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SCHOOL OF CIVIL AND ENVIRNMENTAL ENGINEERING

HYDRAULIC AND WATER RESOURCE ENGINEERING DEPARTEMENT

HYDRAULIC ENGINEERING MASTERS OF SCIENCE PROGRAM

SWAT BASED SOIL EROSION MODELING
CASE STUDY NASHE WATERSHED, ETHIOPIA

BY DEREJE GIZAW NEMOMSA

A Thesis is submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering

December, 2016

Jimma, Ethiopia

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Main Advisor: - Dr. (Ing.) Tamene Adugna (PhD)

Co-adviser:- Megersa Kebede (MSc.)

December, 2016

Jimma, Ethiopia

Declaration

I, Dereje Gizaw, do here by declare to the Senate of Jimma University that this thesis is completely my original work and all other materials are accordingly acknowledged.

This work has not been submitted and presented for any academic degree award at any other University.

	....	....
By Dereje Gizaw.	Signature	Date

Certification

I hereby certify that I have read this thesis prepared under my direction and recommend that it be accepted as fulfilling the thesis requirement. This Thesis has been submitted for examination with my approval as University Supervisor.

Name of Advisor	**Signature**	**Date**
Advisor: - Dr.-Ing. Tamene Adugna (PhD)	……………….	……………..
Name of Co-advisor Mr. Megersa Kebede (MSc.)	………………..	………………

Abstract

Soil erosion modeling is a significant tool for viable conservation of natural, agricultural and built up environments. In this thesis, Soil Erosion modeling of Nashe watershed was done to assess where and when soil erosion potentials has occurred. The study was carried out using SWAT model with GIS interface..

The general objective of this study was to estimate spatial and temporal patterns of soil erosion of Nashe watershed physical based SWAT model. The SWAT (Soil and Water Assessment Tool) with GIS interface which is used to delineate the watershed and extract networks for sub basin watershed. This study assess sediment yield from Nashe watershed at outlet. The stream flow was calibrated for eleven years (1991-2001) and validated seven years (2002-2008) at Nashe station using SWAT-CUP to estimate performance of the model. The suspended sediment was generated by rating curve to compare with sediment suspended simulated by SWAT and showed that acceptable result. In addition, from simulated suspended sediment by SWAT, sediment yields simulated for sub-watershed. Based on simulated sediment yields prone soil erosion of watershed were identified.

The model was successfully calibrated and validated for flow to estimate sediment yield. The model performance for calibration and validation also has been evaluated by using statistical parameters. Flow calibration gave coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) 0.79 & 0.75 respectively. Flow validation gave 0.71 and 0.65 for R^2 and E_{NS} values respectively. Both calibration and validation results indicate that the observed values show good agreement with simulated flow. The SWAT model yields average annual sediment of 60.97 ton/ha for study area.

The annual sediment yield of Nashe sub basin has been obtained from stream flow simulated results. Sediment yield from each sub watershed were also determined and prone soil erosion area has been identified. The erosion prone area which needs immediate soil and water conservation measure in Nashe watershed was identified. The sub watershed (75-150 ton/ha sediment yield) has been identified as Severe soil erosion prone area, priority were needed for conservation measures

***Key words: Modeling, Nashe, Sediment yields, Soil erosion, SWAT, SWAT-CUP**.*

Acknowledgement

First of all, I glorify the almighty God for granting and strengthen me to proceed and walk unpaved way to reach this point in life. Without his encouragement and care this would not have happened in my life. Next, I would like to express my gratitude to Ethiopian Road Authority for providing such chance to continue my study.

I would like to express my very great appreciation to Dr.-Tamene Adugna, my main adviser, for his precious advice, encouragement and important comment during this work. Also, I would like to thank my co-advisor; Mr. Megersa Kebede, for his patient guidance, wholehearted support and constructive suggestions during this thesis work. Their critical comments and valuable advices helped me to take this research in the right direction.

I would like to say special thanks to all my friends and course mates for their support and wonderful social atmosphere.

At last but not least, I am grateful to my relatives for their encouragement and wish of successful accomplishment. Many thanks are due to my father, mother, brother, sister and all other members of my family for their prayers, unconditional love and support. I would like to extend my deepest gratitude to particularly my brother Negera Gizaw and his wife Age Mokonen for their moral support and belongingness throughout the study.

Table of Contents

List of Tables

List of Figures

Acronyms

ArcGIS	Arc Geographical information system
Arc SWAT	Arc Soil and Water Assessment Tool
ARS	Agricultural Research Service
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
FAO	Food and Agriculture Organization of the United Nation
FMWRE	Federal Ministry of Water Resources of Ethiopia
GIS	Geographical Information System
HRU	Hydrologic Response Unit Analysis
LULC	Land Use/ Land Cover
MoWIE	Ministry of Water, Irrigation and Energy
MUSLE	Modified Version of the Universal Soil Loss Equation
NMSA	National Meteorological Service Agency
NSE	Nash-Sutcliffe Efficiency
RUSLE	Revised Universal Soil Loss
SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil and Water Assessment Tool Calibration uncertainty program
USLE	Universal Soil Loss Equation
USDA	United State Department of Agriculture

1. INTRODUCTION

1.1. Backgrounds

Soil erosion is worldwide environmental crisis that threaten agricultural areas at an alarming rate. As it has direct impact on food production, global societies are considerably aware of the crisis alongside energy and global warming problem. Soil erosion occurs when natural or human induced processes decrease the ability of land to support crops and loss nutrients. The 2000 studies conducted by the Consultative Group on International Agricultural Research, soil erosion and degradation had reduced food production on 16% of the world's cropland (Pimentel, 1993). According to (Pimentel, 2006), the current rate of agricultural land degradation worldwide by soil erosion and other factors was found to be leading to an irreversible loss in productivity, ranging from 6 to 10 million hectares of fertile land in a year.

Soil and water are basic natural resources that have been exploited wastefully of the country. In the countries where main revenues are based on agricultural products, soil erosions and water resources management are great concerned. Most of the farmers living on marginal land or mountainous area in Africa region still have the lack of knowledge on suitable soil conservation measures. Consequently, soil erosion problem will face them. This is reliable with(Yang, *et al*., 2003) who studied the trends of global land use and climate change between 1900 and 2090 using the Revised Universal Soil Loss (RUSLE) model. They also pointed out that Africa is the most seriously affected content in the world.

The improper management system and lack of suitable soil conservation measures have been the main causes of soil erosion and land degradation problems in the country. Soil erosion and Land degradation are resulted from increasing cultivation of mountainous and steeper slopes, without protective measures against it. Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the land degradation through soil erosion is increasing at high rate(Hurni H., 1989). To save soil and water resource degradation, immediate measure should be taken.

Soil erosion is caused by variety of natural and human induced effects. Geologic erosion is when erosion occurs without human influence. Sheet erosion is the detachment and removal of soil during rain events. During this process, the soil particles are transported in an uncondensed, thin sheet of water. Splash erosion is when the first falling rain droplets cause soil to detach and ultimately erode from overland flow. Other causes that accelerates soil erosion are; deforestation, overgrazing and poor land management. Human activity increases the rate of erosion. Due to the fast growing population and the density of livestock's in the basin, there is pressure on the land resources, resulting in forest clearing and overgrazing. Soil erosion and Land degradation also resulted from increased cultivation of mountainous and steeper slopes, without proper protection. Soil erosion results from the combined influence of factors such as climate, topography, soil type and land use (Le Bissonnais, 1996).

The land is strictly harmed by process of soil erosion and its associated effects. The process includes the detachment, transport and deposition of soil particles by the erosive force of raindrops and surface flow of water. Erosion of the land surface takes place in the form of sheet erosion, rill and inter-rill erosion, and gully erosion (Awulachew, *et al.*, 2008). Erosion process occurs when detachment of particle through the kinetic energy of raindrop impact or the forces generated by flowing water. After particle detached, entrainment occurs and the particle transported. The shape, size and weight of the particle and the force exerted on the particle by the water affect both entrainment and transport particle. When this force are diminished to the extent that the transport rate is reduced or transport is no longer possible, deposition occur (Ndorimana, *et al.*, 2005).

Soil erosion modeling is an important tool for feasible conservation of natural, agricultural and built up environments. Catchment scale erosion modeling is particularly desirable, since it facilitates more efficient soil conservation planning by providing spatial data over large areas that may be used to decrease erosion related problems (De Jong, *et al*., 1999).

SWAT is the acronym Soil and Water Assessment Tool, a river basin, or watershed scale model developed. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT, a physically based on spatially distributed hydrological model overcomes the limitation and increasingly used to assess the hydrological behavior of large and complex watershed. The other advantage of using SWAT model is that it is GIS interface model. Rapid parameterization of hydrologic models can be derived using remote sensing and GIS as remotely sensed data provides valuable and up to date spatial information of natural resource and physical train parameter (Tyagi, *et al*., 2014).

Generally, Past studies on soil erosion in Ethiopia were mainly based on plot level or empirical model such as Universal Soil Loss Equation (USLE). USLE predicts average annual gross erosion as a function of rainfall energy. Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). In MUSLE, the rainfall energy factor is replaced with a runoff factor. MUSLE improves the sediment yield prediction, eliminates the need for delivery ratios and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because of runoff is a function of antecedent moisture condition as well as rainfall energy.

1.2. Statement of the problem

Soil erosion has been described as one of a serious Environmental hazards issue because of its difficult economic and environmental impacts. Loss of top soil causes environmental problem and reduce agricultural productivity of the watershed. Accelerated erosion due to human activities is a serious environmental problem as it increases level of sedimentation in the rivers and reservoirs reduce their storage capacity and life, causes flood due to reduction in carrying capacity of rivers and streams. Valuable soil nutrients are lost from the land, where they are needed, deposited in the water system and ultimately in reservoirs. These include diminished land resources and reduced land productivity, as well as sediment delivery, which reduce the storage capacity and life span of reservoirs(Ali, 2014).

The Blue Nile River, which originates from the steep mountains of the Ethiopian Plateau, is the major source of sediment loads in the Nile basin. Sediment particles transported through the channel system and eventually deposited in reservoirs, lakes or at sea. Sediment deposition in reservoir and irrigation systems leads to serious problem. It reduces the reservoir storage capacity and hence leading problem threatening the existing and future water resources development in the Nile basin. The benefits gained by the construction of micro-dams in the Upper Nile are threatened by the rapid loss of storage volume due to excessive sedimentation (Betrie, *et al*., 2011).

In 2006, construction of hydropower and irrigation dam Nashe watershed, western Ethiopia, which caused serious land use changes in the watershed. Before the dam was constructed, the communities living in the area were not considered, and therefore have resulted in forests being converted to cultivated land. These changes in land use have made widespread soil erosion. Due to this, an increased in cropland on steep slope has occurred and which potentially has increased erosion and sedimentation problems in the area. The converted to agricultural land without using control measures and appropriate land management practice which potentially has increased soil erosion in the area.

Therefore, study of the SWAT based soil erosion modeling can contribute in lessening the limitations and gaps related to soil degradation due to soil erosion. This study can prioritizes, to minimize erosion and surface runoff for erosion vulnerable areas, attention to improve soil productivity and to avoid additional damage from soil erosion.

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study is to estimate spatial and temporal patterns of soil erosion using Geographic Information System based version of the Soil and Water Assessment Tool model.

1.3.2. Specific objectives

- To calibrate and validate hydrological SWAT model.
- To estimate the average sediment yield from Nashe catchment.
- To identify soil erosion prone areas in Nashe catchment.
- To suggest the management practices for erosion vulnerable areas to treat them sequentially in order to reduce soil erosion of Nashe catchment.

1.4. Research Questions

Based on the listed objectives, the following questions were used to conduct the research process and finally answered from the findings of the study.

1.How to Calibrate and validate the hydrological model of SWAT?

2. What is the mean annual rate of sediment yield from Nashe catchment?

3. How to identify erosion prone areas (hot spots) in Nashe catchment?

4.What are the Conservation measures to be applied for erosion prone areas of the sub watershed?

1.5. Scope of the Study

Water erosion moves nearly 1.9 billion tons of fertile soil from the highlands of Ethiopia annually. This amount is found to be equivalent to an average soil loss of 1.30 tons per hectares per year from cultivated lands (Hurni H., 1989). This study is, actually a watershed level study and thus focuses mainly on the estimation of sediment yields and identification of the erosion vulnerable sub-watersheds. Soil erosion prone more are identified from estimated sediment yield from sub-watershed by SWAT model. It also maps spatial based sediment yields of sub watershed. Significance of the Study

This study will have important role for evaluation of SWAT model performance, estimate sediment yields and identify erosion prone vulnerable sub-watershed problem for watershed management. Spatial and temporal distribution of sediment yields are assessed by SWAT with GIS interface. It makes available data on an Area which are most prone to soil erosion based on sediment yield generated.

1.6. Organization of the Thesis

The thesis is structured in five chapters: Chapter 1 corporate an introduction chapter where the background, statement of the problem, objectives, research question and scope and significant of study were discussed. In Chapter 2, Literature review about the concept of Soil Erosion Globally, Soil erosion in Ethiopia, soil erosion in Blue Nile Basin Previous studies around Nashe Watershed, Hydrological models and Application of SWAT model. Methodology of the research was carefully arranged in Chapter 3 by describing the study areas, Materials used, data and software used, Sensitivity Analysis of parameter selection, Methods used for calibration and validation flow parameter, Chapter 4 describes result and discussion of performance of SWAT model, estimate annual sediment yields, spatial and temporal sediment yield determined, prone area sub watershed were identified. Finally, in Chapter 5; conclusions and recommendations were provided.

2. LITERATURE REVIEW

2.1. Soil Erosion Globally

Soil erosion is the removal of soil particles by water and wind. It is the physical process of degradation caused by loosing particles from soil surface due to rain drop impact and run off effect (De Jong, *et al.,* 1999). (Morris, *et al*., 1998) defined soil erosion as process whereby earth or rock material is loosened or dissolved and removed from any part of the earth's surface.

According to the erosion site, erosion can be classified to sheet, rill, inter rill, gully and channel and according to erosive process raindrop, channel and mass wasting. Inter rill erosion or sheet erosion is the detachment and transport of soil particle due to rain splash and shallow pre-channel flow. Sheet erosion happens when raindrop impact transports particles and becomes runoff traveling over the surface of the ground (Fortuin, 2006). Rill erosion is the detachment and transport of soil particles by concentrated flow in small channel or rill not more than a few centimeters deep that are eliminated by normal cultivation techniques. Rill erosion occurs when water from sheet erosion combines to form small concentrated channels (Fortuin, 2006). Erosion rates increase due to higher velocity flows as rill erosion starts. Gully erosion and channel erosion may refer to either the gradual or the massive erosion of the beds and banks of gullies and stream channels. Mass wasting refers to erosion associated with slope failures, including landslides and similar slope movements. Whereas, gross erosion is the sum of all type of erosion rill, gully, channel erosion and mass wasting. The relative importance of each type of erosion varies from area to area. Sheet and rill erosion occurs particularly in grazing and cultivated area of mild slope where run off is not concentrated in well-defined channel (Morris, *et al*., 1998).

Soil erosion is a complex process that involves soil properties, ground slope, vegetation rainfall magnitude and intensity (Montgomery, 2007). It occurs when soil is exposed to water or wind energy. Rain drops hit exposed soil with great energy and launch soil particles along with water in to the air. The forms of water responsible for soil erosion are raindrop impact, runoff and flowing water (Wischmeier, 1978). Therefore, soil erosion impacts on agricultural production negatively by depleting nutrients needed for plant growth.

Now days, both developed and developing countries are affected by Soil erosion. Erosion induced loss in soil productivity is a major danger to global food and economic security especially among poor farmers. It not only diminishes the quality of soil resource but also makes earning a living from land increasingly difficult. For developing countries, soil erosion is among the most chronic environmental and economic burden and many of these countries are in the tropics and in the drier zones. African countries are experiencing deforestation, mainly from agricultural expansion and land degradation which are leading causes of soil erosion and sedimentation.

In many countries, soil erosion is the main watershed problem. It causes the global environmental and economic problem of losing the fertile top soil and reducing the productivity capacity of the land there by putting at risk global food security. It also impacts negatively on the natural water storage capacity of catchment areas service of manmade reservoir and dam, quality of surface water, aesthetic landscape beauty and ecological balance in general (Teteri, 2009).

According to Tamene, (2005) stated that, reservoir sedimentation deposition is a reflection of watershed erosion and deposition processes which are controlled by train form, soil type, surface cover, drainage networks and rain fall related environmental attributes.

2.2. Soil erosion in Ethiopia

Soil erosion is the major problem and rate of erosion increased by deforestation, overgrazing and poor land management. In Ethiopian, high lands cultivated sloped or hilly land, causing top soil to be washed away during the heavy rains of the rainy period by many farmers. When the cultivated land has low cover in most part of Ethiopia, the high intensity rain fall occurs. Great concentration storms cause substantial erosion and related sedimentation amassed the cost of operation and maintenance and shortening lifetime of water resource infrastructure.

