Jimma University

Jimma Institute of Technology

School of Graduate Studies

Hydraulics and Water Resource Engineering Department

Hydraulics engineering Msc program

SWAT based Evaluation of the effect of Land use change on Reservoir Sedimentation (Case Study of Gomit Reservoir Watershed, Estie Woreda, Amhara, Ethiopia)

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Hydraulics and water resource engineering (Hydraulics Engineering)

by

Amlaku Taye

Dec, 2015

Jimma, Ethiopia

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Amlaku Taye

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

Co-advisor:- Sifan Abera (Msc)

Dec, 2015
Jimma, Ethiopia

DECLARATION

This is to certify that this proposal entitled "*SWAT based evaluation of the effect of land use change on reservoir sedimentation": A Case Study on watershade of Gomit reservoir in Estie Woreda, south Gonder Zone, Amhara, Ethiopia*". submitted in partial fulfillment of the requirements for the award of the degree of Msc, in Hydraulics engineering the School of Graduate Studies, Jimma University through the Department of hydraulics &water resource engineering done by Mr. Amlaku Taye. The matter embodied in this thesis work has not been submitted earlier for award of any degree to the best of my knowledge.

Name of the student: -Amlaku Taye Kassahun

Signature ___________ Date ______

The thesis has been submitted for examination with my approval as a university supervisor.

Name of the Advisor:-Dr-Ing Tamene Adugna (PhD)

Signature _______________ Date_________

Name of: - Co-advisor:-Sifan Abera (Msc)

Signature _______________ Date_________

ABSTRACT

The soil and water assessment tool (SWAT) is examined for the prediction of sediment yield in Gomit River watershed. Poor land use practices and improper management systems have played a significant role in aggravating high soil erosion rates, sediment transport and loss of agricultural nutrients.

Sedimentation reduces water storage capacity and negatively affects water supply, flood control capability, river barge navigation, viability of aquatic life, and the recreational value of reservoirs.

Public funds for best management practices (BMPs) to reduce sedimentation are increasingly limited, and federal, state, and local governments are placing more emphasis on achieving economically efficient sediment reduction. Erosion of cropland is a major source of sediment accumulation in reservoirs. The main objective of this study is to evaluate the effect of land use change on reservoir sedimentation and to predict sediment yields in study area.

A physically based watershed model was applied based on its necessity to Gomit River watershed for modeling of the hydrology and sediment yield. The model is calibrated and validated for both flow and sediment concentration at Gomit dam reservoir outlet (223.81km^2) to estimate the sediment .The calibrated model can be used for further analysis of the effect of land use change on reservoir sedimentation as well as other different management scenarios on stream flows and soil erosion.

The area of watershed is subdivided in to 3 sub basins by using soil water assessment tool (SWAT) model. SWAT_CUP is used to calibrate the model parameters of flow and sediment with the time series of 2000 to 2009 for calibration and 2010 to 2014 for validation. The Calibrated and validated values of stream flow and sediment yields are, (R2=0.80, ENS=0.80 PBIAS=24.5, RSR=0.45) and (R2=0.86, ENS=0.84, PBIAS=17.4 and RSR=0.40) for flow. Similarly

(R2=80, ENS=78, PBIAS=20.5RSR=0.46) and (R2=94, ENS=84, PBIAS=34.6, RSR=0.42) respectively for sediment yields. For this study two watershed management intervention measures are used ;(i) land use redesign for steep slopes greater than30% in the watershed of Gomit (ii) Implementation of Terracing activities in agricultural lands of the watershed. By applying both land use redesign for steep slopes and terracing activities the sediment yields of Gomit watershed reduced by7.64% and18.03% respectively.

Key words: *-SWAT, Sedimentation, validation, Watershed, calibration, Gomit, Ethiopia*

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List of Acronyms

BMPs	Best Management Practices
CN	Curve Number
Cn2	Moisture Condition Curve Number
DEM	Digital Elevation Model
DEW02	Dew Point Temperature Calculator
Dr-In	Doctor Engineer
EHRS	Ethiopian Highland Reclamation Study
GIS	Geographical Information System
HRU	Hydrological Response Unit
LU	Land use
M.a.s.l	Mean at sea level
MoWIE	Ministry of Water Irrigation and Energy
Mm	Mille Meter
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Services Agency
NPSM	Non-Point source Model
NRCS	Natural Resource Conservation Service
PBIAS	Mean Relative Bias (Percent Bias)
PhD	Philosophy of Doctor
SCS	Soil Conservation Service
RSR	RMSE – Observations Standard Deviation Ratio
SWAT	Soil Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
SUFI2	Sequential Uncertainty Fitting Version 2
US	United States
USLE	Universal Soil Loss Equation
USPED	United States Department of Agriculture
USDA	United States Department of Agriculture
USDA-SCS	United States Department of Agriculture – Agriculture Research Service
USDA-SCS	United States Department of Agriculture Soil Conservation Service

CHAPTER ONE

1. Introduction

1.1 Back ground

When a barrier is constructed across some river in the form of a dam, water gets stored on the upstream side of the barrier, forming a pool of water, generally called a dam reservoir or an impounding reservoir or a river reservoir.

Reservoirs are the most important component of a water resources project. It is a storage structure that stores water in periods of excess flow (over demand) in order to enable a regulation of storage to best meet the specific demands. All reservoirs formed by dams on natural water courses are subject to some degree of sediment inflow and deposition. The problem confronting the project planner is to estimate the rate of deposition and the period of time before the sediment will interfere with the useful function of the reservoir. Provisions should be made for sufficient sediment storage in the reservoir at the time of design so as not to impair the reservoir functions during the useful life of the project or during the period of economic analysis. The replacement cost of storage lost to sediment accumulation in American reservoirs amounts to millions of dollars annually (Chow, 1964).

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth’s crust .such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition. Once the sediment particles are detached, they may either be transported by gravity, wind or/and water. The process of moving and removing from the original sources resting place is called erosion.

Sedimentation embodies the processes of erosion, entrainment, transportation, deposition, and the compaction of sediment. These are natural processes that have been active throughout geological times and have shaped the present landscape. Sedimentation is of vital concern in the conservation, development, and utilization of our soil and water resources. Land use land cover change is one of the primary factors that affect sedimentation.

Rainfall, runoff, and river channel erosion provide a continuous supply of sediment that is hydraulically transported in rivers and streams. All reservoirs formed by dams on natural rivers are subjected to some degree of sediment inflow and deposition. Because of the very low velocities in reservoirs, they tend to be very efficient sediment taps. Therefore the amount of reservoir sedimentation over the life of the project needs to be predicted before the project is built. If the sediment inflow is large relative to the reservoir storage capacity, then the useful life of the reservoir may be very short. If the inflow sediments settle in the reservoir, then the clear water way releases may degraded the downstream river channel. There are several methods available for reducing reservoir sedimentation. These methods relate to the reservoir location and size, land use practice in the upstream watershed, and special considerations for the operation of reservoir. In some cases, reservoirs can be operated for long-term sustainable use so that sedimentation eventually fills the reservoirs.

Reservoir sedimentation reduces the value of or even nullifies the dam construction investment. The use for which a reservoir was built can be sustainable or represent a renewable source of energy only where sedimentation is controlled by adequate management, for which suitable measures should be devised. Lasting use of reservoirs in terms of water resources management involves the need for

Desedimentation. The planning and design of a reservoir require the accurate prediction of erosion, sediment transport and deposition in the reservoir. For existing reservoirs, more and wider knowledge is still needed to better understand and solve the sedimentation problem, and hence improve reservoir operation.

Sedimentation reduces water storage capacity and negatively affects water supply, flood control capability, river barge navigation, viability of aquatic life, and the recreational value of reservoirs, because public funds for best management practices (BMPs) to reduce sedimentation are increasingly limited, and federal, state, and local governments are placing more emphasis on achieving economically efficient sediment reduction. Erosion of cropland is a major source of sediment accumulation in reservoirs (Devlin and Barnes, 2008).The study will be mainly focuses on evaluating the impact of land use change on the proposed reservoir for irrigation in the Blue Nile basin at Gomit sub basin in particular. The study is done by using soil water assessment tool (SWAT) that is a continuous time, physically based, distributed watershed model.

1.2 Statement of the problem

As the silt originates from the watershed, the characteristics of the catchment such its areal extent, soil types, land slopes, vegetal cover and climatic conditions like temperature, nature and intensity of rainfall, have a great impact in the sediment production in the form of sheet erosion, gully erosion and stream, channel erosion.

Sedimentation is an immense problem that has threatened water resources development in Ethiopia. An insight into soil erosion/sedimentation mechanisms and mitigation methods plays an imperative role for the sustainable water resources development. High population pressure relaying on natural resources coupled with poor land resources management practices and poverty resulted in severe soil erosion and sedimentation, this in turn has been a serious threat to national and household food security.

It is estimated that the transboundary rivers that originate from the Ethiopian highlands carry about 1.3 billion ton/year of sediment to the neighboring countries (MoWE, 1993), whereas the Blue Nile alone carries131 million ton/year (Betrie *et al*., 2011). Poor upstream watershed management and traditional conservation practices have led to these rates. Uncontrolled deforestation, forest fires, grazing, improper method of tillage, and unwise agricultural and land use practices accelerate soil erosion resulting in a large increase of sediment inflow into streams. Specifically, the challenges and constraints in the study area lack of sediment data, difficulty of gathering this data, parameters of land management due to highly increasing deforestation for search of agricultural land makes the things difficult. This study can evaluate the effect of land use land cover change on reservoir sedimentation and predict sediment yield in the basin. Hence, studying the effect of land use change on reservoir sedimentation of Gomit is significant to implement the strategic plan in rehabilitation of degraded land in the Blue Nile basin to minimize sedimentation in the reservoirs. Evaluating the effect of land use change on reservoir sedimentation is the main concern of this paper.

