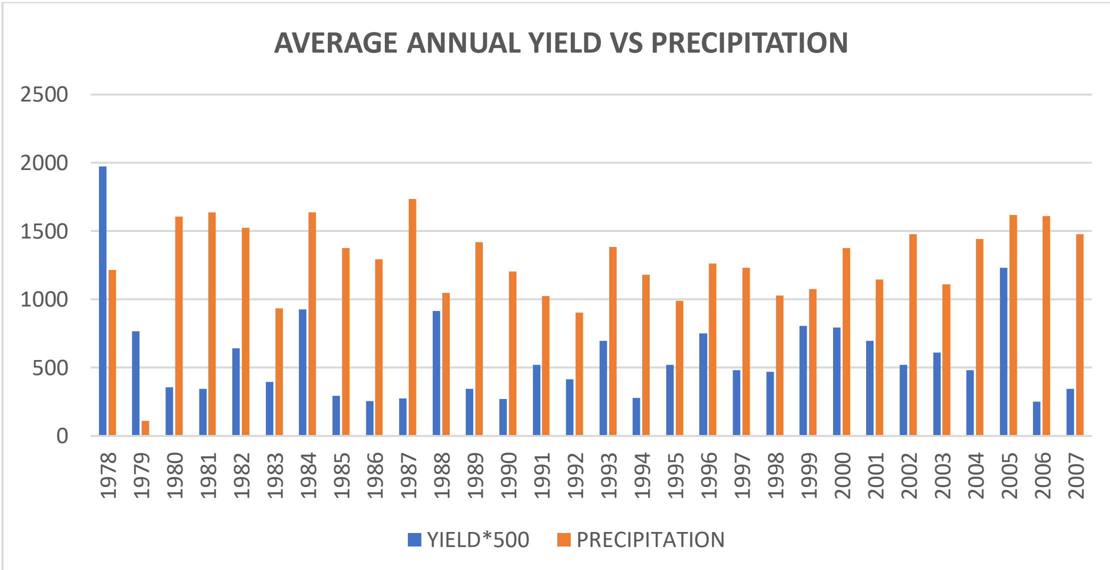

Figure 4.9: Sediment Yield Vs Average Precipitation

Monthly Basin Values

Throughout the study period, 1978 had the highest sediment yield of 3.9tons per hactare (Figure 4.10). This is could be due to increased agricultural activities within the watershed at the start of the long rains and the end respectively. By mid year, most ground is covered by vegetation, hence reduced erosion (Figure 4.11). The highest precipitation was in 1987 at 1734mm.

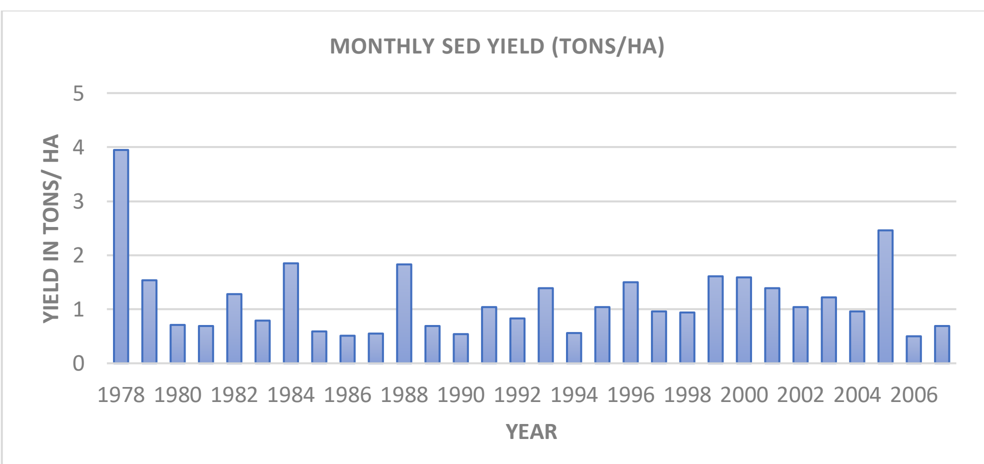

Figure 4.10: Monthly Sediment Yield

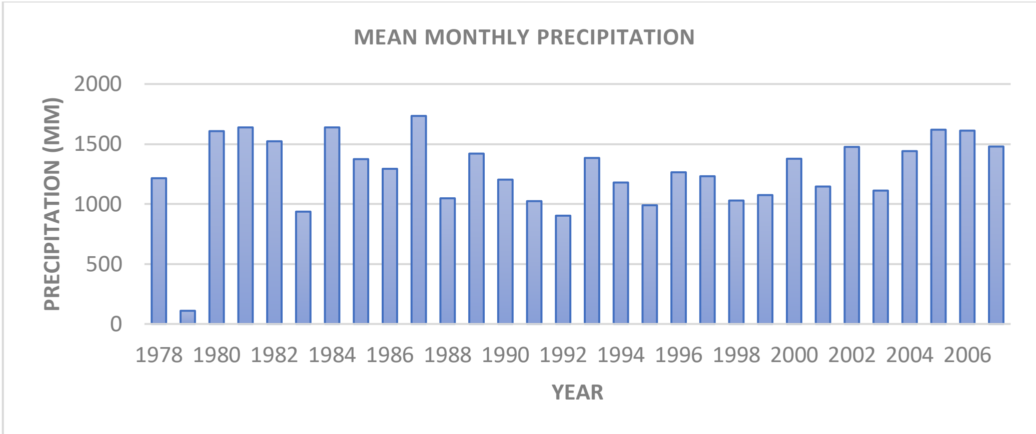

Figure 4.11: Monthly Averages for the Basin

Sediment Concentration and Yield

Being the first year, the factors that led the behaviour in 1978 may not be clear. The highest sediment concentration was 3,552.4mg/l in 1991 with a yield of 1.04Tons/m^3 while the lowest was 612.71mg/l and a yield of 0.59Tons/m^3 in 1985.There is an apparent high sediment concentration in low flows while high flows exhibit low concentration as shown in of Annex 9. This may be resulting from the diminishing sediment supply and the end of the rainy season and improved base flow.

Model performance is improved by selection of sensitive parameters using SWAT-CUP global sensitivity analysis (Misgana, 2012). CN_2 was found to be the most important parameter in the simulation of SWAT (Noor *et al.*, 2014). The parameters are provided in the SWAT-CUP manual and literature. The number of sensitive parameters depend on the modelling effort (Ndomba, 2008). The Soil and Water Assessment Tool (SWAT) model used in conjunction with the Geographic Information System (GIS) and river flow gave a scientifically acceptable approach that reasonably quantified the catchment's hydrologic benefits and the management. Sediment concentration is sometimes high with high flows due to availability of the material for erosion. On other occasions, it can be high in low flows due to the dilution effect. Generally, it follows a hysteric curve. Model behavior and performance is by comparing observed and simulated variables (Krause *et al.*, 2005).