Studies carried out by Assegahegn, *et al*.,(2013) indicates that, Ethiopia is described as the majority soil erosion affected country in the world with recorded yearly soil loss ranging from low of 16tones/ha per year to high of 300 tones /ha per year. The Blue Nile River which originates from the sharp mountains of the Ethiopian highlands is the major source of sediment loads in the Blue Nile basin. The Soil erosion from upstream of the basin and the ensuring sedimentation in the downstream area a huge problem threaten the existing and future water resource development in the Nile basin.

Soil erosion is recognized as a major problem arising from agricultural growth, land degradation and possibly global climatic change. Ethiopia loss about 1.3 billion metric tons of fertile soil every year and the land degradation through soil erosion is increasing at high rate (Hurni, 1989). Land degradation caused by acceleration of agricultural activities, deforestation and urbanization reduce fertile topsoil resulting in a decrease of agricultural productivity. Poor land use practices, improper management systems and lack of appropriate soil conservation measures have a major role for causing land degradation (Setegn, *et al*., 2009).

Climate, topography, soil type and land use are factors that influence soil erosion results. Accelerated soil erosion is soil erosion due to the agricultural activities, erosion from the construction sites, reclaimed land and mine land, erosion due to deforestation, vegetative inundation and etc. In Ethiopia, soil erosion is a serious problem which threatens the agricultural sector (Alemneh, 2003).

2.3. Soil erosion in Blue Nile Basin

Assegahegn, et al., 2013 assessed that, Soil and Water Assessment Tool (SWAT)-Based Erosion modeling in the upper Blue Nile basin of Mizewa watershed. Tool was calibrated and validated against measured flow and sediment data. Both calibration and validation showed result a good match between measured and simulated result. Mizewa is considered as erosion sensitive area as rate of soil loss (40.9t/ha per year) is more fold of the soil formation rate of the region.

Sediment in the Nile basin is mainly originating from the Ethiopian Highlands *(*Ndorimana*, et al.*, 2005). The substitution of forest lands by agricultural lands is common practice in the Blue Nile Basin, because of the rapid growing population and high density of livestock. Due to the shortage of rainfall season the basin is steep and the vegetation is relatively bare. The high intensity of rainfall rate up soil loss in the basin because of the mountainous and steep slopes are cultivated without effective protective measure against soil erosion.

Blue Nile Basin is characterized by high runoff when compared to the White Nile through the catchment area of the White Nile Basin is about three times that of the Blue Nile Basin (Ahmed, 2008). Blue Nile River which accounts for about 86% of the flood season runoff volume is the main source of flow for the Nile River. Also similar proportion of sediment supplied by the river estimated that contribution of the White Nile River to the Nile River sediment load is less than

5% (Ahmed, 2008). Runoff from highlands of Ethiopia through dense gullies formed during intense storm season and tributaries makes its way to the Blue Nile. The main carriers of eroded sediment are these gullies and tributaries.

The significant contribution to the soil erosion in the basin is agriculture based population growth. To prepare more area for farming, the increasing population expands, to forest areas and clear forests. The agricultural lands prepared can be simply detached by precipitation and then transported by surface runoff in the drainage system. In addition to, no erosive of the rain fall, erodiblity of the soil affects soil erosion rate. In Blue Nile Basin soils are erodible and poorly structured (Zaitchik, *et al*., 2012). High drainage density and sharp ground surfaces of the basin help delivery of eroded material in the river.

Shimelis *et al*.,(2009) assessed that; spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. The main objective of this study was to identity the most erosion sensitive areas with GIS Tool combines the slope, land cover and river layers as a major factor which contributes to soil erosion. The SWAT model has indicated that 18.4% of the watershed area has high potential for soil erosion which provides an average annual sediment yield of 30 to 65 tons per hectares(Shimelis, *et al*., 2009).

2.4. Previous studies around Nashe Watershed

Nashe is the sub watershed of Blue Nile. However, most of the studies related to the Blue Nile River have focused on the northern part of the Blue Nile basin. Nashe sub-basin is the western Blue Nile watershed and is less studied area. Fincha'a and Nashe rivers combined at down side and forms common tributary of Blue Nile basin. More researchers have studied on Fincha'a sub-basin from western part of Blue Nile basin but not on Nashe sub-basin. Some studies conducted on Fincha'a also taken for Nashe as they are similar area.

The study carried out (Bezuayehu, 2008) indicates that, the hydropower reservoir constructed in Fincha'a watershed, western Ethiopia, which caused serious land use changes in the watershed. Especially an increase in cropland on steep slopes has occurred, which potentially has increased erosion and sedimentation problems in the area. Land use is one of the major factors determining soil erosion and reservoir sedimentation in Fincha'a watershed. Its mean annual soil losses from grazing land and forestland are much lower than losses from cropland(Bezuayehu, 2008).

Therefore, croplands are major sources of sediment in Fincha'a watershed and which is similar to Nashe watershed.

2.5. Hydrological models

Modeling is defined as the process of organizing, synthesizing and integrating component parts in to a realistic representation of prototype. The following are some of the benefit of modeling. Models sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiment instead of conducting the experiments on the watershed itself (USDA, 1972).

Models can be divided in different categories(Beven, *et al.*, 1982). (a) Empirically based models. Most of these models have been developed based on field observations in specific environmental contexts to which the model was applied (Terranova, *et al*., 2009). (b) Physically based models. These models are the most complex and strict mathematical relationships. This model developed based on the physics such as conservation of mass and momentum.(Terranova, *et al*., 2009) (c) Conceptually based models. These models lie between the empirically based and the physically based models, and display a partial representation of the hydrological sediment yield processes. These take into account the physical processes governing erosion by water through empirical relationships among the involved variables (Terranova, *et al*., 2009)

Hydrological models can be further divided in two event driven models, continuous process models, or models capable of simulating both short-term and continuous events. Event driven models are designed to simulate individual precipitation runoff events. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. Continuous process models simulate instead a long period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long term runoff volume forecasting and for estimates of water yield (Cunderlik, *et al*., 2003).

There are various reasons for modeling erosion, as erosion models can be used as predictive tool for conservation planning, soil erosion inventories, project planning and regulation. Erosion models give an idea of erosion process, as well as the time and amount of possible erosion at the area of interest so as to allow planners to divert resources to reduce erosion.

2.5.1. Application of SWAT model

SWAT has been successfully applied in evaluating the best management practice in various parts of the world (Betrie, *et al*., 2011). The model has good reputation for the best use in agricultural watersheds and its uses have been successfully calibrated and validated in many areas of the USA and other continent (Tripathi, *et al*., 2003). The SWAT model application was calibrated and validated in the some parts of Ethiopia. (Tibebe, *et al*., 2010) Argued that, based on reasonable model results, SWAT turned out to be sensitive to land use changes and would be a good tool to assess soil erosion and the effects of the best management practice in Ethiopia.

SWAT model was tested for prediction of sediment yielding in Finchaa watershed, located in Western Oromia Regional state, Ethiopia by (Ayana, *et al*., 2012). A study conducted on simulating of Finchaa watershed with SWAT model also showed that the SWAT model was successfully calibrated and validated. This study reported that the model is capable for predicting sediment yields and hence can be used for as a tool for water resource planning and management in this the study watershed.

Tamene, *et al*., (2006) Applied that, Soil and water Assessment Tool (SWAT) model to the Northern Highland of Ethiopia for modeling of soil erosion in Mai-Negus catchment, Tigray regional state, northern, Ethiopia. The study was to test performance of SWAT model to predicting stream flow, sediment yield and soil nutrient loading. The model was successfully calibrated and validated for the Mai-Negus catchment. The result showed that the SWAT model can produce the reliable estimates stream flow and sediment yielding from complex watershed.

SWAT model showed a good agreement between the measured and simulated flows and sediment yields with higher values of R^2 and Nash Sutcliffe efficiency in Lake Tana watershed both in calibration and validation period (Setegn, *et al*., 2009). Through modeling of the hydrology and sediment yield (in Lake Tana Basin, Blue Nile, Ethiopia), indicate that stream flow, soil erosion and sediment yield simulated with SWAT were reasonable accurate.

3. MATERIALS AND METHODS

3.1. Study area

The Blue Nile and its tributaries all raise from the Ethiopian plateau at an elevation of 2000 to 3000 m. The Blue Nile starts at Lake Tana, with a general slope to the northwest direction. After leaving Lake Tana it passes through deep Ethiopian gorges and valleys before entering Sudan. The Blue Nile basin encompasses 16 main sub basins with its catchment accounts for about 20% of Ethiopian land surface. The basin is characterized by mean maximum and minimum temperatures of 11°c and 18 °c respectively. The dominant soil types are Alisols and leptosols 21%, followed by Nitosoils 16%, Vertisols 15% and Cambisols 9% (Betrie, *et al*., 2011).

Fincha'a sub basin is the part of Blue Nile river basin which contains three watershed (Fincha'a, Amerti and Nashe) watersheds. Nashe river sub basin, which is the study area, is located in the north western part of the Blue Nile basin and upper of Fincha’a valley. Nashe sub basin is located in western of Ethiopia in Horro Guduru Zone at 350km from Addis Ababa and starts on a highland plateau with valley elevation 2200m above sea level (asl) and the surrounding ridges extends to over 2500m asl. Average annual rainfall in the area is about 1566.5 mm, which falls during 3-month main rainy season from mid- June to mid- September. It is on upper of Fincha’a valley.

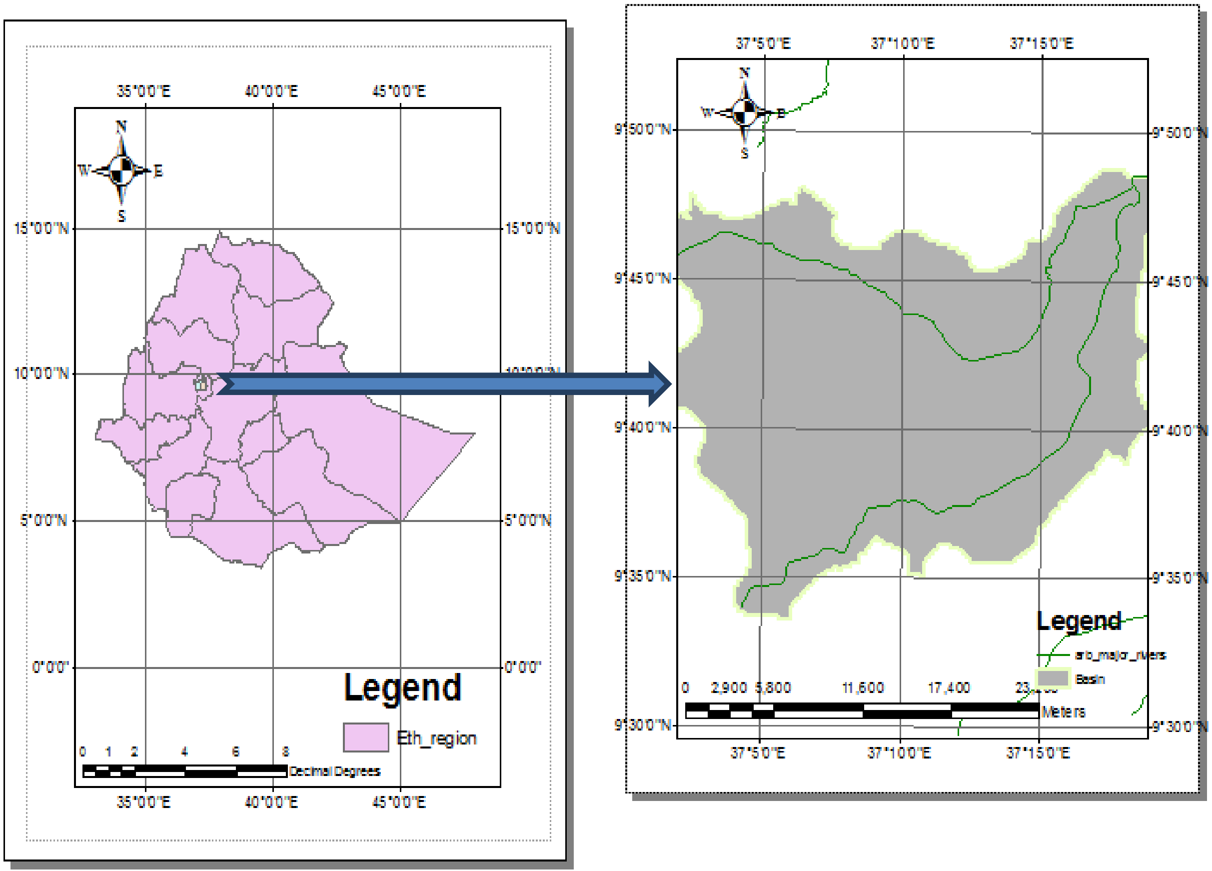


Figure 3.1 the location of study area

3.2. Materials used

Materials and tools used for this study include Arc GIS 9.3, Arc SWAT 2009, PCPSTAT,dew02, SWATCUP and XLSTAT2005.

➢Arc GIS 9.3

Geographical information system is an information system focusing on the collection, modeling, management, display and interpretation of geographical data.ArcGIS9.3 extension is a graphical user interface for the SWAT (Arnold, et al., 1998).ArcGIS9.3 was first installed to display the SWAT2009 toolbars.

➢Arc SWAT

Arc SWAT 2009 was installed by default in folder C:\SWAT\ArcSWAT\ and has been used to simulate hydrological parameters including Sediment yield in Nashe watershed. The SWAT2009 \Arc SWAT interface includes.

1. Personal computer using a recent processor (2008 or more recent), which runs at 2 gigahertz or faster.

2. two GB RAM minimum

3. One Giga byte frees memory on the hard drive for minimal installation an up to 2 gigahertz for a full installation (including sample data set and US STATSGO data).

Software (ArcSWAT) forArcGIS9.3 Versions.

1. The Microsoft Window operating system (e.g. XP, Windows7, server 2008) with most recent kernel patch).

2. Microsoft. Net Framework

3. Adobe Acrobat Reader Version 8 or higher.

4. ArcGIS; Arc View (basic)9.3 with service pack.

5. ArcGIS spatial Analyst extension (ArcGIS 9.3 versions).

- **PCP STAT**

The program PcpSTAT.exe calculates statistical parameter of daily precipitation data used by the weather generator of the SWAT model (userwgn.dbf).

Table 3.1 Statistical parameters of precipitation used by weather generator.

No	Parameter	Definition
1	PCPMM(Mon)	Mean total monthly precipitation
2	PCPSTD(mon)	Standard deviation for daily precipitation in month
3	PCPSKW(Mon)	Skew coefficient for daily precipitation in month
4	PR_W1(Mon)	Probability of a wet day followed by a dry day
5	PR_W2(Mon)	Probability of wet day followed by wet day
6	PCPD(Mon)	Average number of days of precipitation

- **dew02**

The program dew.exe and dew02.exe are designed to calculate the average daily dew point temperature per month using daily air temperature and humidity data. According to (Tamene, et al., 2006)dew.exe is used when average daily temperature is available and dew02.exe is used when minimum and maximum daily temperature data is available. In dew02.exe program the input file storing the maximum and minimum daily temperature and the average relative humidity data must be in ASCII text file with three file. A period of temperature and humidity measurement must start on 1st January and must end on 31st December. Missing data in measurement filled with no value data.

Table 3.2 statistical parameter of temperature used by weather generator

No	Parameter	Description
1	Tmp_max	Average daily maximum temperature
2	Tmp_min	Average daily minimum temperature
3	hmd	Average daily humidity in month
4	dewpt	Average daily dew point temperature

- **XLSTAT2015**

XLSTAT2015 used to calculate missing data by linear regression**.**

- **SWAT-CUP**

It is computer program used for calibration of SWAT model. SWAT-CUP is an interface that was developed for SWAT. The program linksSUFI2,PSO,GLUE,Para Sol, and MCMC procedures to SWAT. Using this generic interface any calibration, uncertainty or sensitivity program can easily linked to SWAT. It enables sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models.

- **SWAT-CUP**

In SUFI 2, uncertainty in parameters accounted from all source of uncertainties such as uncertainties of in driving variables (rainfall), model, parameter and measured data. Propagation of the uncertainties in parameters leads uncertainties in the model output variables, which are expressed as the 95% probability distribution. These are calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variables generated by the propagation of parameter uncertainties using Latin hypercube sampling. This is referred as the 95% prediction uncertainty or 95PPU.

To quantify the fit between simulation result expressed as 95PPUand observation expressed as a single signal by two factors P-factors and R- factors. P- Factor is the percentage of observed data surrounds by modeling results. R-factor is the thickness of the 95PPU envelops. P- Factors range from 0-100% and R-factor 0 to infinitive. P-factor of 1 and R factor of zero are simulation that exactly corresponds to measured data.

3.3. SWAT Model Description

The Soil and water assessment tool (SWAT) is the physical based hydrological model developed by USDA Agricultural Research Service (ARS) (Arnold, *et al*., 1998). SWAT incorporates features of several ARS models. It is long term and computationally efficient watershed model. To model hydrology, sediment, nutrient transport the watershed is divided in to sub basins. SWAT divides area of sub basin in to more land units, possessing similar land use, soil type and applied management strategies for better estimation of the loadings (flows and sediment) from sub basin and predicts the influence of land management practice on constituent yields from a watershed.