1.3 Objective of the study

1.3.1 General objective

The general objective of the study is to evaluate the effect of land use change on reservoir sedimentation in the Blue Nile basin at the Gomit reservoir catchment.

1.3.2 Specific objective

- To prepare land use and soil map of the study area.
- To carryout sensitivity analysis, calibration and validation of SWAT simulation results.
- To determine sediment yield in the Blue Nile basin at Gomit reservoir catchment with existing land use, by applying SWAT model.
- To identify the most erodible sub catchment.
- To assess the present and future land use practice scenarios.

1.4 Research questions

1. How land use land cover changes affect reservoir sedimentation?
2. How sensitive analysis, calibration and validation carried out?
3. What type of measures minimizes sedimentation problems?
4. Which sub catchment is vulnerable by soil erosion?
5. How to improve future land use practices?

1.5Scope of the study

This study cover SWAT based evaluation of the impacts of land use change on reservoir sedimentation and modeling the hydrological aspects of Gomit reservoir catchments. By taking different results model performance sensitivity analysis calibration and validation is carried out. To achieve this, different types of data's was collected from MoWIE.

1.6 Significant of the study

Implementing irrigation by constructing water storage dams is one and the main way of poverty reduction by increasing productivity, is the core aim of our country. Beside this our dams are in serious problem/challenges of sedimentation. And it is clear that sedimentation is influenced by land use land cover and the adopted management practice. This indicates that having a good land use and management practice significantly reduce the sedimentation problem in the reservoir. Hence studying the effect of land use land cover change on the reservoir sedimentation should have a great significance both in designing the storage reservoir and in land use management practices.

CHAPTER TWO

2. Literature Review

2.1 Reservoir Sedimentation, Transportation and Deposition

From an energy point of view the river system can be considered as a continuous process of energy conversion, where the potential energy water embodies at the top of the catchment is converted into the kinetic energy of flow as water is transported to the catchment outlet. During transport, some kinetic energy is dissipated as work as the water moves through the catchment and river channels. This energy dissipation takes many forms including, work, heat, sound, however, from a geomorphological point of view the most important form of energy dissipation is the work done by water as it flows over the bed and banks of river channels.

In this paper terming this geomorphic work as these energy dissipation processes are responsible for creating the unique geomorphological characteristics of the river system arising from deposition and erosion dynamics, including, , bank stability, sand bars, deep pools, channel meander and hence form the foundation for the complex of habitats underlying the fluvial environment.

Understanding the expenditure of geomorphic work along a river channel and how it is affected by the introduction of Irrigation reservoir is therefore fundamental for understanding the implications for sediment transport within the reservoir.

The accumulating sediments successively reduce the water storage capacity (Fan and Morris1992). Consequently, at long term the reservoir operates only at reduced functional efficiency. Reservoir sedimentation involves entrainment, transport and deposition. They originate from the catchment area, river system and settle in the reservoirs. As a river enters the reservoirs, its cross section of inflow is enlarged due to the effect of back water curve. Thus it causes a decrease in the water flow velocity; subsequently the sediment caring capacity of water is reduced too.

All of the sediment transported will deposit in the upstream of the reservoir influenced by the back water curve. Reservoir sedimentation undergoes different process of transportation and settling of sediment. This causes the reservoir to possess different kinds of kinds of deposition at different positions. These differences are controlled by the effect of the sedimentation particle size, hydraulic condition and sediment transportation methods in the reservoir.

Due to different behavior of sediment particles in transportation and deposition, they have different impacts on the reservoir sedimentation pattern and storage loses. Thus it is important to treat each separately, so as to understand how they are deposited and transported in the reservoir. This is strongly needed in analyzing the reservoir sedimentation problems and providing the best measures.

The rate of reservoir sedimentation and form of deposition is affected by the rate of sediment transport and the method of its deposition in a reservoir. Sediment particles are transported by different mechanisms depending on the sediment size and the water sediment holding capacity. Due to existence of different kinds of sediment particles in the stream flow, several transporting and depositing kind occur in the reservoir.

In general, the river sediment is divided in to two major parts; bed-load and suspended load. They exist in the stream inflow at different ranges and different quantities with respect to the time and space. The increase or decrease of any types of sediment has direct reflection on deposition pattern in the reservoir (Nazar, 2006).

There are no accurate data on the rate of reservoir sedimentation worldwide, but it is commonly accepted that about 1-2% of the worldwide storage capacity is lost annually (Jacobsen, 1999). A detail collection of sedimentation rates in regions all over the world can be found in Batuca and Jordaan (2000).The sedimentation rate of each particular reservoir is very variable. It depends more particularly on the climatic situation, the geomorphology and the conception of the reservoir including its outlet works.

A hydrological model is selected based on its capacity to simulate the hydrology and water quality processes in the catchment and give accurate results compared to those measured to check the effectiveness of the model (Rattanaviwatpong, 2001).

Watershed models such as the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) have been widely used to simulate watershed hydrologic processes and the effect of management, such as agro forestry, on soil and water resources (Gassmanet al., 2007). To use model outputs for tasks ranging from aiding policy decision making to research, models should be scientifically sound, accurately parameterized, well calibrated, and validated (USEPA, 2002). Therefore, it is important that landscape features and the condition of the stream channel network be accurately represented and that good-quality calibration and validation data be collected if the results of this branch of science in aiding policymaking and research are to be trusted.

Land use/cover refers to natural vegetation cover and the human activities that are directly related to land, making use of its resources and interfering in the ecological process that determine the functioning of land cover (Niehoff et al., 2002).

Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by wischmeier and Smith (1978). The sediment routing model consists of two components operating simultaneously: deposition and degradation. When water in rills concentrates to form larger channels, it results in gully erosion (Fortuin, 2006). Finally, stream channel erosion takes place when water flows cut into the bottom of the channel and makes it deeper (Fortuin, 2006). Soil erosion may not be obvious on the ground surface as raindrops are transporting some amount of particles but soil erosion will be more noticeable when water flow concentrates to form rills and gullies (Kim, 2006).

Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. SWAT provides two methods for estimating surface runoff volume: the SCS curve number method and the Green & Ampt infiltration method (Green & Ampt, 1911).

The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997).

Rivers are typically considered in terms of the flow and movement of water through a catchment providing a hydrological link between precipitations in the mountain areas with discharge and flooding in the floodplains. However, underlying the hydrological cycle is an equally important energy cycle.

Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 2000).

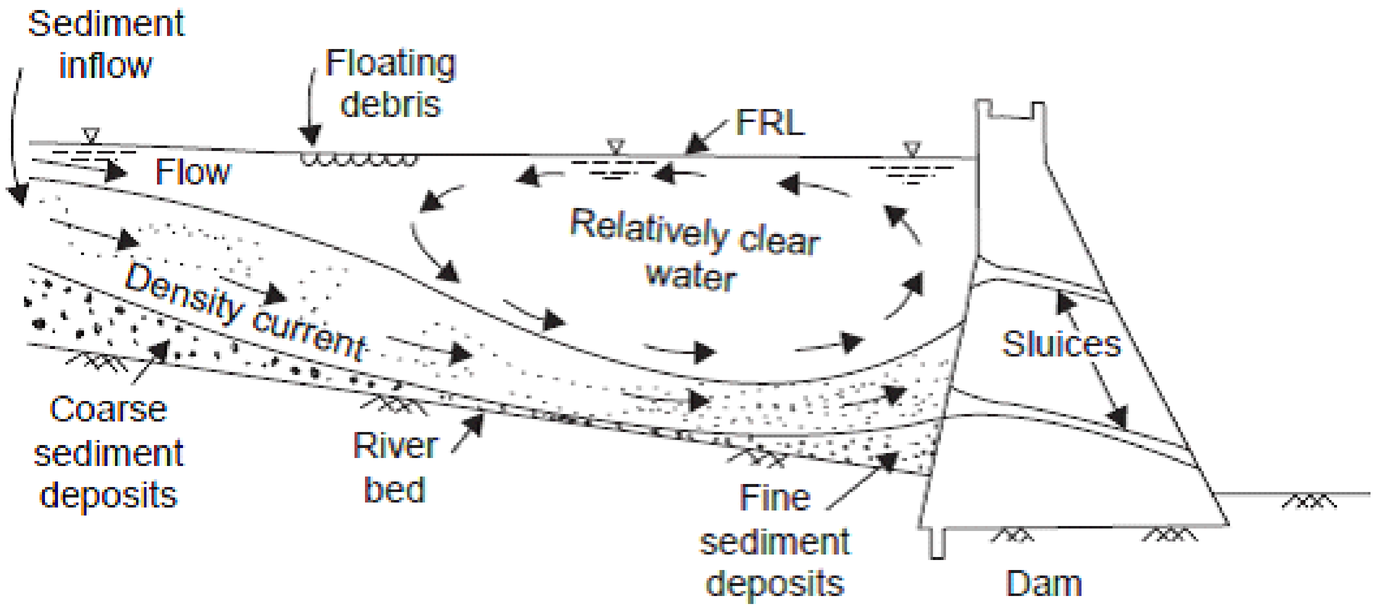

Figure 2.1 Sediment accumulations in a reservoir

2.2 Basic Equations of water Routing

Water is routed through the channel network using the variable storage routing method or Muskingum River routing methods. The equation of continuity is used in hydrologic routing is as the primary equation states that the difference between the flow and the out flow is equal to the rate of change of storage, i.e.