In calibration and validation using SWAT model, values for PBIAS over 80% in assessing sediment flow is considered satisfactory (Santi *et al.*, 2001). For the multiple correlation (R^2), a result >0.6 is deemed acceptable (Santi *et al.*, 2001). The Nash-Sutcliffe efficiency coefficient (NSE) value greater than 0.5 is usually acceptable (Nash, 1970).

The results showed that SWAT model was efficient in simulating the water quality and sediment transport phenomena. Its interface is user friendly. Its joint use with ArcGIS makes it possible to account for spatial variability.

4.4 Scenario Simulation

SWAT enables modification of sediment routing ability and land use for overland flow through application of the numerical model of Vegetative Filter Strip (VFT) according to Park *et al*. (2011). The sub basins trap efficiency can therefore be found.

Scenario analysis has been accepted as an efficient method that assists engineers predict how land use and land use change enables the response of watersheds hydrological processes. Among the strengths of the SWAT model lies in its ability to construct various LULC scenarios.

Three scenarios were considered in this study:

i) Base scenario

ii) Conversion of 30% of summer pastures to forest,

iii) Introduction of strip farming

The scenarios considered in this study are time dependent hence not useful for future predictions but rather assist planners with information to plan the management of land and water resources. SWAT was simulated under observed flow and sediment yields under two management conditions evaluated. This was to inform on the best management practice for this catchment.

4.4.1 Conversion of 30% of Summer Pastures to Forest Compared to Base

The first comparison of the two (base and conversion of pastures to forest) scenarios is illustrated in of Annex 11 and Figure 4.12 considers the sediment concentration in reach by comparing with the base. There was a general reduction of about 67% from the initial concentration.

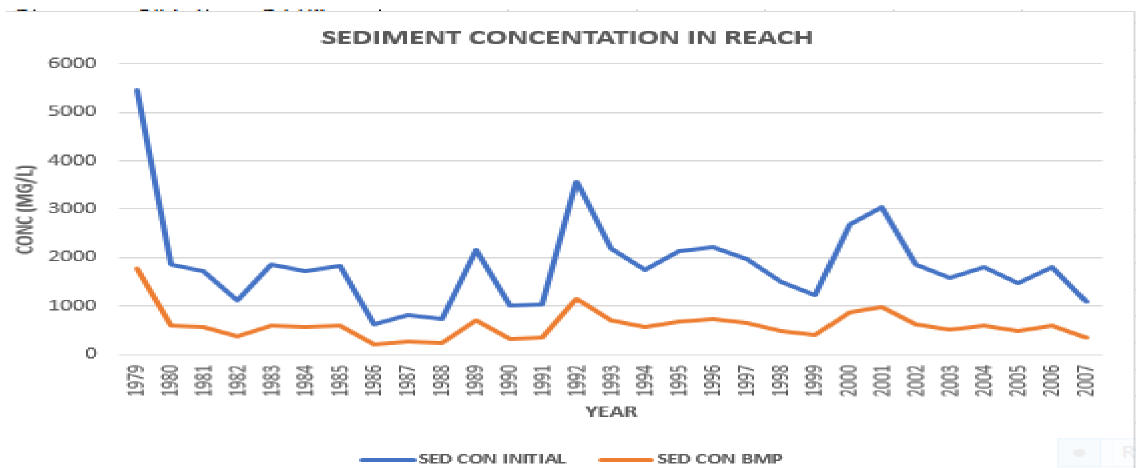

Figure 4.12: Sediment Concentration after BMP1

The quantity of sediment (Tons) that moved into and out of the reach are as shown in Annex 11 and 12 respectively. Both displayed a reduction of about 67%. This denotes the effectiveness of the BMP onto the watershed as illustrated in the Figures 4.13 and 4.14.

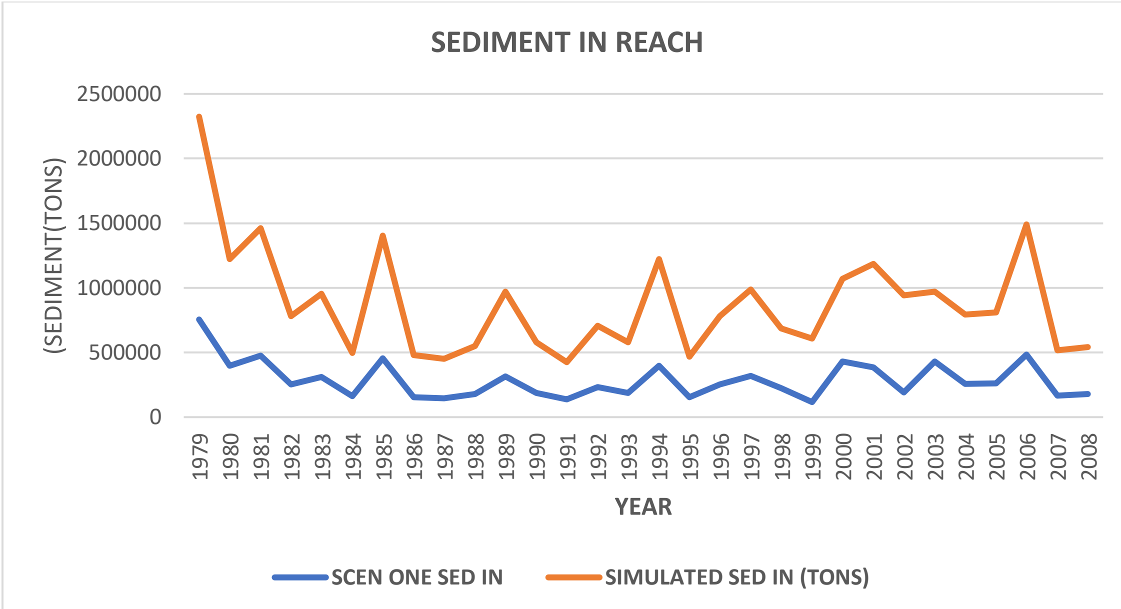

Figure 4.13: Sediment into Reach after BMP1

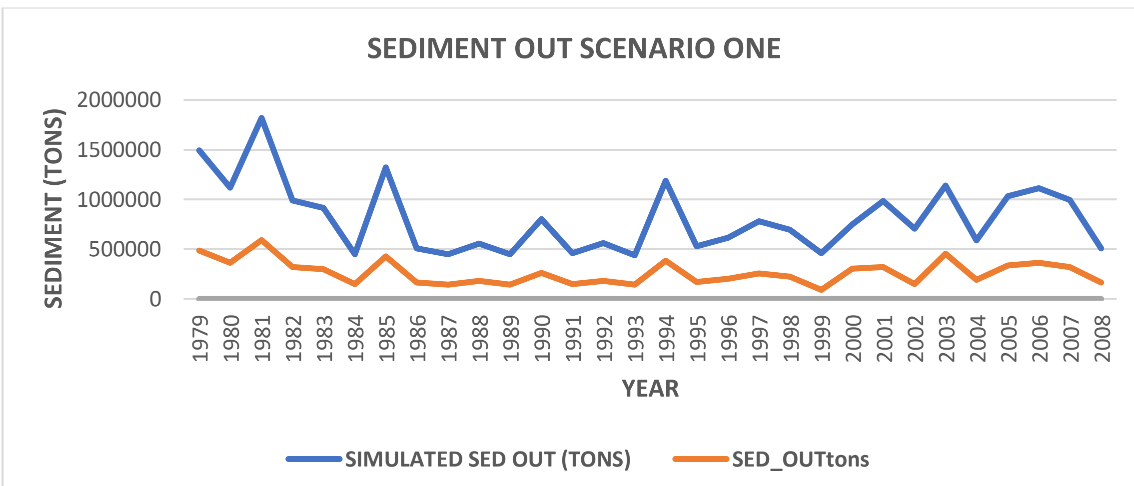

Figure 4.14: Sediment Out of Reach after BMP1

4.4.2 Introduction of Strip Farming Compared to Base

The second comparison of the two (base and introduction of strip farming) scenarios in the catchment. The results for the 25 years simulated period for the sediment concentration in reach were as shown in Annex 13 and Figure 4.15. There was a reduction of between 98% to 62% in sediment concentration.