SWAT has been employed to model watershed of different scales predict the sediment yields, runoff, stream flow and other across the world. The SWAT has recently been adapted to more effectively model hydrological processes in monsoon climates such as Ethiopia (White, *et al*., 2008). Betrie *et al*., (2011) suggest that, the Soil and Water Assessment Tool (SWAT) was used to model soil erosion in the upper catchments of the Blue Nile over the Ethiopian Plateau and output result was successful calibrated and validated. Tamene *et al*.,(2006) Applied that, Soil and water Assessment Tool (SWAT) model to the Northern Highlands of Ethiopia for modeling of soil erosion in Mai-Negus catchment, Tigray regional state, northern Ethiopia. The model was successfully calibrated and validated.

SWAT allows a number of different physical processes to be simulated in a watershed. For modeling purposes, a watershed may be partitioned into a number of sub watersheds or sub basins. The use of sub basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub basins, the user is able to reference different areas of the watershed to one another spatially.

SWAT, a physical based spatially distributed hydrological model overcomes this limitation and is being performed simulation of very large and complex watershed. The other advantage of using SWAT model is the ability of to build different scenarios and GIS interface model. Rapid parameterization of hydrological models can be derived using remote sensing and GIS as remotely sensed data provides valuable and up-to-date spatial information on natural resource and physical terrain parameters (Tyagi, *et al*., 2014).

SWAT, has been recently been adapted to more effectively model hydrological process in monsoonal climates such as Ethiopia (White, *et al*., 2008). Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money, and enables users to study long term impact. In addition, SWAT uses MUSLE to simulate sediment erosion from HRU which replace the traditional USLE equation. MUSLE uses runoff factor than rain fall factor to estimate sediment yield (Williams, *et al*., 1977). Therefore, SWAT model was selected for this study.

3.4. Data collection and source

SWAT is highly data concentrated model that requires specific information about the watershed. The required data for this study were Digital Elevation Model (DEM), land use/land cover map, soil map, and soil data, weather data, sediment and stream flow data.

3.4.1. Digital Elevation Model (DEM) Data

DEM is the basic input of the SWAT hydrological model. To delineate and analyze the drainage patterns of the watershed, DEM data obtained from Ministry of Water, Mineral and Energy(MoWIE) and GIS department, Ethiopia were used.

3.4.2. Land Use /Land Cover Map

The Land cover data combined with soil cover data generates the most important factors that affect runoff, evapotranspration and surface erosion in the watershed. Land use /land cover data for this study area was obtained from Ministry of Water, Mineral and Energy(MoWIE) and GIS department, Ethiopia.

3.4.3. Soil Map

To simulate stream flow, SWAT model requires different soil textural and physio-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk of density and organic carbon content for different layers of each soil type. Soil map of Blue Nile river basin was obtained from Ministry of Water, Mineral and Energy (MoWIE) and GIS department,

Ethiopia.

3.4.4. Weather data

Weather data is among the most prerequisite parameter for SWAT model, to simulate the hydrological process. The required data was collected form station with in and around the study area: Shambu, Nashe, Homi and Alibo. The rainfall and Temperature (maximum and minimum),data for all station is obtained from Ethiopian National Metrological Service Agency (ENMSA) but relative humidity, Wind speed and solar radiation data were a lot of missing and they were filled by weather generator method.

3.4.5. Stream Flow Data

Stream flow is the discharge that is found flowing in stream channel at a given time and at given location which include surface run off and ground water. The Nashe River flow daily data which is used to calibrate and validate the SWAT model were collected from ministry of water, energy and irrigation bureau. Nashe highly seasonal flow with time resolution of daily was used for this study.

3.5. Data Analysis and Processing

3.5.1. Weather data

The necessary metrological data needed for SWAT were; daily precipitation, daily maximum and minimum temperature, daily solar radiation, daily wind speed and daily relative humidity. SWAT can also generate data using weather generator, for missed data.

The precipitation and temperature of all gauging stations (Nashe, Homi, Alibo and Shambu) were prepared in text format. Solar radiation, relative humidity and wind speed were used only for principal stations (Shambu).These data were gathered Ministry of Water, Mineral and Energy (MoWIE) and GIS department. For the principal station and the rest of the station of missed data were generated by SWAT. Finally all weather data and their location were prepared in text format. Weather simulation data consists monthly average values of all required by the SWAT model in order to generate daily values.

3.5.2. Rain fall data

After the data was collected, analysis of collected data was made. Data obtained from MoWIE contained a lot of missing data and unrecorded data for a long period of time continuously. Because of input data lacks the quality and quantity of hydrological data missing data computation method was used. The daily data required for this study area was collected from MoWIE.

3.5.3. Consistency of recording station

Hydrological data necessary checked its consistency before using the recorded data of station. Sometimes a significant change may occur around particular rain gauge station which affects particular collected data. After a number of years, the consistency data of station may be disturbed. For detecting inconsistency, to correct and adjust collected data was bone by double mass curve method.

The four nearby stations are chosen, in the vicinity of uncertain station. These stations have been adjusted the obtained data. The yearly rain fall values, gauged from this group of station are filled consecutive and their mean yearly values worked out for each consecutive year of available records. The cumulative values for both columns have done. It is determined by plotting the cumulative values of observed time series of stations for which consistency need to be checked on Y- axis verses cumulative values observed time series of group of station on X-axis. The data series, which is inconsistency, will be adjusted to consistent values by proportionality. Finally their consistency has been analyzed cumulative rain fall of Shambu verses all stations cumulative rain fall. Therefore, the station to be adjusted for consistency by using equation:

$$Si=\frac{Yi}{Xi} \quad \ldots\ldots 3.5.1$$

Where, S_i: is the slope of section

Y_i: is the change of cumulative catchment for gauge Y between the end point of the section i,

X_i: is the change in the cumulative catchment for the sum of the regional gauges between the end points of sections i.

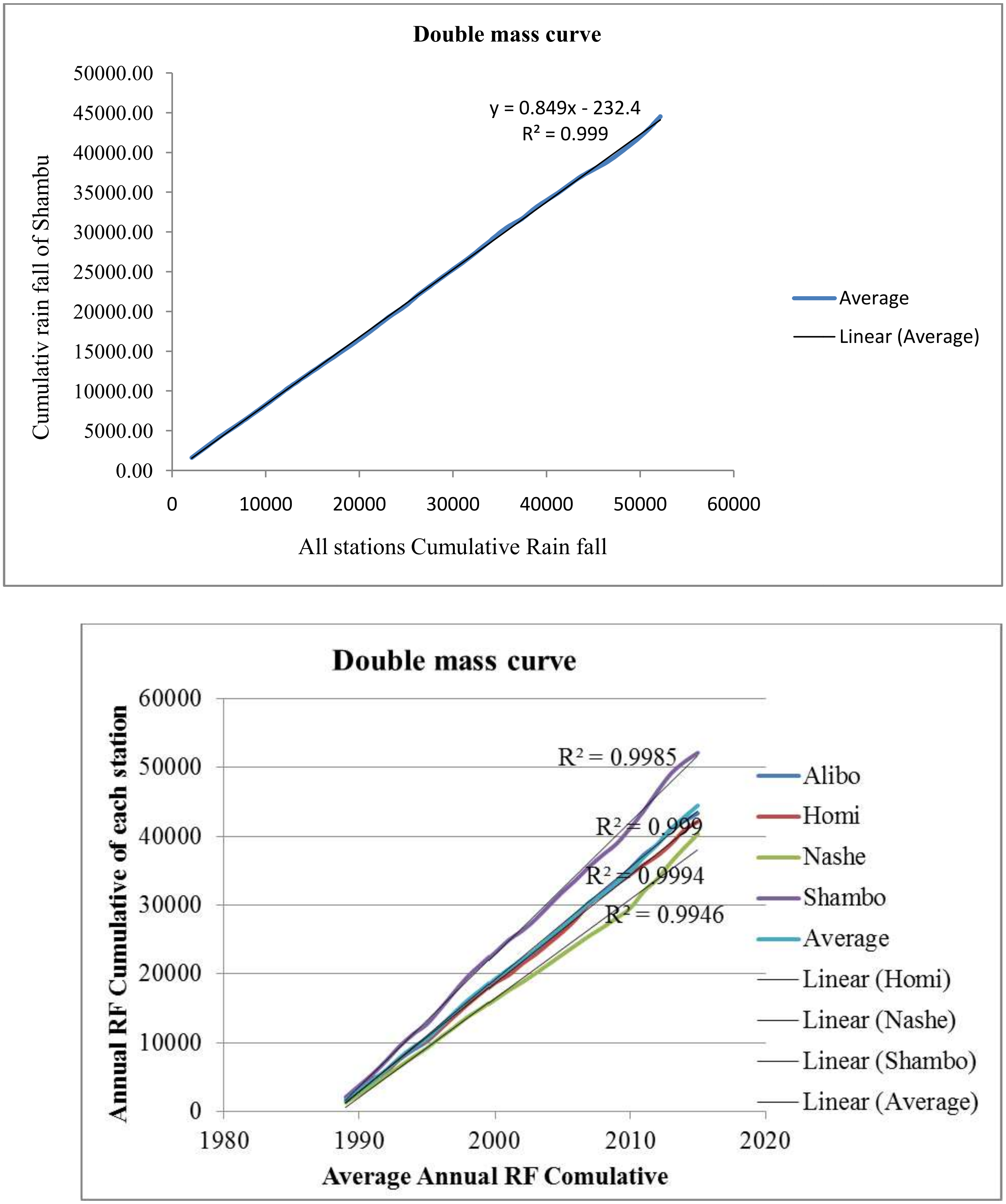


Figure 3.2 Double mass curves

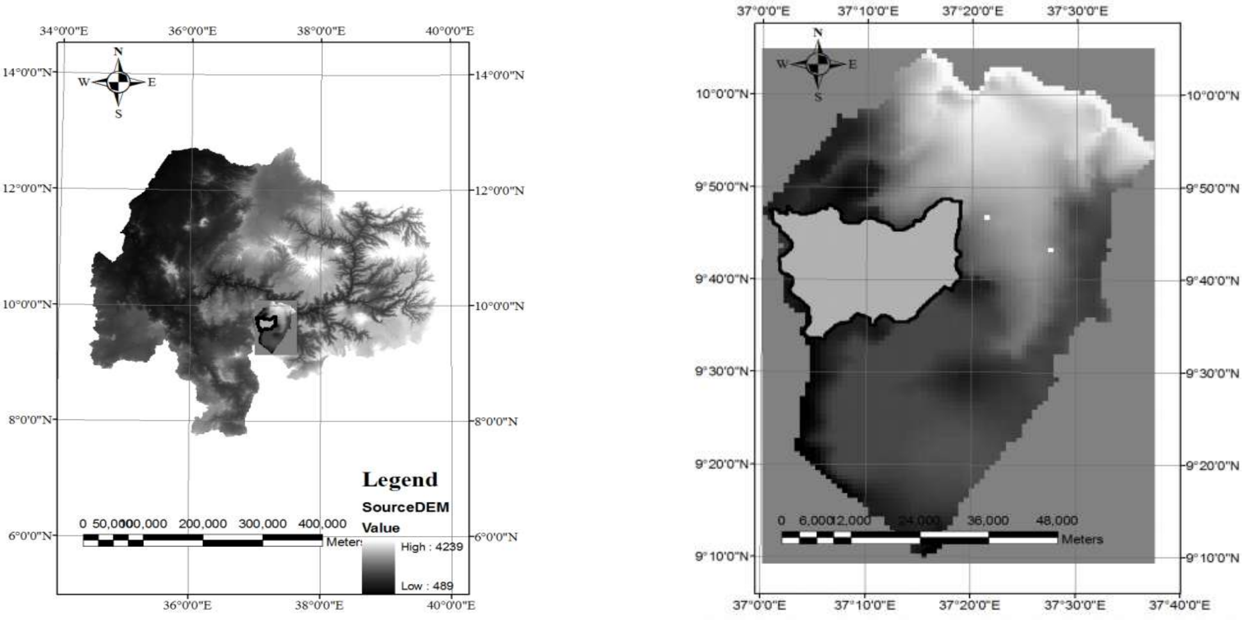
3.6. SWAT Model setup

3.6.1. Watershed delineation

SWAT uses digital elevation model (DEM) data to automatically delineate the watershed in to hierological connected sub watershed. The required datasets were projected to the same projection called Adindan UTM, which is the transverse Mercator projection parameter for Ethiopia, using ArcGIS 9.3. Watershed delineation operation uses and expands ArcGIS and spatial Analyst extension function to perform watershed delineation.

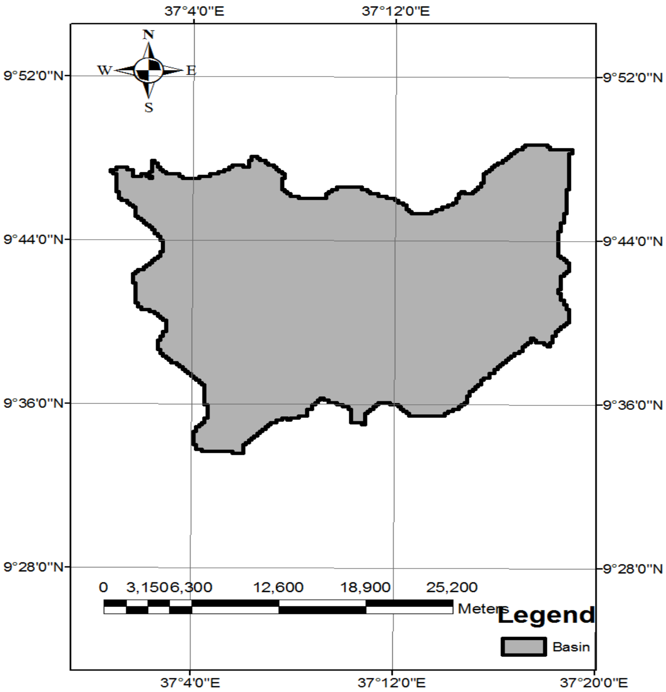
In Watershed the delineated DEM was loaded to the model interface. Its properties were set to verify project and units of measurement. The DEM of Nashe watershed, which is the study area was clipped by using GIS and loaded to ArcSWAT for further processes can described in figure3.3.

After the DEM grid was loaded, the DEM map grid was processed to remove the non-draining zone. The DEM mask was superimposed on the DEM used for stream delineation from masked area. The stream definition and size of sub basin were carefully determined by selecting the threshold area of minimum drainage is required to perform the origin of the streams. Based on drainage area threshold approach stream network and sub basin outlets were defined. The threshold area defines drainage area required to form the beginning of stream. A minimum, maximum and suggested watershed area was shown in the drainage area box. The smaller the threshold, the more detailed the drainage network delineated by the interface but the slower the processing time and the larger memory space required. In this study threshold area was used based on minimum and maximum threshold area.



Abay DEM

Fincha'a DEM



Nashe DEM

Figure 3.3 Digital Elevation Model (DEM) of the study area.

The outlet of discharge for the sub basin and inlet of drainage watershed and definition of point source input or by adding manually point source to each sub basin. The more defined watershed was done by defining the outlets point for the whole watershed. The watershed delineation activity was finalized by calculation of sub-basin parameters. The calculation of sub basin parameter section contains function for calculating geomorphic characteristic of sub basin and reaches, as well as defining number of outlets and number of sub basin were determined.

3.6.2. Hydrologic Response Unit Analysis (HRU)

Hydrologic response unit are lumped land area within the sub basin that are comprised of unique land cover, soil and management combination. SWAT predicts the land phases of the hydrologic cycle separately for each HRU and routes obtained the total loading of the catchment.HRU enables the model to reflect difference in the soil erosion, evapotranspration and other hydrological conditions for each land covers and soils. The total runoff depends on actual hydrologic condition of each land cover/land use and soil present in watershed.

The runoff is estimated separately for each HRU and routed to obtain the total run off for the watershed and hence the sediment yields. This increases the accuracy in flow prediction much better physical description of water balance.

The land use/land cover and soil maps of the study area were imported to model and overlaid to obtain a unique combination of land use, soil and slope within the watershed to the model. The distribution of the hydrological response units within the watershed area were determined after overlay of the land use, soil maps and slope.

The HRU distribution in this study was determined by assigning multiple HRU to each sub basin. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils, and slope classes in each sub basin. After the elimination process, the area remaining land use, or soil was reapportioned so that 100% of land area in the sub-basin was modeled. The SWAT user's manual suggest that a 20% land use threshold, 10% of soil threshold and 20% slope threshold are adequate for most modeling application .However, Setegn *et al*., (2009) suggest that, HRU definition with multiple option that account for 10% land use,20% soil and 10% slope threshold combination better estimation of runoff and sediment component. For this study, 5%

land use, 10% soil and 10% slope was used. After land use, soil/slope definition is done a shape file called 'FULL HRUs' were created.

HRU is finalized by reading report done. Various reports concerning sub basin, land use soil and slope distribution, topographic and HRU properties. HRU's analysis reports under the HRU analysis menu the final HRU distribution report were generated. As per the final reports the watershed numbers of HRUs and sub basin produced were 144 and 15 respectively.

