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Presented by

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TITLE: Determination of Sediment Yield and Assessment of The Impact of Catchment Management Practices. A Case Study of The Upper Nzoia catchment.

Defended on 05/09/2018 Before the Following Committee:

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Declaration

I, **Innocent Okumu Wanyonyi,** hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Certification

This submitted final version was done with the approval of the supervisor, and that all corrections were added as recommended by the examination committee.

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Abstract

Water as a natural resource is becoming under pressure because of the increasing population and other global drivers such as climate change and land-use change. Kenya is classified as a water scarce country because a large part of the country lies under semi-arid climatic conditions, with variable rainfall patterns. Therefore, it is important to manage this scarce resource for sustainability. Hydrological models are becoming important tools that are used by water resource managers to assess and predict hydrological processes that intern help in decision making. Soil erosion is universally recognized as a major problem to the water resources because it leads to increased sediments yield. Therefore, it is important model sediment yield at the catchment level for easy intervention. I this study soil and water assessment tool was selected to simulate flows and sediment yield. The main aim of the study was to determine if the SWAT model could be used to simulate and reasonably estimate sediment yield in the upper Nzoia catchment.

The model was set up using the following data; a 30 by 30m digital elevation model (DEM), a 1 km spatial resolution of land use dataset and 10 km spatial resolution of soil dataset. Daily precipitation data for 5 stations from 1999 to 2009 was available but the maximum and minimum temperature was only available for one station. Monthly flow data obtained from gauging station 1DA02 was used for calibration and validation, and model performance result showed an E_{NS} of 0.7 and R^2 of 0.73 for calibration while validation produced E_{NS} of 0.66 and R^2 of0.68. Both the calibration and validation results are within the acceptable range.

Simulation of sediment yield established four subbasins that yielded higher sediments. They were subbasin 8,1,17 and 21. All of them showed sediment yield above the maximum allowable soil loss. A 20 m filter strip was found to be the best management practice that was most effective for reduction of sediment yield with 69.97% reduction when applied to the entire catchment and 89% when applied to subbasins producing high sediment yields

Résumé

L'eau, en tant que ressource naturelle, subit des pressions en raison de l'augmentation de la population et d'autres facteurs mondiaux tels que le changement climatique et le changement d'affectation des terres. Le Kenya est classé comme un pays pauvre en eau car une grande partie du pays se trouve dans des conditions climatiques semi-arides, avec des régimes de précipitations variables. Par conséquent, il est important de gérer cette ressource rare pour la durabilité. Les modèles hydrologiques deviennent des outils importants qui sont utilisés par les gestionnaires des ressources en eau pour évaluer et prévoir les processus hydrologiques que les stagiaires aident à prendre des décisions. L'érosion des sols est universellement reconnue comme un problème majeur pour les ressources en eau, car elle entraîne une augmentation du rendement des sédiments. Par conséquent, il est important que le rendement des sédiments du modèle au niveau du bassin versant facilite l'intervention. Cet outil d'évaluation des sols et de l'eau a été choisi pour simuler les débits et le rendement des sédiments. L'objectif principal de l'étude était de déterminer si le modèle SWAT pouvait être utilisé pour simuler et estimer raisonnablement le rendement des sédiments dans le bassin versant supérieur du Nzoia.

Le modèle a été mis en place en utilisant les données suivantes ; un modèle d'élévation numérique de 30 m sur 30 m, une résolution spatiale de 1 km d'un ensemble de données sur l'utilisation des terres et une résolution spatiale de 10 km de l'ensemble de données pédologiques. Les données de précipitations quotidiennes pour cinq stations de 1999 à 2009 étaient disponibles, mais les températures maximale et minimale n'étaient disponibles que pour une station. Les données mensuelles de débit obtenues de la station de jaugeage 1DA02 ont été utilisées pour l'étalonnage et la validation, et les résultats de performance du modèle ont montré une ENS de 0,7 et R2 de 0,73 pour l'étalonnage tandis que la validation produisait ENS de 0,66 et R2 de0,68. Les résultats d'étalonnage et de validation sont tous deux dans la plage acceptable.

La simulation du rendement des sédiments a établi quatre sous-bassins qui ont produit des sédiments plus élevés. Ils étaient sous-bassins 8,1,17 et 21. Tous ont montré un rendement de sédiments supérieur à la perte de sol maximale permise. Une bande de filtration de 20 m s'est révélée être la meilleure méthode de gestion pour réduire le rendement des sédiments avec une réduction de 69,97% appliquée à l'ensemble du bassin versant et de 89% appliquée aux sous-bassins produisant des rendements sédimentaires élevés

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Table of Contents

Acronyms

APEX Agricultural Policy/Environmental Extender Model

BMP Best Management Practices

CN Curve Number

CSAs Critical source areas

DEM Digital Elevation Model

ESRI Environmental System Research Institute

FAO Food and Agriculture Organization

GLEAMS Ground Water Loading Effects on Agricultural Management Systems

GIS Geographic Information System

HRU Hydrologic Response Unit

HSPF Hydrological Simulation Program – FORTRAN

LH-OAT Latin Hypercube One Factor-At-a-Time

MUSLE Modified Universal Soil Loss Equation

SCS Soil Conservation Service

SWAT Soil and Water Assessment Tool

USDA-ARS US Department of Agriculture – Agriculture Research Service

USGS United States Geological Survey

USLE Universal Soil Loss Equation

WEPP Water Erosion Prediction Project

List of tables

List of figures

CHAPTER ONE

1 Introduction

1.1 Background

Water is one of the most vital items that supports all forms life on the earth surface, but the harsh reality is that water is neither evenly distributed in space nor in time on the earth surface. You find that some parts of the world are prone to drought thus making water in those areas very scarce while in other regions, they experience torrents which cause floods that leads to loss of property and life. Based on United Nations Environment Programme (UNEP), approximately 40% of world population could live in water scarce regions by the year 2025 (UNEP, 2005) which prompts maintaining the sustainability of water resources to avoid adverse conditions in the future. The world population has grown from 2.5 billion in 1950 to around 7.6 billion, this has led to the doubling of irrigated lands and the amount of water withdrawals has tripled. Therefore, managing sustainability of water resources in both quantity and quality, while maintaining a substantial improvement in global food and energy security is a challenging task (Jordan et al., 2012). Due to these issues underpinning this precious resource, great care should be taken to ensure that this resource is managed well.

The increasing population has led to the human race to device mechanism of survival which in the long run has led to disturbing of natural conditions. One of the effects accompanying the increase in population is land use and land cover change, this phenomenon is local and place specific occurring on an incremental basis that can elude our attention. Without knowing that collectively they add up to one of the most important facets of global environmental change. These changes usually affect mankind both directly and indirectly. The quality of water in our rivers, lakes dams and other sources is deteriorating every day due to non-point sources of pollutants which are influenced by human activities. One of the pollutants which is becoming a menace is sediments which is as a result of erosion in the catchment.

The issue of sedimentation has become one of the major environmental problems as a result of soil erosion. This is because of its ramifications on water quality, reduction of operational capacity of reservoirs and reducing agricultural yield of land as a result of removal of fertile top soils. Sediment yield is defined as the amount of sediment per unit area removed from a watershed by flowing water during a specified period of time. Sediments are as a result of soil erosion which is one of the normal aspects of landscape development where top soil is detached and transported from their point of origin further downstream by erosion agents such as wind and water. These processes are accelerated by human activities that cause land use change. The severity of soil erosion is increased by the decrease in cover material in this case vegetation. The vegetation cover reduces the rate of soil erosion by decreasing the impact of raindrops that cause the detachment of the soil particles, slows down the flow of runoff thus giving more time for infiltration and also the roots of vegetations holds the soil firmly together preventing it from being washed away. Therefore, bare soil is more likely to be eroded compared to soils that is covered by vegetation.

Today soil erosion is universally recognized as a major problem in the world, especially when talking about the environment and agriculture. The top soil that is washed away is the most productive region in terms of agricultural yield because it contains a lot of nutrients making the land more fertile. Thus, erosion leads to loss of productivity and also reduces the value of land. The major problem caused by erosion that my study will focus on is sedimentation. The eroded soils eventually find its way into rivers, reservoirs, irrigation canals affecting water quality and also having an impact on the infrastructures. The effects of sedimentation are far march reaching if not controlled they result in great economic loss.

Hydrological modelling has been established to replicate most of the natural process that take place on the earth surface such as, erosion, sediment transport, runoff, surface and sub-surface flows, chemical and nutrient transport and many others. Hydrological models range from a simple unit hydrograph to more complex models like SWAT. Models are generally used in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (Getachew and Melesse, 2012). Most of these models can be integrated to make a large computer program that can simulated processes in large areas like a big watershed. Models have been used in studying and discovering the relationship between different environmental parameters.

Despite recognizing the problem of erosion and sedimentation by estimating the total soil loss and sediments at various watershed outlets, currently very few studies have been undertaken to determine the variability of sediment yield both spatially and temporally at the micro watershed level. Studies at this level is very important because many of solutions to environmental problems such as, non-point pollution and soil erosion requires changes in management on the landscape scale (Wilson et al. 2000). When sediments yield is measured at the watershed outlet, it only gives a broader view of information concerning what is happening in the watershed. But it does not help pinpoint the specific part of the watershed that is susceptible to erosion and which is contributing to sediments at the outlet. According to Meqaunint and Seleshi (2010), One of the possible solutions to the problem of land degradation due to soil erosion is therefore, to understand the processes causing erosion at the micro watershed level and to implement watershed management measures.

In recent years, researchers are concentrating mostly on the effect of land use change on hydrology but most of them are not giving consideration on sediment flux. This is because it is extremely difficult to measure sediment flux hence the unavailability of sediment flux data to be used for further research. Because of this situation, the use of hydrologic and sediment yield models is tremendously being employed and gaining a lot of recognition.

1.2 Problem statement.

High population growth in most of the catchment areas in Kenya has exerted pressure on the available natural resources which include land. This has led to change in the land use so us to accommodate the surging population. Clearing of land to pave way for Agriculture, urbanization and infrastructures such tarmac roads have modified how the catchment responds in terms of hydrology. One of the effects of this modification is increased soil erosion which translates to increased sediment generations in our rivers and water bodies. Sediment deposition in rivers leads to reduction in storage of both rivers and reservoirs along the rivers which leads to both social-economic and environmental problems such as reduced power generation of hydro power plants, bank flooding especially downstream, increasing the cost of operation & maintenance and shortening lifespan of water resources infrastructure such as irrigation systems and reservoirs. And also reducing the productivity of land in terms of Agriculture as a result land degradation due to erosion in the catchment.

Soil erosion in the area is not only caused by human activity such as deforestation, overgrazing and intensive agriculture, due to population pressure, but also, we have natural phenomena that induce erosion. River Nzoia and its tributaries originate from highlands such as Cherenganyi hills, Mt Elgon and Nandi escarpments which are characterized with heavy rainfalls and steep slopes.

Due to lack of proper institutional framework in Kenya, most data concerning erosion and sediments on most rivers is not available and also some of the rivers are ungauged so it is difficult to conduct measurements and assess the extent of the effect for decision making. In such scenarios models can be employed to estimate and assess the impact in order to facilitate decision making. My study will attempt to model sedimentation process on river Nzoia by integrating spatially integrated hydrological parameters, digital elevation model (DEM), land use and soil map with the ArcGIS interface Soil and Water Assessment Tool (ArcSWAT).

1.3 Objectives

The main objective of this is to estimate the sediment yield for planning management interventions in the upper river Nzoia catchment.

Specific objectives

- To Adopt SWAT model as a tool in sediment yield determination
- To determine e sediment yield using SWAT Model
- To identify vulnerable areas through scenario analysis and suggest the suitable Best Management Practice for reduction of sediment yield

1.4 Relevance of the study

Soil erosion and sedimentation is a global issue because of its severe adverse environmental, social and economic impacts, research shows that soil erosion within the tropical environment is the most serious and least reversible form of land degradation. This study will aim at predicting runoff and sediment yield in the catchment thus helping support decision makers in developing watershed management plans for better soil and water conservation measures. Also, by analyzing the various best management practices, it will help identify which BMP is significant in managing soil erosion

This study is important as it will also aim at adding knowledge to the existing initiatives by understanding spatial variation of sediment generation which affects water quality and also have some bearing on the flooding incidences in the lower parts of the river. The study will also generate a lot of data which can be useful in addressing issues pertaining to environmental development and sustainability of the resources within the catchment.

CHAPTER TWO

2 Literature review

2.1 General literature.

Sediment is ranked as the number one pollutant of surface waters in most parts of the world. The same applies to the case of Kenya. Excessive sediment in surface water causes problems to aquatic life, drinking water treatment plants, industries, Agriculture, and other users of the resource (Vellidis et al., 2003). Suspended Solid (SS) concentrations in many rivers have dramatically changed in recent years (Walling, 2006). Existing evidence suggests that natural sediment loadings have been substantially exceeded in many catchments in the UK, particularly since World War II (Evans, 2006).

Population increase is putting pressure on the resources within the catchment thus accelerating the effects. The problem of population growth causes an increasing demand for food meaning increasing crop land. As a consequence, forest, soil and water resources have been exploited wastefully. According to Githui (2009), there has been an increase of population over the last three decades with an estimated population density of about 221 persons/km2 in 2002 within the River Nzoia basin.

The Nzoia River provides the second largest tributary flowing to Lake Victoria after Kagera (Sutcliffe and Parks 1999). While the area of the Nzoia basin is only 6% of the Lake Victoria land basin, its flow contributes about 14% of the total catchment flow. Studies carried out by Sangale et al (2001) and Okungu and Opango (2001) show that River Nzoia contributes the most sediment loading to Lake Victoria from the Kenyan catchment mainly because of the high mean discharge of 118 m3/s. Sediment and nutrient laden runoff, from urban, agricultural lands and industrial point source pollution, have accelerated eutrophication of Lake Victoria, leading to decreased productivity of the fisheries.

Even though the adverse influences of soil erosion on soil degradation have long been recognized as a key problem for human sustainability (Lal, 1998; Scherr, 1999; Tamene, 2005), estimation of soil erosion is often difficult due to the complex interplay of many factors such as climate, land cover, soil, topography, lithology and human activities. In addition to this, social, economic, political, and methodological components influence the rate of estimated soil erosion (Lal, 1998; Ananda and Herath, 2003).

Many soil erosions predicting models have been developed and used over years, for example USLE (Wischmeier and Smith, 1978), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), European Soil Erosion Model

(EUROSEM) (Morgan et al., 1998), and AnnAGNPS (Bingner and Theurer, 2001). Although USLE has remained the most practical method of estimating soil erosion (Dennis and Rorke, 1999; Kinnell, 2000), the model does not consider the sediment delivery ratio when estimating the sediment delivered to the downstream to the point of interest (Lim et al. 2005). I preferred to use the SWAT model to take advantage of its integration with GIS and locally available data.

2.2 Previous SWAT applications

Variations in sediment yield measured at a point on a river depends majorly on the land use type in the catchment, the soil type, the slope and also the weather aspects of the catchment area. Many models have been developed to simulate sediments transport and runoff discharge from the watershed as well as to predict the impact of watershed management practices on land use changes on sediment transport. Among the models we have CREAMS (Chemical, Runoff, and Erosion from Management Systems) which was developed by the USDA-Agricultural Research Service (ARS). The model simulates the long-term impact of land management on water leaving the edge of a field (Knisel, 1980). Many models have been developed from CREAMS and they are designed for their specific reasons but have limitations for modelling watersheds with hundreds or thousands of sub-watersheds (Spruill et al., 2000).

Several studies have been carried out to understand the dynamics of soil erosion and sediment yield in different regions of the world they include: Defersha and Melesse, 2012; Defersha and Melesse, 2011; Defersha et al., 2012; Defersha et al., 2011; Maalim and Melesse, 2013; Maalim et al., 2013; Setegn et al., 2010). Setegn et al. (2010) used SWAT2005 to examine the performance and feasibility of the model to test the influence of topography; land use, soil, and climate condition on sediment yield in Anjeni gauged watershed, Ethiopia using SUFI-2

Tyagi et al., (2014) carried out a study in two small watersheds located in lower Himalaya, India to assess the applicability of Soil and Water Assessment Tool (SWAT) model in estimating daily discharge and sediment delivery from mountainous forested watersheds and the assessment of the impact of forest cover types on stream discharge pattern and sediment load. Also, Setegn et al, (2008) used SWAT model to the Lake Tana Basin for modelling of the hydrological water balance and the objective of the study was to test for the applicability of the model in the basin. Ndomba et al., (2008) applied SWAT model in a data scarce catchment in Tanzania and the results were satisfactory, which proved that the model can be used in ungauged water shed for hydrological modelling and analysis. SWAT model was applied to study effect of land use change associated with dairy farming on the streamflow and sediment transport of the Sondu River catchment in Kenya by Jayakrishnan et al., (2005). He found out that the simulated discharge compared well with the observed discharge. Xu et al. (2009) also applied SWAT model to simulate the runoff and sediment yield in the Miyun river catchment. The model accurately predicted the daily and monthly runoff and sediment yield with the value of Nash-Sutcliffe efficiency of greater than 0.6. During this study.

2.3 Water resources

Water is life, that is a common phrase that is used to show the significant of water to human beings. It regulates different activities of human beings such as drinking, washing, cooking, growing food, and personal hygiene, and supports all types of aquatic and terrestrial ecosystems (Millennium Assessment, 2005). According to USGS (2012) Approximately 96.5% of all water on the earth is saline ocean water and of the remaining water, 2.5% is fresh water. This 2.5% portion that represents the fresh water is actually enough to meet the combined requirement of agriculture, industry, and households. However, the problem is that this fresh water resources are not evenly distributed around the world (UNEP, 2005) and the demand for fresh water is increasing in many parts of the world due to rapid growth of populations and a significant increase in water use for different purpose such as agriculture and industry (Morrison and Gleick, 2004). While this source of fresh water remains constant in quantity with no additional, therefore, fulfilling the fresh water needs for growing populations and concurrently maintaining fresh water for aquatic life becomes one of the most challenging issues for scientists, technologists, policy makers, and politicians during this 21st century (Postel, 2000). This scenario is leading to overexploitation of the fresh water ecosystem making it one of the most endangered ecosystems in the world. Dudgeon et al., (2006) confirms this by estimating that greater than 20% of the fresh water fish populations have become endangered due to the overuse of fresh water. The fresh water ecosystem is not only being threatened by overuse but also with factors such as water pollution, flow modification, destruction or degradation of habitat, and invasion by exotic species (Revenga et al., 2005). All these factors have one thing in common i.e. they are as a result of increased population. The availability of fresh water to meet the demand of the growing human population and maintain the fresh water ecosystem integrity is a growing concern (Alcamo et al., 2008).

2.4 Water quality

As discussed above one of the factors affecting the fresh water ecosystem is pollution, and this is directly related to increase in population thus mankind through their activities, generate a lot of pollutants with some finding their way into water resources. These pollutants make the water resource impaired. USEPA, (2009) defines an impaired water body as one that cannot be used for the designated purpose such as drinking, navigation, recreation, fishing, and wildlife because of not meeting the quality standard of the intended use. The impairment in the water is due to the accumulation of nutrients and sediment from the watershed. This accumulation could cause serious problems such as oxygen deficiency and instability in the ecosystem that results in water being unsuitable for agricultural, industrial, and human uses (Carpenter et al, 1998). A reference water quality standard is developed to control the water quality of the degraded waterbodies which varies from one waterbody to another depending upon the usage. To develop the standard, factors such as physical, biological, and chemical parameters are considered and not just a single parameter. A Water quality standard consists of three components: designated usage, criteria or threshold, and anti-degradation policy (USEPA, 2009).

2.4.1 Sources of water pollution

It is very important to control water pollution in order to improve and maintain good water quality of a source. But for one to control pollution, he or she must first identify the different sources of pollutants in a watershed. The pollution sources are classified into two major categories; point source and nonpoint source. Point sources are easy to control as they come from a single identifiable source, whereas nonpoint sources are difficult to control due to the associated complex diffuse processes (Chiwa et al., 2012)

2.4.1.1 Point source

Point source is the confined, single, exact point where pollution originates and discharges into waterbodies (USEPA, 2012), they are not controlled by natural processes but are controlled by anthropogenic activities. Examples may include municipal sewage treatment plants, a channel, a pipe, an industrial facility and many others. For these kinds of sources, you can pinpoint exactly where the pollutants are originating from and act on it. Therefore, point source pollution can be measured and controlled periodically at a single place (Carpenter et al., 1998).

2.4.1.2 Non-point source (NPS).

Non-point sources of pollution are spatially diverse load carried by surface and subsurface runoff to receiving waterbodies (Laia et al., 2011). These types of sources are more complex and harder to identify and control, due to complex uncertainties associated with the simulation process (Ding et al., 2010). NPS pollution results from agricultural activities, precipitation, atmospheric deposition, street runoff, infiltration, and drainage (Shi et al., 2012). Pollutants from these sources are primarily transported by runoff from one point to another. Wanga et al., (2012) stated that NPS pollution has drawn attention from both scientific communities as well as government agencies. Because it is the largest threat to the water resources. Agriculture is recognized as the major source of non-point source all over the world, the chemicals and fertilizers used are washed by runoff into rivers and finally into the mouth such as lakes, wetlands oceans etc. nutrients such as sulphates cause eutrophication. Excessive nutrients, especially nitrogen and phosphorus, promote algal blooms resulting in a decrease in dissolved oxygen content. This reduces fish and other aquatic organism populations (Das and Gazi, 2010).