$I - Q = \frac{ds}{dt}$ ………………………………………………………………………….. 2.6

Where I =inflow rate, Q = outflow arte and S =storage. Alternatively, in a small time interval the difference between the total inflow volume and total outflow volume in a reach is equal to the change in storage in the reach.

$\bar{I}\Delta t - \bar{Q}\Delta t = \Delta S$ ………………………………………………………………………. 2.7

Where $\bar{I}$ = average inflow in time Δt, $\bar{Q}$ = average outflow in time Δt and ΔS = change in storage. By taking $\bar{I} = \left(\frac{I1++I2}{2}\right)$, $\bar{Q} = \left(\frac{Q1++Q2}{2}\right)$ and $\Delta S = S2 - S1$ with suffixes 1 and 2 to denote the beginning and end of time interval Δt Eq 2.6.becomes

$$\left(\frac{I1++I2}{2}\right)\Delta t-\left(\frac{Q1++Q2}{2}\right)\Delta t=S2-S1 \quad \text{……} \quad 2.8$$

The time interval should be sufficiently short so that the inflow and outflow hydrographs can be assumed to be straight lines in that time interval. Further Δt must be shorter than the time of transit of the flood wave through the reach.

2.2.1 Muskingum methods of routing

The Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages in a reach segment (After Chow et al., 1988). The volume that would exist if the uniform flow occurred at the downstream depth, i.e. the volume formed by an imaginary plane parallel to the channel bottom drawn at the out flow section water surface. Whereas wedge storage is wedge like volume formed between the actual water surface profile and the top surface of the prism storage.

At affixed section at a downstream section of a river reach, the prism storage is constant while the wedge storage changes from a positive value at an advancing flood to a negative value during a recording flood. The prism storage Sp is similar to a reservoir and can be expressed as a function of out flow discharge, S_P = f (Q).The wedge storage can be accounted for by expressing it as S_W = f (I) the total storage in the channel reach x can be expressed as;

$$S = K[x\, I^m + (1-x)\, Q^m] \quad \text{……} \quad 2.9$$

Where K and x are coefficients and m = a constant exponent, it has been found that the value of m varies from 0.6 for a rectangular channels to values of about 1.0 for natural channel.

$$S_2 - S_1 = K\,[x\,(I_2-I_1) + (1-x)\,(Q_2-Q_1)] \quad \text{……} \quad 2.10$$

Where suffixes 1and 2 refer to the conditions before and after the time interval Δt. The continuity equation for the reach is;

From equation Q_2 is evaluated as;

$$Q_2 = C_0I_2+C_1I_1+C_2I_2 \quad \text{……} \quad 2.11$$

Where;

$$Co=\frac{-Kx+0.5\Delta t}{K-Kx+0.5\Delta t}$$

$$C1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

$$C2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

Note that $C_0 + C_1 + C_2 = 1$ equation 2.10 can be written in general form for the n^{th} time step as;

$Q_n = C_0 I_n + C_1 I_{n-1} + C_2 Q_{n-1}$……………………………………………………………….2.12

It has been found that for best results the routing interval Δt should be so chosen that

$K > \Delta t > 2Kx$. If $\Delta t < 2Kx$, the coefficient C_0 will be negative. Generally negative values of coefficients are avoided by choosing appropriate values of Δt.

CHAPTER THREE

3 MATERIAL AND METDHOLOGIES

3.1 Description of study area

The site of this project area, Gomit earth dam irrigation project, is found in South Gondar Administration Zone, Estie woreda about 9km far away from the capital of the woreda in South direction. The geographical location of this site lies on the coordinates of 11^{0}33’43” North latitude and 38^{0}46’20” East longitude with an average altitude of 2375 above mean sea level.

The project area is classified as Dega agro climatically zone with an average altitude of 2343 m above mean sea level with two rainfall seasons of kiremit and non-promising Belg. The rainfall nature is uncertainly distributed and erratic as it is intercepted by Gunna Mountain.

The mean annual rainfall is computed to be 1642.91mm. The mean annual air temperature of the study area is about 16.4^{0}c. The mean monthly maximum air temperature ranges from 20.1^{0}c to 27.2^{0}c with a mean maximum of 27.2^{0}c occurring in March. The mean monthly minimum air temperature ranges between 7.4^{0}c and 11.1^{0}c with the mean minimum of 7.4^{0}c occurring in the month December.

In general, the hottest months are March and April. The most common explanation of the seasonal distribution of rainfall in Ethiopia is by reference to the position of the Inter-Tropical Convergence Zone (ITCZ), a low pressure area of convergence between tropical easterlies and equatorial wisterias along which equatorial wave disturbances take place.

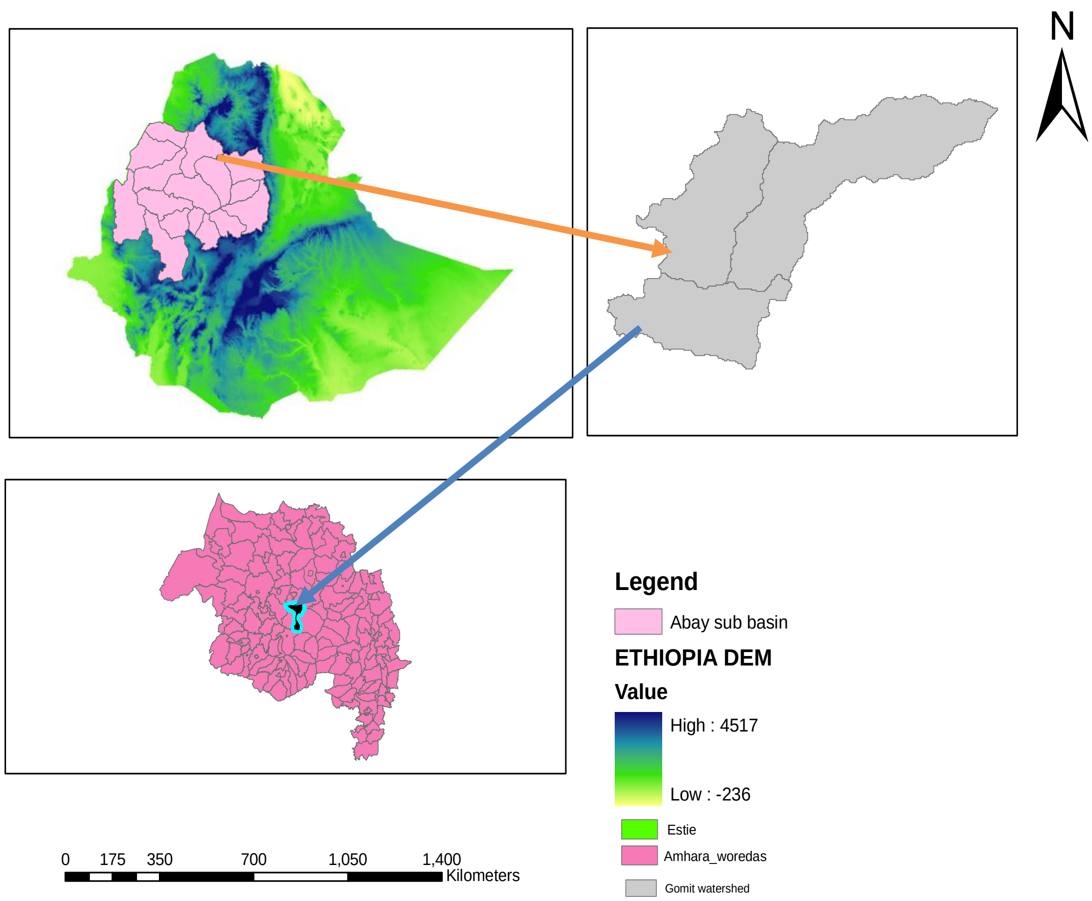

Figure3.1 Map of study area

3.2 Catchment Morphology

The value of catchment morphology is very essential to understand the geometric and geographic features of the watershed. They may indicate the degree of catchment dissection, the nature of drainage pattern and shape of the catchment. Some of the values may directly be involved in runoff and sediment yield estimation.