3.6.3. Land use/land cover

Land cover is one of highly affecting hydrological properties such as runoff, evapotranspration and surface erosion in watershed. Land cover of map of Nashe watershed was clipped from Blue Nile land cover map. The land cover spatial data were loaded in to the ArcSWAT interface in projected shape file format to determine the area and hydrologic parameter of each land soil category simulated within each sub watershed. A look up table was made in DBF file and used to connect the LULC and soil data to the SWAT database and custom soil database respectively. SWAT codes for different categories of land cover. The major land use of the study area presented below in figure (3.4).

Finally, calculation of the area covered by each land use and reclassification were done. Original land use /land cover types and redefined according to the SWAT code and percentage of their Arial coverage as shown in table.

Table 3.3 Original land use/land covers types and redefined according to the SWAT code and their areal coverage.

Original land use	Redefined land use according to SWAT database	SWAT code	Area	
			Ha	%Watershed
Dominantly cultivated	Corn	CORN	30520.00	51.02
Moderately cultivated	Agricultural land -Row-crop	AGRR	24276.00	40.58
Grassland	Pasture	PAST	3604.00	6.03
Water body	Water	WATR	1308.00	2.19
Urban	Urban residential low density	URLD	108.00	0.18

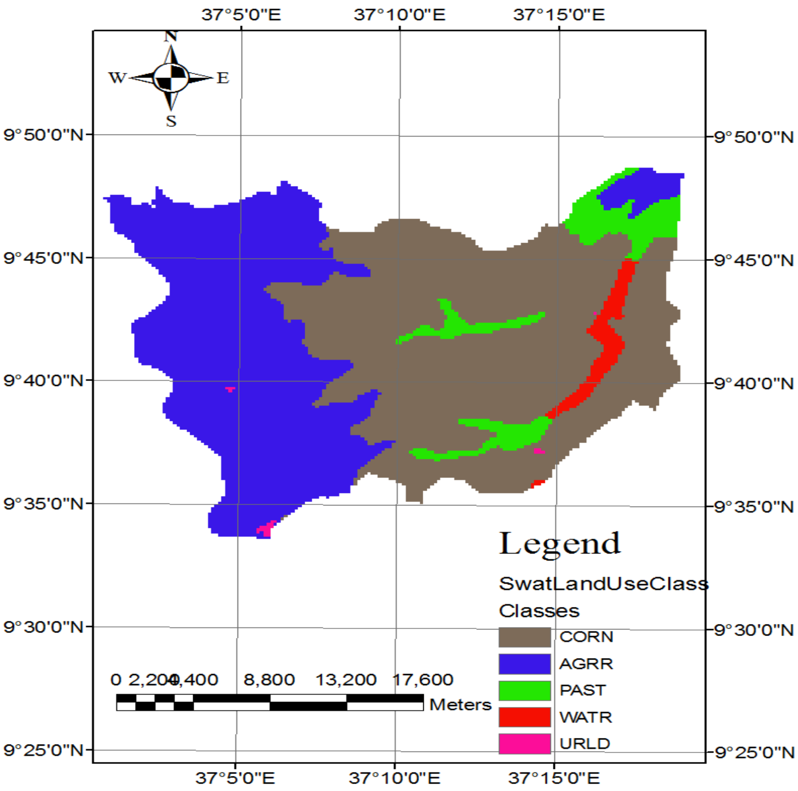


Figure 3.4 Map of the major land use/land cover types of Nashe watershed

3.6.4. Soil map

The obtained soil map shape file was co- referenced with FAO (1998) soil data base to obtain the physical and chemical properties of soil. The soil physical attributes were initially related to the FAO soil database and integrate the related FAO soil database with SWAT database. In order to relate the study area soil in to FAO, MWSWAT was downloaded from (http://www.waterbase.org) which contains physical and chemical soil properties. Finally a look up table prepared was loaded and reclassification applied. The major soils in the sub basin are shown in figure (3.5).

Table 3.4Soil types of the study area with their aerial coverage.

Soil type	Area	
	Ha	% in watershed
Eutric Cambisols	4.00	0.01
Eutric Leptosols	328.00	0.55
Eutric Vertisols	25204.00	42.14
Haplic Alisols	29732.00	49.71
Haplic Arenosols	2244.00	3.75
Marsh	1004.0	1.68
Water	1300.00	2.17

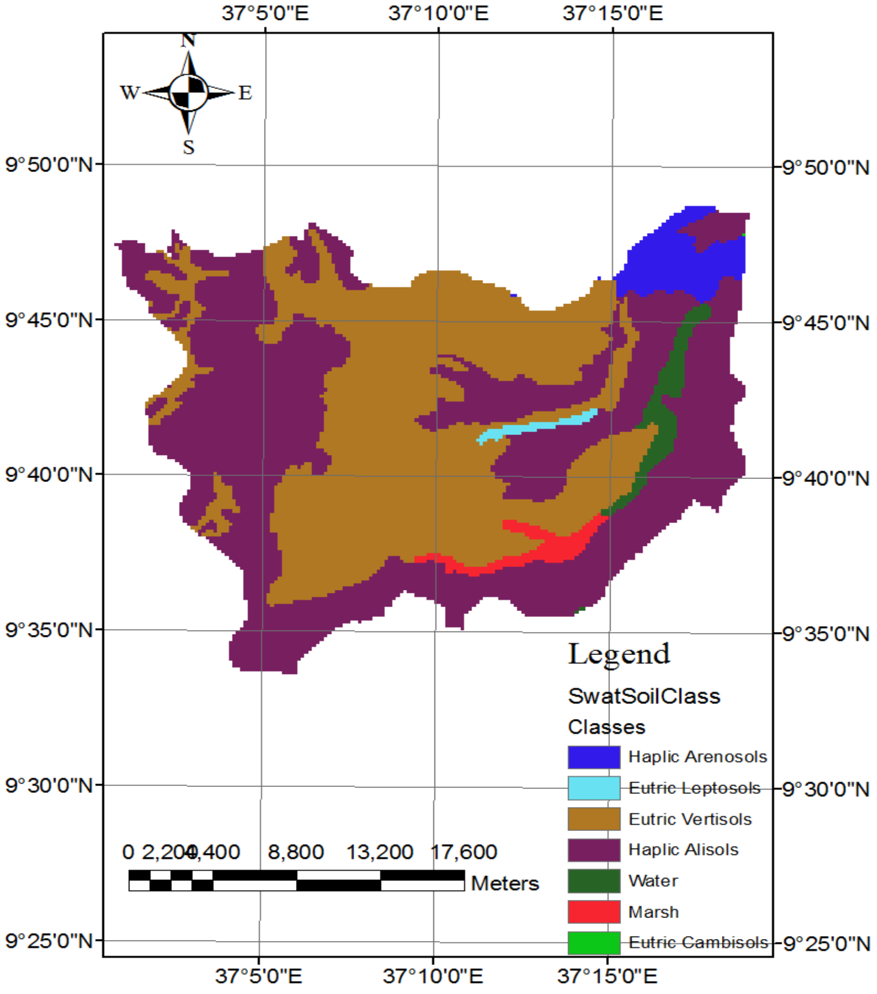


Figure 3.5 Map of the major soil type of Nashe watershed.

3.6.5. Slope map

The land slope was also used for the development of the HRU. Slope is derived from inputted DEM data used during the watershed delineation. For this study multiple slope discretization has been selected over simply a single slope class. ArcSWAT allows the integration land slope classes when defining the hydrological response unit and multiple slope class was used to classify the slope in to four slope class. After reclassification of land use, soil and grids overlay was performed. Catchment was divided into HRU when overlay finished. A detailed report was generated with the based on sub basin land use, soil and slope distribution and topographic and HRUs properties.

Table 3.5 the slope classes of Nashe watershed

Class	Slope range	Land form	Area	
			Ha	%age
Class 1	0-2	Flat	11528.00	19.27
Class 2	2-5	Gentle slope	18868.00	31.54
Class 3	5-8	Steep hill	11384.00	19.03
Cass 4	> 8	Very steep slope	18036.00	30.15

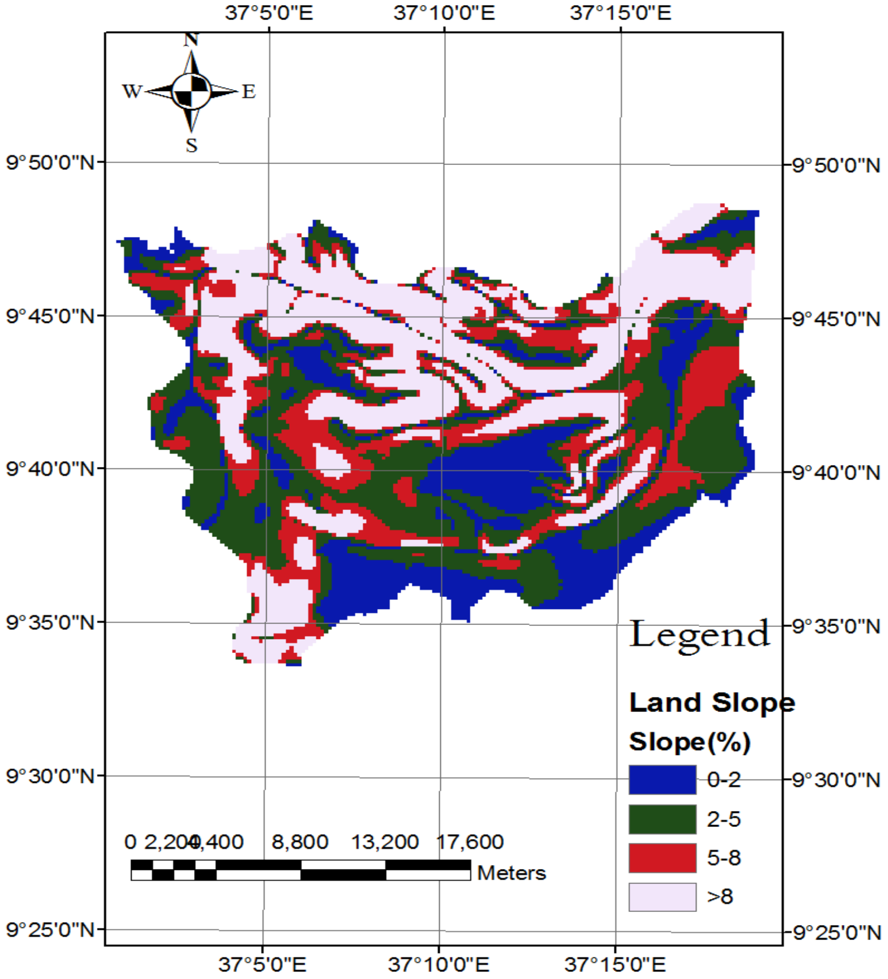


Figure 3.6 Map of slope classes used in the SWAT of Nashe watershed.

3.6.6. Weather Generator and Writing input tables

Weather generator solves the problem of lack of the full realistic long period of climatic data by generating data having same statistical properties as the observed ones. A SWAT built in weather generator called WGEN that is used to fill the gaps for generating missing data. But, the data used for weather generator were prepared using different software.

The writing Input tables menu contains items that allow building database files containing the information needed to generate default input for SWAT. Weather data to be used in a weather simulation was imported once the HRU distribution has been defined. The weather data has been loaded using the weather station command in the write input tables menu item. Using file browser the locations of the weather generator station prepared in the text format was selected. In this study all the weather stations or the weather data definition location were prepared in text format and loaded.

3.6.7. Edit SWAT Input

SWAT editor reads the project database generated by ArcSWAT. In order to use the swat editor, SWAT project under the all write all menu has been created. The editor made to the parameter using ArcSWAT interface is reflected only in the current SWAT project. If the parameters area not defined in the watershed a dialog box notifies the warning.

3.6.8. Simulation SWAT

Finally, the SWAT model has been run and read the SWAT model output by importing files to database and saving to place of interest or by opening the output.std. For this study, the SWAT simulation performed Output times step (Monthly) and rainfall distribution (skew normal) for the watershed. SWAT-CUP is used for sensitivity analysis, calibration and validation.

3.7. SWAT Hydrological processes

3.7.1. Hydrology component

To investigate the soil erosion modeling of Nashe watershed the Soil and Water Assessment Tool (SWAT) model was used. SWAT was developed for the purpose of simulation and to predict impact of land management practice on water and sediment. In SWAT, the water balance is computed from the soil water content which is described by the following equation.

$$SW_t=SW_o+\sum_{i=1}^{t}(Rday-Qsurf-Ea-Wseep-Qgw) \qquad 3.7.1$$

Where SW_t: the final soil water content (mm)

SWo: the initial water content (mm), t : the time (days)

R_{day}: the amount of precipitation on day i (mm)

Q_{surf}: the amount of surface runoff on day i (mm)

E_a: the amount of evapotranspration on day i(mm)

Wseep: the amount of water entering the vadose zone from the soil profile on day i (mm)

Q_{gw} : the amount of the return flow on day i (mm)

3.7.2. Surface runoff component

To set up the model the amount of rainfall is one of the input parameter amongst other weather parameter which is required. The SCS curve number is used to determine runoff depth (USDA, 1972).

$$Qsurf = \frac{(Rday - Ia)2}{(Rday - Ia + S)} \text{……………………………………………………...…} 3.7.2$$

Ia=0.2S

$$S=25.4(\frac{1000}{CN} - 10) \text{...} 3..7.3$$

$$Qsurf = \frac{(Rday - 0.2S)2}{(Rday + 0.8S)} \text{..} 3.7.4$$

Where, Qs_{urf} is the accumulated runoff or rainfall excess (mmH20).

R_{day} is the rain fall depth for the day (mmH_2O).

I_a is the initial abstraction which includes surface storage, interception and infiltration prior to runoff (mmH2O) and commonly approximated as 0.2S.

CN is the curve number for the day.

Runoff only occur when R_{day} >Ia. The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of the storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with modified rational method (Neitsch *et al*.,2005). The corresponding equation is:

$$q\ peak = \frac{CxixA}{3.6} \text{...} 3.7.5$$

where; q peak= runoff rate (m /s) i =rainfall intensity (mm/h)

A= sub basin area (km)C= runoff coefficient

3.7.3. Sediment yield component

SWAT model calculates the surface erosion and sediment yield within each HRU with the modified Universal Soil Loss Equation (MUSLE) (Williams, 1975).The sediment supply from the individual HRU is computed by the modified universal soil loss equation.

Sed =11.8 (S_{urf} x q_{peak} x area$_{hru}$)$^{0.56}$ K_{USLE}X C_{USLE}X P_{USLE}X LS_{USLE}X CFRG..........................3.7.6

Where; Sed= sediment yield (t/day), Q =surface runoff volume (mm), q =peak runoff rate (m /s), area =area of HRU (ha), K USLE= erodiblity factor, C USLE= cover and management factor, P USLE= support practice factor, LS USLE= topographic factor, CFRG =coarse fragment factor.

3.7.4. Sediment rating

Historical data on suspended sediment concentrations/loads for Nashe River were obtained from the Hydrology Department of the MoWIE, Ethiopia. Data availability is limited to very few days in a year and it is highly uneven. A precise estimates of suspended sediment yields of watershed depends on availability of long and reliable records of suspended sediment concentrations. But when these records are unavailable, estimates are often derived from empirical relations between river discharges and corresponding suspended sediment concentrations/loads (Ulke *et al.,* 2009).

$SS = aQ^b$ 3.7.7

Where, SS is suspended sediment concentration/load,

Q is stream flow rate, a and b are constants to be determined from observed discharges and suspended sediment concentrations/loads.

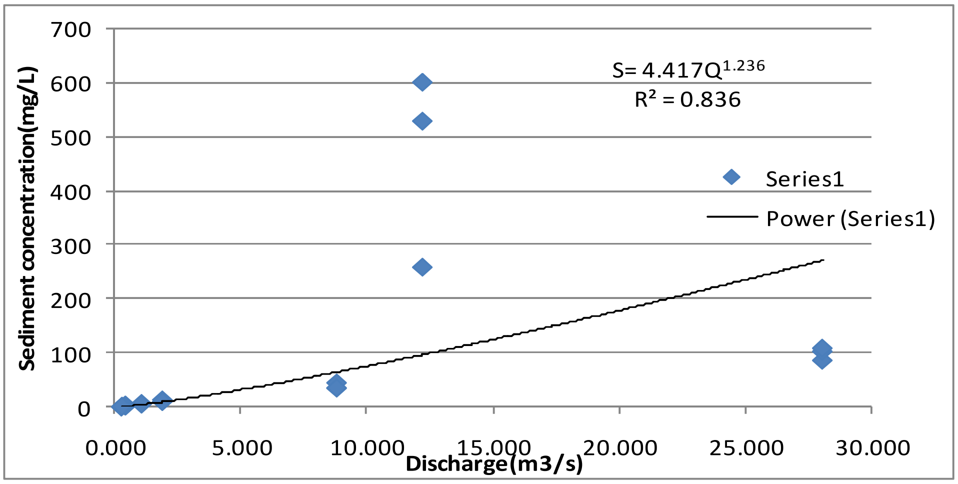


Figure 3.7 Sediment Discharge Rating curve for Nashe station.

From the rating curve figure 3.7 coefficient a is equal to 4.417,power is equal to 1.236 and regression coefficient R2 is equal to 0.836. And to generate the sediment concentration for Nashe is developed by below equation.