2.5 Best management practices (BMPs)

Several mechanisms have been devised to help combat the effect of agricultural non-point source pollution, they include activities such as implementing best management practices (BMPs), management measures, accepted agricultural practices, management measures and others. But this study will majorly focus on how implementing best management practices can effectively have an impact on reducing non-point pollutants especially sediments.

BMPs are practices and procedures that minimize the amount of pollutants in runoff from agricultural activities while providing a viable economic option to the farmers (UNEP, 1998). BMPs are categorized primarily into structural and non-structural (Kaplowitz and Lupi, 2012) and their aim is to reduce non-point pollution through soil erosion control practices, reducing pollutant delivery to waterbodies through filter strip or different types of vegetative barrier and remediation through chemical and biochemical processes (Cunningham et al., 2003). Structural BMPs requires construction or permanent land use change to reduce erosion while non-structural ones do not require construction but modifications of agricultural practices (UNEP, 1998).

Arabi et al. (2008) developed and evaluated a method for representation of BMPs in SWAT. Some researchers have used SWAT to model the impact of BMPs on sediment yield (Vache et al., 2002; Santhi et al., 2005; Bracmort et al., 2006). Bracmort et al. (2006) modeled the impact of structural BMPs in different conditions on water quality in Black Creek Watershed in Indiana, United States using SWAT. They represent grassed waterways, grade stabilization structures, field borders, and parallel terraces in SWAT by modifying relevant parameters. Parajuli et al. (2008) used SWAT in a 950 km^2 Upper Wakarusa Watershed in northeast Kansas to evaluate the effectiveness of vegetative filter strip lengths applied at the edge of fields to reduce sediment yield and fecal bacteria concentration. Also, Yang et al. (2009) used SWAT to assess the efficiency of flow diversion terrace systems on maintaining surface water quality at watershed level in Black Brook Watershed in Canada. In Kenya Mwangi et al., 2015 applied SWAT model in Sasumua Watershed which is 107 km2 in area to evaluate the impact of vegetative filter strips, contour farming, terraces, grass waterways on sediment yield.

The effectiveness of BMPs to control NPS varies from one type to another, and from one site to another. The pollution reduction efficiency of a BMP is site specific (Giri et al., 2012a), as it varies due to topography, soil characteristics, geological formations, climate, crops, and cultural practices (Cunningham et al., 2003). Deciding on which best management practice to use in controlling certain pollutants and on a certain site is very difficult due to conflicting environmental, economic, and institutional interests (Arabi et al., 2007). And also, you may find that some pollutants can only be controlled by multiple BMPs thus before selecting, designing and implementing a best management practice, you must do a thorough evaluation of its potential impact. Not only selection of a BMP is important to its effectiveness, but also placement of BMPs also plays an important role in pollutant reduction efficiency, as pollutant contribution is disproportionate between areas in a watershed (Tripathi et al. 2003).

Implementing best management practices in an entire watershed is not feasible because of the cost implications. In addition, implementation of BMPs randomly throughout a watershed is time consuming, expensive, and resource intensive. Therefore, it is wise to come up with a mechanism of identifying the regions in the watershed that contribute most of the non-point pollutants to the water resource and implement BMPs on them. These areas are usually referred critical source areas (CSAs). CSAs can be identified either by water monitoring from the sub-watershed level or by simulation model or combinations of both (Sharply et al., 2003). But monitoring water quality is expensive, time consuming, and ineffective for larger area, thus simulation models are preferred. Best management practices adoptions in CSAs provide the minimum cost solution for reducing pollution in the watershed. Some powerful watershed computer models are used assess and provide reliable information regarding BMP effectiveness both at field and watershed levels. These models include watershed models such as Soil and Water Assessment Tool (SWAT), Hydrologic Simulation Program FORTRAN (HSPF), Annualized Agriculture Non-Point Source (AnnAGNPS), Agriculture Policy /Environmental eXtender (APEX), GIS Pollutant Load Application (PLOAD), and many more.

2.5.1Types of Best management practices

The Soil and Water Assessment Tool (SWAT) has been used to evaluate water quality benefits of agricultural conservation practices (Arnold and Fohrer 2005). This tool has an advantage over others because It offers the greatest number of management options for modeling agricultural watersheds (Kalin and Hantush 2003). Evaluating the effectiveness of BMPs at a watershed scale is an expensive exercise, and models are often used to identify the most effective BMPs for implementation to mitigate water quality problem. Many conservation practices have been studied for their effectiveness in abating nonpoint source pollution (NPS). The measures include vegetative filter strips, contour farming, parallel terraces, grassed waterways and many others. Best Management Practices (BMPs) are usually designed to address agricultural water pollutants and maintain water quality in a watershed. Bracmort et al. (2006) provide detailed description of the procedure used to represent field borders, filter strips, parallel terraces, and grassed waterways in SWAT at watershed scale.

2.5.1.1 Vegetative filter strips (VFS).

VFS are areas of vegetation designed to remove sediment and other pollutants from surface water runoff through filtration, deposition, infiltration, adsorption, absorption, decomposition, and/or volatilization (Wu et al., 2015). Sediments, nutrients, and pesticides in surface runoff are reduced as the runoff passes through the filter strip (Lovell and Sullivan 2006). Filter strips were originally used as an agricultural treatment practice but have more recently evolved into an urban practice (Wu et al., 2015). The effectiveness of the filter strip in reducing NPS pollution is based on its trapping efficiency, which depends mainly on its width (Yuan et al. 2009). It is not only its width that influence the efficiencies, but also factors such as slope, vegetation, inflow rate, and particle size contribute. Fox et al. (2010) found that trapping efficiency increase with an increase in vegetation cover and to decrease with an increase in inflow rate and slope. Through recent researches it has been established that the presence of a shallow water table in the soil profile reduces the efficiency of VFSs

2.5.1.2 Contour farming

Contour farming is a form of agriculture where farming activities ploughing, planting, cultivating, and harvesting are done along the slope rather than up and down the slope. Runoff is best controlled by following the slope contour, but straight rows can be aligned across the slope to reduce runoff. This practice is usually effective on moderate slopes of between 3-8%. It is a popular means of reducing soil losses in many parts of the world (Stevens et al. 2009). Thes method reduces soil loss and sedimentation by increasing infiltration, this improves the water quality in the catchment. Studies by Arabi et al. (2008) and Stevens et al. (2009) shows that contour farming has a positive impact in reducing sediments and other water pollutants from agricultural lands. And it has been impressed all over the world as a mean to reduce soil loss.

2.5.1.3 Terraces

Terracing is a form of structural BMPs installed on sloping land to prevent rainfall runoff on sloping land from accumulating and causing serious erosion. Terraces consist of ridges and channels constructed across-the-slope. They reduce soil erosion by reducing long slopes into shorter ones that allow runoff water to infiltrate into the ground thus reducing surface runoff and its capacity to cause erosion. The types of terraces that are used in Kenya include level terraces. broad based terraces, Bench terraces, Fanya juu terraces, Fanya chini terraces.

2.5.1.2 Grass waterways

Grassed Waterways are shaped or graded channels with suitable vegetation, designed to intermittently carry surface water runoff at non-erosive velocities to stable outlets (Fiener and Auerswald 2005). The grass in the channel slows down the runoff, traps the sediments and absorbs the nutrients from agricultural land. This mechanism reduces soil loss and encourages sediment deposition

2.6 Soil erosion

2.6.1 Soil erosion processes

Soil erosion is defined as the detachment, transportation and deposition of soil particles (including plant nutrients and organic matter) by water or wind. Erosion is a natural process but it is accelerated by human interference in the environment. Erosion and sedimentation takes place in 3 stages, the first stage is detachment, here is where soil is made loose and dislodged by agents of erosion, it is then followed by the process of transportation where the agents like wind or water shifts the loose soil from its original place and moved to another place, and the final stage is deposition, this is where the agents of transportation are not strong to carry further the accumulated soil particles thus they drop them on the way. Leo C.van Rijn (1993) classified erosion into two major categories i.e. geologic erosion and accelerated erosion.

Geological erosion is also referred to as natural erosion. It is where the process takes place under natural or undisturbed environmental conditions. It can be simplified as erosion without the interference of man's activities. Under natural geologic erosion rates, soil properties and soil profiles develop to approach an equilibrium condition (Dilnesaw; 2006). Usually under natural geologic erosion rates, soil properties and soil profiles develop to approach an equilibrium condition Dilnesaw (2006). This erosion has contributed to the formation and the distribution of soil on the surface of the, it is also responsible for some of the topographical features seen presently. The rate of geological erosion is generally small except for stream channel and shore erosion which is aggressive due to the action of water currents.

On the other hand, accelerated soil erosion is associated with changes in natural cover or soil conditions and is caused primarily by water and wind. It is soil loss in excess of geologic erosion. This type of erosion is intensified by human activities which leaves the soil exposed or loosened. These activities include farming, construction, deforestation and many others. construction is what causes high rate of erosion among the mentioned activities as it involves scooping and loosening of soils. Sheet and rill erosion are, by far, the most widespread types of accelerated water erosion. The rate of both geological and accelerated soil erosion is influenced by several factors Which include:

2.6.1.1 Energy of the eroding agent (erosivity).

This is the ability of rainfall, runoff or wind to cause erosion. For the case of rainfall as an agent of erosion, soil loss is partly related to rainfall through two ways, the detaching power of the raindrop striking the earth surface and the runoff which is as a result of rain contribution. We can have short duration high intensity rains where infiltration capacity is exceeded or long duration low intensity rains that saturate the soil and hence cause runoff. Rain intensity is a major factor determining erosion by overland flow and rills and gullies. The erosivity of a rainstorm is a function of its intensity and duration, and of size, diameter and velocity of the rain drops.

2.6.1.2 Soil erodibility.

In simple terms soil erodibility is the resistances of the soil to both detachment and transportation. This is majorly determined by soil properties although topographic position, slope steepness and the amount of disturbance, such as during tillage also plays a role in the resistance of the soil to erosion. These soil properties usually affect infiltration rate of soil, Infiltration rate depends upon permeability of soil, surface condition and presence of moisture in the soil. Erodibility of the soil varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content. Soils with large particles are not easily eroded because large soil particles are resistant to transport because of the greater force required to entrain them. Also, fine soils are not easily eroded because Fine soil particles are resistant to detachment because of their cohesiveness. According to most findings, the least resistant particles are silts and fine sands. This can be confirmed by Richter & Negendank (1977) who concluded that soils with a silt content above 40 per cent are highly erodible Evans (1980) stated that soils with a low clay content of 9 - 30 % are most susceptible to erosion

2.6.1.2 vegetation cover. It creates the obstacle for raindrops as well as surface runoff. A good vegetative cover completely reduces the effect of rainfall on soil erosion. The plants affect rate of erosion through two major ways. (a) by reducing flow velocity. They dissipate the energy of running water by imparting roughness to the flow, thereby reducing its velocity. Also, the leaves intercepts and reduces the impact of the rain drop in turn reduces the detachment rate. Reduction of velocity gives time for infiltration. (b) by enhancing soil and slope stability. Plant covers generally help to protect the land against mass movements partly through the cohesive effect of the tree roots. The roots hold the soil particles together preventing them being washed away easily. In addition, soil strength is increased by the adhesion of soil particles to the roots.

Other factors which affects erosion include climatic factors, these includes rainfall characteristics, wind velocity and atmospheric temperature that are experienced. And the topography of the area. They include characteristics such as land slope, slope length and shape of the slope. In general, the steeper the slope the increase in erosion.

2.6.1.3 Water erosion process

The erosion that am interested in is that induced by water. This can be by the natural event of rainfall and snowmelt or can be artificially induced through activities such irrigation which a human activity is. If you consider the erosion of rainfall, it occurs at different stages which results in different types of erosion. According to Rose (1988), soil erosion by water can be regarded as a result of four processes: (1) detachment by raindrop impact; (2) transport by raindrop impact (splash erosion); (3) detachment by the shearing forces of flowing water; and (4) transport in surface runoff (sheet or interill erosion, rill and gully erosion). At the onset of a rainfall event, there is detachment of individual soil particles as a result of the impact of rain drops. The rain drop force overcomes interconnecting forces holding the soil particles together. This incidence is commonly referred to as raindrop splash. And the erosion as a result of this is called splash erosion.

As the rain event continues, the process of infiltration takes place where water from the rainfall finds its way into the soil. The rate of infiltration is majorly controlled by two factors the intensity of the rainfall event and the infiltration capacity of the soil in the area where the event is taking place. When the pore spaces in the soils gets filled up that is the infiltration capacity of the soil is exceeded, the excess water starts ponding the soil surface. The ponding process will continue until the water at the surface reaches sufficient depth. At this point the water will start flowing towards the direction of the steepest slope. This hydrologic process is called runoff or overland flow. This water flows uniformly over the land surface in the process it also removes a uniform thin layer of top soil. This type of erosion which removes a uniform thin layer of soil is referred to as sheet erosion according to the study by William W. Doe III et.al (1999). In many cases this kind of erosion is usually overlooked as the damaged of it is not immediately perceptible.

The overland flow in the upland areas starts converging and some portions of the land becomes more concentrated thus becoming sufficiently erosive and become forming some small channels called rills. Rills are actually a metamorphosis of sheet flow. As the water flows through these rills additional soils are detached. The type of erosion occurring in the rills is called rill erosion. Loss in soil quality caused by sheet erosion or inter-rill erosion goes unnoticed and has sometimes been guised in other contexts as over-use of the soil, drought or desertification (Kiome and Stocking, 1995). Sheet and splash erosion occur in areas of shallow sheet or interill flow (few millimetres deep) whereas rill erosion is caused by concentrated rill flow. In the rills, fine sediments are transported as suspended load whereas coarser particles are dragged along as bedload (Okoth, 2003).

With time the erosive power of the water flowing in the rills continues, the both the small and the large rill on the surface converge to form large surface channels called gullies. The erosion itself is called gulley erosion. Gullies are classified as either ephemeral or classic. Ephemeral gullies occur on crop land and are temporarily filled in by field operations, only to recur after concentrated flow runoff. While Classic gullies may occur in agricultural fields but are so large they cannot be crossed by farming equipment. In summary the erosion caused by rainfall occurs in four stages i.e. splash, sheet, rill and gulley.

2.6.2 Estimating erosion using empirical equations

One of the popular empirical equation used to predict soil loss is the U.S. Department of Agriculture's (USDA) Universal Soil Loss Equation (USLE) recently it was updated to Revised Universal Soil Loss Equation (RUSLE) and Modified Universal Soil Loss Equation (MUSLE) (Williams 1975). These equations use climate, soil, topography, and land use to determine erosion occurring in a given area. The USLE and RUSLE predict soil erosion from hillslopes by using rainfall energy (Zhang et al. 2009). On the other hand, the MUSLE uses a runoff function to determine erosion. The MUSLE has an advantage over the USLE and RUSLE because of its ability to determine sediment yield from single storm events (Zhang et al. 2009). Some studies have found that RUSLE usually overestimates sediment erosion rates when applied to a watershed scale by neglecting to fully account for sediment traps such as rills, gullies, and other geomorphologic features (Romero-Diaz et al. 2007). Also, another drawback in using RUSLE is that t requires a high-resolution digital elevation model (DEM of less than 5M resolution) which is very difficult to find (Zhang et al. 2013).

2.7 Sediment transport processes

Whenever we have a high magnitude of precipitation in a catchment, it creates large amount of runoff and the infiltration is usually reduced. This process of overland flow has been shown to erode and carry sediment from hillsides to zones of accumulation (Horton 1945). Naturally, the processes of runoff generation and soil erosion may not occur similarly, since they rely on different soil properties and may be exposed to different land management practices (Kaur et al., 2004).

Sediment yield which is the net result of soil erosion, sediment transportation and deposition depends on several factors. However, the processes involved in sediment yield are not, in general, linearly dependent on the same controlling variables (Duru et al., 2017). For better understanding of the process of sediment transport and deposition, hydrological models are employed to assist in making reasonable prediction and forecasting. sediment yield modeling has been increasingly used to evaluate the impacts of variables controlling sediment dynamics at the basin scale (Chakrapani, 2005).

There are two methods that are usually applied in sediment yield estimation i.e. empirical based model and physical based model. Empirical models are based on defining important factors through field observations, measurements, experiments, and statistical methods relating erosion factors to soil loss

(Foster & Meyer, 1977). On the other hand, physically based models on the other hands, are based on knowledge of the fundamental erosion processes and incorporate the laws of conservation of mass and energy (Petter, 1992)

Sediment process in a watershed is highly random and depends on the characteristic of the basins and the river. As mentioned before sediments in rivers are as a result of the eroded soils being transported into rivers. The transport of sediments in a channel is controlled by two simultaneous processes i.e. deposition and degradation (Neitsch et al., 2005). The two processes affect sediment concentration in the waters of a river or stream. In any river, for deposition or erosion to occur it depends on the incoming sediment flux from the watershed draining through that point and the capacity of the river to transport the sediment load (Arabi et al., 2008). If sediment load in a channel segment is larger than its sediment transport capacity, sediment deposition will be the dominant process; otherwise, channel degradation occurs over the channel segment. (Williams, 1980). Within a given stream channel anthropogenic structures, such as dams, may disrupt the natural movement of the sediment by reducing entrainment and storing the sediment behind the dam (Wohl 2006).

The amount of sediment from a site in a watershed depends on erosional and deposition process. The mass of sediment carried is called sediment load while sediment yield is the amount of eroded soil delivered at a point in a watershed which is away from the point of origin. In a watershed, sediment yield includes erosion from slopes, channels and mass wasting (slumping, sliding, falling, etc.), minus the sediment that is deposited after it is eroded, but before it reaches the point of interest (Dilnesaw 2006).

2.8 Hydrological modeling

Snyder and Stall (1965) defined “model” as simply the symbolic form in which a physical principle is expressed. A hydrologic model can be defined as a mathematical model representing one or more of the hydrologic processes resulting from precipitation and culminating in watershed runoff. Basically, a model has three components, the first one is the input, in our case of hydrological modelling these are things like flow forming factors, secondly, we have outputs these may represent components like flow characteristics. The lastly processes, which transforms the input into outputs. Hydrological models have evolved over the time, its scope and application has broadened. The driving force on which all hydrological models depend on is the hydrological cycle. Hydrologic modeling is related to the spatial processes of the hydrologic cycle and is often used to estimate basin water resources as well as for impact assessment or more precisely water resources management. Most hydrological models have been developed to determine how a watershed reacts under various conditions which are nowadays inevitable such as climate change, land use change and increased climate variability.

When precipitation interacts with the land surface in a watershed water inform runoff is produced as the end product of that interaction. The quantity and quality of this water depends on the intensity of precipitation and the nature of the watershed i.e. in terms watershed management. A watershed which has experienced poor management will tend produce large quantiles with poor quality type of runoff. It is important to model hydrological parameters such as runoff, sediment yield and soil erosion in order to achieve sustainable development in the catchment.

Estimation of hydrological parameters such as runoff and sediment yield from remotely inaccessible areas using conventional methods is tedious and time consuming. Therefore, it is more desirable to use techniques that have been evolved over time that are capable of quantifying hydrological parameters from all parts of the catchment. The use of mathematical models for hydrological evaluation has become the current trend. The capability of these models to perform has been enhanced by being incorporated in both remote sensing and geographical information system platforms.

2.8.1 Classification of hydrological models

Hydrological models can be classified in several ways:

2.8.1.1 Lamped or spatially distributed. Lumped models are those that simulate a spatially averaged hydrologic system. These types of models represent the complete hydrological system as a homogeneous unit. They do not take into account spatial heterogeneity across the modeling domain. They do not give any information about the spatial distribution of input and output variables but they render the average situation of a system. On the other hand, spatially distributed models allow for spatially varying precipitation, temperature, and other climatic variables, and the spatial occurrence of watershed characteristics such as soils, slope, and land cover types (Chow *et al.*, 1988). The hydrologic properties and processes are represented in the models as varying across the catchment. In between the lumped and spatially distributed models we have a model time which is referred to as semi distributed or semi lumped. These models have both lumped and distributed representation of the hydrologic system. Semi-distributed models are a kind of developed lumped models which consider a catchment as a series of lumped models. Therefore, a semi-distributed model simulates the average behavior through small homogeneous units for the entire catchment (Milad et al., 2012). One example of semi distributed model is the SWAT model which I used in this study. One of the advantages of distributed and semi distributed models is that they give a better representation of the natural hydrologic processes than the lumped models but this comes at a price as they as data assembly and processing, and preparation of input files require a lot of effort and time thus it is a challenge to use them in areas with few data. These two types of models also have large number of model parameters that make calibration quite difficult. it is often not possible to find one unique parameter set and this leads to equifinality (Beven and Freer, 2001).

2.8.1.2 Event models or continuous model. This model simulates a single storm event. The duration of the storm can range from a few hours to a few days. Continuous simulates a longer period, predicting watershed response both during and between precipitation events. They are designed to simulate water quantity and quality characteristics in the catchment over an extended period of time, and provide output representing longer-term average conditions.

2.8.1.3 Empirical or physical based model. Empirical models do not take into account the internal structure and response of the catchment; rather they only match the input and output of the catchment system. They are only built upon observation of input and output, without seeking to represent explicitly the process of conversion. Empirical models contain no physical transformation function to relate input to output; such models usually build a relationship between input and output based on hydro-meteorological data (Sarkar & Kumar, 2012). An example of empirical model is the Snyder's unit hydrograph (UH) model. Physical based models involve complex systems of equations based on physical laws and theoretical concepts that govern hydrological processes. Simply they are reduced dimension representation of real world systems. In between the empirical and physical based models, we have the conceptual models. These models represent a logical consideration of simple conceptual elements that simulate processes occurring in the catchment. They are built upon a base of knowledge of the pertinent physical, chemical, and biological processes that act on the input to produce the output.