Figure 3.2 Watershed Sub basins

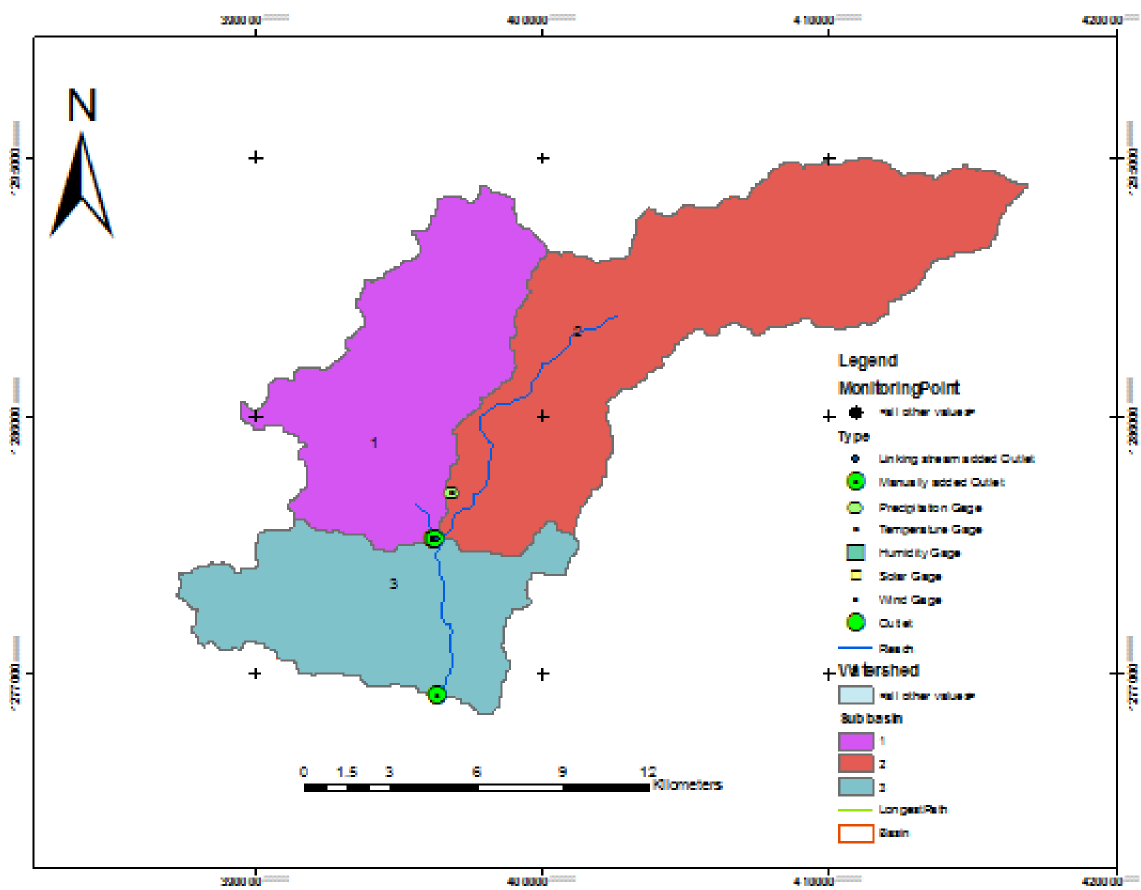

Figure 3.3 Silted up of reservoir at the upstream side (site visited)

3.3 Regional Geology

It is tried to describe the regional geology by surface observation with different field trips and making different traverses and with some in formations form geological map of Ethiopia (by V.Kazmin) with a scale of 1:2,000,000. The general geology of Estie woreda is dominantly covered by tertiary plateau volcanic, which are shield group of Miocene alkali-olivine basalt, tuff, agglomerates with basaltic flows and related spattered cones.

Most part of Estie woreda and vicinity of the area are covered by volcanic rocks of aphanitic and trachy basalt, tuff, and consolidated red ash rock formations.

Geographically the woreda is found in the North western highlands of Ethiopia and it is bounded by Blue Nile (Abay) River in the South part and the area is free from any tectonic and seismic activity or risk.

3.4 Geology of the study area/Catchment

The characteristics of the surrounding rock, which is highly vesiculated and weathered basalt rock, and this rock may serve as an aquifer for the surrounding area.

The area around the approach channel and downstream sides is covered by black cotton clay and below this soil there is highly weathered, vesiculated and saturated trachy basalt rock.

Clay soil which is underlined by highly vesiculated and weathered trachy basalt rock formation as it is observed along the gullies and the River banks. On the banks of the Gomit River in the reservoir area near to the dam axis water leaks in between the clay soil and rock formation and Gomit River itself has base flow and this flow increases downstream side until it joins the Wanka River.

3.5 Soil of the study area

Vegetation, climate and geology have been the main soil forming entitles active in the watershed area. Chromic luvisols cover the largest area of watershed (51.23%). The second largest group of soil in the watershed is Eutric cambisols, which covers (20.56%) of the watershed. Generally the major soil of the study area is chromic luvisols (51.23%), Chromic Vertisols (8.04%), Eutric Cambisols (20.56%), Eutric Nitosols (0.26%), Litho sols (5.18%) and Orthic Luvisols (14.73%) in their respective are coverage. Soil erosion on the hill side slopes and sedimentation at the upstream of the Dam already exists, because of intensive annual crop cultivation.

3.6 Land use and Land cover

3.6.1 Land use

The term Land use and land covers are used interchangeable. Land use deals with the actual economic activity for which the land is used or the purpose of human activity on the land and that of land cover refers to the cover of the earth's surface. The traditionally practiced improper land use change resulted in the existing sever natural resources degradation.

3.6.2 Vegetation Cover

Vegetation protects soil from the erosive forces of rain drop impact and runoff scour in several ways. Vegetation (top growth) shields the soil surface from rain drop impact while the root mass holds soil particles in place. Grass buffer strips can be used to filter sediment from the surface run off. Grass also slow the velocity of runoff, and help maintain the infiltration capacity of soil. The establishment and maintenance of vegetation are the most important factors in minimizing soil erosion.

The vegetation cover of the watershed is very much affected that the area is exposed to sever erosion hazard i.e. only about 9% of the total area is covered by vegetation and moderate ground cover. The main cause for destruction is unwise utilization by the local people for fuel wood and construction material i.e. the main source of fuel wood is the wood and wood products obtained with in the open bush and mainly dense bush land through.

3.7 Slope

Large slopes generate high velocity than smaller slopes and it dispose of runoff faster. For smaller slopes, the balance between rainfall input and the runoff rate gets stored temporally over the area and is able to drain out gradually over time. Haggard et.al. (2005) and Khan et. al. (2007) reported that an increase in surface sloped increase in surface runoff.

Table3.1 Slope and land forms of the watershed

Slope range	Land forms	Area (ha)	Coverage (%)
0-2	Flat	572.702	2.56
2-10	Genteel slope	4471.218	19.98
10-15	Moderately steep	7097.541	31.71
15-30	Steep slope	7772.881	34.73
>30	Very steep slope	2466.759	11.02

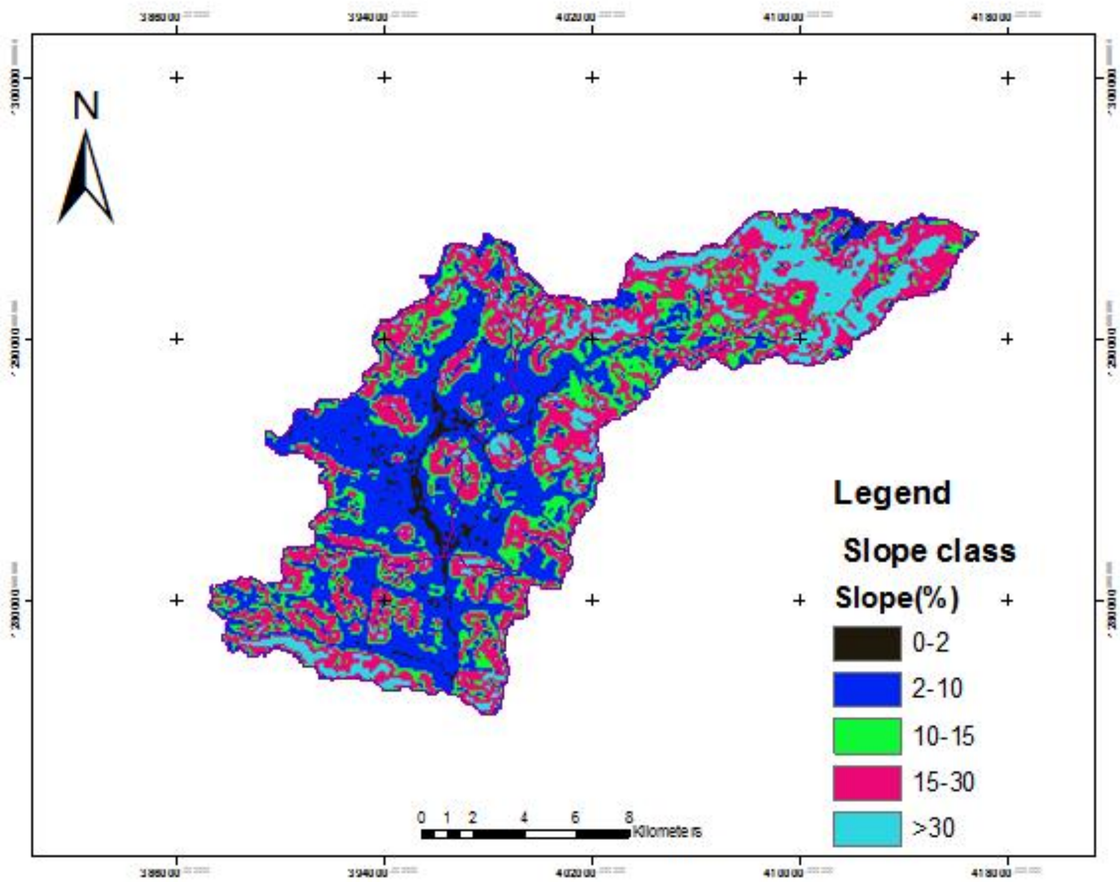

Figure 3.4 Slope class map of study area

3.8 Climate

There is meteorological station operated by the national meteorological services agency (NMSA) at Debre - Tabor town that lies at an altitude of 2612m a.s.l. This is the nearest and most representative station for the project area.