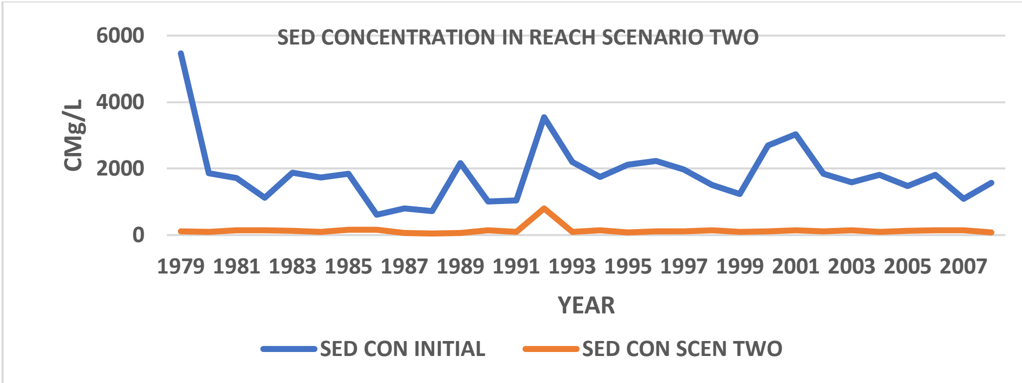

Figure 4.15: Sediment Concentration in Reach after BMP2

The quantity of sediment that was transported into and out of reach (Tons) had an average reduction of 62% for the period of study as shown in Figure 4.16, Figure 4.17 and Annexes 14 and 15 respectively.

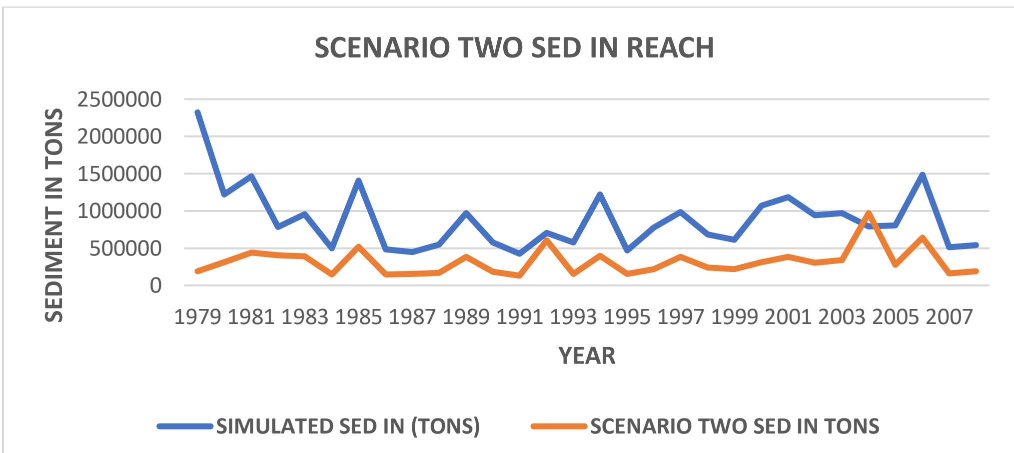

Figure 4.16: Sediment in Reach after BMP2

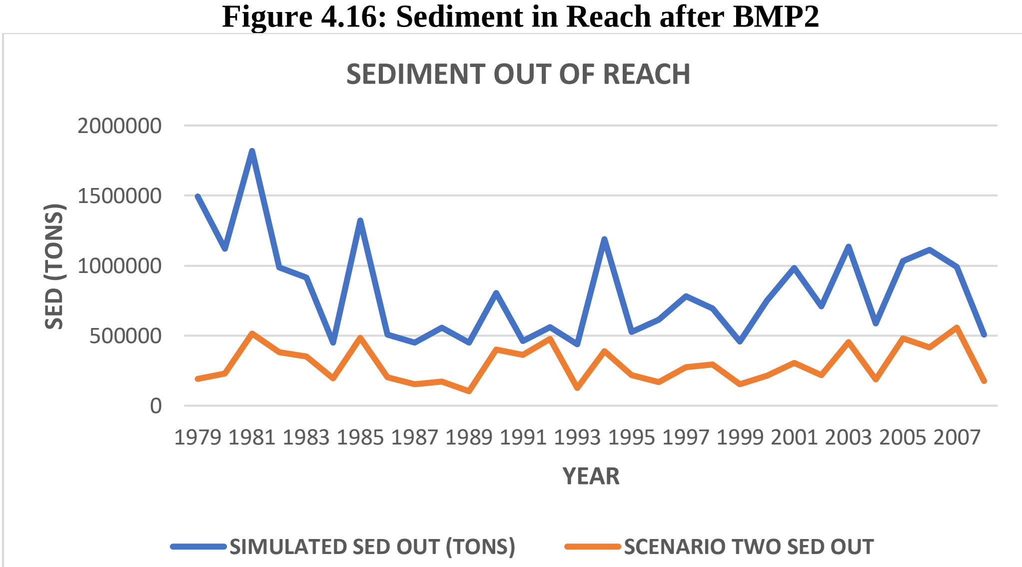

Figure 4.17: Sediment in Reach after BMP2

The impact of soil conservation measures can best be assessed by comparing simulations in the absence and presence of conservation measures on similar HRUs (Vigiak *et al.*, 2016)**.** At different river scales, the relation between water quality and the type of Land use may not be the same (Tian YM, 2006). Prediction of flow and soil loss are two important factors for risk assessment of soil erosion hence coming up with appropriate soil conservation and land uses for a specific watershed. SWAT enables modification of sediment routing ability and land use for overland flow through application of the numerical model of Vegetative Filter Strip (VFT) according to Park, *et. al* (2011). The sub basins trap efficiency can therefore be found. Three scenarios were compared for sediment concentration, sediment entering and leaving the reach. The highest sediment concentration in scenario 1 was 1780 mg/l in 1979. The same year had the largest quantity (232.37 x 10^3 Tons) of sediment flowing into the reach. The year 1983 had the highest outflow of 438.406 x 10^3 Tons. Considering the second scenario, 1992 had the highest concentration of sediment of 803mg/l. The year with the highest sediment inflow of 971.200 x 10^3 tons was 2004 while 2007 saw the largest out flow of 557.55 x 10^3 tons. Land use change is the most pervasive force that drives ecosystems degradation (J, 2008).