2.8.1.4 Deterministic and Stochastic models. Deterministic models are where all the input, parameters, and processes that takes place in the model are considered free of random variation and known with certainty. In this model a given input always produces the same output. Therefore, these models can be used for forecasting. On the other hand, stochastic models describe the random variation and incorporates the description in the predictions of output. stochastic modeling emphasizes on reproducing the statistical characteristics of hydroclimatic time-series. No attempt is made to model input-output relationships.

2.9 process-based models for estimating sediments

There exist several process-based models that have been applied in the prediction and estimation of sediment yield, soil erosion and runoff. Several factors influence the choice of which model to use for your project, these factors include the size of your project, data availability and the scope of the project. While in my project I will use SWAT, other models such as Water Erosion Prediction Project (WEPP) and its GIS integrated form GeoWEPP have been successful in a wide range of applications.

The Water Erosion Prediction Project (WEPP) is a process-based model that was developed to determine net soil loss both spatially and temporally (Nearing et al. 1989). This model can be used in multiple climatic and topographic conditions. The ability of the WEPP model to differentiate between the high and low magnitude precipitation events makes it more superior to RUSLE. WEPP can only be used to model a small area of not more than 5 ha effectively. The Environmental Systems Research Institute's (ESRI) developed an ArcGIS extension version of WEPP called GeoWEPP. The advantage of this version is that it can model areas that are greater than 5 ha. And this extension allows the WEPP model data inputs to be used in a GIS environment and allows ArcMap users to customize DEM inputs and land use scenarios (Renschler 2003). One of the limitations of GeoWEPP is that when it is in large areas than are greater than 500 mi^2 it tends to overestimate sediment yield (Maalim et al. 2013).

The Soil and Water Assessment Tool (SWAT) is a process-based, conceptual, continuous time, hydrologic model created to help managers better understand impacts on water supply originating from non-point source pollution (Arnold et al. 1998). The hydrologic cycle, climate, and land management are the major components of SWAT (Chaubey et al. 2010). The SWAT model usually divides large watershed into sub-watersheds, which the user can define the size. The sub watershed is further subdivided into smaller units called hydrological response units (HRUs). HRUs are characterized by similar land use, soil and slope. Parameters for each HRU can then be modified to develop a true description of processes occurring within the watershed (Chaubey et al. 2010).

2.10 SWAT model

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) was developed to predict the effects of different management practices on water quality, sediment yield and pollution loading in watersheds. This model has not disappointed as it has proven to be an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental conditions across the globe. The SWAT model is used by many users for simulating stream flow and sediment load due to its capability of handling GIS-based inputs and other user-friendly options. A detailed description of SWAT is given in Neitsch et al. (2005) and Arnold et al. (1998). The model was developed to be applied to ungauged watersheds (Arnold et al. 1998; Chaubey et al. 2010). SWAT is capable of accurately modeling both small (Gitau et al. 2008) and large areas (Green et al. 2006). Temporally, SWAT is capable of modeling a range of steps from daily to yearly (Renschler and Lee 2005; Heathman et al. 2009). The SWAT model is flexible as it can operate on a daily, monthly or annual time steps.

There are different types of SWAT models that can be downloaded freely from the internet. They are classified according to the platform on which they run. There is the QSWAT that works on the QGIS platform and the MWSWAT that works on the Map Window interface. Both map windows and QGIS are free sources so anyone can use MWSWAT and QSWAT. Then finally we have the Arc SWAT that runs on the ArcGIS platform. ArcGIS is however commercial and therefore limits the usage of the Arc SWAT. In this study the ArcGIS version of SWAT (ArcSWAT) will be used. The soil and water assessment tool is a potential tool for predicting sediment yield at the catchment scale. It is applicable for analysis of both spatial and temporal of sediment yield. Temporal and spatial variations in sediment yield is based on different physical variables.

The major components of this model include weather, hydrology, soil characteristics, plant growth, nutrients, pesticides, and land management practices (Gassman et al., 2007). Surface runoff is calculated either by the Soil Conservation Service (SCS) curve number or by the Green and Ampt infiltration method. Sediment yield for hydrologic response units is calculated by the Modified Universal Soil Loss Equation (MUSLE), and Manning's equation is used for flow calculation (Neitsch et al., 2005). The efficiency and performance of the SWAT model calibration and validation can be assessed according to Nash Sutcliffe coefficient (Nash and Sutcliffe, 1970). Modelling discharge and sediment yield using SWAT have been applied in many regions of the world and the studies shows satisfactory results of acceptable accuracies.

2.11 sensitivity analysis of the model

Despite the development of hydrological models, there has been always uncertainties in the model simulation output due to model selection, calibration procedures and model calibration data errors. This problem has acted as a limitation in the use of models. The most important steps in calibration of a model to be used in a certain area for simulation is parameter identification i.e. identifying sensitive parameters and estimation of optimal values for sensitive parameters. This step usually helps determine the predominant processes for the component of interest. SWAT model is one of the most complex hydrological models available because of its large number of parameters. These parameters are process based thus it is very important to keep them within a reasonable uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed (Abbaspour, 2013). Sensitivity analysis provides insights on which parameters contribute most to the output variance due to input variability (Holvoet et al., 2005). It helps reduces the computational time required during calibration. Therefore, methods to reduce the number of parameters via sensitivity analysis are important for the efficient use of these models (Van Griensven et al., 2006).

Many modelers have stressed the importance of sensitivity analysis for a model. The ability of a watershed model to sufficiently predict constituent yields and stream flow for a specific application is evaluated through sensitivity analysis, model calibration, and model validation (White and Chaubey 2005). Also, Wang *et al*. (2005) pointed out that, after sensitivity analysis, it would be worthwhile to get more information about the most influential parameters and to calibrate those parameters to give the optimal fit to observations. Though sensitivity analysis has been recognized as an important process, there is no single, well accepted procedure (Beres and Hawkins 2001).

There are two methods used for sensitivity analysis; local sensitivity analysis also known also known as one-at-a-time and global sensitivity analysis. These two may yield different results during the sensitivity analysis process because sensitivity of one parameter depends on the value of other related parameters. Each process has its own advantages and disadvantage.

2.12 Local (one-at-a-time) sensitivity analysis

The one-at-a-time sensitivity analysis shows the sensitivity of a variable to changes in a parameter if the all other parameters are kept constant at reasonable values. In the local sensitivity method, analysis is carried out on one parameter at a time only while keeping the value of other parameters constant. Because the sensitivity of one parameter often depends on the value of other related parameters, for the local method, the correct values of other parameters that are fixed are never known (Abbaspour, 2013). This is one of the major disadvantages of using this method.

2.13 Global sensitivity analysis.

In this sensitivity analysis all the values of the parameters are changed simultaneously. It performs the sensitivity analysis of one parameter while the values of other related parameters are also changing. The major drawback of this method is that it needs large number simulations.

2.14 calibration

Calibration is the second step after sensitivity analysis. Model parameters to be used in SWAT for a watershed varies depending on the outcome of the sensitivity analysis, calibration, and validation of the SWAT model (Arnold et al. 2012). Several people have used different criteria in choosing model parameters, some choose to use all of the calibrated parameters to keep the integrity of the model (Heuvelmans et al. 2004), while others use some formulas to remove the subjectivity from choosing the parameters (Sellami et al. 2014). Some have used as many as 16 parameters (Gitau and Chaubey 2010).

The calibration process of the SWAT model can be classified broadly into 2 classes; manual calibration and automatic calibration. In manual calibration values for small number of input parameters selected are modified and then the model is run to observe whether the modification led to improvement in the fit between model predictions and observed data. it is possible for an experienced hydrologist to obtain very good and hydrologically sound parameters using manual calibration, but manual calibration is tedious, time-consuming, subjective, and cannot easily include consideration of the interaction among parameters (Madsen 2000).

In automatic calibration it involves computation of the prediction error using an equation (objective function) and an automatic optimization procedure (search algorithm) to search for parameter values that optimize the value of the objective function (Gupta *et al*., 1998)

Many ways have been used to calibrate the ArcSWAT model depending on different scenarios, they include; Bayesian Total Error Analysis (BATEA), Differential Evolution Adaptive Metropolis (DREAM), Generalized Likelihood Uncertainty Estimation (GLUE), Particle Swarm Optimization (PSO), Parameter solutions (ParaSol) and the Sequential Uncertainty Fitting (SUFI). Several studies have been carried out using these methods. Masau et al., 2014 successfully used HydroPSO R to calibrate parameter and analyze uncertainties of the SWAT model In the Nzoia river basin in Kenya, Faramarzi et al. (2009) used SWAT to build a hydrologic model of Iran and calibrated and validated it with the SUFI-2, Abbaspour et al. (2007) performed a multi-objective calibration, uncertainty analysis and validation of the Thur watershed in Switzerland for discharge, sediment, nitrate and phosphate using SUFI-2. In this study, The Sequential Uncertainty Fitting (SUFI-2) global sensitivity method within SWAT Calibration and Uncertainty Procedures (SWAT-CUP) will be used to identify the most sensitive sediment load parameters.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 description of the area of study.

Upper Nzoia River Basin is found in the Lake Victoria north catchment area, it lies between latitudes 1º 30’N and 0º 05’S and longitudes 34º and 35º 45’ E. The Nzoia River originates from Cherengany Hills at a mean elevation of 2300 m Above Sea Level and drains into Lake Victoria at an altitude of 1000 m just a few kilometers north of the Yala swap. The upper part of the basin which is my area of study is mainly covered with heavy forest while the lower reaches of the basin is covered with low trees and bushes. The lower region especially Budalangi in Busia county experiences perennial floods. These flood prone areas are generally flat and swampy. The average annual discharge is about 1740 x 10^6 m^3. The upper nzoia catchment from gauging station 1DA02 at Webuye has a catchment area of about 8354 km^2. The flow regime of the Nzoia is varied and during some period it can fall as low as $20m^3/s$, while during extreme floods it may surpass $1,100m^3/s$.

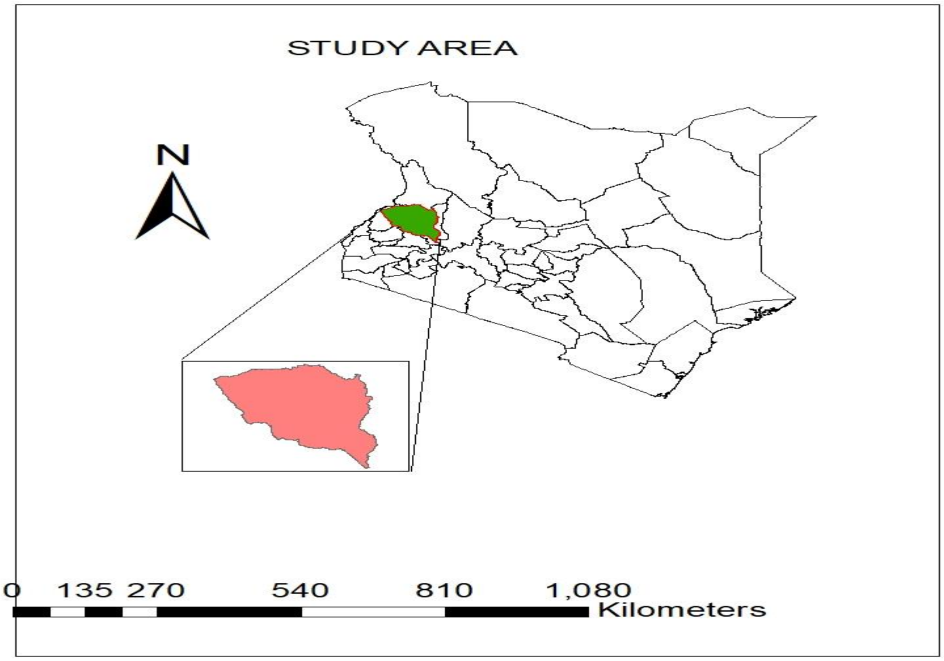


Figure 3.1 The upper Nzoia catchment

Data type	Data format	Data source
Digital elevation model	Raster file	USGS (Earth Explorer)
Soil data	Shape file	FAO website, 10km resolution
Stream Flow Data	Daily data in excel sheet	Water Resource Management AuthorityKakamega office
Sediment load data	Monthly data in excel sheet	Water Resource Management Au Kakamega Office
Land use data	Raster file	ESACCI-LC https://www.esa-landcover-cci.org/
Climate Data	Daily data in excel sheet	Kenya Meteorogical Depertment

Table 3.1 Data

3.1.1 climate

The Nzoia river basins mainly experience tropical humid type of climate. The catchment receives a mean annual rainfall that varies from a minimum of 1076 mm in the lowlands to a maximum of 2235 mm in the highlands. The average temperatures range from 16ºC in the highlands to 28º C in the lower semi-arid areas. The weather of the basin is also influenced by the effect of the inter-tropical convergence zone (ITCZ) that results into four seasons namely; the long rains season that occurs between March to May. This is also the planting period in the region, the short rain season which occurs between October and December. We also have two dry periods which occur in the month of January to February and in some parts from June to September. The local relief coupled with the influence of the Lake Victoria plays a role in modifying the local weather pattern. There are two rainfall peaks in the catchment; the first peak comes in the months of April to June, while the other occurs in July to September.

3.1.2 Land use and land cover

The most dominant land use in river Nzoia basin is Agriculture where farmers engage in growing both cash crops and food crops. The food crop grown include maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava while the cash crops grown consist of coffee, sugar cane, tea, wheat, rice, sunflower and some horticultural crops. Most agricultural practice in the area is rain fed. The basin comprises of four distinct zones: mountain zone that is forested but suffers severe land degradation; plateau zone which is majorly under farming, transition zone and lowland zone (Odira, *et al*., 2010).

3.2 Arc SWAT model description

SWAT is a physically based, continuous time and public domain hydrologic model, which was designed to simulate the impact of farming activities on surface water quality (Arnold et al., 1998). It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watershed with varying soils, land use and management conditions over long periods of time (Lijalem et al. 2007). In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics (Neitsch et al., 2005). SWAT incorporates the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, groundwater flow, crop growth, nutrient yielding, pesticide yielding and water routing, as well as the long-term effects of varying agricultural management practices (Neitsch *et al*., 2002, 2005). The SWAT model has the following characteristics that help the researcher to achieve the intended objective, the model is physically based (calibration is not possible on ungauged catchments); it uses readily available inputs; it is computationally efficient to operate on large basins in a reasonable time; and it is continuous in time and capable of simulating long periods for computing the effects of management changes (Neitsch et al., 2005, 2011).

According to Neitsch *et al*., 2002, SWAT uses Hydrologic Response Units (HRUs) to describe spatial heterogeneity in terms of land cover, soil type and slope within a catchment. The model operates in two phases, the land phase which controls the amount of sediment, nutrient and pesticides loading to the main channel in each sub-basin and the routing phase which defines the movement of water nutrients and sediments through the channel.

3.2.1 The land phase of the hydrological cycle.

The land phase of the hydrologic processes is simulated by the model based on the water balance equation in (Setegn et al. 2009), it is defined as:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right)$$

Where: *SWt* -is the final soil water content (mm H2O), *SW*0 -is the initial soil water content on day *i* (mm H2O), *t* -is the time (days), *Rday* -is the amount of precipitation on day *i* (mm H2O), *Qsurf* -is the amount of surface runoff on day *i* (mm H2O), *Ea* -is the amount of evapotranspiration on day *i* (mm H2O), *Wseep* is the amount of water entering the vadose zone from the soil profile on day *i* (mm H2O), and *Qgw* -is the amount of return flow on day *i* (mm H2O).

3.2.2 Surface Runoff/overland Flow

When precipitation falls on the earth surface, some of it may be intercepted and held in the vegetation canopy or fall to the soil surface. The part that reaches the earth surface takes different paths, part of it will infiltrate into the soil profile and the other will flow overland as surface runoff. The runoff moves from all parts within the watershed accumulating along the way and moving quickly to the stream channel.

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch et al., 2011). If at the start of the storm, the initial condition of the soil is dry, the rate of infiltration will be high. But as the soils become wetter, the rate of infiltration begins to reduce. In a case where the rainfall intensity is higher than the rate of infiltration, the depression on the earth surface will start to fill. Once all the depressions are filled, surface runoff will commence (Neitsch et al., 2011). There are two know method in SWAT for estimating surface runoff: The Green and Ampt infiltration method (Green and Ampt, 1911) and the SCS curve number procedure (SCS, 1972). The SCS curve number is a function of the soil's permeability, land use and antecedent moisture conditions (SCS, 1972) whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity (Green and Ampt, 1911). For this study, the SCS curve number was adopted for the simulation of surface runoff in SWAT since it requires the readily available daily data that can be obtained.

The SCS curve number equation can be written as,

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} + 0.8S)}$$

Where Q_{surf} is the accumulated runoff or rainfall excess in mm, R_{day} is the rainfall depth for the day in mm, Ia is the initial abstractions which includes surface storage, interception and infiltration prior to runoff in mm, and S is the retention parameter in mm. The retention parameter varies spatially due to changes in soil water content and it has an inverse relationship with the surface runoff, that is, the higher the value of S the smaller the surface runoff produced. The retention parameter is given by the equation below:

$$S = 25.4\left(\frac{100}{CN} - 10\right)$$

CN in this equation stands for the curve number for the day.

In the SCS curve number method, three antecedent moisture conditions are defined: I – dry (wilting point), which is the lowest value the daily curve number can assume in dry conditions, II – average moisture and III – wet (field capacity). The CN depends on soil type, land use and management practice which distinguishes amount of infiltration and surface runoff in particular rain event (Bijay K & Krishna P, 2015). Higher CN value infers higher runoff and less infiltration (Zhan and Huang, 2004). The curve number 1 and 3 can be computed from equations below:

$$CN_1 = CN_2 - \frac{20*(100-CN_2)}{(100-CN_2+exp[2.533-0.0636*(100-CN_2)])},$$

$$CN_3 = CN_2 * exp[0.00673 * (100 - CN_2)]$$

Where CN_1 is the moisture condition 1 curve number, CN_2 is moisture condition 2 curve number, and CN_3 is the moisture condition 3 curve number.

3.2.3 Sediment modeling

Sediment fluxes in SWAT are modelled using the Modified Universal Soil Loss Equation (MUSLE). This helps to model the HRU-level soil erosion. It uses runoff energy to detach and transport sediment (Williams and Berndt, 1977). MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978) (Neitsch et al., 2011). The different between the USLE and MUSLE in predicting sediment is that the USLE predicts the average annual gross erosion as a function of rainfall energy. Whereas in MUSLE the rainfall energy is replaced with a runoff factor which improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events (Neitsch et al., 2011).

$$\mathrm{Sed} = 11.8(\mathrm{Q_{surf.}q_{peak.}area_{hru}})^{0.56}.\mathrm{K_{USLE}}.\mathrm{C_{USLE}}.\mathrm{P_{USLE}}.LS_{\mathrm{USLE}}.\mathrm{CFRG}$$

Where: Sed is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume(mm/ha), qpeak is the peak runoff rate (m3/s), areahru is the area of the HRU (ha), K_{USLE} is USLE soil erodibility factor (0.013 metric ton m2 h/ (m3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor CFRG is the coarse fragment factor

3.2.4.1 Sediment routing

In the routing phase, SWAT uses Manning's equation to calculate the rate and velocity of flow. According to Setegn et.al (2008), sediment transport in the channel network consists of two components operating simultaneously, which are deposition and degradation. In this study the main component we are concerned about is the routing of sediments. Previous versions of SWAT used stream power to estimate deposition/degradation in the channels (Arnold et al, 1995). In this version of SWAT, the equations have been simplified and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. The routing of sediments does not only take place in the channel networks but also on the land. On the landscape, SWAT keep tracks of the particle size distribution of eroded sediments and routes them through ponds, channels, and surface waterbodies (Neitsch et al., 2011).

The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity and is calculated by Equation below:

$$CONC_{sed.ch.mx} = C_{sp} \times v_{ch.pk}^{sp\ exp},$$

The peak channel velocity $v_{ch;pk}$ is obtained by the equation below:

$$v_{ch.pk} = \frac{q_{ch.pk}}{A_{ch}},$$

$q_{ch,pk}$ is the peak flow rate in $m^{3/s}$ and Ach is the cross-sectional area of flow in the channel in $m^{2.}$.the equation for getting peak flow rate $q_{ch,pk}$ is given below:

$$q_{ch.pk} = prf \times q_{ch}$$

where prf is the peak rate adjustment factor, and q_{ch} is the average rate of flow in $m^{3/s}$. The manning's equation is used for calculation of the average rate of flow.

As mentioned before the process of sediment transport is governed by two processes; deposition and degradation. In cases where deposition is the dominant process taking place, the net amount of sediment deposited is calculated from the equation below.

$$sed_{dep} = \left(conc_{sed,ch,i} - conc_{sed,ch,mx}\right) \times V_{ch}$$

where seddep is the amount of sediment deposited in the reach segment (metric tons), concsed,ch,i is the initial sediment concentration in the reach (kg∕l or ton∕m3), and Vch is the volume of water in the reach segment (m3). While in the case where degradation is the dominant process in the reach, the net amount of sediment is calculated by:

$$sed_{deg} = \left(conc_{sed,ch,mx} - conc_{sed,ch,i}\right) \times V_{ch} \times K_{ch} \times C_{ch}$$

sed_{deg} is the amount of sediment reentrained in the reach segment (metric tons), K_{ch} is the channel erodibility factor, and C_{ch} is the channel cover factor.