SS=$4.417Q^{1.236}$..3.7.8

3.8. Sediment yield

Sediment is fragment material, primary shaped by the physical and chemical breakup of rocks from the earth's crust. Sediment yield refers to the amount of sediment exported by a basin cover period of time and sediment discharged by a stream at any given point; it is the total amount of fluvial sediment exported by the watershed tributary to a measurement point and is the parameter of primary concern in reservoir studies. They ranges in size also vary in specific gravity and mineral composition. Once the sediment particles are detached, they may either be transported by gravity, wind and water.

The highlands watershed factors such as average slope, land use and land cover, soil property and hydro-climatic are the basis for formulating empirical models which are old to estimate sediment yield on a watershed scale. Empirical models are developed with the help of statistical method based on parameters of observed in the field. Such models are easily valid but frequently criticized for their spatial and temporal flexibility limitations. The models can simply forecast the erosion and sediment yield for the areas in which they were developed and for the specific time period measured for their formulation. For the specific situations of different parts of the world, dissimilar sediment yield quantification equations have been projected.

3.9. Determination of soil erosion prone area

After assigning ranking based on every single parameter, rated values for each watershed were averaged to arrive at a composite value. Based on the average value of sediment yield generated, the sub watershed having the highest value of sediment yield is assigned the highest priority denoted by severe soil erosion; the sub watershed with next highest value sediment yield is assigned a priority denoted by number moderate soil erosion, and so on. The sub watershed that got the highest sediment yield (75-150) is assigned the severe soil erosion. Lastly, the final soil erosion of Nashe watershed classifications were given into three major classes i.e. severe soil erosion, moderate soil erosion and Low soil erosion.

3.10. Watershed Management and Conservation measures

Watersheds in their natural state are focus to continuous processes of change erosion, sedimentation, flooding, and change in water quality. The difficulty of watershed degradation is that these processes of change are accelerated and their harmful impacts become further marked. For example, soil erosion is a natural process, but it can be accelerated by overgrazing, deforestation, the expansion of road networks, and inadequate soil and moisture conservation measures on cultivated lands. The more rapid erosion quickly reduces the depth of fertile topsoil, creates gullies in the land, and causes sedimentation of streams.

Watershed management helps to reduce soil erosion, reservoir sedimentation, flood damage, decrease the loss of green space, and improve water quality. Soil Conservation is a combination of the appropriate land use and management practices that promote the productivity and sustainable use of soils and in the process minimizes soil erosion and other form of land degradation. Soil and water conservation practices are the primary step for watershed management. The Conservation practices for management can be divided into two main categories as in-situ and ex-situ management. The in- situ managements are Land and water conservation practices, made within agricultural fields like construction of contour bunds, Stripping, terraces building, and agro forestry or furrow practice and other soil-moisture conservation practices. These practices protect land degradation, improve soil health, and increase soil-moisture availability and groundwater recharge. Moreover, construction of check dam, farm pond, gully control structures, pits excavation across the stream channel is known as ex-situ management. Ex-situ watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds.

3.11. Sensitivity Analysis

Sensitivity analysis is the process of identifying the rate of change in model output with a change of model input. An important function of sensitivity analysis is to minimize the number of parameters to be used in calibration by selecting the most sensitive parameters. The model parameters that have high sensitivity must be chosen with the care because small variation in the values can cause large variation in model output, and therefore it is important to ensure that the parameter value is the best possible estimate.

In SWAT-CUP, two types of sensitivity analysis were generally performed. The first method is global which is allowing all parameter value to change. Parameter sensitivities are determined by calculating the following multiple regression system, which regress the Latin hypercube made parameters in contradiction of the objective function value;

$$g=\alpha+\sum_{i=1}^{n}\beta ibi \quad \ldots\ldots 3.8$$

A t-test is the used to identify the relative significance of each parameter bi. The sensitive given by above are estimate changes in the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing. The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect).The large, (in absolute value) the value of t-stat and the smaller value of p-value, are the more sensitive parameter.

The second method is the One-at-a-time sensitive. One-at-a-time sensitive indicates the sensitive of variable to the change in the parameters are kept constant at some value. The difficulty here is that the correct value of other parameter that are fixed never kwon. This is a significant consideration as the sensitive of the parameter depends on the value of the parameters.

3.12. Model calibration and validation

To improve the results of the model simulation and uncertainties the model calibration was used. SWAT model considers many parameters, and calibration was supported by the sensitivity analysis to identify the effective parameters which governs the stream flow. To calibrate the model 10 most sensitive parameters were used and the remaining parameters have been considered in calibration according to their order of importance. Simulated and observed data were compared to calibrate the model parameter evaluation and typically done by comparing stream flow data.

The model has been calibrated to the measured data of the 4 gauging stations, namely Shambu, Nashe, Homi and Alibo stations. Records of stream flow data of the river Nashe from 1989-1990 for warm up and 1991 to 2008 for calibration and validation model was used. A periods of record has been divided in to two, i.e. from 1991-2001 data for has been used for calibration model, while the data 2002-2008 has been used for model validation. Calibrated parameters were been carried out for validation of the model.

3.13. Model Performance Assessment

To evaluate the accuracy of overall model calibration and validation, different statistical indicators are used for SWAT model. For this study, four statistical indicators like coefficients of determination (R^2), Nashe Sutcliffe modeling efficiency (N_{SE}), Root mean square error observation standard deviation ratio (RSR) and present bias (PBIAS) have been used.

Coefficient of determination (R^2): Is the indicator of relationship between the measured and simulated values. R^2 ranges from 0 to 1; with higher value the more approach to 1 indicating better agreement and value less than 0.5 indicates a poor performance of the model.

$$\mathbf{R^2}=\left[\frac{\sum_{i-1}^{n}(Oi-O\prime)(Si-S\prime)}{\sqrt{\sum_{i-1}^{n}(Oi-O\prime)2}\sqrt{\sum_{i-1}^{n}(Si-S\prime)2}}\right]$$

Where Oi = Observed stream flow

Si= Simulated stream flow,   S'=Mean Simulated stream flow

O'=Mean Observed stream flow,   n=Number of observation

Nash-Sutcliffe Efficiency (N_{SE}): NSE measures the degree of fitness of the observed and simulated data variance. The more the NSE approaches to 1, indicates the better will be the model performance.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)2}{\sum_{i=1}^{n}(Oi - O')2}$$

Percent bias (PBIAS): PBIAS is another parameters used to evaluate the performance of model and which measures the average tendency of simulated data to be larger or smaller than the observed values. The lower the absolute value of the PBIAS is the better will be the model performance.

$$PBAIS = \left[\frac{\sqrt{\sum_{i=1}^{n}(Oi - Si) * (100)}}{\sqrt{\sum_{i=1}^{n}(Oi)}}\right]$$

4. RESULT AND DISCUSSION

4.1. Sensitivity analysis

A sensitivity analysis was conducted to determine which of the unknown variables and most sensitive parameters have the largest effect on the stream flow in the model result. Prior to applying the sufi-2 for calibration the most sensitive parameter were selected by running the sensitivity analysis. The result from sensitivity analysis was provided by ranking of input parameters that have most impact on stream flow output. To perform the model calibration from twenty seven (27) ranked parameters were considered. Out of these parameters only ten (10) of them, which have greatest influence on model output, were selected as parameters for calibration process.

Table 4.1 result from the sensitive analysis are shown below table

Parameters	Rank	P -value	t -value	Fitted value	Min value	Max value
CN2	1	0.000	-15.187	0.000	-0.200	0.200
ESCO	2	0.413	-0.826	0.900	0.800	1.000
SOL_AWC	3	0.345	-0.954	0.100	-0.200	0.400
SOL_BD	4	0.787	0.271	0.050	-0.500	0.600
GW_REVAP	5	0.490	-0.695	0.100	0.000	0.200
CH_K2	6	0.282	1.089	67.500	5.000	130.00
CH_N2	7	0.490	1.041	0.150	0.000	0.300
SFTMP	8	0.994	-0.006	0.000	-5.000	5.000
GWQMN	9	0.280	1.094	1.000	0.000	2.000
GW_DELAY	10	0.000	-14.702	240.000	30.000	450.00

4.2. Calibration and validation

Calibration and validation was done for Nashe watershed. The stream flow of (1991-2008) measured daily flow was changed to the monthly flow and made as per SWAT -CUP requirement for calibration and validation. The period was divided into two for calibration and validation. Eleven years monthly stream flow data from (1991-2001) was used for calibration and seven years (2002-2008)monthly stream flow data was used for validation using fifteen ten sensitive parameters.

The performance of the model to simulate the stream flow during the calibration and validation period has been assessed based on the figured results of the displayed and recommended model performance ranking values. The computed statically values indicates that very good performance model for Nashe watershed.

4.2.1. Model calibration

Calibration was performed, after the most sensitive parameter was identified. It refers to the processes of selecting the best model parameters to compare the simulated outputs and observed data. After the sensitive parameters had been recognized, the calibration process focused on modifying model sensitive input parameters determined from sensitivity analysis to compare the observed and simulated monthly flow from 1991-2001for calibration period. Model calibration is an important step in catchment modeling studies that helps to reduce uncertainties in model predictions(Abbaspour, *et al*., 2007). Two years flow data for warming period and the rest of period for model calibration were taken**.** Ten(10) most sensitive parameters were selected during the stream flow model calibration process.

The calibration result simulated stream flow on monthly based perform well for Nashe watershed catchment as shown goodness of fit. The statically result for the model performance displayed satisfactory (coefficient of determination R^2 and the Nash -Sutcliffe equation N_{SE}) between simulated and observed flow was 0.79 and 0.75 respectively. This indicates that results were estimated by evaluating the modeled results are within the acceptable level with the measured stream flow at Nashe River gauging station.

Generally, efficiency values ≥ 0.50 for N_{SE} and ≥ 0.60 for R^2 are considered adequate for SWAT model application in management planning as it captures the variability of simulated and observed values well (Santhi, *et al*., 2001). SWAT model was calibrated successfully on monthly basis by considering the model statistics (N_{SE} and R^2) for flow calibration. This show the last value of the model sensitive parameters chosen during the calibration indicate that those parameters in the study area.

The visual comparison of graphs also another measures of the model performance during calibration for stream flow (figure 4.1) which is important to identify model partiality and variation in the timing and amount of peak flows simulated. It shows the relationship between the model simulation output and observed data for model calibration.

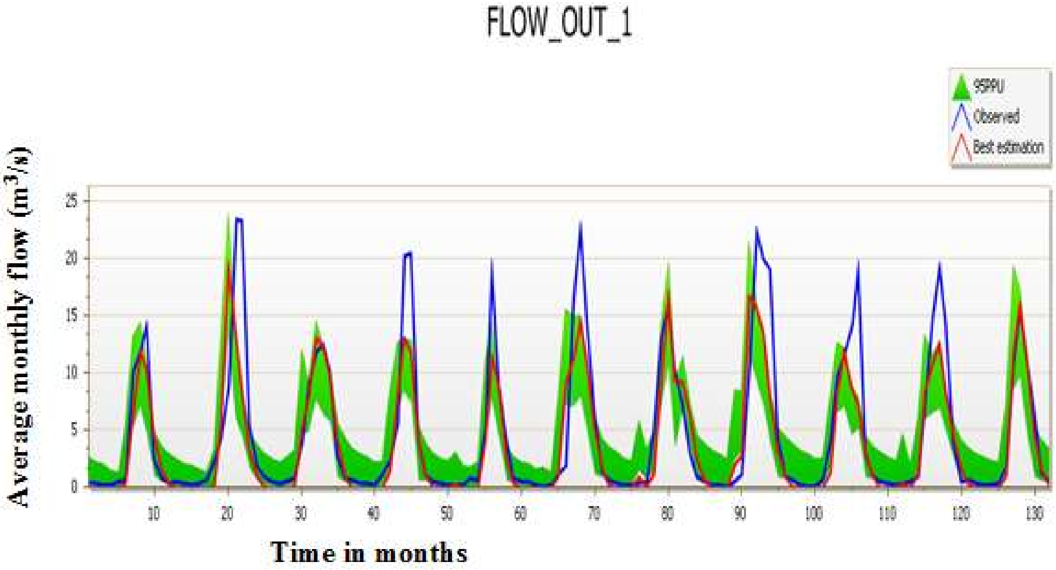


Figure 4.1 Calibration results of monthly observed and simulated flows by SUFI-2 of Nashe watershed.

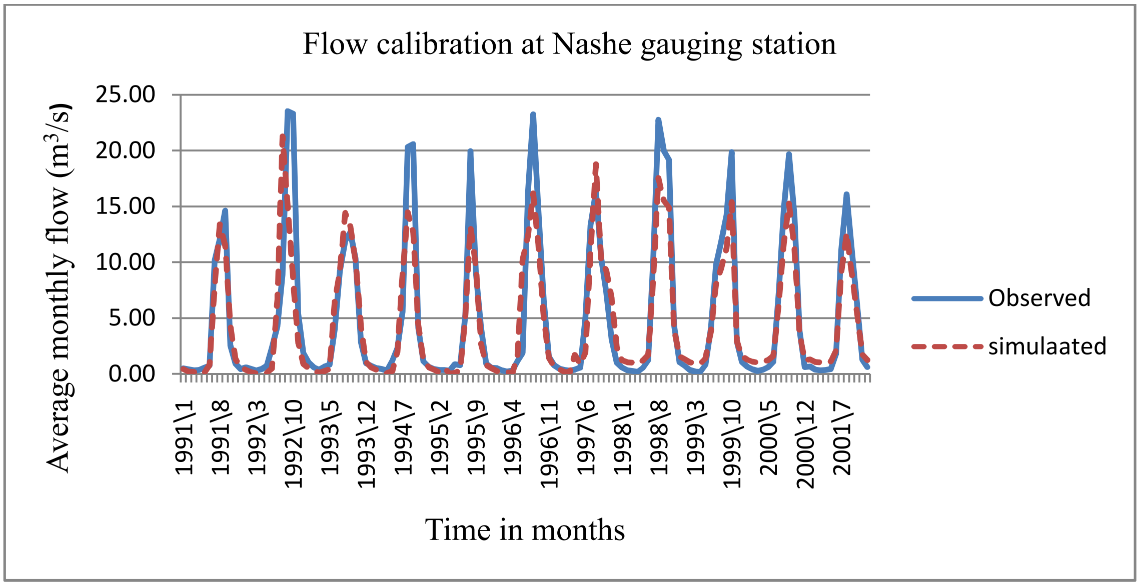


Figure 4.2 Calibration results of monthly measured and simulated flow.

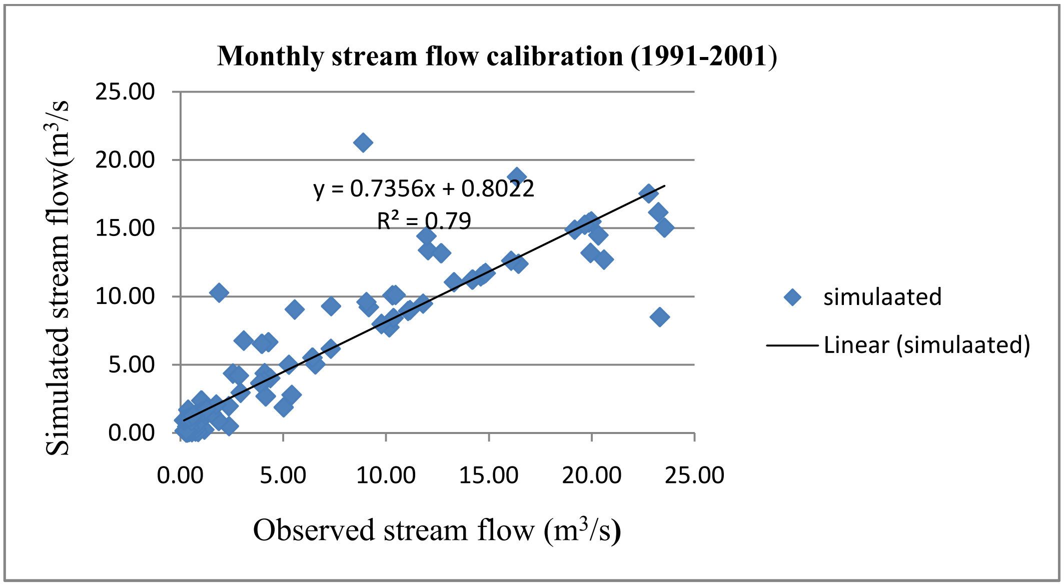


Figure 4.3 scatter plot of observed and simulated stream flow for Nashe watershed during calibration period.

4.2.2. Model Validation

The calibrated model was then run from 2002-2008 to validate the model. The final calibration and validation simulation output closely each other. During this validation period the model is capable of accurately predicting stream flow in Nashe watershed. This close correction represents that SWAT model accurately predict stream flow, by showing the relationship between the simulated output and observed data.

Generally, model prediction ability for the monthly stream flow is successfully for the study catchment as it is greater than (0.50 and 0. 60) for N_{SE} and R^2 respectively. For this study, monthly validation of statistical analysis showed that good agreement between observed and simulated stream flow, which was explained by R^2 and N_{SE} values (0.71 for $R^2$and 0.65 for N_{SE}). Figure (4.4) shows the relationship between the model simulation output and observed data for validation.