CHAPTER FIVE

5.0 CONCLUSION AND RECCOMENDATIONS

5.1 Conclusion

Long time data readily should now be used to monitoring land cover changes in all the watersheds. This will assist in scientifically manage and conserving the water resources from degradation and pollution.

Flow prediction and soil loss assist in the assessment of soil erosion risks; hence determine suitable watershed's land use and soil conservation measures. This in turn may help in maximizing the benefits of land use and minimize the negative impacts of land other environmental problems. Decision makers require Land use change analysis to determine changes in environment and make development studies that are sustainable. Yala watershed within a period of 27 years (1973-2000) underwent great changes in land use/cover with more land being turned to cultivation at the expense of the forest cover. It is concluded that the area under vegetation reduced from 56% to 20.7% while settlements grew from 20% to 67.9%.Since land is finite, the situation may run out of control if left to continue.

The Soil and Water Assessment Tool (SWAT, 2009) integrated with the Geographic Information System (ArcGIS, 10.3) were used for this study. Model performance was evaluated, focusing on the stream flow and sediment load of the Yala basin. SWAT effectively simulates sediment transfer and water phenomena. Integrating data is laborious but with a friendly interface. SWAT was calibrated and validated to provide streamflow. It was concluded that the model evaluation coefficients for flow were found to be good for calibration and satisfactory for validation.

The SWAT model analyzed the way Yala Watershed responded hydrologically to the impact of land use/ land cover change (LULCC) based on the three different types of scenario. Based on the initial conditions, SWAT has shown to be sensitive to vegetative filter strip and the conversion of 30% of the pastureland to forest cover. The two scenarios however have different sensitivities. Converting 30% of the pastureland to forest reduced sediment concentration, sediment in and out of reach by 67%. Vegetative strip farming reduced concentration by 80% while sediment in and out of reach reduced by 62%. It is therefore important to implement both after analyzing the response per HRU. The results of this study reveals that an effort to manage this watershed will produce significant reduction in sediment movement.

5.2 Recommendations

The global human population has been permanently increasing and this affects consumption patterns. More land will therefore be required for agriculture and accommodation. Land use land cover will therefore keep changing. Management practices are therefore needed to the existing land to mitigate future negative effects. This research recommends future studies be carried out with special attention being paid to assessment of the climate variability and change in the catchment for a long period. This could assist in understanding the real cause of the land dynamics of the catchment. The shifting of the current land tenure system where each family has rights to split can arrest the high changes of land use to residential. Most developed and developing countries have designated areas for residential while the remaining is for agriculture and forests.

While SWAT proved effective in simulating the land use changes, there may be other models that may give better results.

There is need for the development of land-use scenarios to analyze how land use change impact on the stream flow using hydrological models based on future scenarios.

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ANNEXES

Annex 1a: LULC Attributes

LULC1973

OBJECTID *	Shape *	GRIDCODE	Class_1973	Area1973
1	Polygon	1	Forest	1687.960463
2	Polygon	2	Water	12.366194
3	Polygon	3	Urban Built	590.347076
4	Polygon	4	Pastures	690.942116

Annex 1b: Area Change

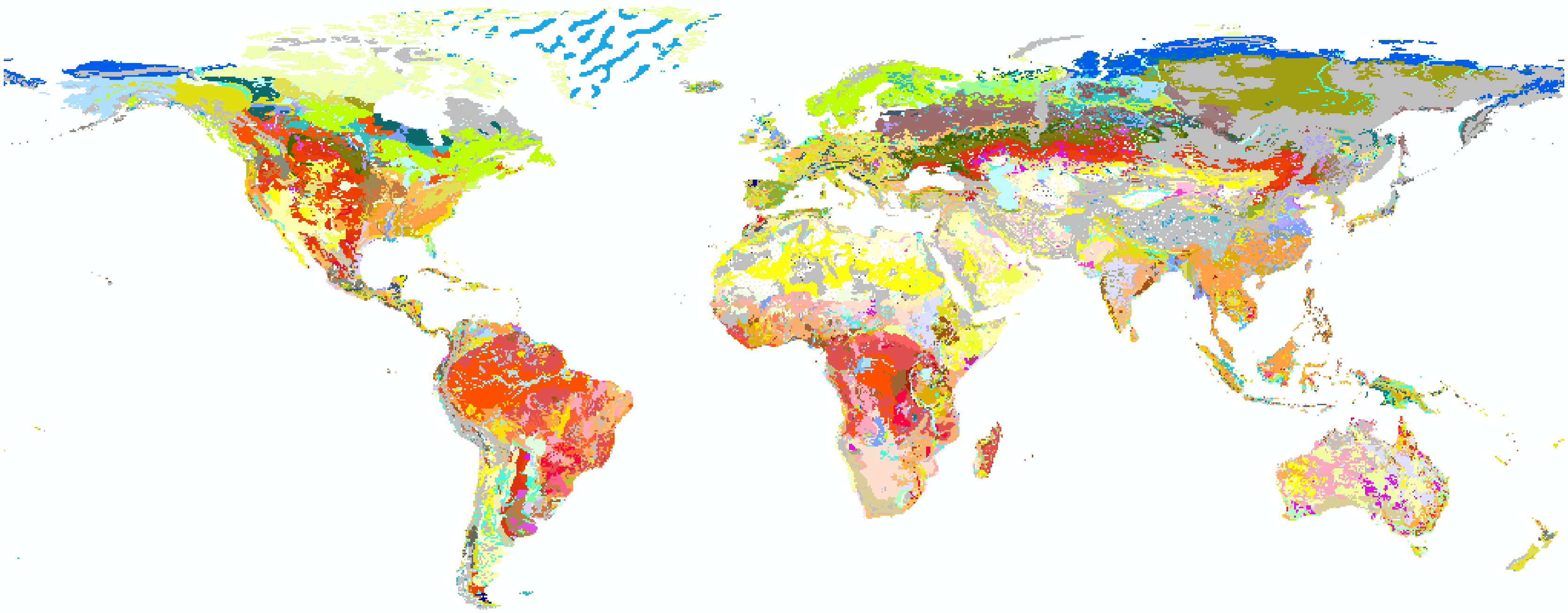
Change (1973_2000)	Area Change (KM^2)
Forest – Forest	520.4714075
Forest – Pastures	121.9531899
Forest - Urban Built	1042.558207
Forest – Water	0.156413863
Pastures – Forest	41.49994478
Pastures – Pastures	84.7778345
Pastures - Urban Built	563.440236
Pastures – Water	0.041249205
Urban Built – Forest	39.27490806
Urban Built – Pastures	94.26371761
Urban Built - Urban Built	455.0334134
Urban Built – Water	0.191459022
Water – Forest	0.371737549
Water – Pastures	0.094206803
Water - Urban Built	1.092020354
Water – Water	10.79921617