After calculation of the amount of deposition and degradation, the final amount of sediment in the reach is determined by the equation:

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg}$$

3.3 Components of SWAT model

SWAT as a model has various components which are fused in the model to help it achieve its intended use. The model includes the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, nutrient yielding, groundwater flow, crop growth, pesticide yielding, water routing and the long-term effects of varying agricultural management practices (Neitsch et al., 2011). At the sub-watershed level, the SWAT components are divided into eight major components, hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. I will only discuss in details the components that are important to my study.

3.3.1 Hydrology

The hydrology component of the SWAT model is mainly based on the water balance equation. This equation is related to the processes that take place in the hydrological cycle which include; surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snow melt, transmission losses, ponds and soil water. Not all these processes are important during modelling, for example, the groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream flow somewhere outside the watershed. Also, water that percolates deep into the aquifer is not considered because it is assumed to be lost from the system thus the only percolation that is considered is that one to shallow aquifer from vadose zone.

3.3.2 Weather

Swat model requires daily time step weather data of five variables to run, they are precipitation data, temperature data and this include both minimum and maximum temperature, solar radiation, wind speed, and relative humidity. These data can be entered directly in to the SWAT model as daily or sub-daily values. In some cases, not all the weather variables are available so the weather generator can be used to generate other variables from the available ones.

3.3.3 Sediment component.

This is where the study is focused on, the swat model has an inbuilt Modified Universal Soil Loss Equation (MUSLE) that is responsible for generating sediments from the watershed. The MUSLE estimates erosion and sediments for each HRU. Sediment yield is simulated by using the amount of runoff generated. The hydrological component estimates the runoff volume and peak runoff rate within the sub basin area and uses these variables to calculate the runoff erosive energy variable. Also, another important factor to consider is the crop management factor, this is recalculated every day that runoff occurs. Crop management factor is a function of above ground biomass, residue on the soil surface, and the minimum crop factor for the plant.

3.4 SWAT Data collection and preparation

3.4.1 Digital Elevation Model (DEM)

The DEM is one of the main inputs of the SWAT model, it forms the base for delineation of the watershed boundary, stream network and create sub-basins. It is used along with other data such as land use and soil to generate the hydrological response units (HRUs). The resolution of the Digital Elevation Model (DEM) is the most critical input parameter when developing a SWAT model (Gassman et al., 2007) because it affects the number of watersheds generated during delineation, stream networks and also the number of hydrological response units. The number of HRUs and sub basin generated affects the predicted sediment yield in a watershed (Bingner et al.,1997). Chaubey et al., (2005) pointed out that a decrease in DEM resolution resulted in decreased stream flow and watershed area. And since the runoff volume and total sediment load depends on the watershed area, therefore a decrease in the DEM resolution will result in large error in the predicted output.

For this study a 30m by 30m spatial resolution Shuttle Radar Topography Mission (STRM) digital elevation model was used. It was extracted from U.S. Geological Survey’s (USGS). My study area is covered by more than one frame therefore I merged them by using the mosaic tool found in the Arc tool box in the ArcGIS software. The DEM was then projected into Arc 1960 zone 37S using the raster projection in ArcMap toolbox before it was imported to ArcSWAT. By using the river gauging station at Webuye as a pourpoint I generated the watershed boundary of my area of interest.

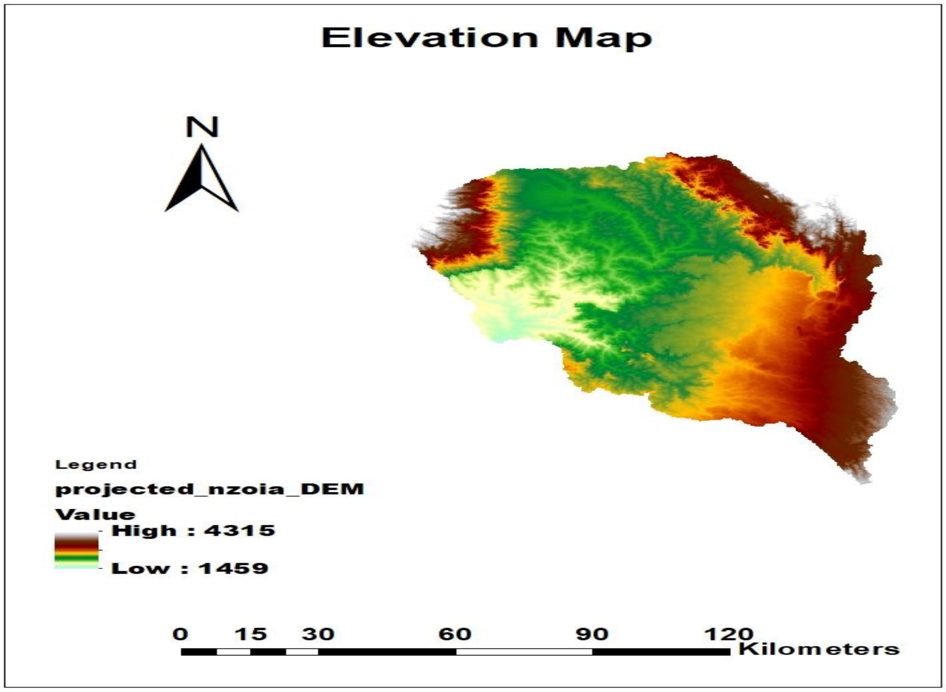


Figure 3.2 *DEM map of the upper Nzoia region*

3.4.2 Soil data

Soil data used in this study was obtained from Food and Agriculture Organization of the United Nations (FAO) (FAO, 1995) at a spatial resolution of 10 km. It came in the form of a shapefile format but the SWAT model requires it to be in raster form for easy compatibility thus it was converted to raster using the conversion tools in the Arc toolbox. The soil dataset was projected into Arc 1960 zone 37S for easy compatibility with other datasets to be used in SWAT such as the DEM and land cover. Just like the DEM the resolution of the soil dataset is bears a significant impact on the modelling of stream flow, sediment load and nutrient content. The data was accompanied by database files that contained soil parameters such as organic carbon, total nitrogen, soil reaction (pH), cation exchange capacity, CaCO3 content, electrical conductivity of, bulk density, sand, silt clay, (mass %) content of coarse fragments, available water capacity landform, lithology, drainage class, depth of layer and many others that can be processed using spreadsheets.

If a soil with a lower resolution is used in the generation of HRUs it makes a lot generalization, it may assign same soil type for larger area of the watershed that actually may have different soil types. And as it is known different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity and other properties, in the long run this will disturb the water balance, runoff generated and sediment yield from a given watershed. Therefore, if you want to achieve a high predictive accuracy it is advised to use high resolution soil dataset. The dominant soil that cover the upper Nzoia region is the ferralsol soils. It is in three categories humic ferralsols, rhodic ferralsol and haplic ferralsols. Of these three categories the haplic and humic ferralsos cover the larger area.

The FAO soils cannot be used directly in ArcSWAT because the database of SWAT is different with the food and agricultural organization soil dataset. I used the dataset of MSWAT which luckily uses the FAO soil as database. I replaced the user soil of SWAT database with that one from MSWAT database. The soil distribution of the study area is shown in figure 3.3

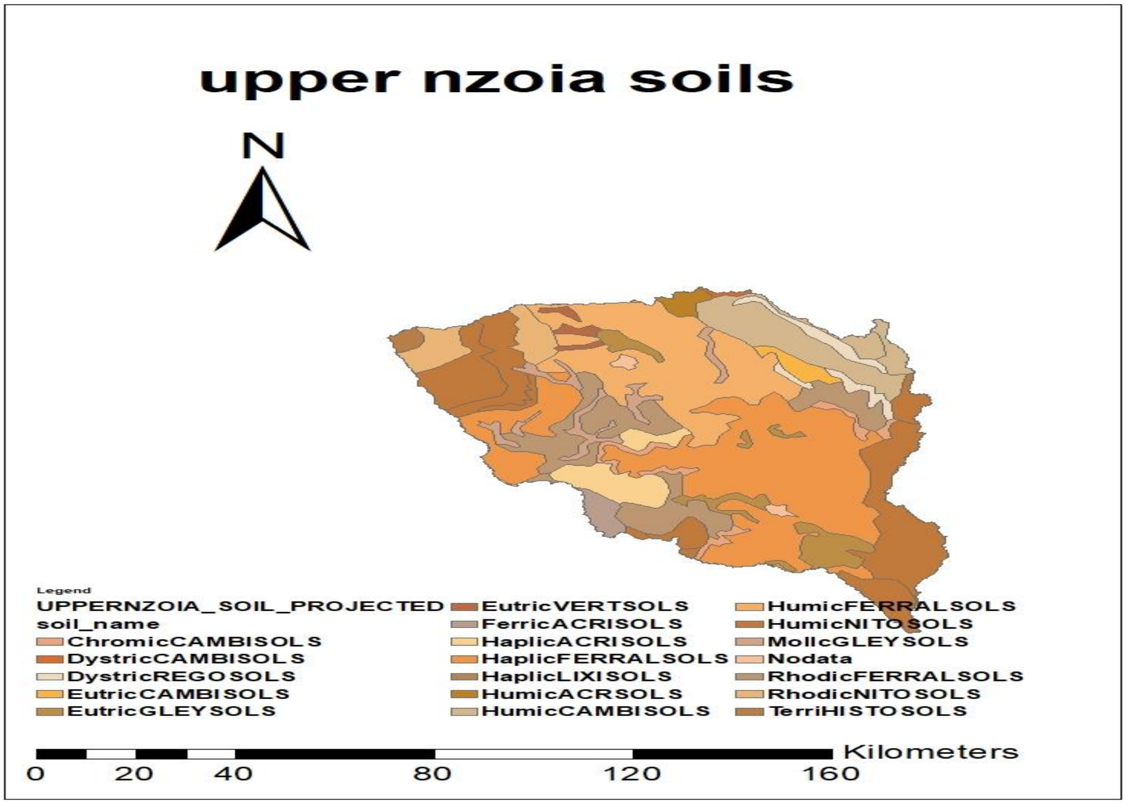


Figure 3.3 *upper Nzoia soil types*

3.4.3 Land use and land cover

The land cover used in this study was obtained from CCI land cover. It is a prototype high resolution land cover map over Africa. It was released in September 2017. The map was developed at a resolution of 20m, based on 1 year of Sentinel-2 A satellite observations from December 2015 to December 2016. Its legend was built upon reviewing various existing typologies such as Africover, LCCS, LCML, Globeland30 and others. The legend includes 10 generic classes that appropriately describe the land surface at 20m: Trees cover areas, shrubs cover areas, grassland, cropland, vegetation aquatic or regularly flooded, lichen and mosses / sparse vegetation, bare areas, built up areas, snow and/or ice and open water. the distribution of theses land uses is shown in figure 3.4 below. The land use data was clipped to a small area which was the entire Lake Victoria north water catchment and projected to Arc 1960 zone 37S using the Arc Toolbox tools.

In the upper Nzoia region the dominant land use is Agriculture which cover around 80% of the total area covered it is followed by forest which is about 13%.

Land use	**Area (ha)**	**Percentage (%)**
Forest (FRSD)	114328.4760	13.69
Range-Brush (RNGB)	8325.6016	1.00
Range-Grasses (RNGE)	45552.6979	5.45
Agricultural Land-Generic (AGRL)	662515.1824	79.31
Wetlands-Mixed (WETL)	156.4891	0.02
Barren (BARR)	285.3905	0.03
Residential (URBN)	3896.5315	0.47
Water (WATR)	329.7211	0.04

Table 3.2 distribution of landuse

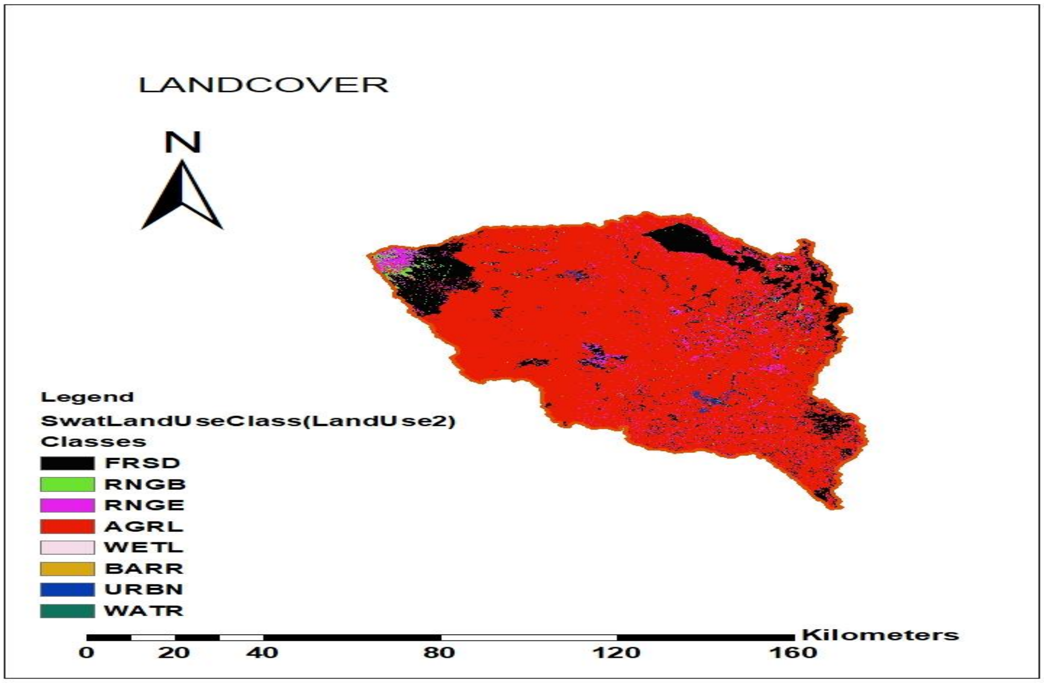


__Figure 3.4__ upper Nzioa land use classes

3.4.4 Hydrological data

The hydrological data required for this study were discharge (stream flow) and sediment data.

3.4.4.1 Streamflow

Observed stream flow data are required for SWAT calibration and validation process. I obtained the streamflow data for station 1DA02 which is Nzoia at Webuye from the Lake Victoria north water resource management authority. The discharge at the webuye gauging station were in daily timesteps from 1990-2013, however there is a substantial amount of data missing throughout the period.

3.4.4.2 Sediment data

The available data were the total suspended solids which were obtained through grab sampling process. The measurement was carried out once a month. The assumption was that the measured quantity represents the mean monthly total suspended solids. The TSS data for station 1DA02 was available from 2009-20012 and also a substantial amount of data was missing as sampling was not carried out for some of the month. The only year which had data for all the months was 2009. TSS is given in mg/l but can also be converted into tons/day using the formula below.

$$Q_R = 0.0864 * Q_S * C_S$$

Where Q_R is the sediment discharge in tons/day, Q_S is water discharge in m3/s and C_S is sediment concentration in mg/l.

station code	**lab ref no.**	**date sampled**	**T.S.S (mg/l)**	**flowrate (m3/s)**
1DA02	010/09	09/01/09	35	17.07
1DA02	047/09	08/02/09	30	14.6
1DA02	117/09	08/03/09	40	9.84
1DA02	238/09	10/04/09	120	11.37
1DA02	299/09	13/05/09	560	77.561
1DA02	374/09	07/06/09	130	17.657
1DA02	429/09	04/07/09	160	17.011
1DA02	489/09	05/08/09	180	15.800
1DA02	600/09	14/09/09	170	12.652
1DA02	681/09	06/10/09	190	14.733
1DA02	763/09	09/11/09	100	15.125
1DA02	879/09	14/12/09	320	12.342
1DA02	015/010	14/01/10	120	29.072
1DA02	075/010	09/02/10	60	10.413
1DA02	187/010	03/03/10	600	58.634
1DA02	297/010	24/04/10	130	17.736
1DA02	393/010	24/05/10	100	73.63
1DA02	454/010	15/06/10	140	56.713
1DA02	641/010	08/12/10	330	58.938
1DA02	823/10	20/11/10	70	53.15

Table 3.3 *TSS data for station 1DA02 for 2009 and 2010*

3.4.5 Climate data

The weather variables for driving the hydrological balance are precipitation, air temperature, solar radiation, wind speed and relative humidity. Daily rainfall from 1970- 2009 for five stations in the upper Nzoia catchment was obtained from the Kenya meteorological department, these stations were: Eldoret, Kitale, Turbo, Chorlim and Chebororwa. Major stations like Kitale and Eldoret had few gaps but the remaining stations had substantial missing data. maximum and minimum temperature were only available for two stations; Kitale and Eldoret. The data gaps in the data were filled with the weather generator found in the SWAT model. The Arc SWAT weather generator model WXGEN input file contains statistical data needed to generate representative daily climate data for the sub-basins. The generator generates data in two cases; when there is missing data in the loaded data files or when the user specifies that simulated weather will be used. The weather data were prepared into the correct format for Arc SWAT use i.e. Text (Tab delimited) of the daily data. Also obtaining and analyzing the required monthly statistical weather parameters for Eldoret weather station to be used by the weather generator was done. SWAT usually requires spatially distributed precipitation stations, thus only stations which are inside the study area are beneficial. Below is the table of the location of the weather station.

Station index	**Longitude**	**Latitude**	**Name**
8835013	34.800	1.033	Chorlim
8834098	34.983	1.000	Kitale
8935158	35.367	0.933	Chebororwa
8935170	35.083	0.633	Turbo
8935181	35.283	0.533	Eldoret

Table 3.4 *location of weather stations*

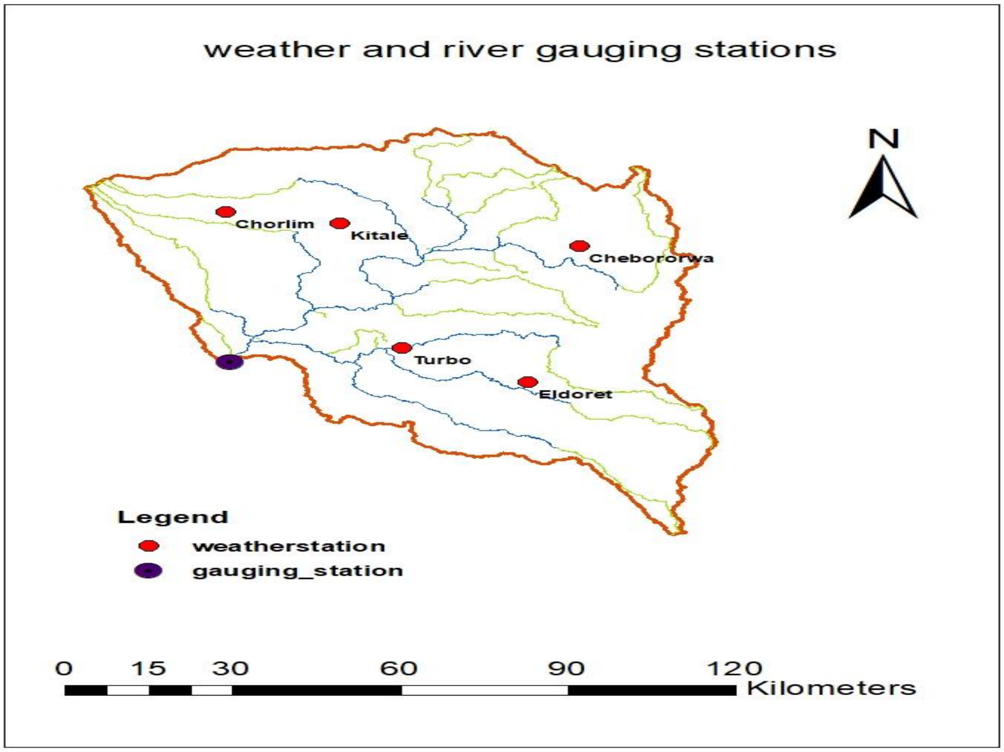


Figure 3.5 location of weather stations and river gauging station

3.5 Arc SWAT model set up.

3.5.1 Watershed delineation

All data input in Arc swat are designed to have spetial characteristics. After setting up a new SWAT project, watershed delineation from a digital elevation model is the first step in creating SWAT model input. The DEM was clipped using the Lake Victoria north watershed boundary in which the area of study is found, it is slightly larger than the study area. The DEM was then projected into Arc 1960 zone 37S which is usually used in the region of the area of study. This process was carried out through five major steps: (a)DEM setup, where the units for Z value was specified, (b) stream definition, for generating streams from DEM, (c) outlet and inlet definition, all sub-basin outlets defined by SWAT and only one was added manually. (d) watershed outlets selection, this is a point where the water exits from the watershed, it helps generate the watershed boundary. And (e) definition and calculation of sub-basin parameters. Selecting the boundary of the main outlet is quite important in terms of defining the border of the watershed. For my sake I selected the river gauging station as my outlet to utilize the measured data at the station. I added the station as a layer to help in the delineation. During the watershed delineation 21 sub basins were created in the upper Nzoia region.