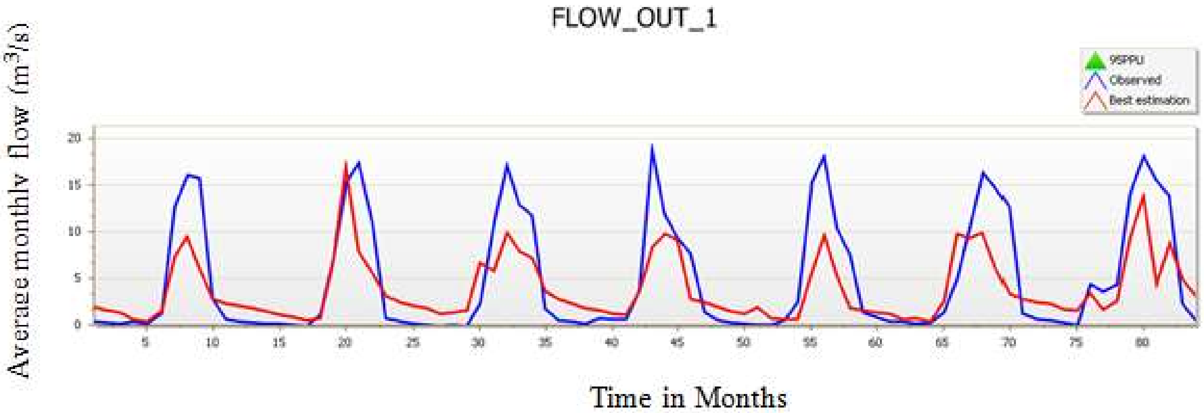


Figure 4.4 Validation results of monthly observed and simulated flows by SUFI-2 of Nashe watershed

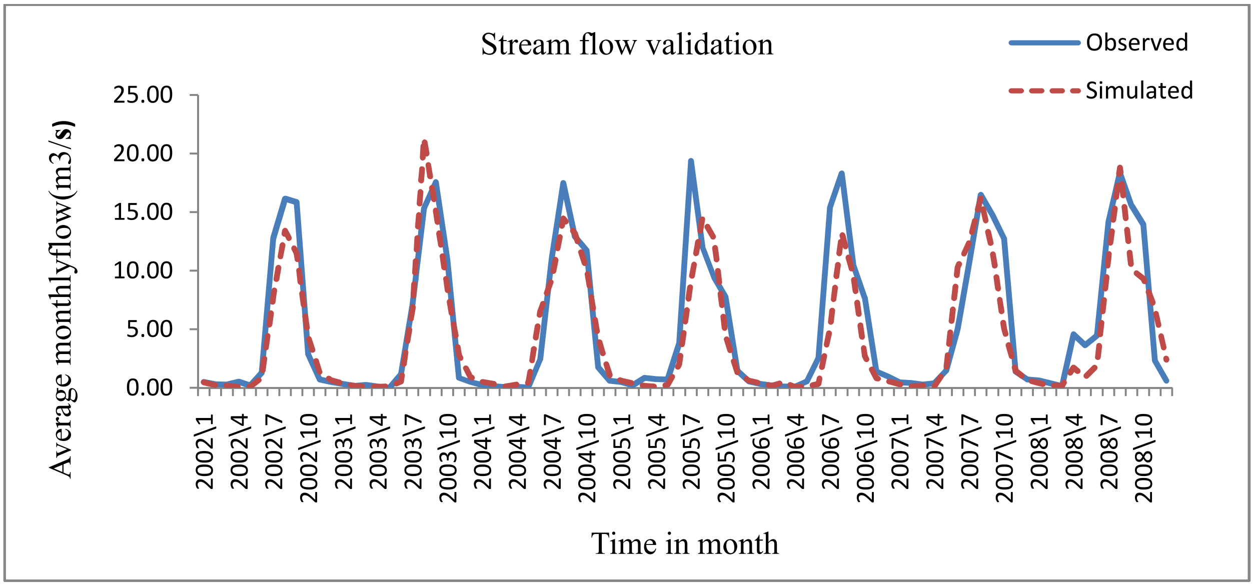


Figure 4.5 Validation results of monthly measured and simulated flow.

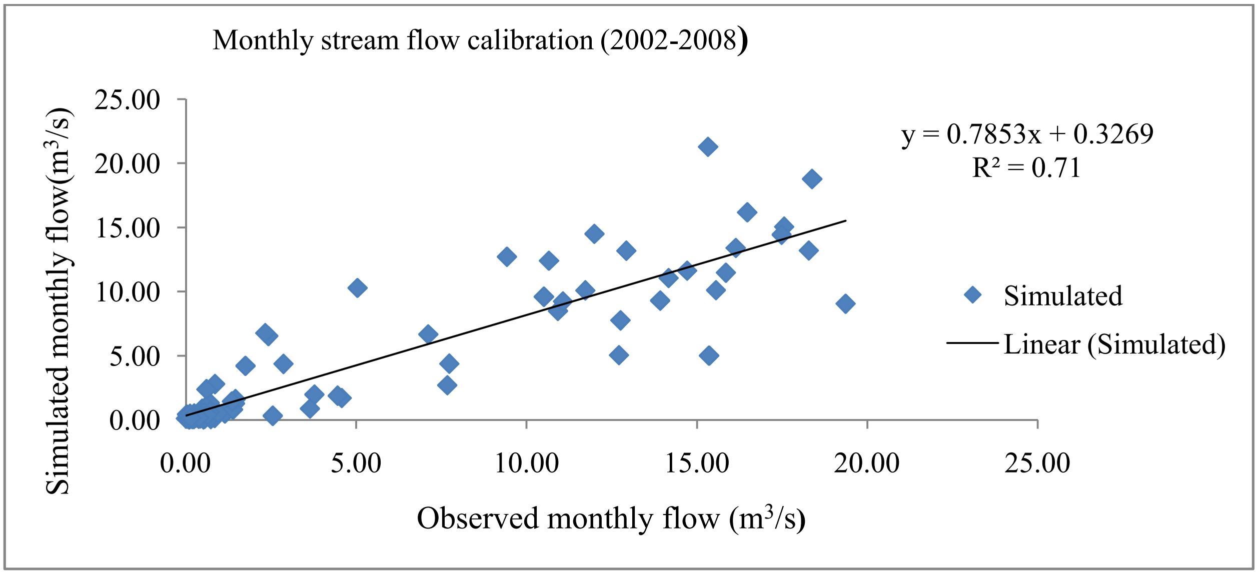


Figure 4.6 Scatter plot of observed and simulated stream flow for Nashe watershed during validation periods.

The summary of statistical parameters for calibration and validation obtained from SWAT-CUP, SUFI-2 were shown in table.

Table 4.2 Stream flow calibration and validation results of monthly basis

Parameter	Calibrated(1991-2001)	Validated(2002-2008)
R^2	0.79	0.71
E_{NS}	0.75	0.65
PBIAS	13	21.6

4.3. Sediment yield

The Obtained Sediment concentration data was not sufficient for calibration and validation. Calibration and validation need continuous observed data. Daily flow and sediment concentration for Nashe river were obtained from MoWE, Ethiopia have a few sediment data. For Nashe river, continuous sediment data was develop from observed flow and a few sediment data by using rating curve method.

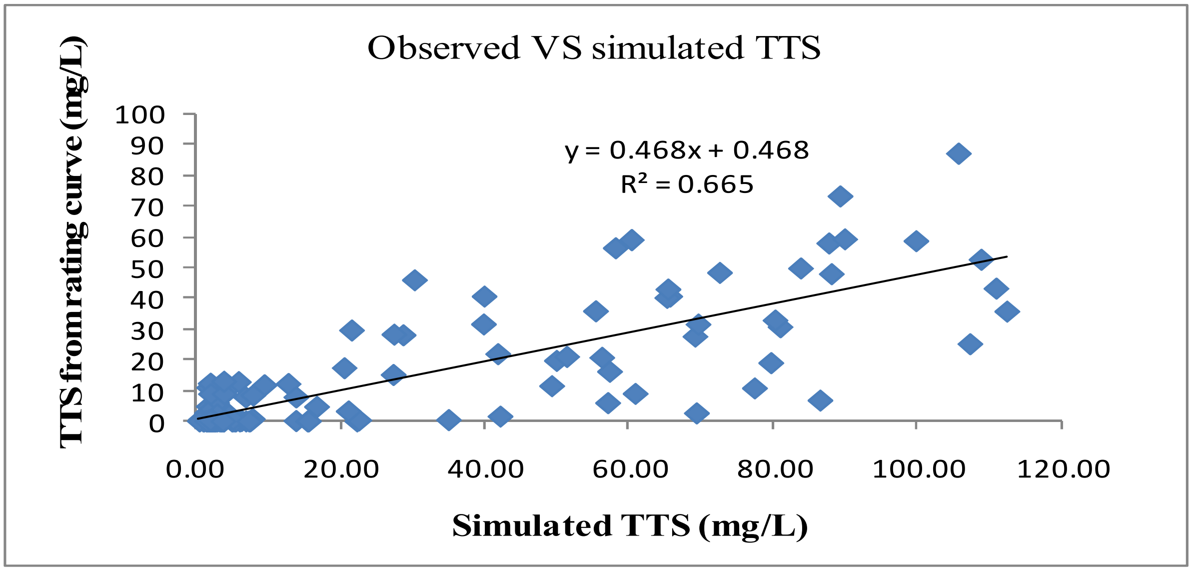


Figure 4.7 Comparison between simulated sediment and obtained from rating curve.

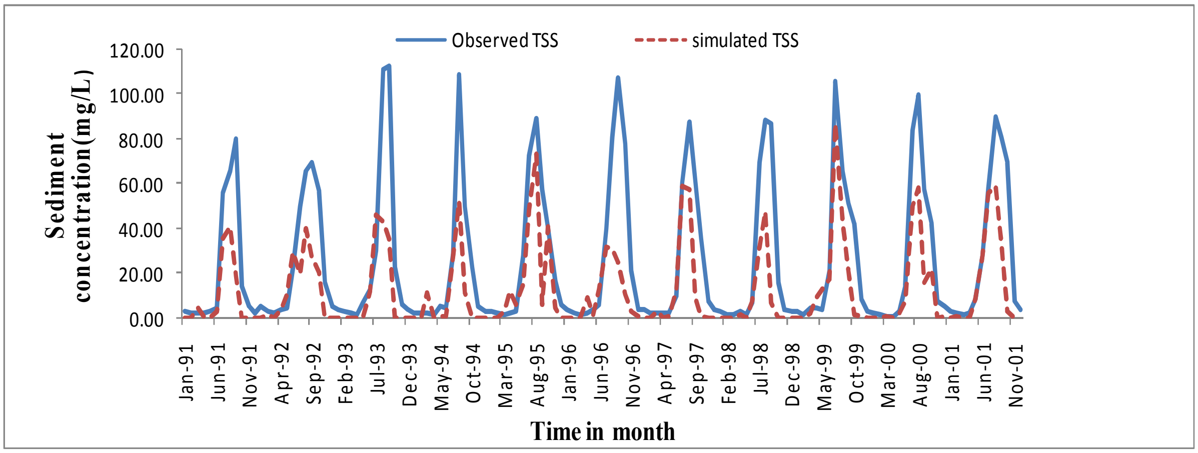


Figure 4.8 Simulated and computed sediment concentration.

The sediment data from rating curve is not suggested for calibration and validation for does not correspond to actual sediment data. From the Nashe gauged station the result indicates that good agreement between rating curve and SWAT model on predicting sediment loads. These showed that the simulated sediment yield from stream flow simulation by SWAT model was acceptable.

Based on SWAT model simulation of stream flow result, sediment yield was estimated from the watershed with their respective distribution among the sub basin. The average annual sediment yield obtained result from stream flow simulation was used to spatial based soil erosion map for each sub basin of watershed. The increasing of sediment yield was primarily due to increases in surface runoff. The average sediment yield of the basin was simulated and represented by RCH 1 at the outlet of the watershed. Based on this simulation, the average sediment yield at outlet from the watershed was 0.285Mton/year.

Betrie *et al*., 2011 estimated that sediment load of upper Blue Nile as 131 Mt per year. Since the study area is small it contributes small effects to Blue Nile.

Table 4.3 Sediment yield at Outlet of each sub-basin

Rich	**Sediment yield at outlet(M ton/yr)**	**Sub basin by name**
1	0.285	N-1
2	0.014	N-2
3	0.223	N-3
4	0.207	N-4
5	0.196	N-5
6	0.07	N-6
7	0.059	N-7
8	0.010	N-8
9	0.050	N-9
10	0.137	N-10
11	0.029	N-11
12	0.053	N-12
13	0.006	N-13
14	0.063	N-14
15	0.021	N-15

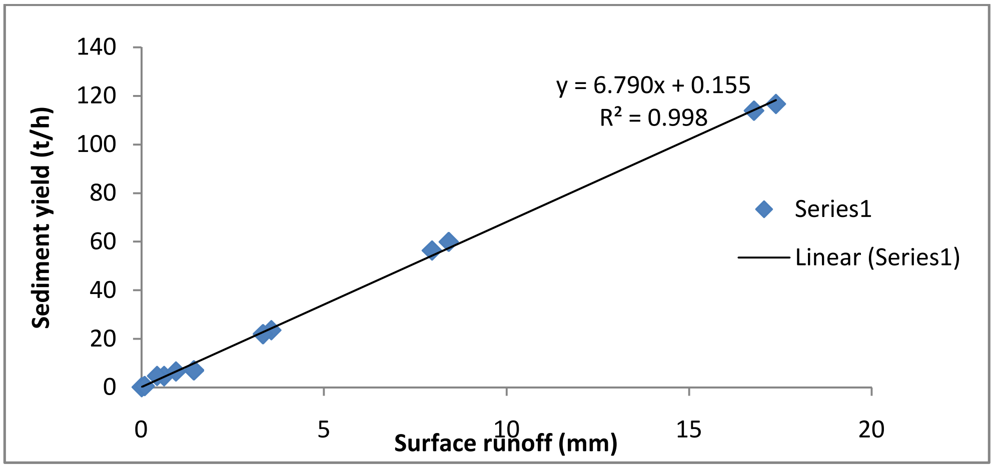


Figure 4.9 Sediment yield runoff relationship

Table 4.4Sediment yield at Outlet of each sub basin

Sub basin	Sediment yield (Ton/Ha)	Sub basin by name
1	4.82	N-1
2	51.13	N-2
3	26.83	N-3
4	22.18	N-4
5	25.67	N-5
6	38.75	N-6
7	28.50	N-7
8	107.88	N-8
9	38.13	N-9
10	103.96	N-10
11	108.43	N-11
12	32.39	N-12
13	28.87	N-13
14	10.32	N-14
15	74.74	N-15

4.4. Soil Erosion Prone Area

To identify the prone soil erosion area in Nashe watershed was one of other objective of this study. However, there was soil erosion in watershed which was not uniformly varied through in catchment. To encourage management planning and discouraging mismanagement of catchment a clear soil erosion prone area is a vital one.

SWAT model divides Nashe watershed in to 15 sub basin during stream network delineation and prone soil erosion in the basin. The soil loss situation in the western part of Ethiopia has become very crucial due to increased intensity of cultivation and clearing of forests, which has led to soil erosion problems. The rate of soil formation for Ethiopia and found that the range of tolerable soil loss level for various agro-ecological zone of Ethiopia from 2 to 18 tons/ha (200 to 1800 tons/Km^2 (Hurni, 1989). Assegahegn *et al*., (2013); they reported that observed soil loss in the upper Blue Nile basin of Mizewa watershed was 40.9 tons/ ha per year. In this study area, the simulated sediment yield was 60.97 ton/ ha which is found in the tolerable rate range.

According literature the extent of soil erosion of sub basin has been divided in to four soil loss classes namely low (0-25 t/ha/yr.), medium (25-75 t/ha/yr.), high (75-150 t/ha/yr.), and very high (greater than 150t/ha/yr.).

Table 4.5 The severity of soil erosion corresponding to area in Nashe watershed.