Annex 2: Area Change from the Years 1973 to 2000

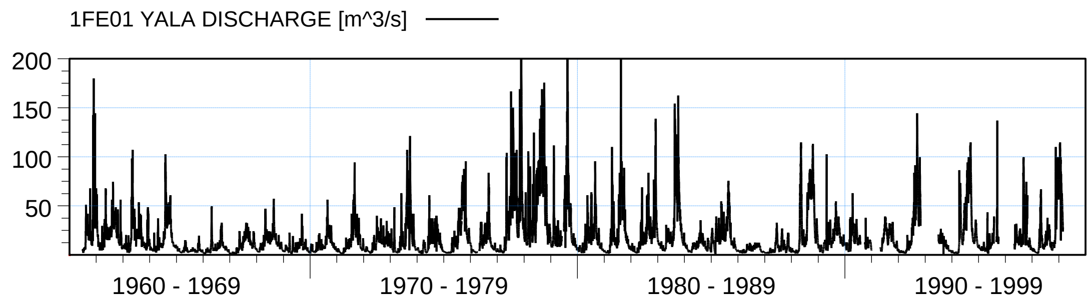
Area change 1973_2000A

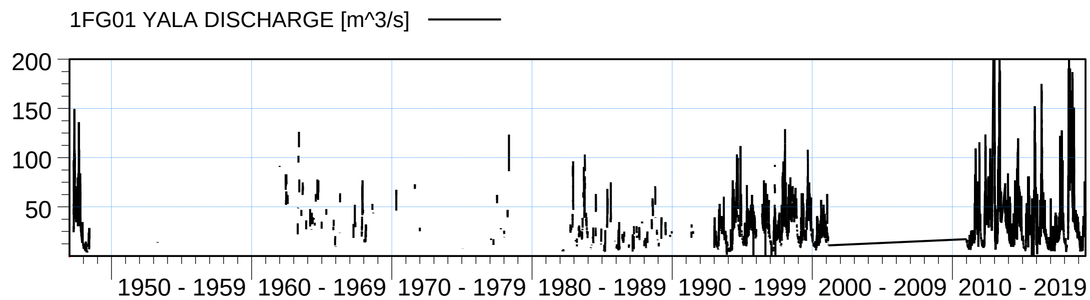
Class_1973	Area1973	FID_lulc20	GRIDCODE_1	Shape_Le_1	Shape_Ar_1	Class2000	Area2000	Change
Forest	1687.960463	1	1	6928742.31671	603262270.817	Forest	603.262271	Forest - Forest
Forest	1687.960463	2	2	38390.125215	11194461.1718	Water	11.194461	Forest - Water
Forest	1687.960463	3	3	10267725.8893	301969318.786	Pastures	301.969319	Forest - Pastures
Forest	1687.960463	4	4	16068563.1675	2066349364.47	Urban Built	2066.349364	Forest - Urban Built
Water	12.366194	1	1	6928742.31671	603262270.817	Forest	603.262271	Water - Forest
Water	12.366194	2	2	38390.125215	11194461.1718	Water	11.194461	Water - Water
Water	12.366194	3	3	10267725.8893	301969318.786	Pastures	301.969319	Water - Pastures
Water	12.366194	4	4	16068563.1675	2066349364.47	Urban Built	2066.349364	Water - Urban Built
Urban Built	590.347076	1	1	6928742.31671	603262270.817	Forest	603.262271	Urban Built - Forest
Urban Built	590.347076	2	2	38390.125215	11194461.1718	Water	11.194461	Urban Built - Water
Urban Built	590.347076	3	3	10267725.8893	301969318.786	Pastures	301.969319	Urban Built - Pastures
Urban Built	590.347076	4	4	16068563.1675	2066349364.47	Urban Built	2066.349364	Urban Built - Urban Built
Pastures	690.942116	1	1	6928742.31671	603262270.817	Forest	603.262271	Pastures - Forest
Pastures	690.942116	2	2	38390.125215	11194461.1718	Water	11.194461	Pastures - Water
Pastures	690.942116	3	3	10267725.8893	301969318.786	Pastures	301.969319	Pastures - Pastures
Pastures	690.942116	4	4	16068563.1675	2066349364.47	Urban Built	2066.349364	Pastures - Urban Built

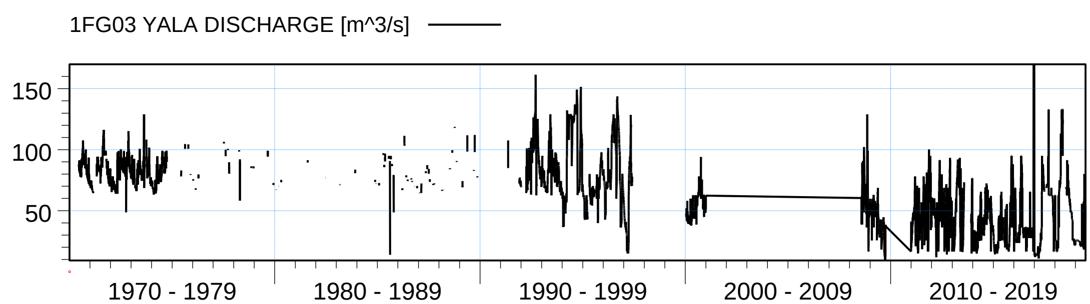
Annex 3: FAO Digital Soil Map of the World