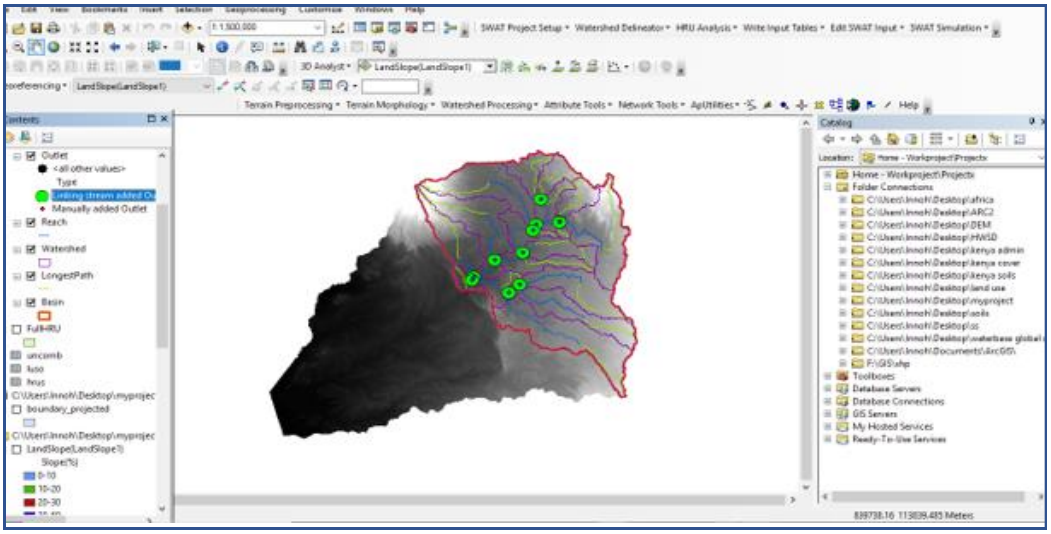


Figure 3.6 *Automatic watershed delineation in SWAT*

3.5.2 Hydrological response unit definition (HRUs)

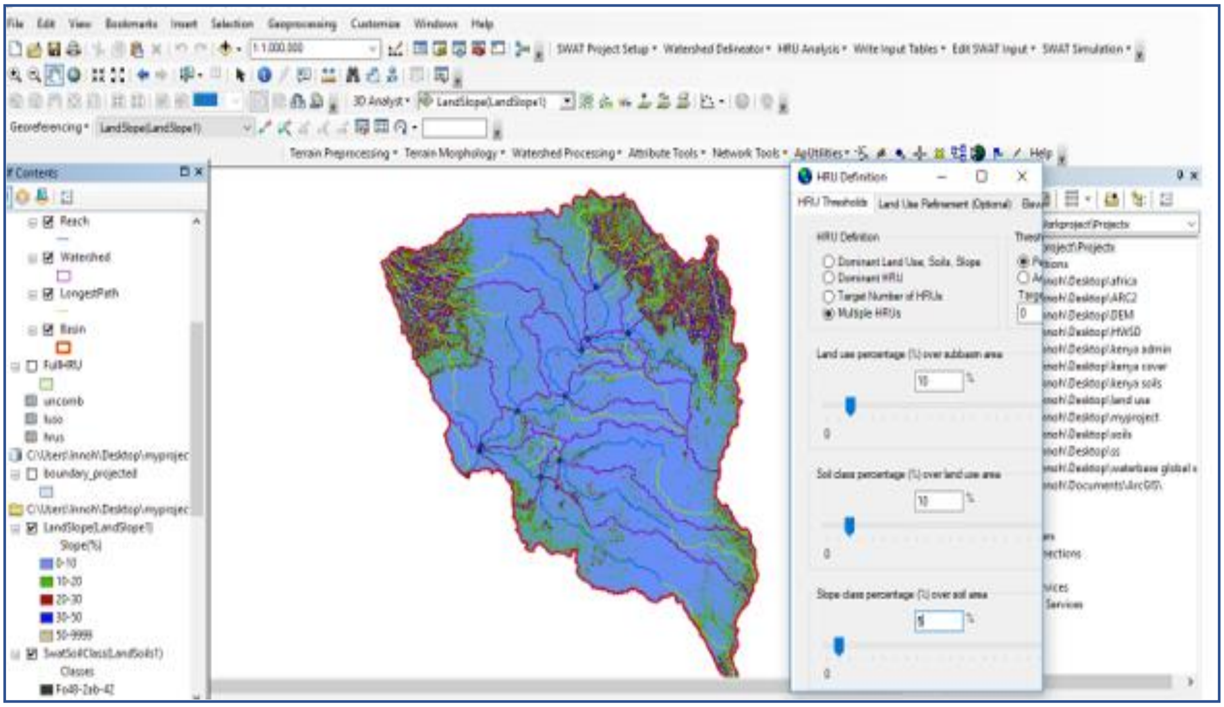
After watershed delineation, the next step is to identify unique areas in the watershed by considering three components: land use, soil type and slope delineation of the region. The HRU analysis tool in ArcSWAT helped to load land use, soil layers and slope map to the project. The first to be loaded was the land use, as the SWAT model was developed to be used in the United States of America, adjustments must be made in order to be used. For this reason, the different land use from the upper Nzoia were reclassified according to the available SWAT land cover classes in the SWAT database. I prepared a look up table to help fit the land use input table to SWAT (table 2.2). Dabrowski, (2013) recommended that SWAT model should be updated with the land use from a particular catchment if the study have to reflect the land use detail of the catchment. However most of the land use classes found in the SWAT database are common in Kenya thus for this study I decided to use the land cover types that were already available in the SWAT database for simplicity. After loading the land use layer, the model clipped the file to fit the study area.

For soil data, the global FAO soil was used and its soil dataset was incorporated into the SWAT database. The model reclassifies the soil data and clipped them to fit the existing delineated catchment as the case of land use. The information for each soil class that was required in user soil database include: **NLAYER** which is the number of layers found in the soil class, **HYDGRP** it represents the soil hydrologic group, it is usually based on the infiltration characteristics of the soil. There are four soils hydrologic groups,

SOL_AWC the available soil water capacity, SOL_ZMX represents the maximum rooting depth of the soil profile, **SOL_Z** is the depth from the surface to the bottom of the layer, **SOL_BD** refers the moist bulk density, **SOL_K** this is the saturated hydraulic conductivity of the soil layer, **SOL_CBN**, the Organic carbon content **SOL_ALB**, moist soil albedo. The clay, silt, sand and rock content denoted as **SOL_CLAY, SOL_SILT, SOL_SAND, SOL_ROCK** respectively. And **USLE_K** which refers to the USLE equation soil erodibility factor (K).

The final step before overlay operation is to define slope classes that will be used to establish hydrological response units (HRUs). The upper Nzoia watershed slope was divided into five classes of slope definition: 0-10, 10-20, 20-30, 30-50 and >50. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. After overlaying process, the program generated a report which detailed the distribution of land use, soils and slope classes within the watershed.

The SWAT model uses the dominant land uses and soil types to designate a single HRU for each sub-basin. The model gives the option of assigning either a single HRU or multiple HRUs in a single sub basin. If the option for a single HRU is chosen, the model will use the dominant land use category, soil type and slope class to designate the HRU. But for multiple HRUs, the user needs to identify a threshold percentage value of land cover and soil type for each HRU. I selected multiple HRU option for my study with the following thresholds: land use was set to 10%, soil class was set to 10%, and slope class to 5%. These values refer to the percentages of the land use, soil or slope class that covers the sub basin under which the area is considered negligible and is excluded from the analysis. After HRU definition report was obtained, it was found that the area was subdivided into 21 sub basins and the number of HRUs were 1263.



HRU Definition

○ Dominant Land Use, Soils, Slope
○ Dominant HRU
○ Target Number of HRUs
● Multiple HRUs

Land use percentage (%) over subbasin area: 10 %

Soil class percentage (%) over land use area: 10 %

Slope class percentage (%) over soil area: 5 %

__Figure 3.7__ Definition of the Hydrologic Response Units (HRU)

3.5.3 Weather data definition

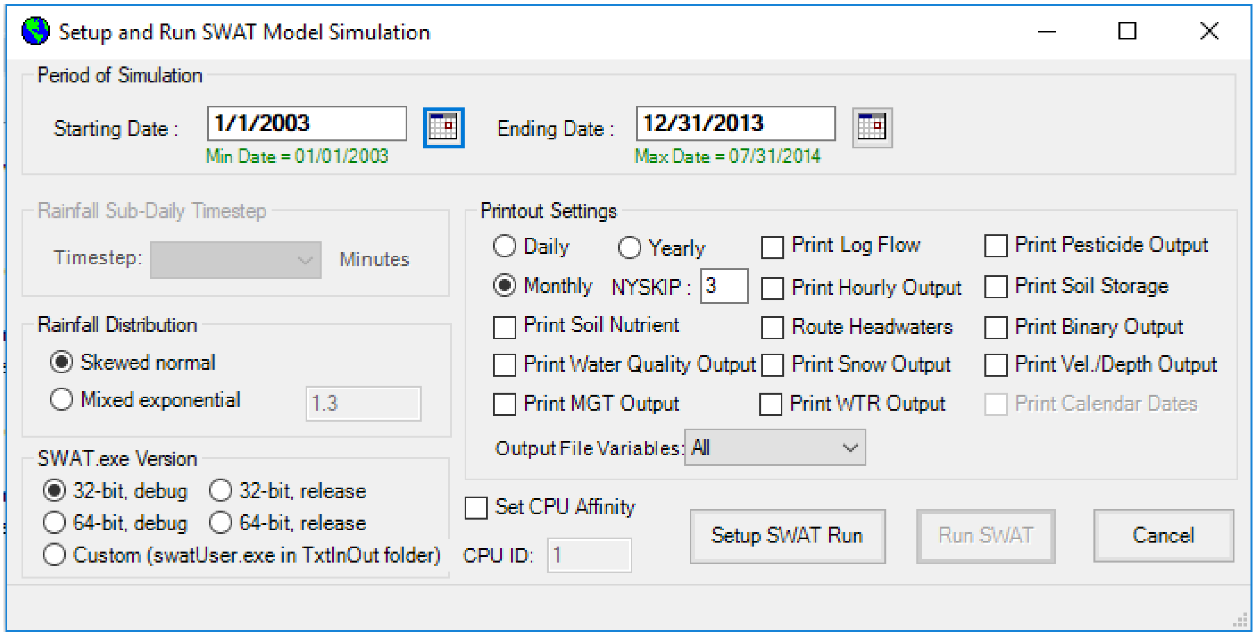
The model requires daily values for weather data including precipitation, temperature, wind speed, evaporation, solar radiation, and relative humidity. Among these the most important is daily rainfall. The SWAT model contains built-in weather dataset consists of simulated weather data input in the United States. Bias corrected rainfall data for the seven data points were provided in text (tab delimited) format which also contained a text file containing the location of the weather sites linked with the data files. The location table was linked to the SWAT weather database where the observed weather data was stored. The weather generator tab was not used to fill the data gaps in the data files. The WGEN user option was selected. The minimum and maximum data was also loaded in by using the locator table. Since I used the Hargreaves method, the other data like wind speed, relative humidity and solar were not required.

3.5.4 Writing input files

After all the types of data were loaded into the model, the “write all files” option in the software was selected to write all required input files. The default values in SWAT were engaged in order to build the initial watershed input files.

3.5.5 Running the SWAT model.

For this study the period of simulation was set starting from 1/1/2003 and ending 12/31/2013 with monthly time intervals. I used a period of 3 years as warm up and the rainfall distribution was set as skewed normal. The rest of the parameters were left as default and the "Setup SWAT Run" icon was activated then the simulation was run by clicking on the Run SWAT button.


Setup and Run SWAT Model Simulation

Period of Simulation
Starting Date : 1/1/2003
Min Date = 01/01/2003
Ending Date : 12/31/2013
Max Date = 07/31/2014

Rainfall Sub-Daily Timestep
Timestep: Minutes

Rainfall Distribution
● Skewed normal
○ Mixed exponential 1.3

SWAT.exe Version
● 32-bit, debug ○ 32-bit, release
○ 64-bit, debug ○ 64-bit, release
○ Custom (swatUser.exe in TxtInOut folder)

Printout Settings
○ Daily ○ Yearly ☐ Print Log Flow ☐ Print Pesticide Output
● Monthly NYSKIP : 3 ☐ Print Hourly Output ☐ Print Soil Storage
☐ Print Soil Nutrient ☐ Route Headwaters ☐ Print Binary Output
☐ Print Water Quality Output ☐ Print Snow Output ☐ Print Vel./Depth Output
☐ Print MGT Output ☐ Print WTR Output ☐ Print Calendar Dates
Output File Variables: All

☐ Set CPU Affinity
CPU ID: 1

Figure 3.8 The set-up menu for the process of running SWAT model in Arc map.

3.6 The concept of Calibration and validation

Arnold et al, (2012) defined calibration as an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainties of the model. In summary calibration is the testing of a model with known output and adjusting parameters which will result in a more accurate representation of the system being modelled, in this case a catchment. For a model to be useful for its intended purpose in a system it must be calibrated well. On the other hand, Arnold et al (2012) describe validation as the process of demonstrating that a given site-specific model is capable of making sufficient accurate simulation. But sufficient accurate results can vary based on the goal of the project. There are various criteria's that have been put in place to determine the accuracy of the model.

3.6.1 measuring the efficiency of the model

This the assessment of the dynamic and systematic behavior of the model by plotting simulated flow and observed flow on the same coordinate system and comparing them to see if the model overestimated or underestimated. In this study two methods will be used: the coefficient of determination (R^2) which is defined as the squared value of the coefficient of correlation. The R2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause *et al*., 2005). higher values that is values close to 1 indicate better agreement while values close to 0 indicates poor performance or agreement, it is given by the equation below;

$$r^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - \bar{q}_s)^2 \sum_{i=1}^{n}(q_{oi} - \bar{q}_o)^2}$$

And the Nash-Sutcliffe efficiency coefficient (E_{NS}). E_{NS} is used to assess the predictive power of hydrological models and indicates how well the plot of the observed versus simulated values ft. The value of E_{NS} varies from 1.0 to $-\infty$. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al., 2005). The E_{NS} value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data, the value of 1.0 shows a perfect fit. ENS has been reported in the scientific literature for model simulations of flow and water quality constituents such as sediment, nitrogen, and phosphorus yields (Moriasis *et al*., 2007). Moriasi et al (2007) also assessed the simulating quality of model under four levels; 0.75<NSI=1: very good, 0.65<NSI=0.75: good, NSI<0.50: dissatisfaction. It is given by;

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})^2}{\sum_{i=1}^{n}(q_{oi} - \bar{q}_o)^2}$$

where ENS = the Nash-Sutcliffe efficiency of the model and r^2 is the coefficient of determination, q_{oi} is the measured values of the quantity in each model time step, q_{si} is the simulated values of the quantity in each model time step, q_s with a bar is the average simulated value of the quantity in each model time step, q_o with a bar is the average measured value of the quantity in each model time step.

3.6.2 Sensitivity analysis, model calibration and validation

3.6.2.1 Sensitivity analysis

Sensitivity analysis, a technique to identify the responsiveness of parameters. Given that SWAT is a complex model with many parameters that makes manual calibration difficult, sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and observed data. SWAT as a model has many parameters that affect different hydrological aspects like discharge, sediments, nutrients etc. Sensitivity analysis helps to determine the relative ranking of which parameters most affect the output variance due to input variability (van Griensven et al., 2002). In this study sensitivity analysis was carried out to determine the influence a set of parameters have on predicting total flow and sediment. In this study, parameters used in sensitivity analysis were chosen based on the previous documentation.

The sensitivity analysis was carried out in SWAT CUP which uses a combination of global sensitivity analysis and One-At-a-Time sensitivity analysis methods. 16 flow parameters were selected for sensitivity analysis between a period of 2000-2005.

S/NO	parameters	description	Bound	
			Lower	Upper
1	CN2	Runoff curve number	-25	25
2	ALPHA_BF	Baseflow recession	0	1
3	SOL_AWC	Soil available water capacity	-25	25
4	Esco	Soil evaporation compensation factor	0	1
5	Epco	Plant uptake compensation factor	0	1
6	GW_Delay	Ground water delay (days)	-10	10
7	Gwqmn	Threshold water depth in the shallow aquifer for flow	0	5000
8	Gw_Revap	Ground water ‘revap’ coefficient	-0.036	0.036
9	Rchrg_Dp	Deep aquifer percolation fraction	0	1
10	Sol_K	Saturated hydraulic conductivity	-25	25
11	Biomix	Biological mixing efficiency	0	1
12	Ch_K2	Channel effective hydraulic conductivity	0	150
13	Ch_N	Manning’s n value for main channel	0	1
14	Revapmn	Threshold water depth in the shallow aquifer for ‘revap’ or percolation to deep aquifer to occur	0	1000
15	surlag	Surface runoff lag time	1	24
16	SOL_Z	Soil depth (for each layer)	0	3500

Table 3.5 parameters considered for sensitivity analysis

3.6.2.2 Model calibration

The hydrologic component flowrate of the model was calibrated using observed discharge data of Nzoia at Webuye 1DA02 gauging station. Calibration was done on monthly timesteps by using the mean monthly flows obtained from daily flows. The period of calibration was between 2002-2006. After running the model and obtaining the initial results, manual calibration using the manual calibration helper in the SWAT model was carried out on major parameters such as the runoff curve number (CN2), the baseflow recession (ALPHA_BF), the soil available water capacity (SOL_AWC), soil evaporation compensation factor (Esco), Threshold water depth in the shallow aquifer for flow (Gwqmn) and the Groundwater "revap" coefficient (Gw_Revap). These parameters were modified by replacement, by addition of an absolute change or by a multiplication of a relative change. The procedure followed for manual calibration of the SWAT model.

The manual calibration did not give acceptable results and also carrying out manual calibration is time consuming and frustrating, so another method of calibrating the model was needed in order to fine tune the parameters so that the model produces sufficiently predicted flows from station 1DA02, preferably automatic calibration. The earlier version of Arc SWAT contains both options for manual and automatic calibration, but the Arc SWAT 2012 provides only manual calibration. For calibration SWAT CUP 2012 from the SWAT website was downloaded.

SWAT CUP provides various procedures for calibration and validation which includes PSO, McMc, parasol, GLUE and SUFI2. This program links these procedures to SWAT thus enabling sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models (Abbaspour, 2014). For this project SUFI2 was used for the process.

3.6.2.4 Model validation

This the final step. Validation entails comparison of the model outputs with an independent data set without making further adjustments. Validation for this study was carried out for the period between 2007-2009. The same procedure that was applied during model calibration was used also for validation.

3.7 Simulation of best management practices in SWAT

Before implementation of BMPs first of all hot spot areas are supposed to be identified. The identification of these areas was done on the basis of average annual sediment yields simulated using SWAT were validated the observed values of TSS concentration from the gauging station. two best management practices were chosen to be used for comparison to assess their effect on sediment generation. The BMPs applied were; filter strips and terraces. The effect of the BMPs must be measured from a certain reference point which is referred to as baseline. The baseline values for the input parameters could be selected by a model calibration procedure be it manual or automatic calibration, or it can be a value suggested either from the literature, previous studies in the study area, or prior experience of the analyst. For this exercise our baseline values were selected from the model calibration exercise.

3.7.1 Simulating filter strips.

To simulate this BMP the filter strip width parameter (FILTERW) in SWAT was adjusted. The effectiveness of filter strips in sediment yield reduction in SWAT is based on the trapping efficiency, which is modeled as per equation below (Neitsch et al. 2005).

$$trap_{eff-sed} = 0.367 \times FILTERW^{0.2967}$$

where $trap_{eff\_sed}$ is the efficiency of trapping sediments and $FILTERW$ is the width of the filter strip (m). the filter strips were applied to agricultural land areas with a slope between 0-10%. This was the first scenario. filter strip of width 5,10 and 20. This was achieved by changing the parameter FILTERW in SWAT to reflect the width that was to be modelled.

3.7.2 simulating terraces.

These were simulated by adjusting PUSLE, and CN (Arabi et al. 2008). In SWAT. In order to reduce soil loss, the USLE practice factor was reduced in the MUSLE equation. Increasing soil infiltration was factored in by increasing the CN. The terraces were applied to Agricultural land with slope between 0-10% as scenario 2. Terraces were also implemented on agricultural land by manipulating the curve number (CN). This was reduced by 5 from the calibrated value (SCS Engineering Division 1986). The p factor was manipulated as follows; o.1 for slope between 1 to 2%, 0.12 for slopes 3-8% (Schwab et al.1995).

Contour farming

Contour farming. Here the CN was reduced by 2 from the calibrated value and the p factor was set at 0.5 for slopes between 1 to 2% and 0.6 for slopes between 3 to 8%.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Watershed delineation.

The watershed was delineated from a digital elevation model of resolution 30m by 30m. the stream channels were defined as DEM cells having at least a 25000-hectare contributing area. The watershed was delineated with the gauging station on the river being used as the outlet. This resulted in 21 subbasins that added up to an area of 8354 km^2. Area coverage by each subbasin is presented in Table 4.1. the HRU definition resulted into a total of 173 hydrological response units.