The climatic data elements observed at the station are rainfall, daily temperature, daily heaviest fall, wind speed, relative humidity, sunshine hours and radiation. Actually summarized data of wind speed, relative humidity and sunshine hours are obtained where as monthly data of rainfall, daily temperature and daily heaviest fall of years of record are available for this project analysis. There is only one rainy season starting in May and ending in September with a peak in July. The month with very little or no rain is January. The mean annual rainfall is computed to be 1642.91mm. The mean annual air temperature of the study area is about 16.4^0c. The mean monthly maximum air temperature ranges from

20.1^0c to 27.2^0c with a mean maximum of 27.2^0c occurring in March. The mean monthly minimum air temperature ranges between 7.4^0c and 11.1^0c with the mean minimum of 7.4^0c occurring in the month December. In general, the hottest months are March and April. The most common explanation of the seasonal distribution of rainfall in Ethiopia is by reference to the position of the Inter-Tropical Convergence Zone (ITCZ), a low pressure area of convergence between tropical easterlies and equatorial wisterias along which equatorial wave disturbances take place. This low pressure zone, which may not be continuous in space or time, is often traceable in Ethiopia between May and November.

The Debre - Tabor area is situated in the region categorized as warm - temperate zone having only one rainy season covering five months namely May, June, July, August and September. The annual rainfall is un-modal with a peak rainfall in July. The months January, February, March, April, October, November and December are dry. The figure below shows rain fall, relative humidity, maximum and minimum temperature, wind speed and solar radiation.

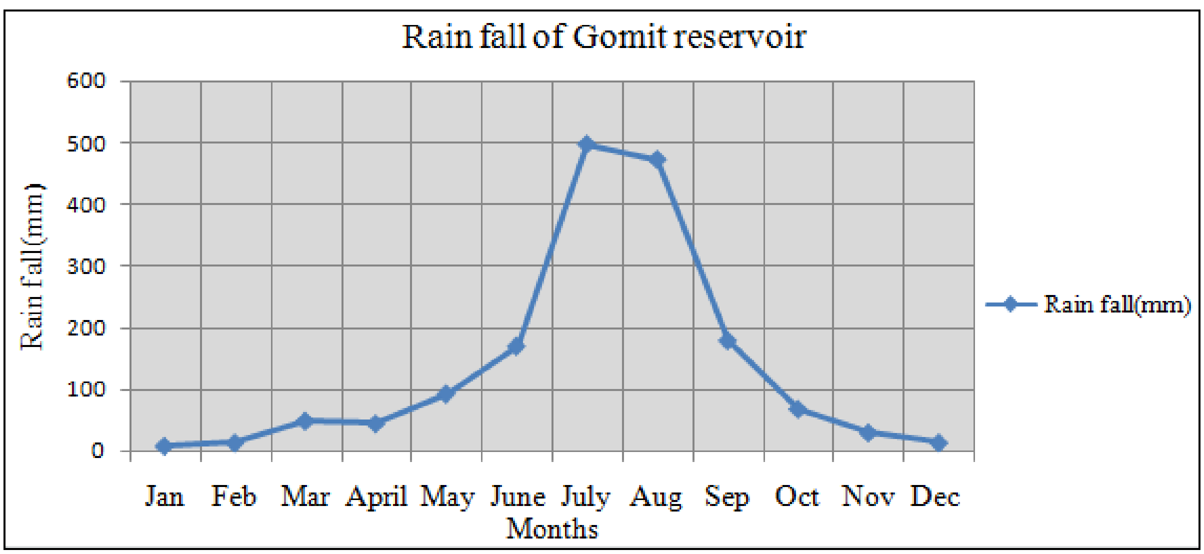

Figure3.5 Rain fall of Gomit water shed

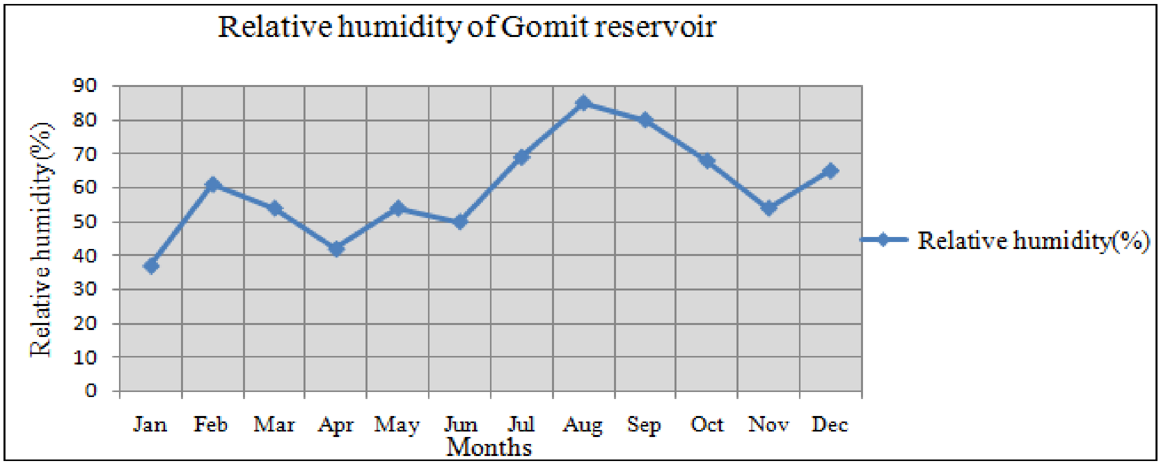

Figure3.6 Relative humidity

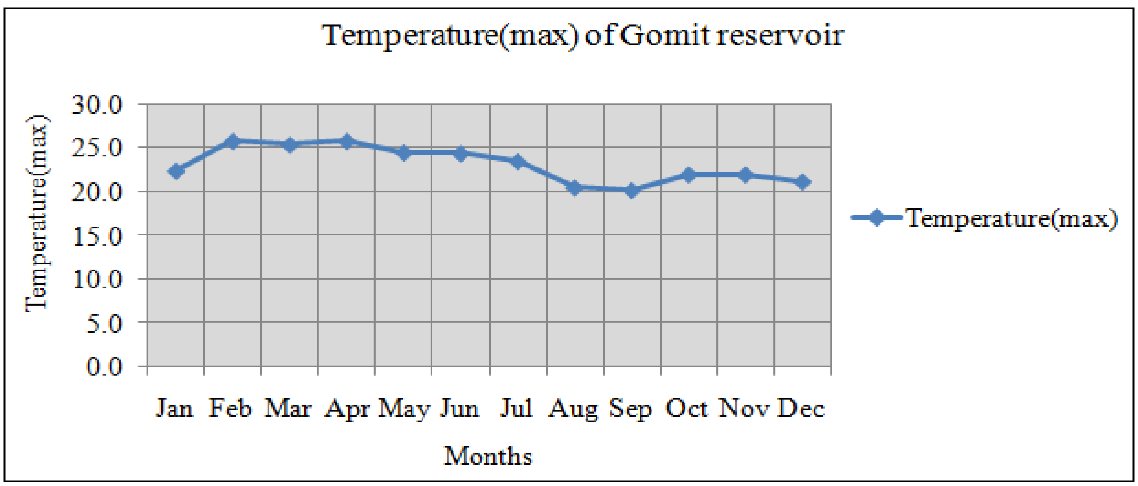

Figure3.7 Temperature (max)

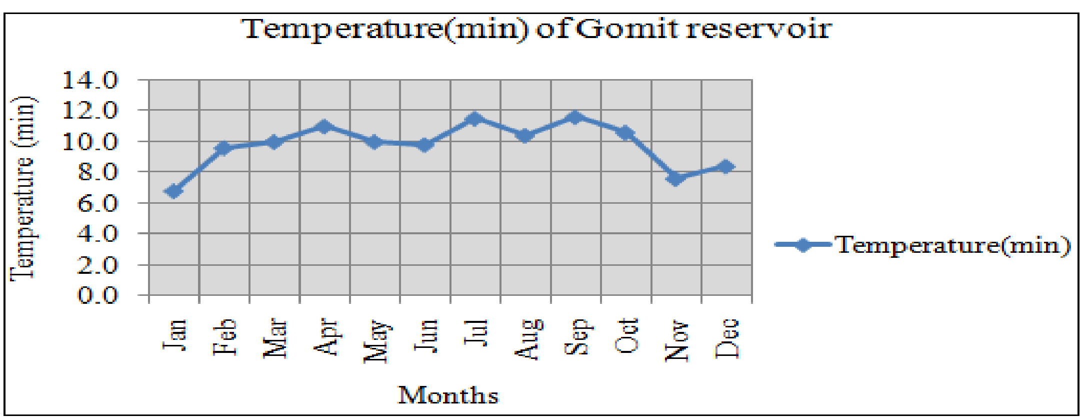

Figure3.8 Temperature (min)