Soil erosion condition	Sediment yield (ton/ha/yr)	Percent of area coverage (%)	Watershed Area
Low erosion	0-25	20	N-1,4 & 14
Moderate erosion	25-75	60	N-2,3, 5, 6,7,9,12,13 & 15
Severe erosion	75-150	20	N- 8, 10 & 11
Extreme erosion	Above 150	0	none

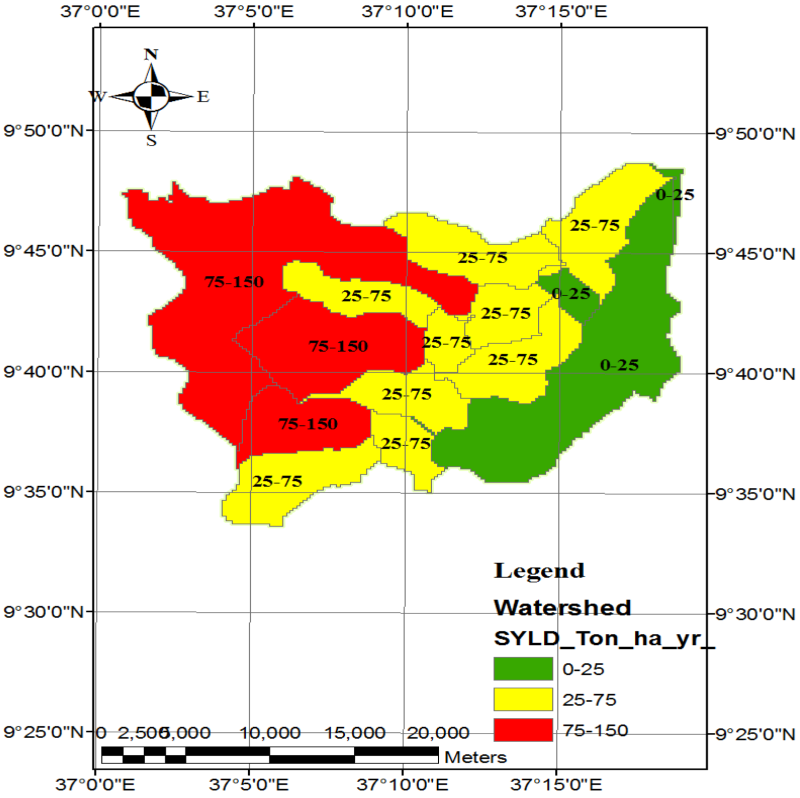


Figure 4.10 Spatial based distribution of sediment yield in Nashe watershed

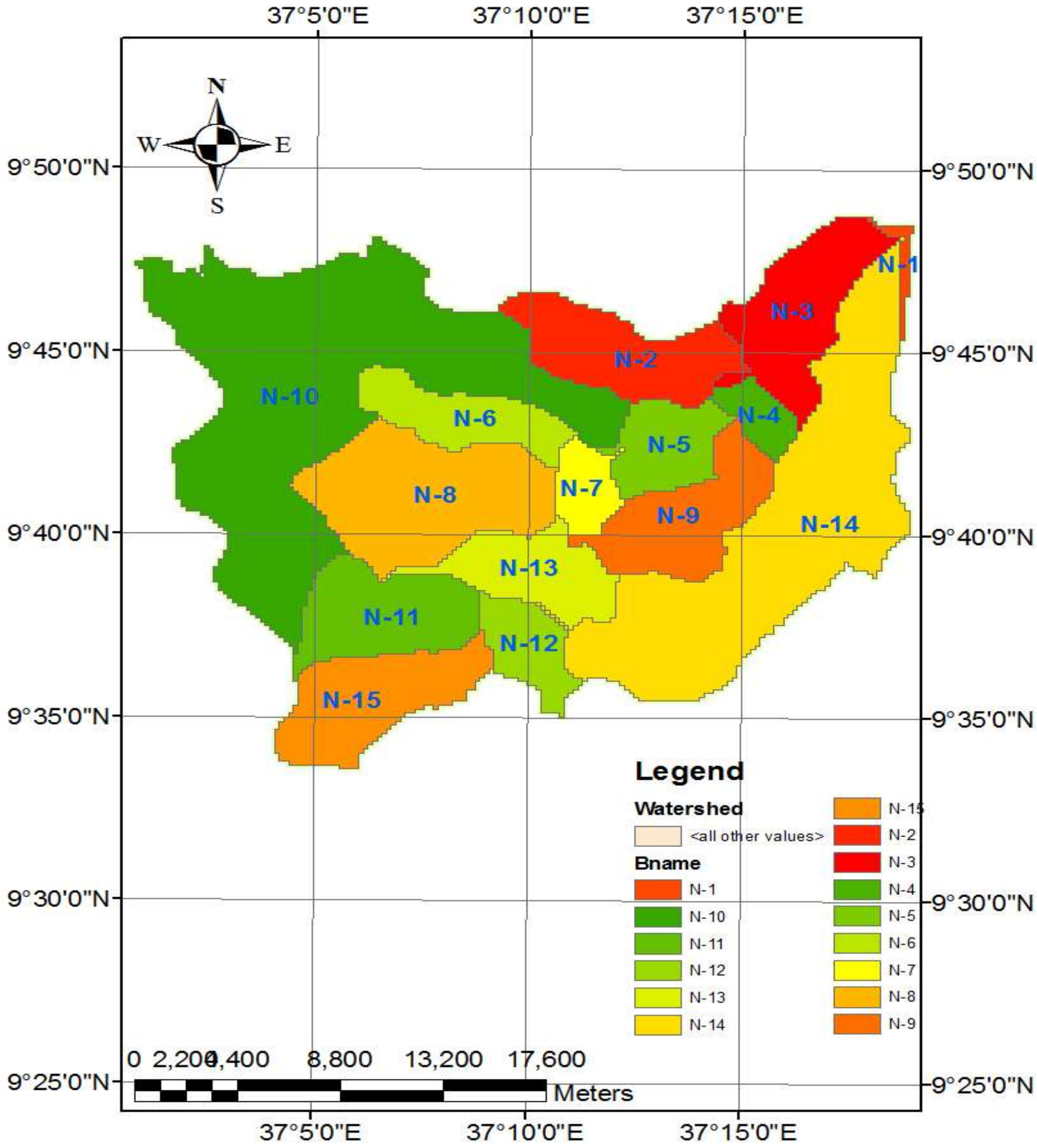


Figure 4.11 Nashe watershed map sub-basin for priority management.

The temporal distributions of soil erosion have been estimated entire Nashe watershed based on the SWAT simulated average monthly sediment yields. According to the results, average sediment yields generated during July and August almost double average sediment yields of June & September. The temporal distribution sediment yields of the study area has been divided into four soil loss classes namely (January, February, March, April, November and December) monthly Low erosion time, (May) Monthly Moderate Erosion time, (June & September) Monthly Severe soil erosion time and (July & Aug) Monthly Extreme Soil erosion time.

Table 4.6 Temporal based distribution of sediment yield in Nashe watershed.

Month	Jan.	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Sediment Yield (M ton)	0.001	0.01	0.024	0.011	0.063	0.140	0.314	0.301	0.150	0.059	0.017	0.007
Total	1.0878 M tons											

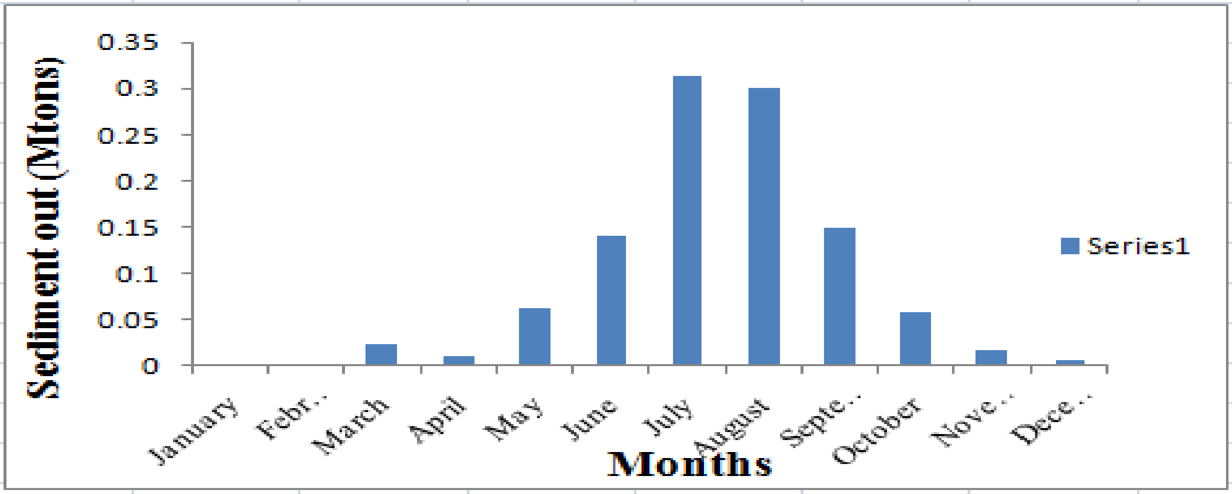


Figure 4.12 Temporal based distribution of sediment yield in Nashe watershed

4.5. Conservation measure for management

Although, the watershed management is essential for sustainable natural resource management, managing the whole watershed at once is very difficult. The most susceptible area of soil erosion of sub watershed is priorities for phase wise implementation plan for management. Depending on their erosion potential, the conservation practice for management divided into two main categories as in situ and ex situ management. The sub watershed with erosion risk, soil conservation measures have been implemented and well maintained. Thus both management types were recommended. But for sub watershed of low and medium soil erosion potential available ex-situ management were recommended.

The in-situ management is land and water conservation practices, made within agricultural fields such as construction of physical structures (terraces) to reduce overland flow thereby preventing removal of soil, soil fertility improvement practices, agro-forestry and reforestation of deforested hilly area. And at the outside of the agricultural fields, gully protection activities such as check-dam (a physical structure constructed in gullies to reduce flow of water thereby reducing damage to the land) construction, gully-side embankment protection and grass waterway is known as ex-situ management. Therefore, for sub watersheds (N-8, 10&11) both conservation measures have to apply consecutively. These show that, the sub watershed was in bare vegetation, high relief and steep slope, that it demonstrates poorer infiltration and higher overflow than all other sub watershed of the basin. In the same way; in-situ management were recommended for the sub Watersheds falling in Medium priority classes (N-2,3,5,6,7,9,12,13&15) specifies comparatively moderate soil erosion zone and be made up of moderate slopes, less bare vegetation and shape parameters. Also, for sub watersheds categorized under low priority classes (N-1,4 & 14) are very slight erosion susceptibility zone. These sub watersheds are mild slope and flat land need measures such as Contour farming, Strip cropping and Mixed cropping during the rainy season and seeding time can reduce soil erosion

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This thesis work mainly based on soil erosion modeling by using SWAT model. The annual sediment yield of Nashe sub basin has been obtained from stream flow simulated results. Sediment yield from each sub watershed were also determined and prone soil erosion area has been identified. Soil erosion control measures have been suggested for Nashe watershed according to generation of their sediment yields from each sub watershed.

The average monthly simulated flows were compared with the average monthly observed values using graphical and statistical methods. As the measured data were not available on sediment yield, the simulated data has been used to determine sediment yields from sub basin. Stream flow has been calibrated and validated for watershed and reasonably good with coefficient of determination (R^2) values of 0.79and 0.75 and Nash-Sutcliffe values of 0.75 and 0.65 for calibration and validation respectively. This shows SWAT is good model to simulate hydrological process of the catchments.

In this study, sub basin were categorize in terms of their sediment yield per hectare which is very important data with high erosion rates leading to land degradation where conservation measures are required. According to generation of sediment yields soil erosion prone areas have been identified and priority sub watershed required are suggested to reduce maximum soil erosion.

In general, the ability of SWAT model performance was adequately to simulate stream flows from Nashe sub basin and successfully result were obtained. Therefore, SWAT model is an acceptable tool for extra study of the hydrological response in Nashe sub basin.

5.2. Recommendations

Since the Nashe hydropower and irrigation project was new, there was no data on sediment yields. The consistency of data is crucial significance for carrying out any modeling studies. Therefore, the statistical dependability and dependency of this data needs to be tested prior to its application. It has taken from SWAT result to identify area of prone soil erosion but, further in future studies should also has been evaluated for the performance of this model study on sediment yield.

The most susceptible area of soil erosion of sub watershed is priorities for phase wise implementation plan for management. The Sub watersheds (N- 8, 10 & 11) showed alarming sediment yield which cause severe soil erosion (75-150ton/ha). These sub-watersheds will need to give a first priority for soil erosion mitigation. The Sub-Watershed number (N-2,3,5,6,7,9,12,13& 15) will need to give second priority for recovery and conservation process. The sub watershed number (N-1,4 & 14) it should be given lastly priority in sub-basin conservation practices.

Effective wise programs and the strategy for the future should to be have forests in upland, where slope are steep, with will minimize land sliding and leads to lesser sediment yields. Therefore, government and policy makers have to give required soil erosion control measures in those watersheds High Priority, Medium priority and low priority respectively to reduce further erosion.

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Appendices

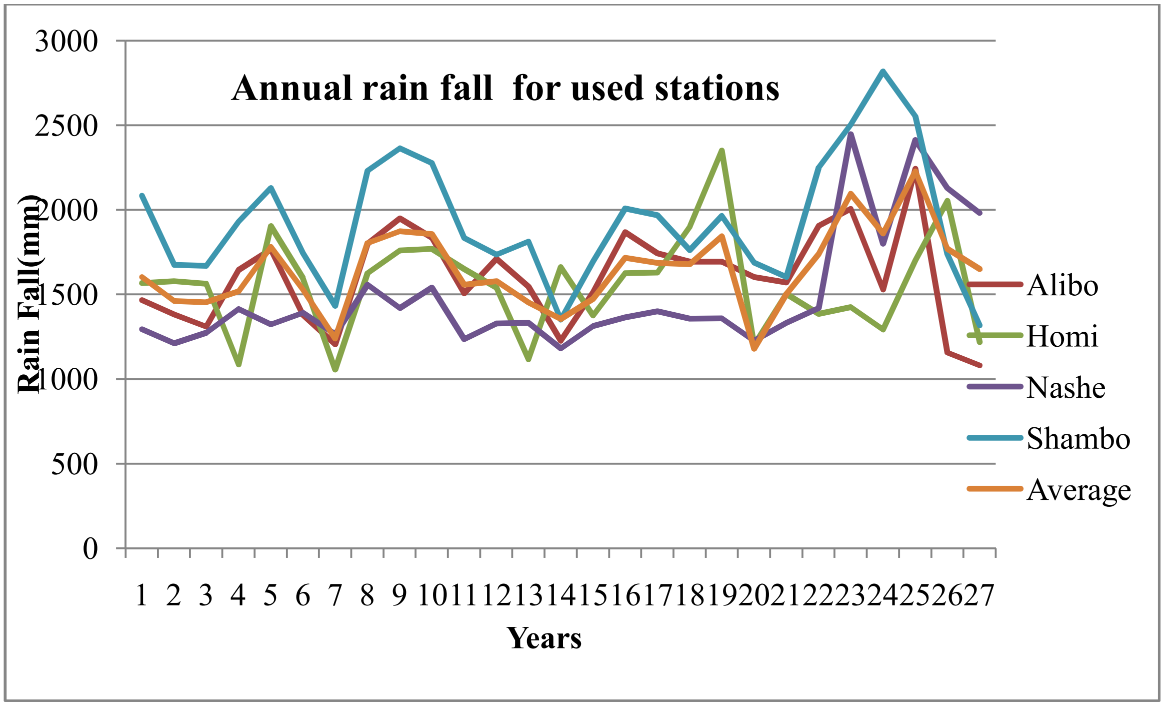
Temporal sediment yields.

MON	YIELD(Ton/Ha)
January	0.01
February	0.09
March	1.44
April	0.62
May	3.56
June	7.96
July	17.38
August	16.78
September	8.42
October	3.33
November	0.95
December	0.43
Total	60.97

Annual rain fall for gauged station

Yearly RF(mm)					
Year	Alibo	Homi	Nashe	Shambu	Average
1989	1468.1	1567	1295.3	2084.1	1603.63
1990	1382.3	1579.4	1211.6	1676.6	1462.48
1991	1310.5	1564.2	1275	1671	1455.18
1992	1644.5	1086.1	1414.4	1930.9	1518.98
1993	1765.9	1904.8	1324	2129.1	1780.95
1994	1379.6	1597.4	1392.9	1746.8	1529.18
1995	1206.5	1056.5	1265.9	1433.5	1240.60
1996	1801.2	1626.5	1558.1	2232.8	1804.65
1997	1950.7	1760.1	1421.4	2363.6	1873.95
1998	1836.8	1770.4	1542.2	2278.4	1856.95
1999	1508	1651.6	1236.7	1835.8	1558.03
2000	1711.7	1541.7	1329.4	1737.2	1580.00
2001	1546.4	1117.7	1333.9	1814.3	1453.08
2002	1227.4	1662.2	1182.1	1351.9	1355.90
2003	1513	1377.1	1314.9	1697.5	1475.63
2004	1868.5	1626.8	1366.2	2008.1	1717.40
2005	1743.8	1631.1	1402.1	1968.4	1686.35
2006	1694.3	1901.5	1358.8	1763.7	1679.58
2007	1695.4	2351.6	1360	1966.3	1843.33
2008	1603	1199.6	1227.5	1690	1180.03
2009	1570.8	1503.1	1334.4	1604.5	1503.20
2010	1906.5	1385.6	1421.4	2250.7	1741.05
2011	2006.4	1426	2448.3	2503.9	2096.15
2012	1529.6	1292.5	1801.8	2818.4	1860.58
2013	2243.3	1702.3	2413.3	2554.4	2228.33
2014	1157.8	2055.1	2129.7	1737.9	1770.13
2015	1081.5	1218.9	1982.6	1318.7	1650.43

The graphical representations of rain fall data.