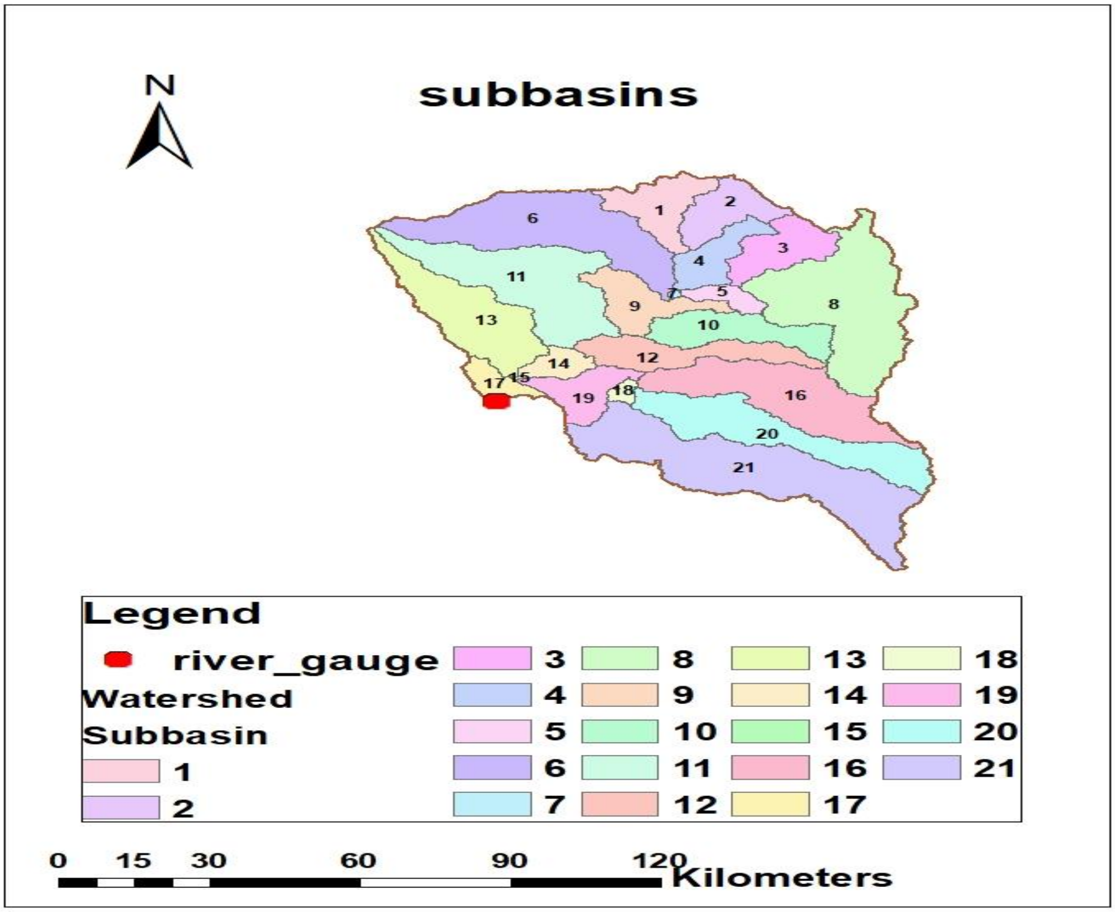


Figure 4.1 *map showing delineated sab basins in the upper Nzoia watershed.*

Subbasin	**Area (km^2)**	**subbasin**	**Area (km^2)**
1	289.9	12	343.0
2	258.4	13	575.8
3	279.1	14	110.5
4	216.3	15	2.1
5	89.2	16	710.0
6	859.4	17	106.2
7	6.1	18	33.5
8	1004.2	19	222.2
9	273.4	20	653.7
10	345.6	21	1179.1
11	796.3		

Table 4.1 Area covered by sub basins

4.2 SENSITIVITY ANALYSIS

Sensitivity analysis was carried out for both the discharge and sediment. The analysis was done separately because some parameters are sensitive to both flow and sediment, some are sensitive to flow only and others sensitive to sediment only (Abbaspour et al., 2007). Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. Some parameters do not have any influence on the model output while some may have little effect, hence sensitivity analysis does away with these kinds of parameters reducing the model run time.

4.2.1 Parameter sensitivity analysis for flow

Global sensitivity analysis for flow was done for the parameters shown in *Table 4.2.* According to the result from the analysis, the curve number (CN2) was found to be the most sensitive parameter followed by the soil available water capacity (SOL_AWC), SOL_K and Deep aquifer percolation fraction

(Rchrg_Dp) as shown in table 4.3. Other parameters that showed significant sensitivity were the Soil evaporation compensation factor ESCO and GW _Delay. Among all the parameters that were assessed Alpha_ bf was the least sensitive followed by Gw_Revap. The parameters with their t-stats and p-values are shown in the table 4.3 below.

S/NO	**Parameters**	**Description**	**Bound**	
			Lower	**Upper**
1	CN2	Runoff curve number	-25	25
2	ALPHA_BF	Baseflow recession	0	1
3	SOL_AWC	Soil available water capacity	0	1
4	Esco	Soil evaporation compensation factor	0	1
5	Epco	Plant uptake compensation factor	0	1
6	GW_Delay	Ground water delay (days)	30	500
7	Gwqmn	Threshold water depth in the shallow aquifer for flow	0	2000
8	Gw_Revap	Ground water ‘revap’ coefficient	-0.036	0.036
9	Rchrg_Dp	Deep aquifer percolation fraction	0	1
10	Sol_K	Saturated hydraulic conductivity	-25	25
11	Biomix	Biological mixing efficiency	0	1
12	Ch_K2	Channel effective hydraulic conductivity	0	150
13	Ch_N	Manning’s n value for main channel	0	1
14	Revapmn	Threshold water depth in the shallow aquifer for ‘revap’ or percolation to deep aquifer to occur	0	1000
15	Surlag	Surface runoff lag time	1	24
16	SOL_Z	Soil depth (for each layer)	0	3500

Table 4.2: parameters selected for sensitivity analysis

Parameter	**t-stat**	**P-value**	**Rank**
CN2	-27.7	0.00	1
SOL_AWC	5.76	0.00	2
SOL_K	-4.02	0.00	3
RCHRG_DP	-1.53	0.13	4
ESCO	-1.18	0.24	5
BIOMIX	1.07	0.29	6
CH_K2	-1.04	0.30	7
ALPHA_BF	-0.99	0.32	8
GWQMN	-0.79	0.43	9
SURLAG	-0.67	0.50	10
CH_N2	0.49	0.63	11
REVAPMN	0.39	0.70	12
GW _Delay	0.39	0.70	13
GW_REVAP	0.29	0.77	14

Table 4.3: summary of global sensitivity analysis for flow

Determining which parameter is sensitive was done depending on P-value and t-stat. The t-stat provides a measure of sensitivity and hence larger absolute values obtained indicates that the parameter is more sensitive. While P-value indicates the significance of the sensitivity and hence a value close to zero has more significance.

4.3 Model Calibration and validation results

4.3.1 Calibration for flows

The SWAT model calibration for flows was carried out using the mean monthly flows obtained from flows measured at gauging station 1DA02 (Nzoia at Webuye). This was also the outlet for the entire upper Nzoia catchment area. The calibration was carried out for the year 2000-2005 and the scatter plots given in Figure 4.3 for monthly time step show a very good agreement between modeled and observed stream flow values of the upper Nzoia catchment. The scatter plot figure illustrates a 73% correlation between observed and simulated discharge. Also simulated and observed stream flow values show a very close trend. A time-series plot of the observed and simulated monthly stream flows in Figure 4.4 shows that the magnitude and trend in the simulated monthly flows closely follow the measured data most of the time. Although there are some mismatches in the simulated flow, particularly during the dry seasons. The Nash Sutcliffe efficiency and coefficient of determination gave high values for calibration period indicating the predictive ability of the model for monthly mean values of river discharge. The simulated monthly flows represented observed values for the calibration period with values of 0.7 for the Nash-Sutcliffe Simulation efficiency (E_{NS}) and a value of 0.73 for the goodness-of-fit measures correlation coefficient (R^2). The average simulated values were lower than the mean observed value during calibration as indicated in table 4.4 below. If you assess the daily flows as indicated in figure 4.2, the simulated flows depict very high peaks and also shows a lot of mismatches. Thus, the model did not predict well when daily time steps were used.

Period (monthly time steps)	Average flow (m^3/sec		R^2	E_{NS}
	Gauge	simulated		
2000-2005	60.73	53.17	0.73	0.70

Table 4.4 flow calibration results

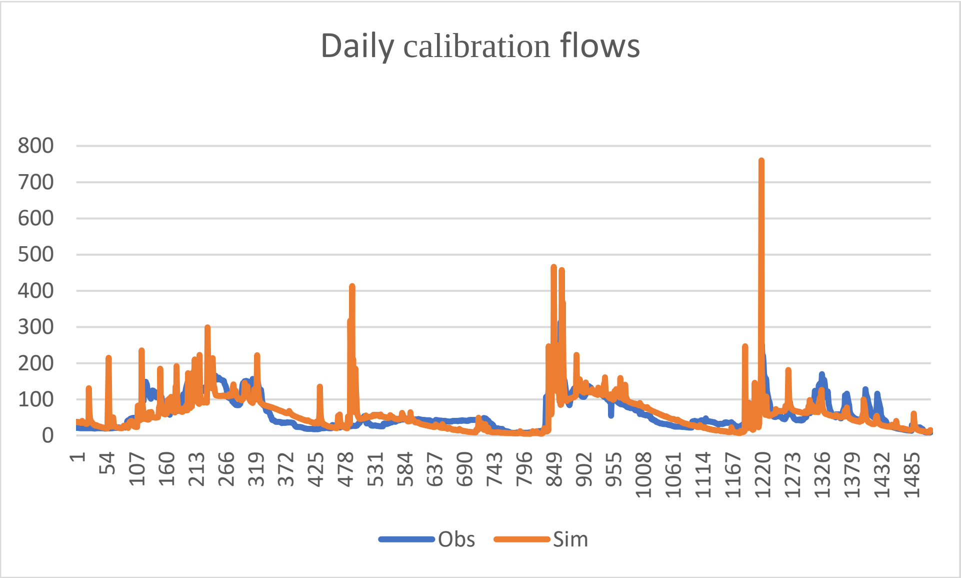


Figure 4.2 comparison of daily simulated and observed flow for the calibration period

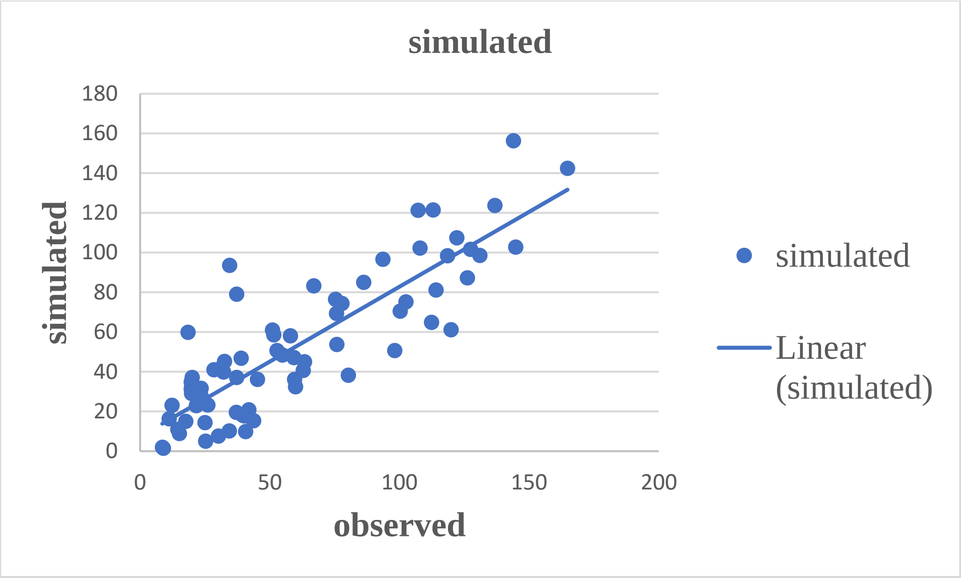


Figure 4.3 scatter plot of mean monthly flow for model calibration period 2000-2005

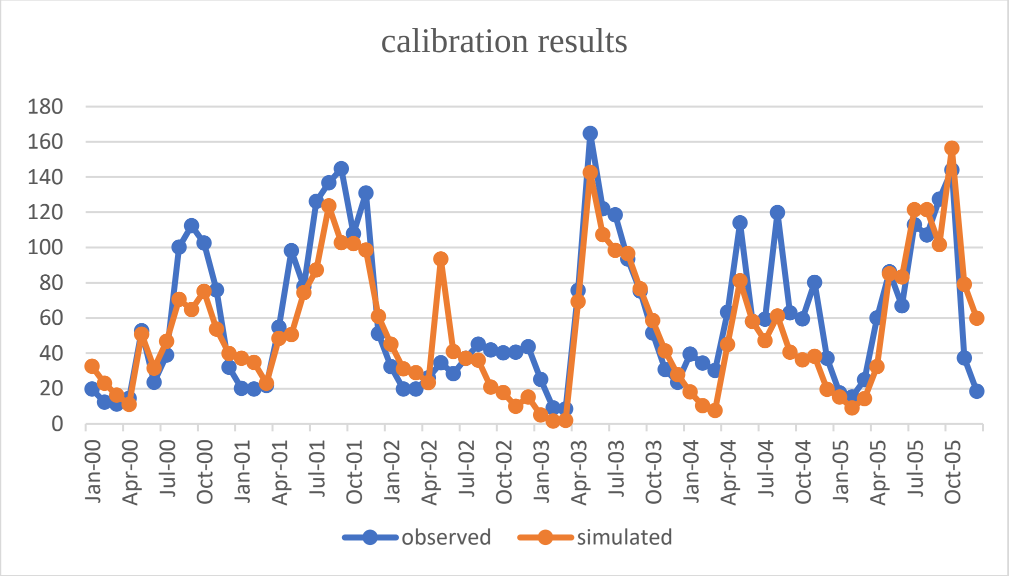


Figure 4.4. comparison of observed mean monthly flows and simulated (calibrated) flows for upper Nzoia catchment

After sensitivity analysis the sensitive parameters which were chosen for flow calibration were the CN2, Rchrg_Dp, ESCO, GW _Delay, Gwqmn, Gw_Revap, ALPHA_BF and others. The fitted values for these parameters after calibration are shown in table 4.5 below.

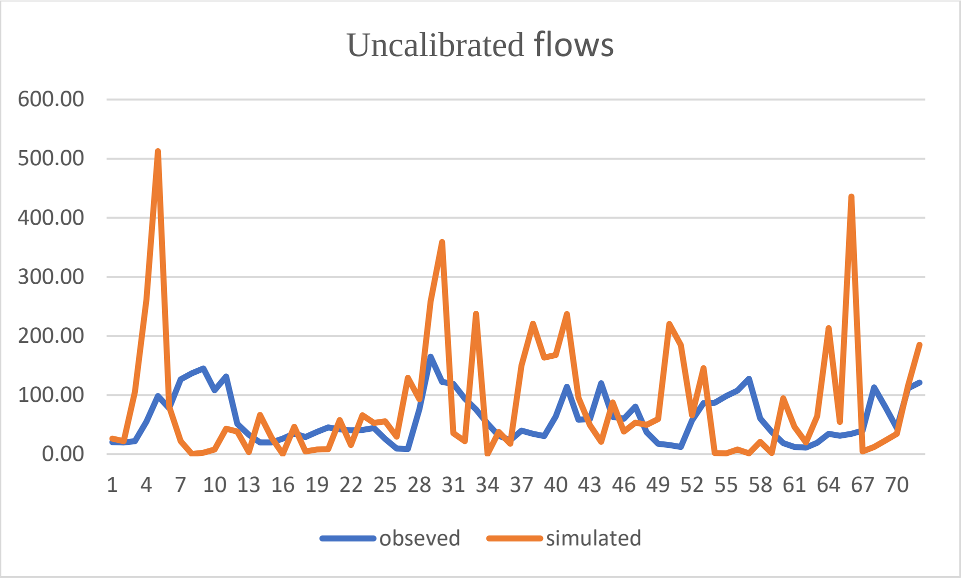


Figure 4.5 comparison of simulated and observed flow before calibration.

From figure 4.4 it can be observed that the model was underestimating the flows most of the time during the calibration period. Conversely the uncalibrated simulation flows showed that the model was overestimating the flows, this can be confirmed from figure 4.5. Also, from the series of calibrated flows, it can be observed that some months estimated better than others, the reason behind this may be due to weather stations inaccurately measuring total precipitation. Only five stations of weather were used in an area of 8354 km^2, thus some rainfall events may have been overestimated or underestimat

parameters	Default value	Fitted value
CN2	83	63.12
ALPHA_BF	0.048	0.0234
GW_DELAY	31	56
GWQMN	1000	750
RCHRG_DP	0.05	0.075
__GW_REVAP	0.02	0.0245
REVAPMN.	750	750
ESCO	0.95	0.975
SOL_AWC	0.143	0.118
SURLAG	2	4

Table 4.5 fitted value of calibrated parameters

4.3.2 Validation of flow data

The main purpose for validation is to confirm whether the model has the ability to estimate output hydrology for other time periods or conditions different from those which the parameter values were adjusted to fit (calibrated). In summary validation is rerunning the model of a different period from the calibration duration without changing the calibrated parameters. In this case, the mean monthly flow data between the period of January 2006 to December 2009 for the gauging station 1DA02, Nzoia at Webuye was used for the validation period. Just as the calibration, two goodness of fit measures, the coefficient of correlation (R^2) and the Nash-Sutcliffe simulation efficiency (E_{NS}) were calculated and used to assess the plots.

During the validation also, a satisfactory agreement between the simulated and observed data at the outlet was obtained. An R^2 value of 0.68 and an E_{NS} of 0.66 was realized. Table 4.6 below summarizes the findings.

Period (monthly time steps)	Average flow (m^3/sec		R^2	E_{NS}
	Gauge	simulated		
2006-2009	59.79	57.21	0.68	0.66

Table 4.6 flow validation

From the assessment of the calibration and validation results, in general we can conclude that the model set up can accurately simulate time periods outside the calibrated period hence the set of sensitive parameters used during calibration process for the watershed can be taken as the representative set of parameters for the upper nzoia catchment.

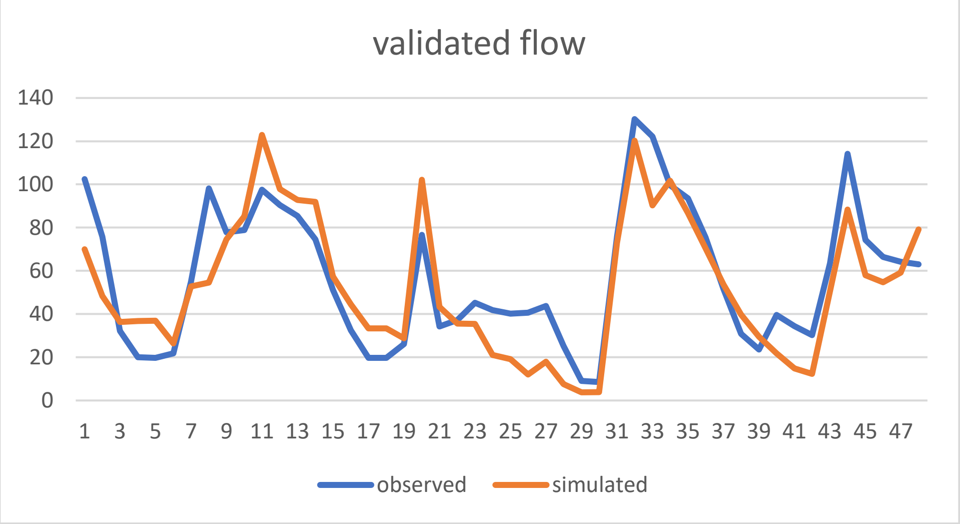


Figure 4.6 comparison of observed mean monthly flows and simulated during validation between 2006-2009

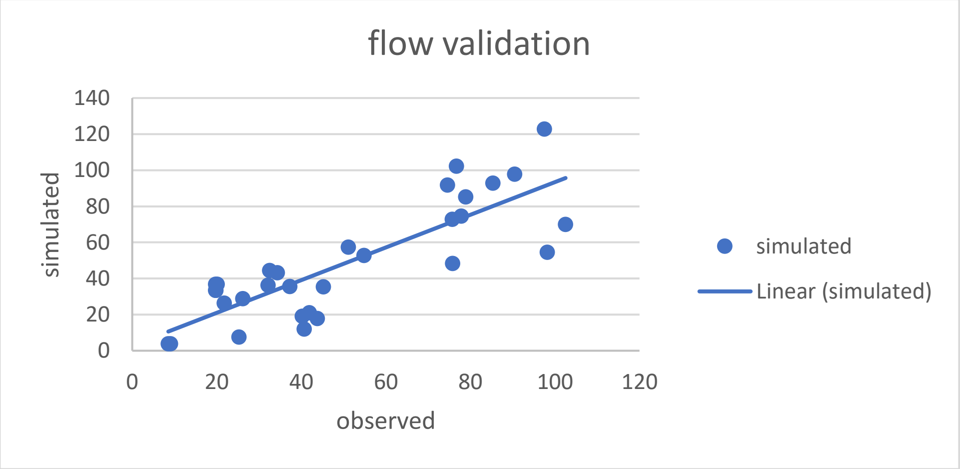


Figure 4.7 scatter plot of simulated and observed flows for validation period 2006-2007

4.4 Sensitivity analysis and Calibration of sediment.

Sediment transportation is usually categorized into two components, the landscape component and the channel component. Each component is affected by different parameters. Due to this the parameters are divided into two categories; upland parameters i.e. those that affect the landscape component and channel parameters that affect the channel component of sediment transport. Thus, the used parameters for sensitization should relate to the corresponding component.