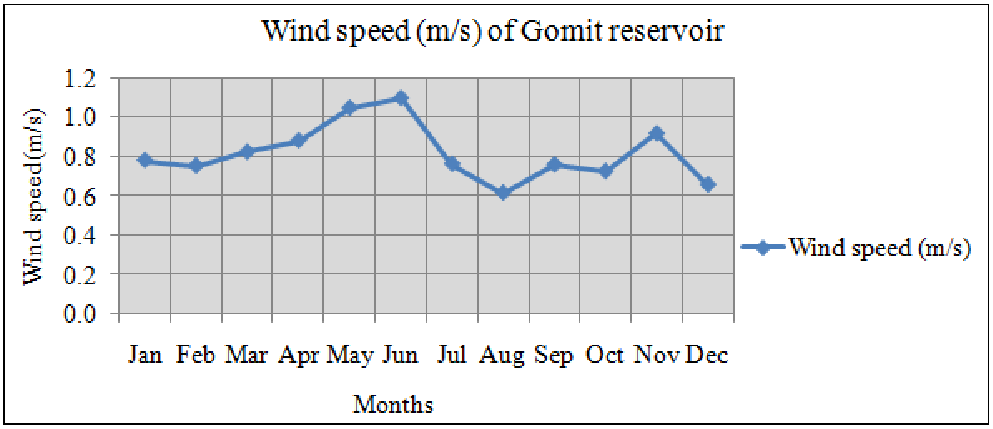

Figure 3.9 wind speed of Gomit

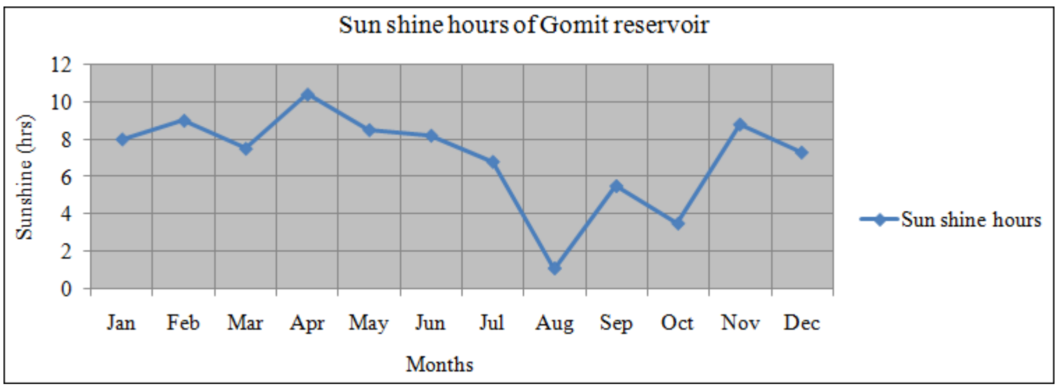

Figure 3.10 sun shine

Figure3.11 Partial view of Gomit reservoir and staff gauge (source site visit)

3.9 Design of the Study/ Procedure

The following flow chart indicates the overall framework of the methodology and analysis to be followed throughout the study of this thesis.

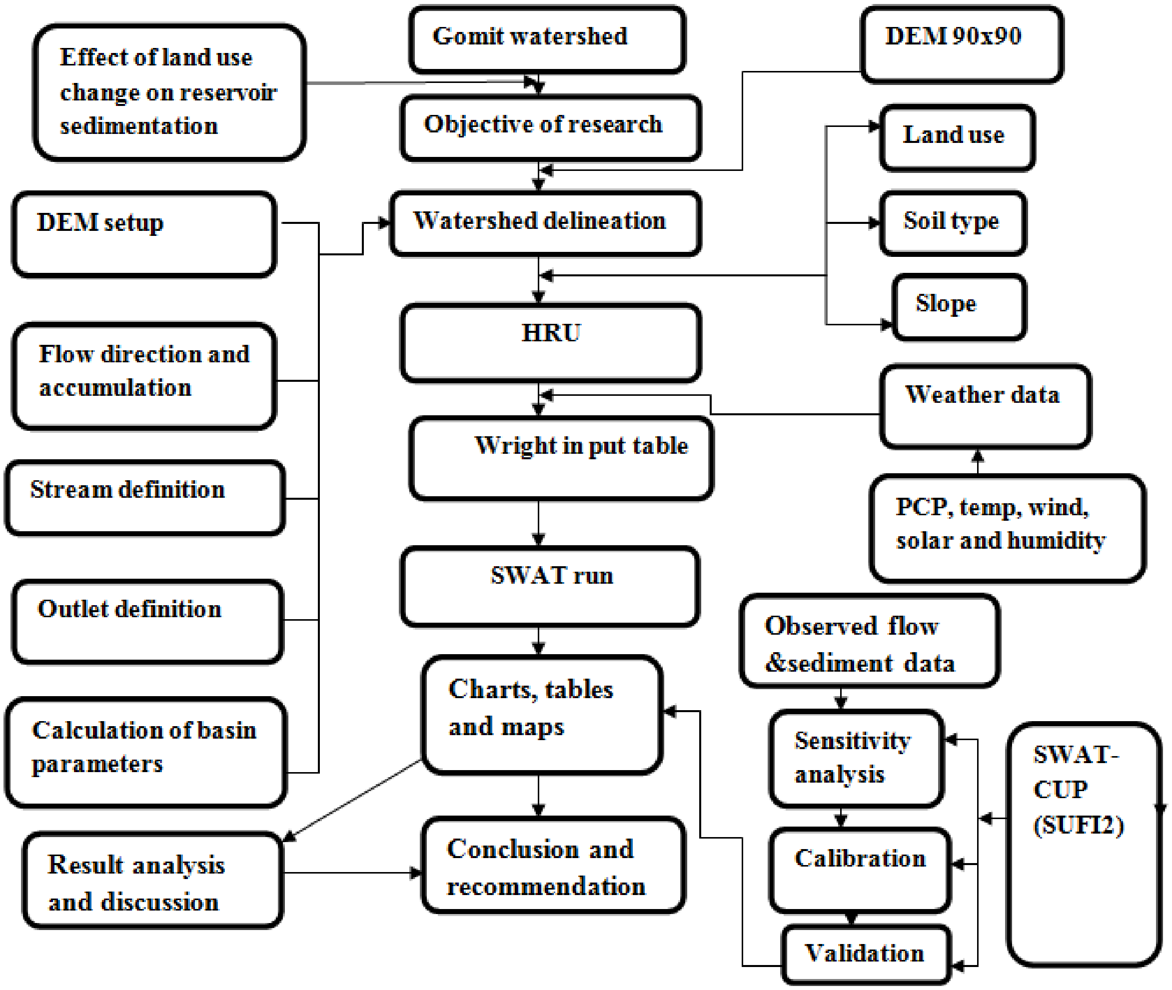

Figure 3.12 Conceptual frame works of research design

3.10 Data collection

Field investigation for the gathering of important data and collection of topographic map, soil data, land use/land cover data, Digital model (DEM), Meteorological data, hydrological data are required for modeling of them by using SWAT, Arc GIS model. Daily rain fall and temperature data of Estie (Mekan eyessue) Meteorological station and the same year of rainfall temperature wind speed relative humidity and sunshine hour data of Debre Tabor Meteorological station are collected from national meteorological agency. Sediment and flow of Gumara river data's are collected from ministry of water irrigation and energy resource.

3.11 Method of analysis

The methodology and analysis should be done with the aid of SWAT model by using the required data. Gomit River is ungauged and also it is intermittent river so that recorded suspended and bed load data's are not available. Sediment and flow data of Gumara River have been used to determine flow and sediment yield of Gomit reservoir. Because Gomit and Gumara have similar catchment characteristics and they are Neighbors. The similarity is checked by RAINBOW Homogeneity Test of rain fall, stream flow and sediment. Prediction of sediment yield in the watershed by using SWAT model for different land use land cover condition and determination of sedimentation into the Reservoir should be done. The data's going to be input to the model are DEM data, topographic map, land use map, soil map and hydrological data's. After having all input data to the model, running the model results/outputs from the model is obtained. Finally all the results of the model are going to interpret to define how land use change affects the sediment yield of the catchment.

3.12 Materials that are used

- Arc SWAT (software)
- SWAT CUP (SUFI2)
- SWAT model (software) for determination of sediment yield from the catchment area.
- Topographic map to determine geographic location and elevation.
- Soil map
- Sediment and flow data
- Dew02
- PCPSTAT
- Land use map
- Metrological data

3.13 Estimation of missing rain fall data

The annual precipitation values, P1, P2, P3….Pm at neighboring M stations 1, 2, 3… M respectively are given. It is required to finding the missing annual precipitation Px at a station x not included in the above M stations. Further, the normal annual precipitation N1, N2……Ni at each of the above (m+1) stations including station x are known. If the normal annual precipitation at various stations is within above 10% of the normal annual precipitation x. then for this study a simple arithmetic average procedure is followed to estimate Px.

$$Px = 1 + \frac{1}{M}(P1 + P2 + \cdots + Pm) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

If the normal precipitations vary considerably, then Px is estimated by weighting the precipitation at the various station x by the ratio if normal annual precipitation. This method known as the normal ratio method, gives Px as;

$$Px = +\frac{Nx}{M}(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pm}{Nm}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3.2$$

3.14 Computation of Areal Rain fall

Point sampling of the areal distribution of a storm represented by Rain gauges. Arithmetic mean, Theissen polygon and Isohyetal are some of the methods used to convert point rain fall at a stations into an average values over a watershed. Arithmetic mean methods were used for this study due to its simplicity. This is the simplest method of computing the average rainfall over a basin.

As the name suggests, the result is obtained by the division of the sum of rain depths recorded at different rain gauge stations of the basin by the number of the stations.

If the rain gauges are uniformly distributed over the area and the rainfall varies in a very regular manner, the results obtained by this method could be quite satisfactory and could not differ much than those obtained by the methods .This method can be used for the storm rainfall, monthly or annual rainfall average computations.