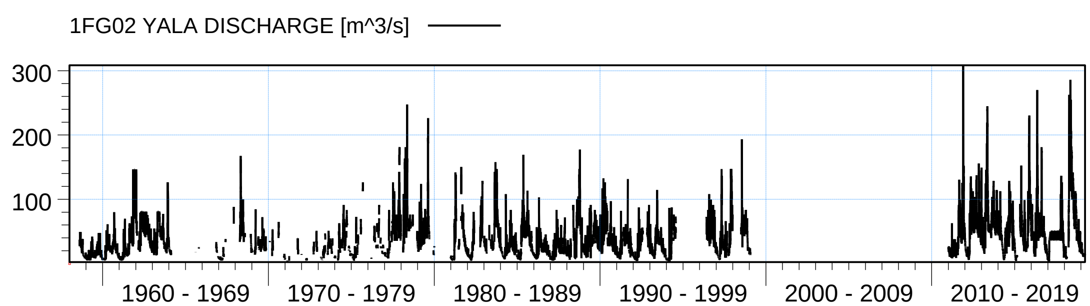


Annex 4: Yala River Hydrographs

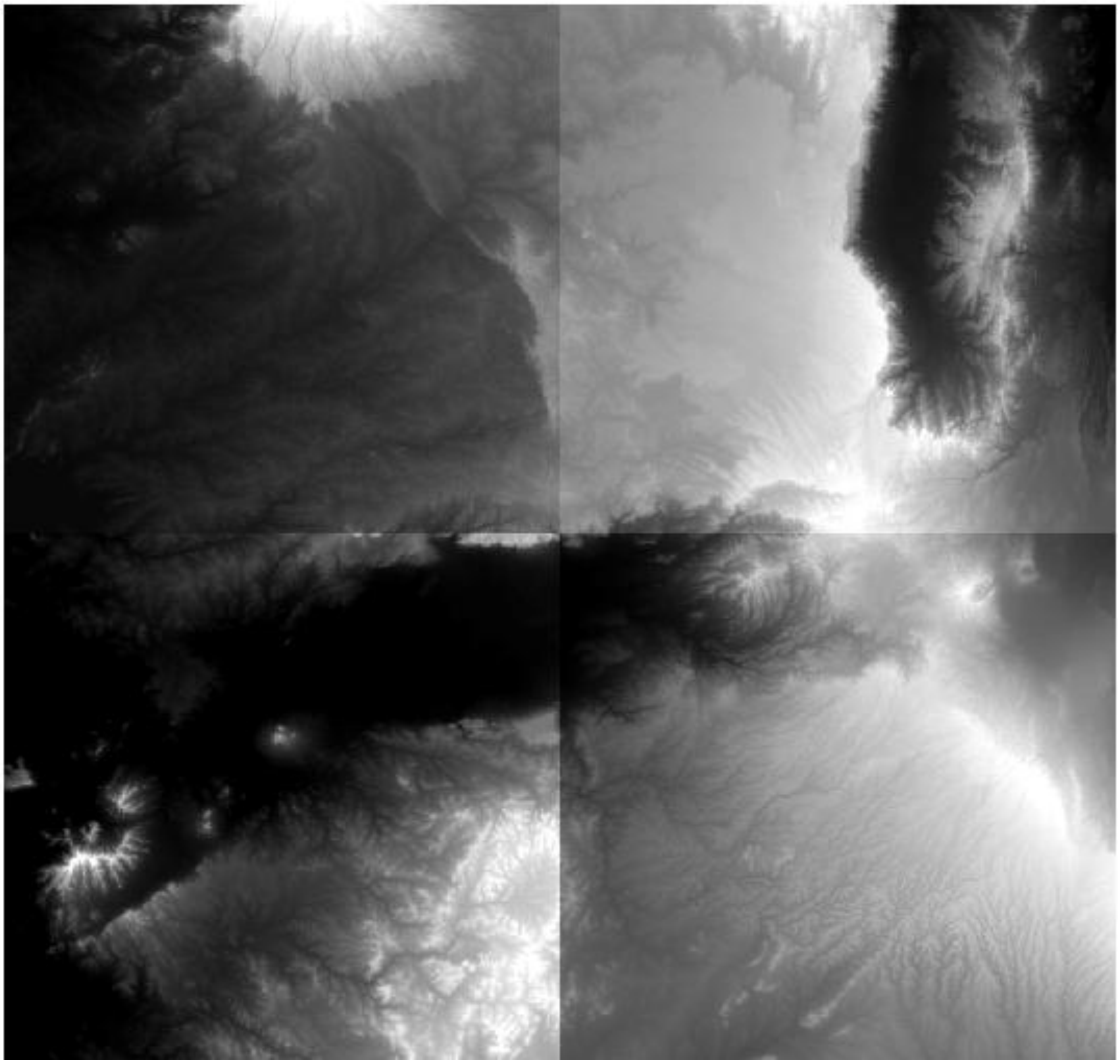




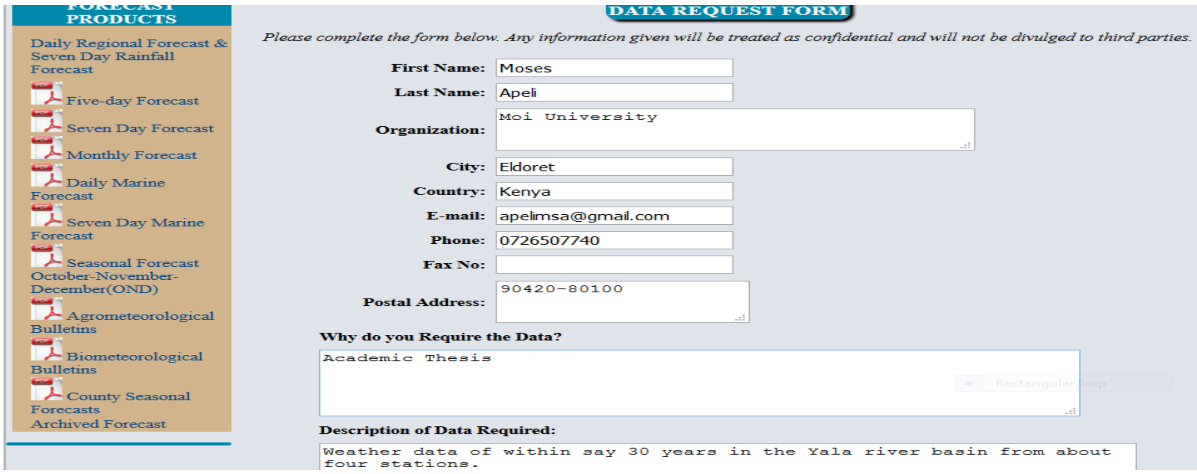




Annex 5: Yala Basin Tiles



Annex 6: Yala Basin Data Request



FORECAST PRODUCTS

Daily Regional Forecast & Seven Day Rainfall Forecast
Five-day Forecast
Seven Day Forecast
Monthly Forecast
Daily Marine Forecast
Seven Day Marine Forecast
Seasonal Forecast October-November-December(OND)
Agrometeorological Bulletins
Biometeorological Bulletins
County Seasonal Forecasts
Archived Forecast

DATA REQUEST FORM

Please complete the form below. Any information given will be treated as confidential and will not be divulged to third parties.

First Name: Moses
Last Name: Apeli
Organization: Moi University
City: Eldoret
Country: Kenya
E-mail: apelimsa@gmail.com
Phone: 0726507740
Fax No:
Postal Address: 90420-80100

Why do you Require the Data?
Academic Thesis

Description of Data Required:
Weather data of within say 30 years in the Yala river basin from about four stations.

Annex 7: Annual Sediment In and Out of Reach Parameter

Year	Sediment in Reach (10^3) (Tons)	Sediment Out of Reach (10^3) (Tons)
1979	2323.7	1492.7
1980	1221.52	1118.52
1981	1462.95	1818.65
1982	781.13	987.33
1983	954.38	914.08
1984	497.158	450.008
1985	1404.87	1320.47
1986	480.24	507.04
1987	449.07	449.57
1988	549.53	555.23
1989	969.595	449.125
1990	578.58	803.18
1991	425.06	459.85
1992	708.18	559.94
1993	579.866	438.406
1994	1220.88	1188.88
1995	468.32	526.7
1996	780.674	614.744
1997	987.25	780.55
1998	684.13	692.45
1999	609.685	459.335
2000	1068.5	751.14
2001	1183.27	981.67
2002	941.72	708.22
2003	970.98	1137.28
2004	794.41	588.41
2005	808.4	1033.2
2006	1488.85	1112.25
2007	515.36	992.26
2008	543.63	508.33