Parameters that are classified as upland factors include, USLE _ K, USLE _ C, USLE _ P, BIOMIX, RSDIN, HRU _ SLP, and SLSUBBSN, while those that fall under channel parameters are, SPCON, SPEXP, CH _ COV1, and CH _ COV 2. In most cases the upland factors are more sensitive to sediment than the channel factors

The parameters which responded sensitively to sediment yield during calibration were the, USLE support practice factor (USLE_P), Average slope length (SLSUBBSN), Exponential re-entrainment parameter (SPEXP), Initial residue cover (RSDIN) and Channel cover factor (CH_COV2). Other parameters that were relatively sensitivity were, USLE soil erodibility factor (USLE_K), Linear re-entrainment parameter for channel sediment routing (SPCON), Average slope steepness (HRU_SLP), Channel erodibility factor [cm/h/pa] (CH_COV1) and Biological mixing efficiency (BIOMIX).

The quality of sediment data available were not good enough to obtain a good calibration because, firstly TSS was the one to be used to determine sediment load. TSS may not be a good measure of the sediment load for any given time period depending on the streamflow. TSS samples would not be expected to adequately estimate the total sediment load especially during period of high flows when there is a lot of bedload being transported by the river. It can only apply during low flows when conditions when bedload is negligible. Secondly the TSS sample were only carried out once a month which cannot represent mean monthly TSS values and lastly the method used for sampling was grab sampling making it not to be representative.

During the calibration period the model underestimated the suspended solids during both the peaks and low flows as shown in fig 4.8. But this may not be the truth on the ground because of the quality of data used for the calibration. The sediments were calibrated on the monthly time step and the Coefficient of determination (R^2) value and Nash-Sutcliffe model efficiency (ENS) statistic computed between the simulated and observed ENS of 0.7 and R^2 sediment were 0.60 and negative -0.34 respectively. This was not a surprise given the quality of observed data used during the calibration period. This result was unsatisfactory and the Nash-Sutcliffe value was negative which means observed mean is a better predictor than the model.

For this reason, sediment calibrated parameters were discarded. Since sediments are sensitive to hydrological components like flow particularly the amount and timing of surface runoff that is predicted by the model, the calibrated parameters for flow were used to simulate the sediment output of the catchment. Andresen 2017 used calibrated flow parameters only to simulate the sediments and obtained satisfactory results.

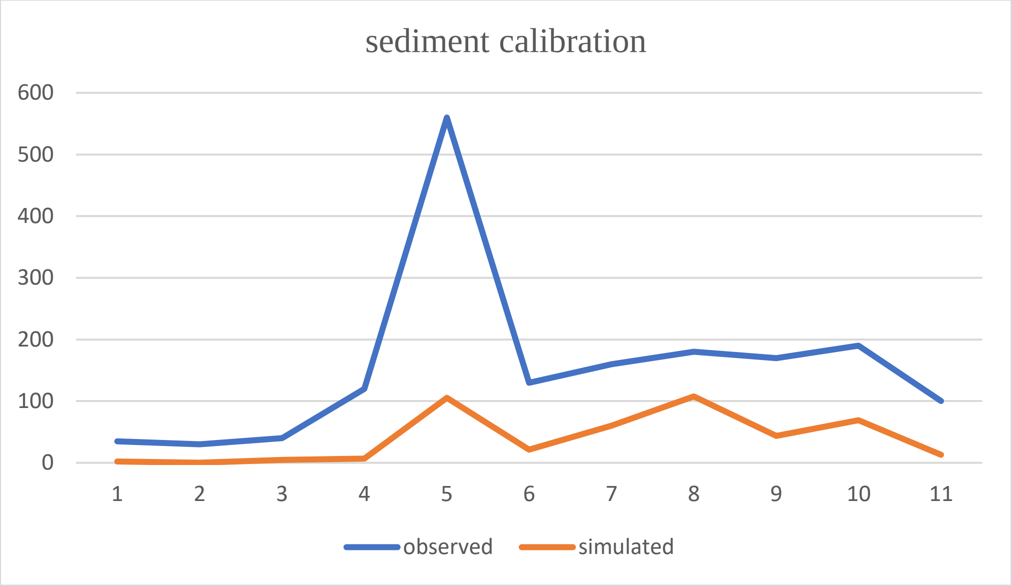


Figure 4.8 comparison of calibrated and simulated sediments

4.5 Sediment yield as modeled by SWAT

The model was updated with the flow calibrated parameters before doing the simulation. The period of calibration between 2000-2005 was used to obtain the result of modelled sediment yield. The decision to choose this period was due to the acceptable result obtained during the calibration period. The yearly sediment yield for each subbasin is given in table 4.7. for this study sediment yield were presented as metric tons per hectare per year. This measurement indicates the spatial distribution of the sediment generation in the entire catchment helping to identify which sub basins generate much sediment per ha per year and mapping them as hotspots that should be given priority for conservation practices.

4.5.1 Critical subbasins of the upper Nzoia catchment.

The subbasins in the study area were classified into three different classes according to their sediment yield. Either high, medium or low. This was based on the amount of sediment yield recorded in that basin.

This classification was used to give priority to critical subbasins so that they can be earmarked for conservation purposes

Sub basin	**Average yearly Sediment yield (tons/ha/year)**	**Area (ha)**	**Sediment yield level**	**Rank**
1	13.482	28990	HIGH	2
2	4.506	25840	MEDIUM	13
3	8.605	27910	HIGH	5
4	0.692	21630	LOW	21
5	1.418	8920	LOW	20
6	5.765	85940	MEDIUM	6
7	2.186	610	MEDIUM	17
8	19.356	100420	HIGH	1
9	2.654	27340	MEDIUM	16
10	1.989	34560	LOW	18
11	4.757	79630	MEDIUM	10
12	5.124	34300	MEDIUM	9
13	3.701	57580	MEDIUM	14
14	5.722	11050	MEDIUM	7
15	5.682	210	MEDIUM	8
16	2.67	71000	MEDIUM	15
17	11.008	10620	HIGH	3
18	1.959	3350	LOW	19
19	3.985	22220	MEDIUM	12
20	4.572	65370	MEDIUM	11
21	10.193	117910	HIGH	4

Table 4.7 specific sediment yield distribution for the delineated sub basins

4.5.2 Spatial distribution of sediments

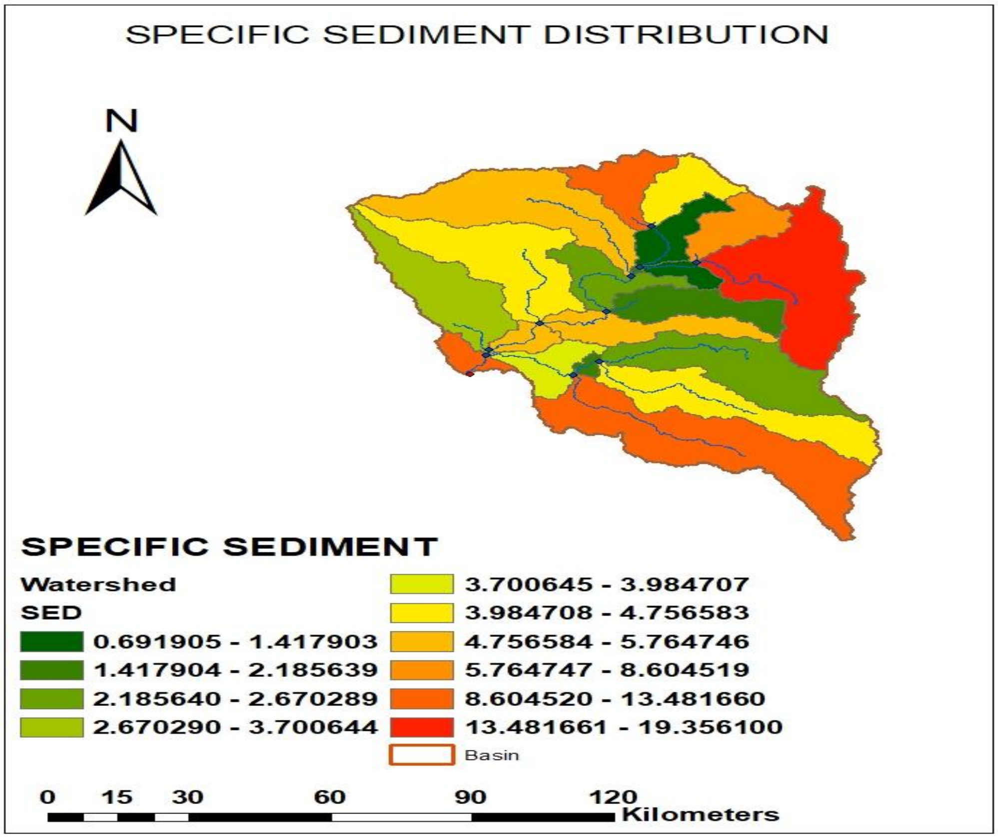


Figure 4.9 spatial distribution of sediment yield in tons/ha/year

The identification of areas that are prone to soil erosion in a catchment is important so as to enable management practices for reduction of the sediment yield to be applied on critical areas. SWAT has the capability of spatially analyzing sediment prone areas during sediment simulation. It is a powerful tool for spatial visualization that is used both at the sub basin and HRU level to identify areas which produce highest sediments and those that produce less sediments.

For the flow calibration period which is now the observation period for sediments, the average specific sediment yield for each sub-basin in the study area was determined and mapped out as shown in figure 4.9 above. The sub-basins were ranked from those with low specific sediment yield of 0.69 tons/ha/year to those with high specific sediment yield of around 19.094 tons/ha/year.

The sub basins which recorded high specific sediment yield were 1,8,17and 21 with 8 recording the highest as shown by the deep red color shade while those that recorded the lowest as indicated by the shade of green color in fig 4.8 above were sub basin 4,5,9,10,13 and 16, with subbasins 4 and 5 recording the least yield. Subbasin 17 appears to produce high specific sediment yield but in actual terms it may not. The high values are because of it being where the outlet of the entire catchment is located. The high sediment yield in the catchment may be attributed to the fact that the main land cover in the area is agriculture as shown in figure 3.4 which involves high disturbance of the soil. The areas that were depicted to produce high specific sediment yield in the eastern and southern part of the upper Nzoia catchment (sub basin 8 and 21) are located in the highlands (figure 3.2) which has steep slopes, from logical point of view, areas of higher relief are expected to have a higher sediment yield. These areas consist of steep slopes that are capable of transporting greater amounts of sediment from overland flow, or erosion. Also, intensive agriculture is practiced in the region, in addition the area receives high rains. These three factors may explain the reason for the high sediment yield in the 2 subbasins. When assessing the soils that cover these areas it was found that ferralsols were the most dominant soils though some parches of cambisols, nitisols and acrisols are also found. Ferralsols are more stable soils thus the high values of specific sediments cannot be attributed to the soil type.

The areas which produced less specific sediment yield as shown by shades of green in figure 4.9 are located near the center of the map i.e. subbasin 10,9,4 and 5, they are characterized by fairly flat topography and low relief. Subbasin 16 also yielded low sediments though majority of it is found in high altitude areas. The dominant soils in these regions are ferralsols as indicated in figure 3.3. The low values of sediment yield registered by subbasin 13 can be attributed to the presence of forest cover around mt Elgon (figure 3.4).

YEAR	**SED IN tons/ha/year**
2000	1.7689
2001	5.0313
2002	3.0527
2003	4.7924
2004	3.6384
2005	6.7067
2006	6.9796

Table 4.8 *yearly sediment yield for upper Nzoia catchment.*

The results of simulated sediment yields show a fluctuation in trend throughout the calibration period with even years such us 2000, 2002, 2004 recording lower values while odd year that included, 2001,2003 and 2005 recorded high values. This trend can be depicted from figure 4.10 below. The variation in sediment yield maybe due to the varying rainfall received in each year. The highest sediment yield recorded was 6.9796 tons/year/ha in the year 2006 while the lowest was 1.7689 tons/year/ha in the year 2000.

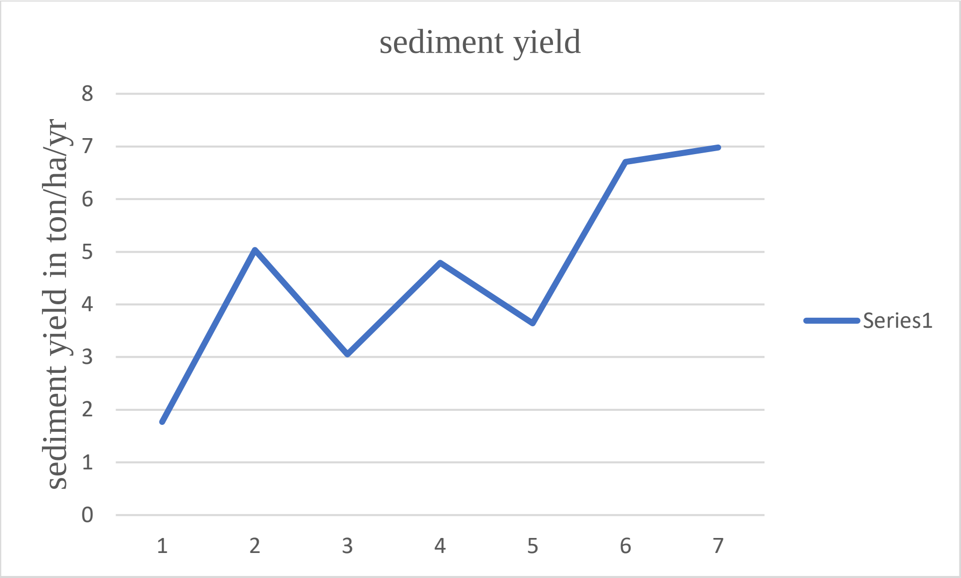


Figure 4.10 simulated sediment yield in tons per ha per year for the period 2000-2006

4.6 Best Management Practices

This study helped to identify sub-watersheds that have the potential of producing a higher sediment yield. They were distributed all over the catchment as shown by fig 4.9. several scenarios of BMPs were establish to see the response of the catchment on sediment yield. The effect of the scenarios was assessed on the entire catchment and also on the individual subbasins that were deemed to produce high sediment yield. Additionally, these best management practices were implemented only on Agricultural land because agriculture was the dominant land use in the study area.

4.6.1 Impact of filter strips on sediment reduction

Filter strips reduces sediment yield by reducing overland flow velocity which results in the deposition of eroded soils. The area occupied by the filter strips acts as an area of increased infiltration, reducing both the runoff volume and non-particulate contaminants. As stated earlier, the filter width was varied to assess how different filter width reduces sediment.

When a filter strip of 5m width was applied on agricultural HRUs it resulted in an overall reduction of 17% in sediment yield for the entire basin and when applied on the individual subbasins which manifested high sediment yield, the reduction rate was 59.16% for both subbasin 1 and 21, 58.87% for subbasin 8 and 6.44% for subbasin 17.

Filter strip with 10 m width showed a reduction of 37.40% in sediment on the entire catchment. When applied to the individual subbasins, it reduced sediment yield with an equal percentage of 72.67% for subbasin 1 and 21, in subbasin 8 sediments were reduced by 72.31% while for subbasin 17 was 7.64%.

The last scenario of filter strip to be applied was with 20 m width. it had the highest reduction effect on sediment. 69.97% reduction was realized in the entire study area, 89.26% for subbasin 1 and 21, 89.98% for subbasin 8 and 33.22% for subbasin 17

The low reduction rate realized in subbasin 17 can be attributed to the fact that it is the one that contain the outlet of the entire catchment. It can be noted that as the width of the filter strip increase, the reduction effect also increases. Filter strip with width 20 had the highest percentage of reduction while filter strips with 5 m width had the lowest reduction.

Reduction in sediment yield as a function of VFS width was almost linear (figure 4.10). there is higher reduction in sediment with the 20 m width as shown by the gradient of the series.

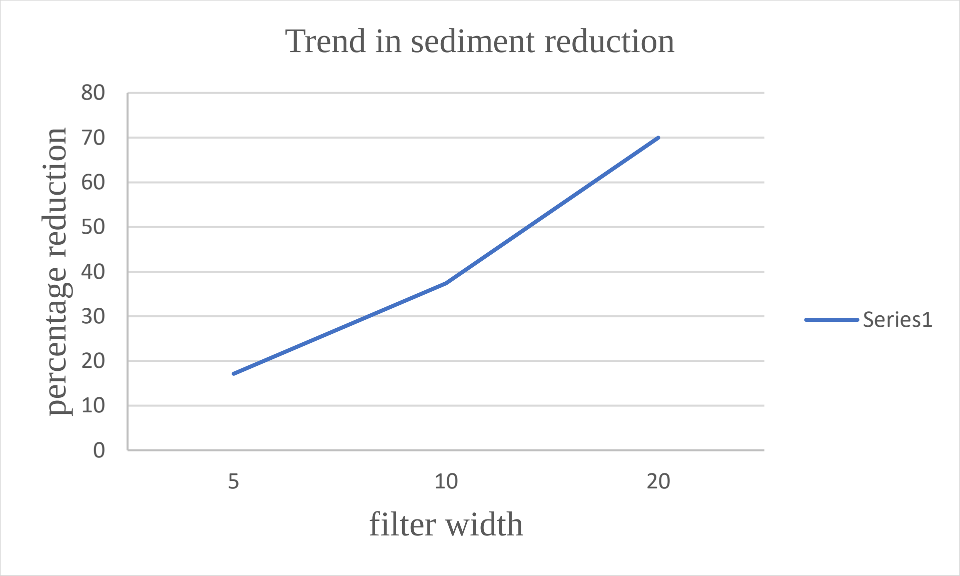


Fig 4.10 comparison of filter strip width and reduction percentage

4.6.2 Impact of terraces

Terraces influence sediment reduction by enhancing ponding of water on the surface and allow higher rates of infiltration, they reduce the velocity of surface runoff translating to reduction in its erosivity. Arabi et al. 2008 observed that terraces also reduce slope length and reduce the peak runoff rate. Peak runoff is directly proportional to soil erosion rate thus reducing it will have an impact on sediment yield. Terracing managed to reduce the sediment inflow on average by 44.12% on the entire study area. in subbasin 21 it was reduced by 63.87%, 58.25% for subbasin 1, 50.65% in subbasin 8 and subbasin 17 was reduced by 9.73%.

4.6.3 Impact of contour farming.

Contour farming as a best management practice managed to reduce sediments by 21% for the whole upper nzoia catchment. subbasins 1, 8, 17 and 21 were reduced by 29.3, 24.5, 6.7 and 31.5 respectively.

Rank	**BMP**	**Baseline (tons/ha/year)**	**Sediment at outlet(tons/ha/year)**	**Reduction (%)**
1	20 m filter strip	4.57	1.37	69.97
2	Terraces	4.57	2.55	44.12
3	10 m filter strip	4.57	2.86	37.40
4	Contour farming	4.57	3.60	21.12
5	5 m filter strip	4.57	3.78	17.13

Table 4.9 sediment reduction at the catchment outlet as a result of best management practice intervention

BMP	**Sub-basin**	**Baseline (tons/ha/year)**	**Sediment at outlet(tons/ha/year)**	**Reduction (%)**
20 m filter strip	1	13.14	1.41	89.27
	8	6.22	0.70	88.82
	17	31.65	19.58	38.13
	21	2.88	0.31	89.27
Terraces	1	13.14	5.49	58.25
	8	6.22	3.07	50.65
	17	31.65	28.56	9.73
	21	2.88	1.04	63.87
10 m filter strip	1	10.81	2.96	72.67
	8	6.22	1.72	72.31
	17	31.65	29.23	7.64
	21	2.88	0.79	72.67
Contour farming	1	13.14	9.29	29.25
	8	6.22	4.70	24.48
	17	31.65	29.53	6.70
	21	2.81	1.93	31.50
5 m filter strip	1	13.14	5.37	59.16
	8	6.22	2.56	58.87
	17	31.65	29.61	6.44
	21	2.88	1.18	59.16

Table 4.10 *impact of BMPs on the critical subbasin*

CHAPTER FIVE

5. Conclusion

Due to increased anthropogenic activities on the earth surface as a result of increased human population, sediment yield as a result of increased erosion is becoming a serious issue in many watersheds. The main aim of this research was to show that physical based models like SWAT can be used to reasonably estimate sediment yield in a catchment. In any modelling process the correct result is obtained from a well calibrated model, therefore, the quality of data to be used is important. The luck of good quality measured sediment data for calibration and the complexity of the catchment may have increased the uncertainty of the modelled results obtained in this study.

The model reasonably simulated the river flows for the upper Nzoia catchment because the results during calibration and validation period were satisfactory. When model performance was evaluated the E_{NS} and R^2 for the calibration were 0.7 and 0.73 respectively. The validation period obtained E_{NS} of 0.63 and R^2 of 0.64. For case of Sediment, the quality of the measured data was not good and during calibration an E_{NS} of -0.34 and R^2 of 0.6 was obtained. Which was not a good result.

From the global sensitivity analysis, the most sensitive parameters for flow were curve number (CN2), the soil available water capacity (SOL_AWC), Saturated hydraulic conductivity (SOL_K), and Deep aquifer percolation fraction (RCHRG_DP). The sensitivity analysis of the SWAT parameters showed that sediment yield is most sensitive USLE support and practice factor (USLE_P), Average slope length (SLSUBBSN), Exponential re-entrainment parameter (SPEXP) and Initial residue cover (RSDIN).

After mapping sediment yield for each subbasin in the study area, 4 subbasins were found to have higher sediment yield above the allowable soil loss of 10 tons/ha/year. The highest was subbasin 8 with 19.356 tons/ha/year, subbasin 1, 17 and 21 generated 13.482, 11.008 and 10.193 tons/ha/ year respectively.