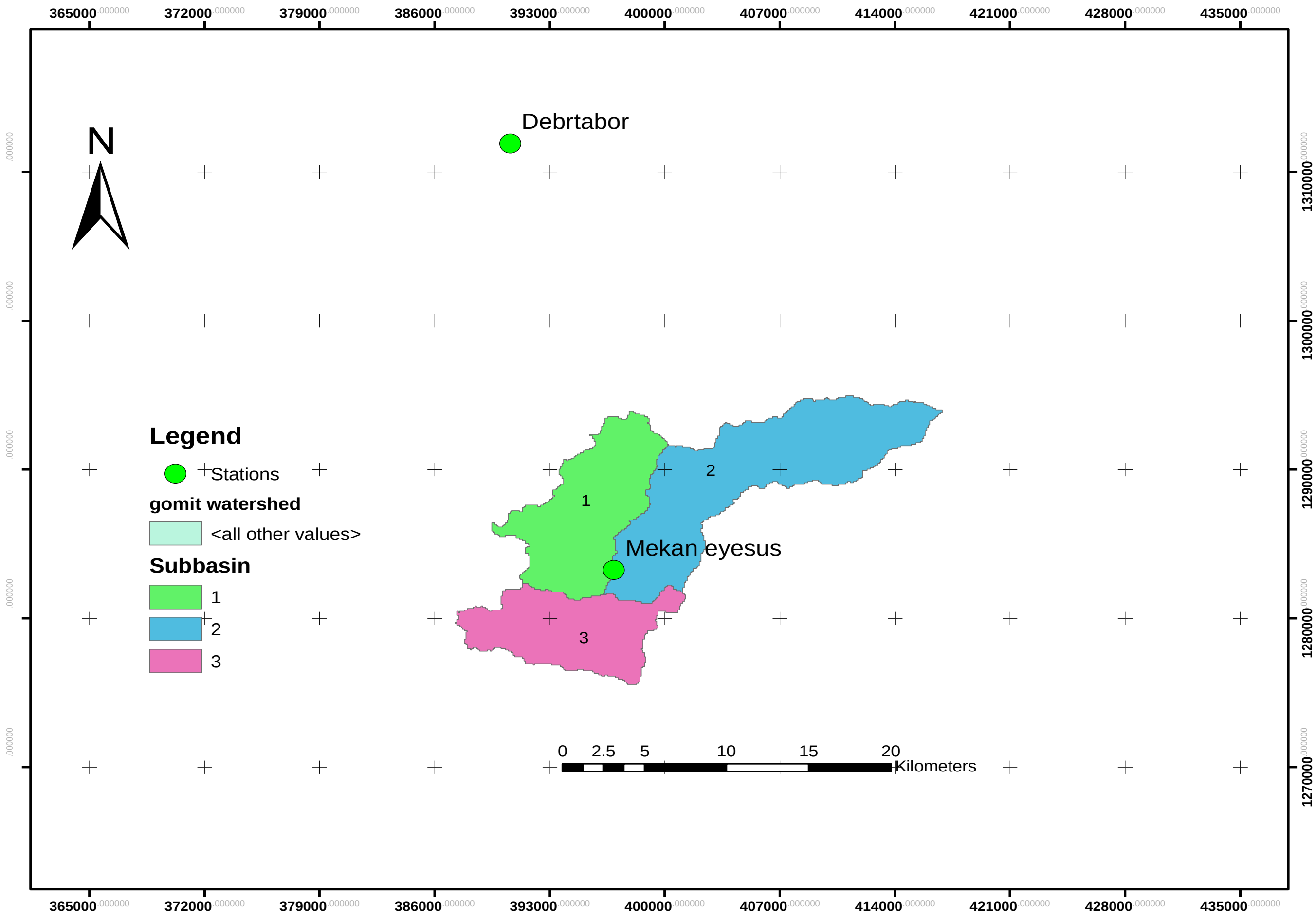

Figure 3.13 Stations of study area

3.15 Homogeneity Test

Rainbow software is used to check the homogeneity of the data. Frequency analysis of rainfall, flow and sediment data and their potential use in agro-meteorological decision-making processes requires that the data be of long series; they should be homogeneous and independent.

Homogeneity is an important issue to detect the variability of the data. In general when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environment characteristics and structures, and location of stations. Method for outlier identification includes use of statistical test like Grubbs test (Chow, 1988).The restrictions of homogeneity assure that the observations are from the same population. In RAINBOW the test for homogeneity is based on the cumulative deviation from the mean. The following figure shows the homogeneity test of rain fall, flow and sediment in the study area.