Cumulative annual rain fall for gauged station

Cumulative RF (mm)					
Year	Alibo	Homi	Nashe	Shambu	Average
1989	1468.1	1567	1295.3	2084.1	1603.63
1990	2850.4	3146.4	2506.9	3760.7	3066.10
1991	4160.9	4710.6	3781.9	5431.7	4521.28
1992	5805.4	5796.7	5196.3	7362.6	6040.25
1993	7571.3	7701.5	6520.3	9491.7	7821.20
1994	8950.9	9298.9	7913.2	11238.5	9350.38
1995	10157.4	10355.4	9179.1	12672	10590.98
1996	11958.6	11981.9	10737.2	14904.8	12395.63
1997	13909.3	13742	12158.6	17268.4	14269.58
1998	15746.1	15512.4	13700.8	19546.8	16126.53
1999	17254.1	17164	14937.5	21382.6	17684.55
2000	18965.8	18705.7	16266.9	23119.8	19264.55
2001	20512.2	19823.4	17600.8	24934.1	20717.63
2002	21739.6	21485.6	18782.9	26286	22073.53
2003	23252.6	22862.7	20097.8	27983.5	23549.15
2004	25121.1	24489.5	21464	29991.6	25266.55
2005	26864.9	26120.6	22866.1	31960	26952.90
2006	28559.2	28022.1	24224.9	33723.7	28632.48
2007	30254.6	30373.7	25584.9	35690	30475.80
2008	31857.6	31573.3	26812.4	37380	31655.83
2009	33428.4	33076.4	28146.8	38984.5	33159.03
2010	35334.9	34462	29568.2	41235.2	34900.08
2011	37341.3	35888	32016.5	43739.1	36996.23
2012	38870.9	37180.5	33818.3	46557.5	38856.80
2013	41114.2	38882.8	36231.6	49111.9	41085.13
2014	42272	40937.9	38361.3	50849.8	42855.25
2015	43353.5	42156.8	40343.9	52168.5	44505.68

Graphical representation of double mass curve

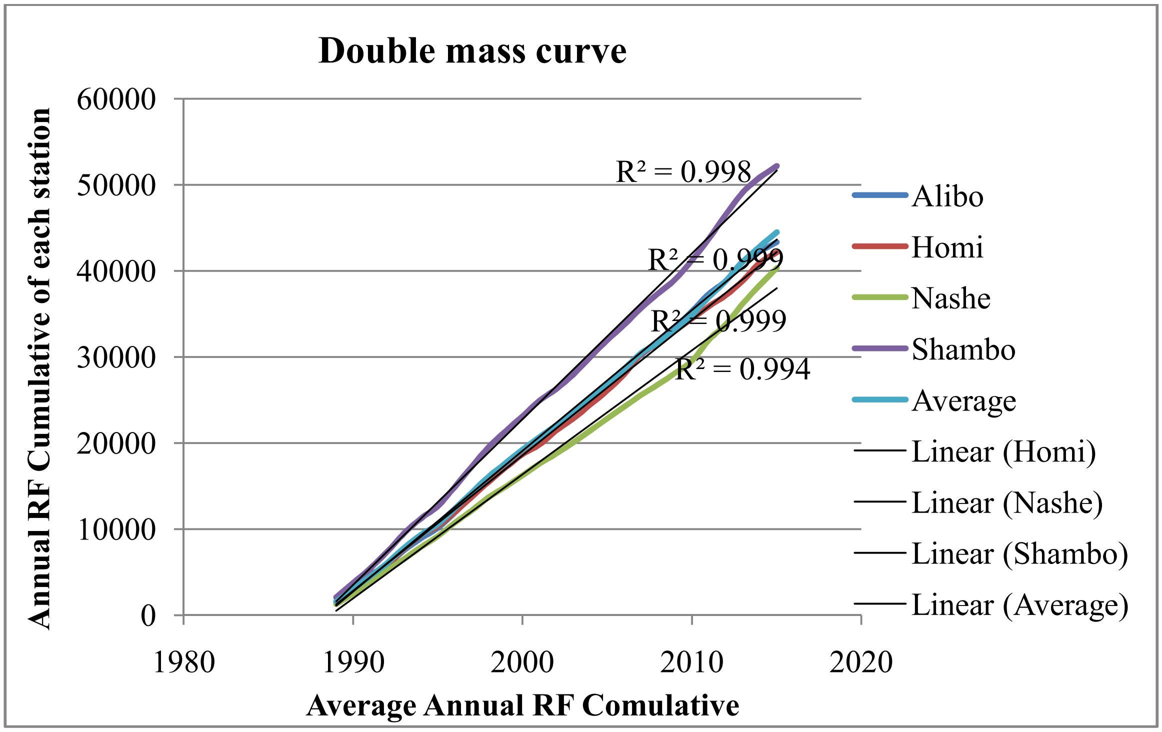


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Table the location of Metrological stations and the data year within and around the watershed

No	Station Name	Elevation (m)	Latitude	Longitude	**Observation period**					
					PCP	Temp	Rel.hum	Wnd.sp	Sol.rad.	Flow
1	Shambu	2400	37.121	9.5712	1989-2015	1989-2015	1989-2015	1989-2015	1989-2015	No data
2	Nashe	2060	37.268	9.732	1989-2015	1989-2015	No data	No data	No data	1989-2006
3	Homi	2317	37.241	9.621	1989-2015	1989-2015	No data	No data	No data	No data
4	Alibo	2513	37.074	9.886	1989-2015	1989-2015	No data	No data	No data	No data

Table The sensitive parameter

No	Parameters	Description
1	Alpha_Bf	Base flow alpha factors
2	Biomix	Biological mixing efficie
3	Blai	Maximum leaf area index
4	Canmx	Maximum canopy storage
5	Ch_K2	Effective hydraulic conductivity in main channel
6	Ch_N2	Manning’s “n” value for the channel
7	Cn2	Curve number
8	Epco	Plant uptake compensation
9	Esco	Soil evaporation compensation factor
10	Gw_Delay	Groundwater delay
11	Gw_Revap	Groundwater "revap" coefficient
12	Gwqmn	Threshold depth of water in the shallow aquifer for return flow
13	Revapmn	Threshold depth of water in the shallow aquifer for “revap” to occur
14	Sftmp	Snowfall temperature
15	Slope	Average Slope
16	Slsubbsn	Average slope length
17	Smfmn	Minimum melt rate for snow during the year
18	Smfmx	Maximum melt rate for snow during the year
19	Smtmp	Snow melt base temperature
20	Sol_Alb	Moist soil albedo
21	Sol_Awc	Available water capacity
22	Sol_K	Saturated hydraulic conductivity
23	Sol_Z	Depth from soil surface to the bottom of layer
24	Surlag	Surface runoff lag time
25	Timp	Snow pack temperature lag time
26	Tlaps	Snow average soil profile lag length
27	Sol_BD	Soil moist bulk density

Table preparation of pre SWAT-CUP data

For Calibration					
1	FLOW_OUT_1_1991	0.50	67	FLOW_OUT_7_1996	16.43
2	FLOW_OUT_2_1991	0.41	68	FLOW_OUT_8_1996	23.23
3	FLOW_OUT_3_1991	0.33	69	FLOW_OUT_9_1996	14.74
4	FLOW_OUT_4_1991	0.35	70	FLOW_OUT_10_1996	6.56
5	FLOW_OUT_5_1991	0.56	71	FLOW_OUT_11_1996	1.52
6	FLOW_OUT_6_1991	0.74	72	FLOW_OUT_12_1996	0.78
7	FLOW_OUT_7_1991	10.15	73	FLOW_OUT_1_1997	0.46
8	FLOW_OUT_8_1991	12.04	74	FLOW_OUT_2_1997	0.34
9	FLOW_OUT_9_1991	14.60	75	FLOW_OUT_3_1997	0.28
10	FLOW_OUT_10_1991	2.55	76	FLOW_OUT_4_1997	0.38
11	FLOW_OUT_11_1991	0.92	77	FLOW_OUT_5_1997	0.54
12	FLOW_OUT_12_1991	0.43	78	FLOW_OUT_6_1997	5.02
13	FLOW_OUT_1_1992	0.57	79	FLOW_OUT_7_1997	13.30
14	FLOW_OUT_2_1992	0.42	80	FLOW_OUT_8_1997	16.36
15	FLOW_OUT_3_1992	0.29	81	FLOW_OUT_9_1997	10.46
16	FLOW_OUT_4_1992	0.42	82	FLOW_OUT_10_1997	7.33
17	FLOW_OUT_5_1992	0.73	83	FLOW_OUT_11_1997	3.08
18	FLOW_OUT_6_1992	2.36	84	FLOW_OUT_12_1997	1.02
19	FLOW_OUT_7_1992	4.28	85	FLOW_OUT_1_1998	0.56
20	FLOW_OUT_8_1992	8.88	86	FLOW_OUT_2_1998	0.32
21	FLOW_OUT_9_1992	23.53	87	FLOW_OUT_3_1998	0.27
22	FLOW_OUT_10_1992	23.31	88	FLOW_OUT_4_1998	0.19
23	FLOW_OUT_11_1992	5.41	89	FLOW_OUT_5_1998	0.55
24	FLOW_OUT_12_1992	1.87	90	FLOW_OUT_6_1998	1.21
25	FLOW_OUT_1_1993	0.99	91	FLOW_OUT_7_1998	10.36
26	FLOW_OUT_2_1993	0.59	92	FLOW_OUT_8_1998	22.76
27	FLOW_OUT_3_1993	0.38	93	FLOW_OUT_9_1998	19.98
28	FLOW_OUT_4_1993	0.63	94	FLOW_OUT_10_1998	19.17
29	FLOW_OUT_5_1993	0.82	95	FLOW_OUT_11_1998	4.37
30	FLOW_OUT_6_1993	3.96	96	FLOW_OUT_12_1998	1.03
31	FLOW_OUT_7_1993	9.16	97	FLOW_OUT_1_1999	0.72
32	FLOW_OUT_8_1993	11.96	98	FLOW_OUT_2_1999	0.33
33	FLOW_OUT_9_1993	12.68	99	FLOW_OUT_3_1999	0.19

34	FLOW_OUT_10_1993	10.31	100	FLOW_OUT_4_1999	0.17
35	FLOW_OUT_11_1993	2.84	101	FLOW_OUT_5_1999	0.80
36	FLOW_OUT_12_1993	0.94	102	FLOW_OUT_6_1999	4.07
37	FLOW_OUT_1_1994	0.72	103	FLOW_OUT_7_1999	9.77
38	FLOW_OUT_2_1994	0.51	104	FLOW_OUT_8_1999	11.79
39	FLOW_OUT_3_1994	0.42	105	FLOW_OUT_9_1999	14.21
40	FLOW_OUT_4_1994	0.29	106	FLOW_OUT_10_1999	19.86
41	FLOW_OUT_5_1994	1.16	107	FLOW_OUT_11_1999	2.93
42	FLOW_OUT_6_1994	2.35	108	FLOW_OUT_12_1999	1.05
43	FLOW_OUT_7_1994	5.56	109	FLOW_OUT_1_2000	0.65
44	FLOW_OUT_8_1994	20.32	110	FLOW_OUT_2_2000	0.39
45	FLOW_OUT_9_1994	20.59	111	FLOW_OUT_3_2000	0.27
46	FLOW_OUT_10_1994	4.10	112	FLOW_OUT_4_2000	0.39
47	FLOW_OUT_11_1994	1.12	113	FLOW_OUT_5_2000	0.61
48	FLOW_OUT_12_1994	0.64	114	FLOW_OUT_6_2000	1.09
49	FLOW_OUT_1_1995	0.42	115	FLOW_OUT_7_2000	7.31
50	FLOW_OUT_2_1995	0.36	116	FLOW_OUT_8_2000	14.84
51	FLOW_OUT_3_1995	0.34	117	FLOW_OUT_9_2000	19.65
52	FLOW_OUT_4_1995	0.28	118	FLOW_OUT_10_2000	14.19
53	FLOW_OUT_5_1995	0.87	119	FLOW_OUT_11_2000	3.88
54	FLOW_OUT_6_1995	0.78	120	FLOW_OUT_12_2000	0.61
55	FLOW_OUT_7_1995	5.27	121	FLOW_OUT_1_2001	0.68
56	FLOW_OUT_8_1995	19.94	122	FLOW_OUT_2_2001	0.37
57	FLOW_OUT_9_1995	9.04	123	FLOW_OUT_3_2001	0.31
58	FLOW_OUT_10_1995	4.15	124	FLOW_OUT_4_2001	0.33
59	FLOW_OUT_11_1995	0.91	125	FLOW_OUT_5_2001	0.42
60	FLOW_OUT_12_1995	0.53	126	FLOW_OUT_6_2001	1.75
61	FLOW_OUT_1_1996	0.52	127	FLOW_OUT_7_2001	11.06
62	FLOW_OUT_2_1996	0.31	128	FLOW_OUT_8_2001	16.08
63	FLOW_OUT_3_1996	0.21	129	FLOW_OUT_9_2001	11.16
64	FLOW_OUT_4_1996	0.28	130	FLOW_OUT_10_2001	6.42
65	FLOW_OUT_5_1996	1.16	131	FLOW_OUT_11_2001	1.28
66	FLOW_OUT_6_1996	1.88	132	FLOW_OUT_12_2001	0.61

	For Validation				
1	FLOW_OUT_1_2002	0.49	43	FLOW_OUT_7_2005	19.36
2	FLOW_OUT_2_2002	0.30	44	FLOW_OUT_8_2005	11.99
3	FLOW_OUT_3_2002	0.27	45	FLOW_OUT_9_2005	9.42
4	FLOW_OUT_4_2002	0.52	46	FLOW_OUT_10_2005	7.73
5	FLOW_OUT_5_2002	0.19	47	FLOW_OUT_11_2005	1.45
6	FLOW_OUT_6_2002	1.27	48	FLOW_OUT_12_2005	0.55
7	FLOW_OUT_7_2002	12.76	49	FLOW_OUT_1_2006	0.34
8	FLOW_OUT_8_2002	16.14	50	FLOW_OUT_2_2006	0.20
9	FLOW_OUT_9_2002	15.85	51	FLOW_OUT_3_2006	0.12
10	FLOW_OUT_10_2002	2.87	52	FLOW_OUT_4_2006	0.10
11	FLOW_OUT_11_2002	0.71	53	FLOW_OUT_5_2006	0.55
12	FLOW_OUT_12_2002	0.49	54	FLOW_OUT_6_2006	2.55
13	FLOW_OUT_1_2003	0.33	55	FLOW_OUT_7_2006	15.36
14	FLOW_OUT_2_2003	0.18	56	FLOW_OUT_8_2006	18.28
15	FLOW_OUT_3_2003	0.24	57	FLOW_OUT_9_2006	10.51
16	FLOW_OUT_4_2003	0.11	58	FLOW_OUT_10_2006	7.67
17	FLOW_OUT_5_2003	0.00	59	FLOW_OUT_11_2006	1.38
18	FLOW_OUT_6_2003	1.15	60	FLOW_OUT_12_2006	0.95
19	FLOW_OUT_7_2003	7.12	61	FLOW_OUT_1_2007	0.46
20	FLOW_OUT_8_2003	15.33	62	FLOW_OUT_2_2007	0.42
21	FLOW_OUT_9_2003	17.56	63	FLOW_OUT_3_2007	0.29
22	FLOW_OUT_10_2003	10.92	64	FLOW_OUT_4_2007	0.38
23	FLOW_OUT_11_2003	0.86	65	FLOW_OUT_5_2007	1.46
24	FLOW_OUT_12_2003	0.48	66	FLOW_OUT_6_2007	5.04
25	FLOW_OUT_1_2004	0.25	67	FLOW_OUT_7_2007	10.66
26	FLOW_OUT_2_2004	0.14	68	FLOW_OUT_8_2007	16.48
27	FLOW_OUT_3_2004	0.04	69	FLOW_OUT_9_2007	14.71
28	FLOW_OUT_4_2004	0.10	70	FLOW_OUT_10_2007	12.71
29	FLOW_OUT_5_2004	0.03	71	FLOW_OUT_11_2007	1.36
30	FLOW_OUT_6_2004	2.43	72	FLOW_OUT_12_2007	0.70
31	FLOW_OUT_7_2004	11.07	73	FLOW_OUT_1_2008	0.64
32	FLOW_OUT_8_2004	17.48	74	FLOW_OUT_2_2008	0.39
33	FLOW_OUT_9_2004	12.93	75	FLOW_OUT_3_2008	0.15
34	FLOW_OUT_10_2004	11.73	76	FLOW_OUT_4_2008	4.58
35	FLOW_OUT_11_2004	1.75	77	FLOW_OUT_5_2008	3.64
36	FLOW_OUT_12_2004	0.60	78	FLOW_OUT_6_2008	4.46
37	FLOW_OUT_1_2005	0.48	79	FLOW_OUT_7_2008	14.17
38	FLOW_OUT_2_2005	0.21	80	FLOW_OUT_8_2008	18.38
39	FLOW_OUT_3_2005	0.84	81	FLOW_OUT_9_2008	15.56
40	FLOW_OUT_4_2005	0.73	82	FLOW_OUT_10_2008	13.92
41	FLOW_OUT_5_2005	0.72	83	FLOW_OUT_11_2008	2.33
42	FLOW_OUT_6_2005	3.78	84	FLOW_OUT_12_2008	0.61