Annex 8: Annual Sediment Yield

Year	Sediment Yield (Tons/Ha)
1978	3.9473
1979	1.5365
1980	0.71
1981	0.69
1982	1.28
1983	0.79
1984	1.85
1985	0.59
1986	0.51
1987	0.55
1988	1.83
1989	0.69
1990	0.54
1991	1.04
1992	0.83
1993	1.39
1994	0.56
1995	1.04
1996	1.50
1997	0.96
1998	0.94
1999	1.61
2000	1.59
2001	1.39
2002	1.04
2003	1.22
2004	0.96
2005	2.46
2006	0.50
2007	0.69

Annex 9: Sediment Yield vs. Outflow

Year	Sediment Yield(Tons/Ha)	Outflow (M^3X100)
1978	3.95	2.00
1979	1.54	2.04
1980	0.71	3.67
1981	0.69	3.43
1982	1.28	3.75
1983	0.79	1.89
1984	1.85	3.62
1985	0.59	3.06
1986	0.51	2.65
1987	0.55	4.36
1988	1.83	1.77
1989	0.69	3.27
1990	0.54	2.49
1991	1.04	1.96
1992	0.83	1.39
1993	1.39	3.41
1994	0.56	2.46
1995	1.04	1.59
1996	1.50	2.11
1997	0.96	2.77
1998	0.94	1.47
1999	1.61	1.99
2000	1.59	2.76
2001	1.39	1.76
2002	1.04	3.35
2003	1.22	1.62
2004	0.96	3.27
2005	2.46	3.18
2006	0.50	4.02
2007	0.69	3.30

Annex 10: Sediment Yield vs Concentration

Year	Conc (mg/cm)	Yield (Tons/cm)	Variance
1978	5.4664	3.9473	1.5191
1979	1.85197	1.5365	0.31547
1980	1.72402	0.71	1.01402
1981	1.11557	0.69	0.42557
1982	1.86975	1.28	0.58975
1983	1.72605	0.79	0.93605
1984	1.83764	1.85	-0.01236
1985	0.61271	0.59	0.02271
1986	0.80984	0.51	0.29984
1987	0.72851	0.55	0.17851
1988	2.17337	1.83	0.34337
1989	1.01416	0.69	0.32416
1990	1.04462	0.54	0.50462
1991	3.5524	1.04	2.5124
1992	2.19888	0.83	1.36888
1993	1.78623	1.39	0.39623
1994	2.12276	0.56	1.56276
1995	2.22432	1.04	1.18432
1996	1.96864	1.5	0.46864
1997	1.51398	0.96	0.55398
1998	1.233	0.94	0.293
1999	2.6961	1.61	1.0861
2000	3.0374	1.59	1.4474
2001	1.85118	1.39	0.46118
2002	1.58199	1.04	0.54199
2003	1.80515	1.22	0.58515
2004	1.48223	0.96	0.52223
2005	1.8067	2.46	-0.6533
2006	1.09659	0.5	0.59659
2007	1.56672	0.69	0.87672

Annex 11: Sediment Concentration in Reach Before and After Scenario One BMP

Year	Sed Con Base	Sed Scenario One	Reduction	%Reduction
1979	5466.4	1780.2	3686.2	67.43
1980	1852	605.6	1251.4	67.39
1981	1724	563.9	1160.1	67.29
1982	1115.6	366.2	749.4	67.17
1983	1869.8	610.6	1259.2	67.34
1984	1726	565	1161	67.27
1985	1837.6	600.8	1236.8	67.31
1986	612	202.6	409.4	66.90
1987	809.8	266.6	543.2	67.08
1988	728.5	240.1	488.4	67.04
1989	2173	710.2	1462.8	67.32
1990	1014.2	332.8	681.4	67.19
1991	1044.6	342.7	701.9	67.19
1992	3552.4	1158.3	2394.1	67.39
1993	2198.9	720	1478.9	67.26
1994	1756.2	583.7	1172.5	66.76
1995	2122.8	692.1	1430.7	67.40
1996	2224.3	725.3	1499	67.39
1997	1968.6	643.2	1325.4	67.33
1998	1514	495.9	1018.1	67.25
1999	1233	418.3	814.7	66.07
2000	2696	880	1816	67.36
2001	3037	991.4	2045.6	67.36
2002	1851	617.2	1233.8	66.66
2003	1582	517.6	1064.4	67.28
2004	1805	590.3	1214.7	67.30
2005	1482	485.5	996.5	67.24
2006	1806	591.4	1214.6	67.25
2007	1096	360	736	67.15
2008	1566.7	512.6	1054.1	67.28

Annex 12: Sediment into Reach

Year	Scene One Sed In	Simulated Sed In (Tons)	Variance
1979	755088.6	2323700	67.50
1980	397094	1221520	67.49
1981	475517	1462950	67.50
1982	253952.2	781130	67.49
1983	310447.8	954380	67.47
1984	161570.2	497158	67.50
1985	456688.6	1404870	67.49
1986	156005.8	480240	67.52
1987	146026.2	449070	67.48
1988	178783.8	549530	67.47
1989	315461.4	969595	67.46
1990	188111	578580	67.49
1991	138132.1	425060	67.50
1992	230313.1	708180	67.48
1993	188362.8	579866	67.52
1994	397051.4	1220880	67.48
1995	152160.2	468320	67.51
1996	253846.3	780674	67.48
1997	320820.4	987250	67.50
1998	222638.6	684130	67.46
1999	116388.8	609685	80.91
2000	429639.4	1068500	59.79
2001	384710.6	1183270	67.49
2002	191286.6	941720	79.69
2003	431148.1	970980	55.60
2004	258297.4	794410	67.49
2005	262835	808400	67.49
2006	484013.8	1488850	67.49
2007	167536.2	515360	67.49
2008	176713.4	543630	67.49

Annex 13: Sediment Out of Reach

Year	Simulated Sed Out (Tons)	Bmp Sed_Out (Tons)	Variance
1979	1492700	485209.841	67.49
1980	1118520	363957.641	67.46
1981	1818650	591187.841	67.49
1982	987330	321132.241	67.47
1983	914080	297399.441	67.46
1984	450008	146316.161	67.49
1985	1320470	429392.641	67.48
1986	507040	164997.841	67.46
1987	449570	146093.841	67.50
1988	555230	180835.841	67.43
1989	449125	145980.961	67.50
1990	803180	261219.041	67.48
1991	459850	149586.521	67.47
1992	559940	181975.121	67.50
1993	438406	142424.401	67.51
1994	1188880	386615.041	67.48
1995	526700	171417.401	67.45
1996	614744	199865.881	67.49
1997	780550	253880.441	67.47
1998	692450	225147.441	67.49
1999	459335	90839.208	80.22
2000	751140	302832.234	59.68
2001	981670	319460.241	67.46
2002	708220	147506.648	79.17
2003	1137280	452904.114	60.18
2004	588410	191244.241	67.50
2005	1033200	335959.041	67.48
2006	1112250	361941.841	67.46
2007	992260	322756.241	67.47
2008	508330	165465.441	67.45