Management scenarios were implemented to assess their impact of sediment reductions and it was found that a filters strip of 20 m width was the most effective BMP as it able to reduce the sediment yield by 69.97% in the entire catchment if applied to agricultural HRUs. And it also manifested a reduction of approximately 89% when applied to individual subbasins that yielded high sediments yield during simulation. Contour farming and filter strips of 5 m were the least effective management measures in sediment reduction.

References

Abbaspour, K.C., Vejdani, M., Haghighat, S. 2007. SWATCUP Calibration and Uncertainty Programs for SWAT. In: Oxley, L., Kulasiri, D. (Eds.), Proc. Intl. Congress on Modeling and Simulation (MODSIM'07). Modeling and Simulation Society of Australia and New Zealand, Melbourne, Australia, pp. 1603–1609.

Abbaspour, K. C. 2013. SWAT-CUP 2012: SWAT calibration and uncertainty programsA user manual. Swiss: Eawag and Swiss Federal Institute of Aquatic Science and Technology.

Alcamo, J., Vorosmarty, C., Naiman, R. J., Lettenmaier, D., Pahl-Wostl, C. 2008. A grand challenge for freshwater research: understanding the global water system. Environmental Research Letters 3, 1–6.

Ananda, J. Herath,G**.** 2003. Soil erosion in developing countries: a socio-economic appraisal. Journal of Environmental Management, 68:343-353.

Andresen. D.A. 2017. Modeling sediment yield in the sink creek and purgatory creek watersheds near san Marcos, Texas. Master’s thesis.

Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold, J.G. 2007. Representation of agricultural conservation practices with SWAT. Hydrologic Processes 22, 3042-3055.

Arabi M, Frankenberger J.R., Enge, B.A., Arnold, J.G. 2008. Representation of agricultural conservation practices with SWAT. Hydrol Process.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R. 1998. Large area hydrologic modeling and assessment part I: model development. J. Am. Water Resour. Assoc. 34 (1), 7389.

Arnold, J. G., Haney, E.B., Kiniry, J. R., Neitsch, S.L., Srinivasan, R., Neitsch, S. L., & Williams, J. R. 2012. Soil and water assessment tool theoretical documentation version 2012. Texas Water Resources Institute.

Beres, D.L, Hawkins, D.M. 2001. Plackett-Burman technique for sensitivity analysis of many parameterized models. Ecological modelling 141: 171-1 83

Beven, K. and J. Freer. 2001. Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE methodology, Journal of Hydrology. 249: 11-29.

Bijay K & Krishna P. 2015. Assessing the Efficiency of Alternative Best Management Practices to Reduce Nonpoint Source Pollution in the Saline Bayou Watershed, Louisiana

Bingner, R. L., Garbrecht, J., Arnold, J. G., & Srinivasan, R. 1997. Effect of watershed subdivision on simulation runoff and fine sediment yield.Transactions of the ASAE, 40(5), 1329-1335.

Bingner R.L., Theurer F.D. 2001. AnnAGNPS: estimating sediment yield by particle size for sheet and rill erosion. Proceedings of the Sedimentation: Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference, Reno, NV, pp.1-7.

Bracmort, K., Arabi, M., Frankenberger, J., Engel, B., and Arnold, J.2006. Modeling long-term water quality impact of structural BMPs, T. ASABE, 49, 367–374.

Carpenter, S.R., Caraco, N.E., Correll, D.L., Howarth, W., Sharpley, A.N., Smith, V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Application 8(3), 559-568.

Chakrapani, G. J. 2005. Factors controlling variations in river sediment loads. Current Science.

Chaubey, I., Chiang, L., Gitau, M. W., & Mohamed, S. 2010. Effectiveness of best management practices in improving water quality in a pasture-dominated watershed. Journal of Soil and Water Conservation, 65(6), 424-437.

Chiwa, M., Onikura, N., Ide, J. K, A. 2012. Impact of N-Saturated Upland Forests on Downstream N Pollution in the Tatara River Basin, Japan. Ecosystems 15, 230–241.

Chow, V.T., D.R. Maidment and L.W. Mays. 1988. Applied Hydrology. McGraw-Hill: New York.

Cunningham, J. H., Benham, B. L., Brannan, K. M., Mostaghimi, S., Dillaha, T. A., Pease, J. W.2003. An assessment of the quality of the agricultural best management practices implemented in the James River basin of Virginia. Conference paper, page,281-190.

Das, K., Gazi, N. H. 2010. Random excitations in modelling of algal blooms in estuarine systems. Ecological Modelling 222(14), 2495-2501.

Defersha, M.B., Melesse, A.M.2012. Effect of rainfall intensity, slope and antecedent moisture content on sediment concentration and sediment enrichment ratio. CATENA 90, 47–52. Defersha, M.B., Melesse, A.M., McClain, M. 2012. Watershed scale application of WEP Pand EROSION 3D models for assessment of potential sediment source areas and runoff flux in the Mara River Basin, Kenya. CATENA 95, 63–72.

Defersha, M.B., Melesse, A.M. 2011. Field-scale investigation of the effect of land use on sediment yield and surface runoff using runoff plot data and models in the Mara River basin, Kenya.

Dennis M.F., Rorke M.F. 1999. The relationship of soil loss by interill erosion to slope gradient. Catena, 38:211-222.

Ding, X. W., Shen, Z. Y., Hong, Q., Yang, Z. F., Wu, X., Liu, R. M. 2010. Development and test of the export coefficient model in the upper reach of the Yangtze River. Journal of Hydrology 383, 233–244.

Dilnesaw, A. (2006). Modelling of Hydrology and Soil Erosion of Upper Awash River Basin (Doctoral dissertation, PhD Thesis. University of Bonn, Germany

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Knowler, D., Leveque, C., Naiman, R. J., Prieur-Richard, A-H., Soto, D., Stiassny, M. L. J., Sullivan, C.A. 2006.Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Review 81, 163-182.

Duru U, Arabi M, Ellen E. Wohl. 2017. Modeling stream flow and sediment yield using the SWAT model: a case study of Ankara River basin, Turkey.

Evans, R. 2006. Land use, sediment delivery and sediment yield in England and Wales. In: Owens, P.N. and Collins, A.J., CAB International, Wallingford, pp 70- 84 Event Load Estimation. Water Resources Research, 32(7): 2299-2310.

Faramarzi, M., Abbaspour, K.C., Schulin, R., Yang, H. 2009. Modeling blue and green water availability in Iran. Hydrol. Proc. 23 (3), 486–501.

Flanagan D.C. Nearing M.A .1995. USDA-Water Erosion Prediction Project (WEPP) – Technical Documentation, National Soil Erosion Research Laboratory, Report No. 10, USDA-ARSMWA, West Lafayette, IN.

Foster, G. R., & Meyer, L. D. 1977. Soil erosion and sedimentation by water – an overview. In Proceedings, national symposium on soil erosion and sedimentation by water (pp. 1–13). St. Joseph, MI: American Society of Agricultural Engineers.

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future research directions Invited Review Series.

Getachew, H. E., & Melesse, A. M. 2012. The Impact of Land Use Change on the Hydrology of the Angereb Watershed, Ethiopia. International journal of water sciences vol, 1.

Giri, S., Nejadhashemi, A.P., Woznicki, S.A. 2012a. Evaluation of targeting methods for implementation of best management practices in the Saginaw River Watershed. Journal of Environmental Management 103, 24-40.

Gitau, M. W., Gburek, W. J., & Bishop, P. L. 2008. Use of the SWAT model to quantify water quality effects of agricultural BMPs at the farm-scale level. Transactions of the ASABE, 51(6), 1925-1936.

Githui, F., Wilson G., Francis, M., & Willy, B.2009. Climate change impact on SWAT simulated stream flow in western Kenya. Int J of Climatology 29:1823– 1834. doi:10.1002/joc.1828.

Gupta, H. V, Sorooshian, S, Yapo, P. O. 1998. Towards improved calibration of hydrologic models: Multiple and noncommensurable measures of information. Water Resour Res 34:751-763.

Heuvelmans, G., Muys, B., & Feyen, J. 2004. Analysis of the spatial variation in the parameters of the SWAT model with application in Flanders, Northern Belgium. Hydrology and Earth System Sciences Discussions, European Geosciences Union, 8(5), 931-939.

Holvoet, K., van Griensven, A., Seuntjens, P., & Vanrolleghem, P. A. 2005. Sensitivity analysis for hydrology and pesticide supply towards the river in SWAT. Physics and Chemistry of the Earth, Parts A/B/C, 30(8), 518-526.

Horton, R. E. 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological society of America bulletin, 56(3), 275-370.

Jayakrishnan R, Srinivasan R, Santhi C, Arnold JG. 2005. Advances in the application of the SWAT model for water resources management. Hydrological Processes 19(3): 749–762.

Kaur R, Singh O, Srinivasan R, Das SN, Mishra K. 2004. Comparison of a subjective and a physical approach for identification of priority areas for soil and water management in a watershed — a case study of Nagwan watershed in Hazaribagh District of Jharkhand, India. Environ Model Assess; 9:115–27.

Kaplowitza, M. D., Lupi, F. 2012. Stakeholder preferences for best management practices for non-point source pollution and stormwater control. Landscape and Urban Planning 104, 364– 372

Kinnell, P.A. 2000. AGNPS–UM: applying the USLE–M within the agricultural nonpoint source pollutionmodel. Environmental Modelling and Software, 15: 331-341.

Kiome, R.M., and Stocking, M. 1995. Rationality of Framer Perception of Soil Erosion: The Effectiveness of Soil Conservation in Semi-arid Kenya. Global Environmental Change, 5, 4: 281-295.

Knisel, W. G. 1980. CREAMS: A field-scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Report, (26)

Krause, P., Boyle, D. P., & Bäse, F. 2005. Comparison of different efficiency criteria for hydrological model assessment. Advances in Geosciences, 5, 89-97.

Laia, Y.C., Yangb, C.P., Hsiehc, C.Y., Wua, C.Y., Kao, C.M. 2011. Evaluation of non-point source pollution and river water quality using a multimedia two-model system. Journal of Hydrology 409(3-4), 583-595.

Lijalem, Z.A., Jackson, R., & Dilnesaw, A. 2007. Climate Change Impact on Lake Ziway Watershed Water Availability, Ethiopia, Catchment Lake Res., 136, 376–385, doi: 10.1061/(ASCE)WR.1943-5452.

Lal, R.1998. Soil quality and sustainability. In: Lal R, Blum WH, Valentine C, Stewart BA, eds. Methods for assessment of soil degradation. Boca Raton, FL: CRC Press, pp. 1

Lim, K.J., Sagong, M., Engel, B.A., Tang, Z., Choi, J., Kim, K. 2005. GIS-based sediment assessment tool. Catena, 64:61- 80. 7-30

Maalim, F.K., Melesse, A.M. 2013. Modeling the impacts of subsurface drainage systems on runoff and sediment yield in the Le Sueur Watershed, Minnesota. Hydrol. Sci. J. 58 (3), 1–17.

Maalim, F.K., Melesse, A.M., Belmont, P., Gran, K. 2013. Modeling the impact of land use changes on runoff and sediment yield in the Le Sueur Watershed, Minnesota using GeoWEPP. Catena 107, 35–45.

Madsen, H. 2000. Automatic calibration of a conceptual rainfall-runoff model using multiple objectives. J Hydrology 235: 276-288

Millennium Assessment. 2005. Ecosystems and Human Well- Being: Synthesis. Island Press: Washington, DC.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Binger, R. L., Harmel, R.D., & Veith., T. L. 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the American Society of Agricultural and Biological Engineers, 50(3), 885–900.

Morgan R.C., Quinton J.N., Smith R.E., Govers G, Poesen J.A., Auerswald K, Chisci G, Torri D, Styczen M.E. 1998. The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms, 23:527-544.

Morrison, J., Gleick, P. 2004. Fresh water resources: Managing the risks facing the private sector. Pacific Institute, Okland, California.

Musau, J., Sang, J., Gathenya, J., Luedeling, E., Home, P. 2015. SWAT model parameter calibration and uncertainty analysis using the HydroPSO R package in Nzoia Basin, Kenya.

Nash, J. E., & Sutcliffe, J. V. 1970. River flow forecasting through conceptual models, part I—A discussion of principles. Journal of Hydrology, 10(3), 282–290.

Ndomba, P., Mtalo, F., & Killingtveit, A. 2008. SWAT model application in a data scarce tropical complex catchment in Tanzania. Physics and Chemistry of the Earth, Parts A/B/C, 33(8), 626-632.

Nearing, M. A. 1998. Why soil erosion models over-predict small soil losses and underpredict large soil losses. Catena (32), 15–22.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. 2005. Soil and Water Assessment Tool (SWAT). SWAT User Manual, Version 2005. Grasland, Soil and Water Research Laboratory, Temple, Texas, USA.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. 2011. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.

Odira, P. M. A, Nyadawa, M. O., Okello, B., Juma, N. A., and Obiero, J. P. O. 2010. Impact of Land Use/Cover dynamics on Stream flow: A case Study of Nzoia river Catchment, Kenya. Nile Water Science and Engineering Journal, 3(2), 64-78

Okungu. J, Opango, p. 2001. Pollution loads into Lake Victoria from Kenyan catchment, Regional Scientific Conference Held at Kisumu, Kenya, 2001.

Parajuli, P.B., Nelson, N.O., Frees, L.D., Mankin, K.R. 2009. Comparison of AnnAGNPS and SWAT model simulation results in USDA-CEAP agricultural watersheds in south-central. Kansas. Hydrological Processes 23, 748-763.

Postel, S. 2000. Entering an era of water scarcity: The challenges ahead. Ecological Applications 10(4), 941-948.

Revenga, C., Campbell, I., Abell, R., Devilliers, P., Bryer, M. 2005. Prospects for monitoring freshwater ecosystems towards the 2010 targets. Philosophical Transactions of the Royal Society B 360, 397–413.

Renschler, C. S. 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. Hydrological Processes, 17, 1005-1017.

Romero-Diaz, A., Alonso-Sarriá, F., & Martínez-Lloris, M. 2007. Erosion rates obtained from check-dam sedimentation (SE Spain). A multi-method comparison. Catena, 71(1), 172-178.

Santhi, C., Srinivasan, R., Arnold, J., and Williams, J. 2005 A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas, Environ. Modell. Softw., 21, 1141–1157.

Scherr, S. J**.** 1999. Soil degradation: a threat to developing-country food security by 2020? Food, Agriculture, and Environment Discussion Paper 27, International Food Policy Research Institute, USA.

Setegn, S. G., Srinivasan, R., & Dargahi, B. 2008. Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. The Open Hydrology Journal, 2(2008), 49-62.

Setegn, Shimelis G., Dargahi, B., Srinivasan, R., Melesse, Assefa M. 2010. Modeling of sediment yield from Anjeni gauged watershed, Ethiopia using SWAT model. JAWRA 46 (3), 514–526.

Sharpley, A.N., Daniel, T., Sim, T., Lemunyon, J., Stevens, R., Parry, R. 2003. Agricultural phosphorus and eutrophication, second edition. USDA-ARS. Publication no. ARS 149.

Shi, Q., Deng, X., Wu, F., Zhan, J., Xu, L. 2012. Best management practices for agricultural non-point source pollution control using PLOAD in Wuliangsuhai watershed. Journal of Food, Agriculture & Environment 10 (2), 1 3 8 9 - 1393.

Spruill, C. A., Workman, S. R., Taraba, J. L. 2000. Simulation of daily stream discharge from small watersheds using the SWAT model. Transactions of the ASAE. American Society of Agricultural Engineers, (43), 1431.

Sutcliffe, J.V. and Parks, Y.P. 1999. The hydrology of the Nile. Wallingford: IAHS Press, IAHS Special Publication no. 5.

Tamene, L. 2005. Reservoir siltation in the drylands of northern Ethiopia: causes, source areas and management options. Pub. PhD Thesis, Centre for Development Research, University of Bonn, German.

Tripathi, M.P., R.K. Panda., N.S. Raghuvanshi. 2003. Identification and prioritization of critical sub watersheds for soil conservation management using the SWAT model. Biosystems Engineering 85(3), 365-379.

Tyagi, J. V., Rai, S. P., Qazi, N., & Singh, M. P. 2014. Assessment of discharge and sediment transport from different forest cover types in lower Himalaya using Soil and Water Assessment Tool (SWAT). International Journal of Water Resources and Environmental Engineering, 6(1), 49-66.

UNEP,2005. Challenges of water: scarcity.http://www.siwi.org/documents/Resources/Reports/Challenges_water_scarcity_business_case_study_2005.pdf.

UNEP. 1998. Best management practices for agricultural nonpoint sources of pollution. CEP technical report no. 41. Available at:

http://www.cep.unep.org/publications-andresources/technical reports/tr41en.pdf.

USEPA. 2009. National water quality inventory: Report to congress, 2004 reporting cycle. USEPA Doc. 841-R-08-001. U.S. EPA, Washington, DC.

USEPA. 2012. National management measures for the control of nonpoint pollution from agriculture. EPA-841-B-03-004. Washington,

DC.USGS. 2012. Where is earth's water located. Available at: http://ga.water.usgs.gov/edu/earthwherewater.html. Accessed on May15

Vache, K., Eilers, J., and Santelmann, M., 2002.Water quality modeling ´of alternative agricultural scenarios in the us corn belt, J. Am. Water Resour. As., 38, 773–787.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., & Srinivasan, R. 2006. A global sensitivity analysis tool for the parameters of multi-variable catchment models. Journal of hydrology, 324(1), 10-23.

Vellidis, Leibowitz G., S. G., Ainslie W.B., Pruitt B. A. 2003. prioritizingwetland restoration for sediment yield reduction: A conceptual model. Environ. Manage. 31(2): 301-312.

William W. Doe III, David S. Jones, and Steven D. Warren. 1999. The Soil Erosion Model Guide for Military Land Mangers: Analysis of Erosion Models for Natural and Cultural Resources ApplicationsTri-Service CADD/GIS Technology Center. Colorado State University, Center for Ecological Management of Military Lands.

Williams, J.R. 1975. Sediment-yield predictions with universal equation using runoff energy factor. In Present and Prospective Technology for Predicting Sediment Yield and Sources. U.S. Dept. Agr., ARS-S-40. Washington, D.C. p. 244-252.

Williams, J. R. & Berndt, H. D. 1977. Sediment Yield Prediction Based on Watershed Hydrology. Transactions of American Society of Agricultural Engineers, 20(6), 1100-1104.

Williams JR. SPNM. 1980. A model for predicting sediment, phosphorus, and nitrogen yields from agricultural basins. Water Resour Bull

Walling, D.E. 2006. Human Impact on Land-Ocean Sediment Transfer by the World’s River. Geomorphology 79: 192-216.

Wang, X., Melesse, A.M. 2005. Evaluations of the SWAT model's snowmelt hydrology in a Northwestern Minnesota watershed. Trans. ASAE 48 (4), 1359–1376.

Wanga, X., Wanga, Q., Wua, C., Liang, T., Zhengc, D., Weid, X. 2012. A method coupled with remote sensing data to evaluate non-point source pollution in the Xin'anjiang catchment of China. Science of the Total Environment 430, 132-143.

White, K. L. and Chaubey, I. 2005, Sensitivity analysis, calibration and validations for a multisite and multivariable swat model, Journal of the American Water Resources Association, 41(5):1077-1089.

Wilson, J., Gallant, C. 2000. Digital Terrain Analysis. In: Wilson, J.P., Gallant, J.C. [Eds] Terrain analysis: principles and applications, Wiley

Wischmeier WH, Smith DD. 1978. Predicting rainfall erosion losses- a guide to conservation. Agricultural Handbook no. 537. United States Department of Agriculture: Washington, DC.

Wohl, E. 2006. Human impacts to mountain streams. Geomorphology, 79(3), 217-248.

Yang, W; Sheng, C., Voroney, P. 2005. Spatial targeting of conservation tillage to improve water quality and carbon retention benefits. Canadian Journal of Agricultural Economics 53, 477-500.

Zhang, Y., Degroote, J., Wolter, C., & Sugumaran, R. 2009. Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS framework to assess soil erosion risk. Land Degradation & Development, 20(1), 84-91.

Zhang, H., Yang, Q., Li, R., Liu, Q., Moore, D., He, P., Ritsema C. J., & Geissen, V. 2013. Extension of a GIS procedure for calculating the RUSLE equation LS factor. Computers & Geosciences, 52, 177-188.

Appendix:Expenditure

SNO	ITEM	ITEM DESCRIPTION	COST
1	Data	• Weather data which included rainfall, minimum and maximum temperature from the Kenya meteorological department	KSH 50000 USD 515.46
		• Hydrological data (river discharge and sediment data) from the water resource authority.	KSH 40000 USD 412.37
2	Mobile services	• Internet service to accesses reading materials • Airtime for making calls	KSH 30000 USD 309.27
3	Insurance cover	• As a requirement before undertaking the internship you must be insured. I took a 3 months cover from Madison insurance	KSH 10000 USD 103
4	Training	• Undergoing training on the use of SWAT and WATERCAD model (2-week training at Citech)	KSH 35000 USD 360.82
5	Software	• Acquiring ArcGIS that supports ArcSWAT software from Esri Eastern Africa.	KSH 12000 USD 123.71
6	Printing and binding	• Printing and binding of my master's thesis	KSH 10700 USD110.30
7	Transport	• Air fare round trip from Algers to Nairobi + fair from Telmcen to Algers and back	DZ 86044+4000 USD 803
		• Fare for meetings with my supervisor	KSH 16000 USD 164.95
		• Car hire to visit the area of study at the outlet and also doing ground truthing in the area of study.	KSH10000 USD 103.09
TOTAL IN USD			**3002.97**