Annex 14: Scenario 2 Sediment Concentration in Reach

Year	Sed Con Initial	Sed Con Scen Two	Reduction	% Reduction
1979	5466.4	106.728	5359.672	98.05
1980	1857	103.683	1753.317	94.42
1981	1724	147.468	1576.532	91.45
1982	1115.6	136.758	978.842	87.74
1983	1869.8	126.993	1742.807	93.21
1984	1726	102.6225	1623.3775	94.05
1985	1837.6	152.823	1684.777	91.68
1986	612	152.823	459.177	75.03
1987	809.8	57.63	752.17	92.88
1988	728.5	47.6655	680.8345	93.46
1989	2173	69.684	2103.316	96.79
1990	1014.2	146.838	867.362	85.52
1991	1044.6	97.971	946.629	90.62
1992	3552.4	802.6322	2749.7678	77.41
1993	2198.9	96.48	2102.42	95.61
1994	1756.2	143.268	1612.932	91.84
1995	2122.8	85.791	2037.009	95.96
1996	2224.3	107.673	2116.627	95.16
1997	1968.6	109.983	1858.617	94.41
1998	1514	141.168	1372.832	90.68
1999	1233	104.271	1128.729	91.54
2000	2696	104.8275	2591.1725	96.11
2001	3037	138.018	2898.982	95.46
2002	1851	110.193	1740.807	94.05
2003	1582	142.323	1439.677	91.00
2004	1805	102.8115	1702.1885	94.30
2005	1482	130.143	1351.857	91.22
2006	1806	145.578	1214.6	67.25
2007	1096	150.303	736	67.15
2008	1566.7	73.5585	1054.1	67.28

Annex 15: Scenario 2 Sediment Concentration in Reach

Year	Simulated Sed In (Tons)	Scenario Two Sed In (Tons)	Reduction
1979	2323700	192885.258	91.70
1980	1221520	310695.258	74.56
1981	1462950	440370.258	69.90
1982	781130	401835.258	48.56
1983	954380	392385.258	58.89
1984	497158	148995.258	70.03
1985	1404870	519750.258	63.00
1986	480240	147315.258	69.32
1987	449070	150990.258	66.38
1988	549530	168840.258	69.28
1989	969595	379995.258	60.81
1990	578580	184590.258	68.10
1991	425060	131040.258	69.17
1992	708180	604564.146	14.63
1993	579866	155925.258	73.11
1994	1220880	394905.258	67.65
1995	468320	156660.258	66.55
1996	780674	220185.258	71.80
1997	987250	379785.258	61.53
1998	684130	238560.258	65.13
1999	609685	215250.258	64.69
2000	1068500	315210.258	70.50
2001	1183270	383775.258	67.57
2002	941720	302295.258	67.90
2003	970980	337470.258	65.24
2004	794410	971199.786	-22.25
2005	808400	274470.258	66.05
2006	1488850	642705.258	56.83
2007	515360	158550.258	69.24
2008	543630	189315.258	65.18

Annex 16: Scenario 2 Sediment Out of Reach

Year	Simulated Sed Out (Tons)	Scenario Two Sed Out (Tons)	Reduction
1979	1492700	192675.258	87.09
1980	1118520	228270.258	79.59
1981	1818650	515655.258	71.65
1982	987330	382725.258	61.24
1983	914080	350280.258	61.68
1984	450008	195405.258	56.58
1985	1320470	483000.258	63.42
1986	507040	201810.258	60.20
1987	449570	152460.258	66.09
1988	555230	171045.258	69.19
1989	449125	103215.258	77.02
1990	803180	399735.258	50.23
1991	459850	362589.021	21.15
1992	559940	477676.896	14.69
1993	438406	126840.258	71.07
1994	1188880	387870.258	67.38
1995	526700	218085.258	58.59
1996	614744	169575.258	72.42
1997	780550	273525.258	64.96
1998	692450	294630.258	57.45
1999	459335	153615.258	66.56
2000	751140	212415.258	71.72
2001	981670	305025.258	68.93
2002	708220	217665.258	69.27
2003	1137280	454125.258	60.07
2004	588410	188790.258	67.92
2005	1033200	479115.258	53.63
2006	1112250	417690.258	62.45
2007	992260	557550.258	43.81
2008	508330	177975.258	64.99

Annex 17: Sediment Parameter

WATER RESOURCES AUTHORITY

Water Resources Authority
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Sediment load- Yala River at IF02			
Year	Concentration (mg/l)	Discharge (m^3/s)	Yield (Tons/day)
1980	4.872222222	4.217530556	1.775411663
1981	3.002777778	5.757152778	1.493635717
1982	5.072222222	6.336616667	2.776958888
1984	5.180555556	11.87175278	5.313796545
1985	2.936111111	6.107647222	1.549387947
1987	1.888888889	4.748791667	0.7750028
1988	5.897222222	9.687825	4.936140594

Sediment load formula:

S = 0.0864*TSS*Discharge

S= Sediment load Tones/day

TSS in mg/l

Discharge in m^3/sec

Fanuel Onyango

Snr. Water Quality and Laboratory Services Officer

Water Resources Authority

Kisumu Regional Water Quality Laboratory.

Annex 18: Excel Calibration Report

Observed Results

	1979	1980	1981	1982	1983	**Average**
January	329.0702	231.4727	157.9829	234.8816	376.2601	265.9335
February	665.553	194.096	140.3262	183.0644	286.468	293.9015
March	387.7087	205.1742	251.9419	159.2419	238.2263	248.4586
April	441.6144	351.5397	811.9684	255.7643	288.1312	429.8036
May	395.5347	627.7146	511.1254	514.4853	543.5649	518.485
June	573.2073	474.5083	387.2897	473.443	478.4485	477.3793
July	839.5183	710.0467	640.8034	458.7327	421.2578	614.0718
August	1391.286	751.4646	1105.433	837.2812	948.9116	1006.875
September	825.1462	644.5881	946.9429	629.6857	1052.441	819.7608
October	506.3475	399.4974	643.653	542.6032	1089.33	636.2863
November	388.3337	272.123	397.2045	774.4663	653.6635	497.1582
December	285.6279	208.0469	268.6118	845.4867	427.1008	406.9748

Simulated Results

	1979	1980	1981	1982	1983	**Average**
January	235.2527	28.84321	33.50529	106.0254	80.72	96.86983
February	614.3461	26.18548	40.10488	37.00607	82.26	159.9802
March	479.9067	28.83226	425.649	78.385	51.78	212.9108
April	531.3544	73.67024	354.2619	309.7799	87.73	271.3596
May	500.1832	300.5502	292.369	378.369	393.54	373.0032
June	656.9473	296.2464	284	291.8333	296.17	365.0395
July	946.7163	184.6071	386.9524	329.2143	379.32	445.3623
August	1396.139	326.8978	298.869	322.75	436.77	556.286
September	843.7477	223.6081	231.4762	223.2857	369.33	378.2902
October	572.5455	204.9073	126.881	212.0595	244.89	272.2572
November	460.0737	171.5675	84.675	261.9762	110.95	217.849
December	382.8259	150.2369	73.9819	105.3452	166.12	175.7011

R^2=	0.723783
NSE =	0.788775
BIAS=	0.432847