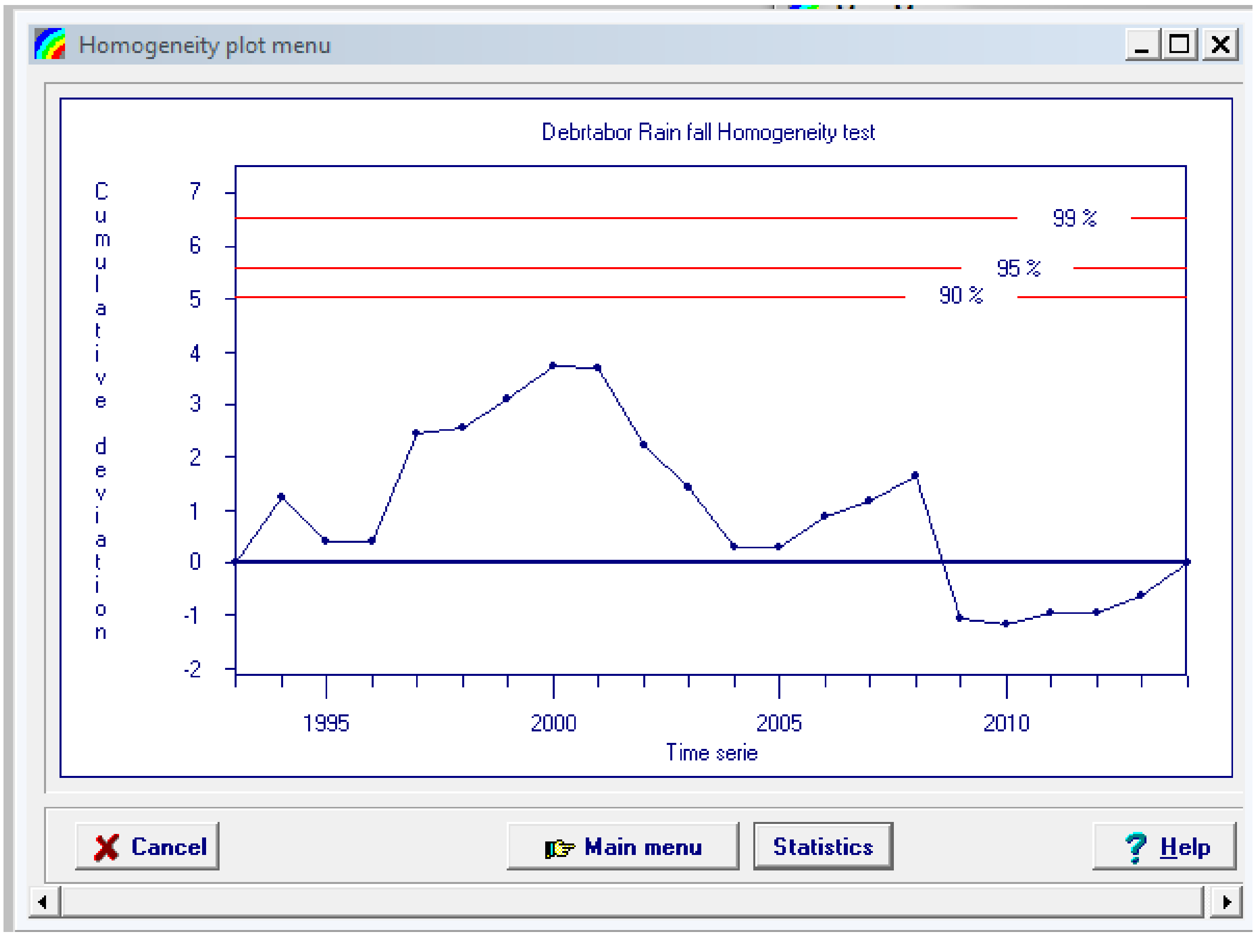

Figure 3.14 Cumulative Deviation of Sediment Concentration at Debretabor station

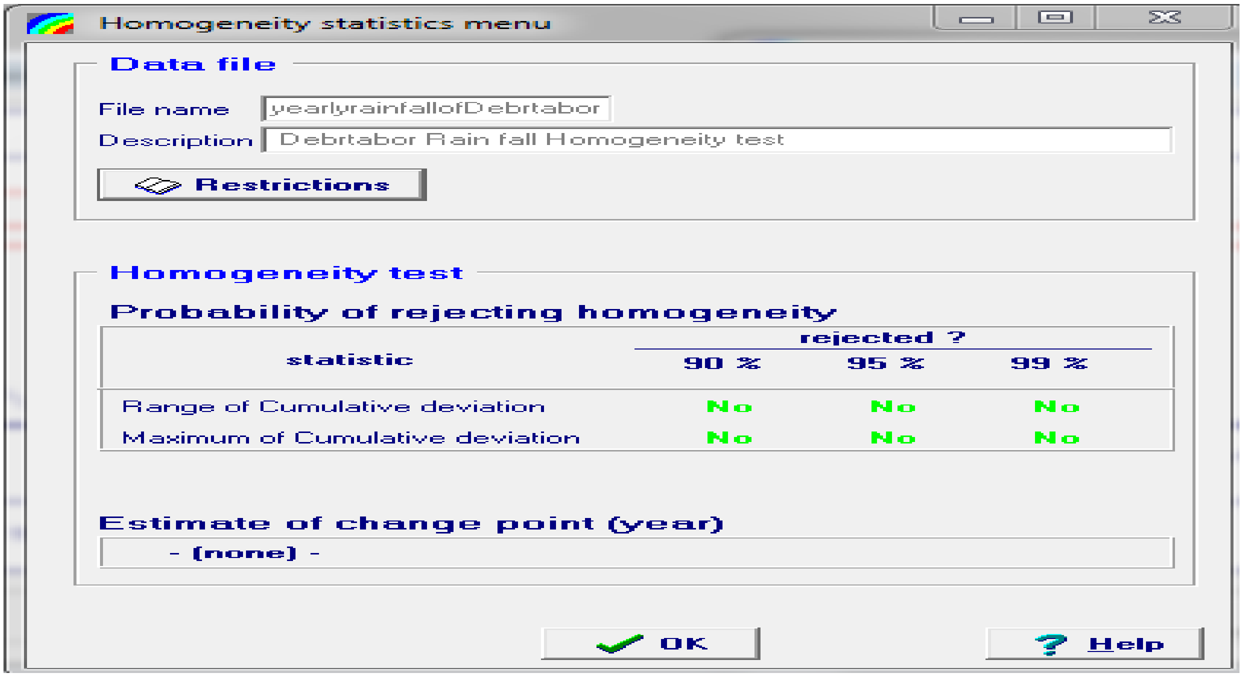

Figure 3.15 Probability of Rejecting Rain fall at Debretabor Station

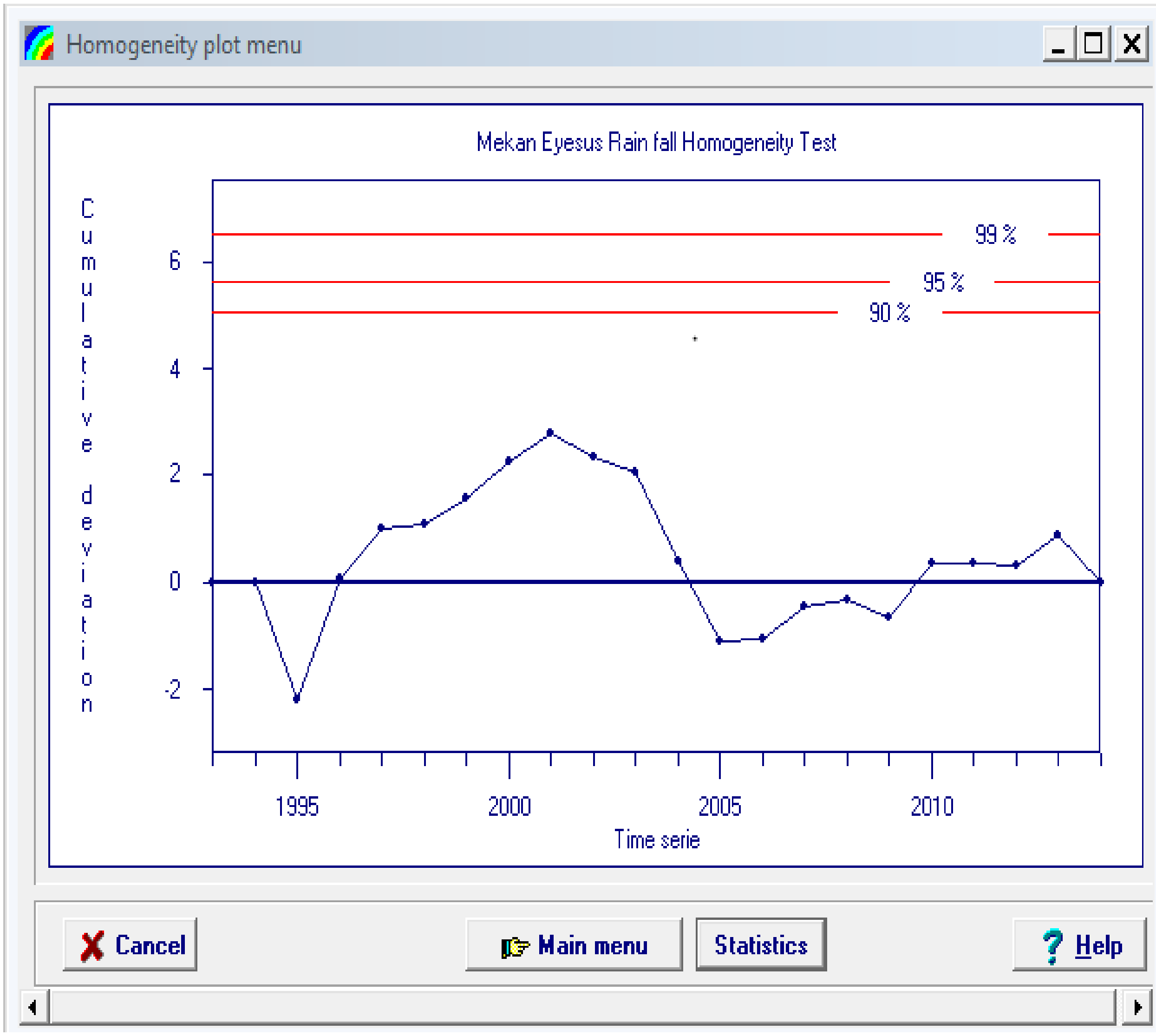

Figure 3.16 Cumulative Deviation of Rain fall at Mekaneyesus Station

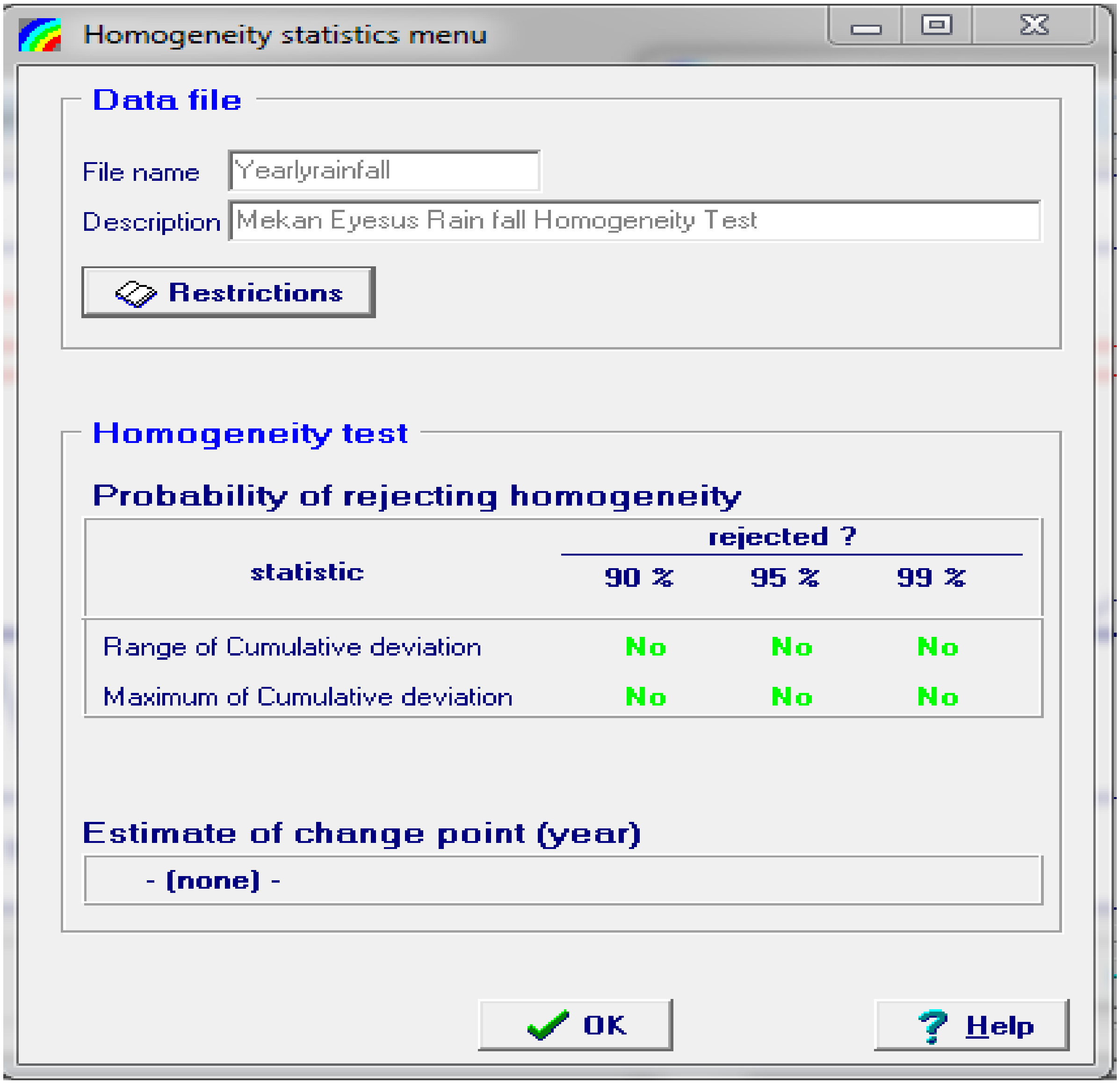

Figure 3.17 Probability of Rejecting Rain fall at Mekaneyesus Station

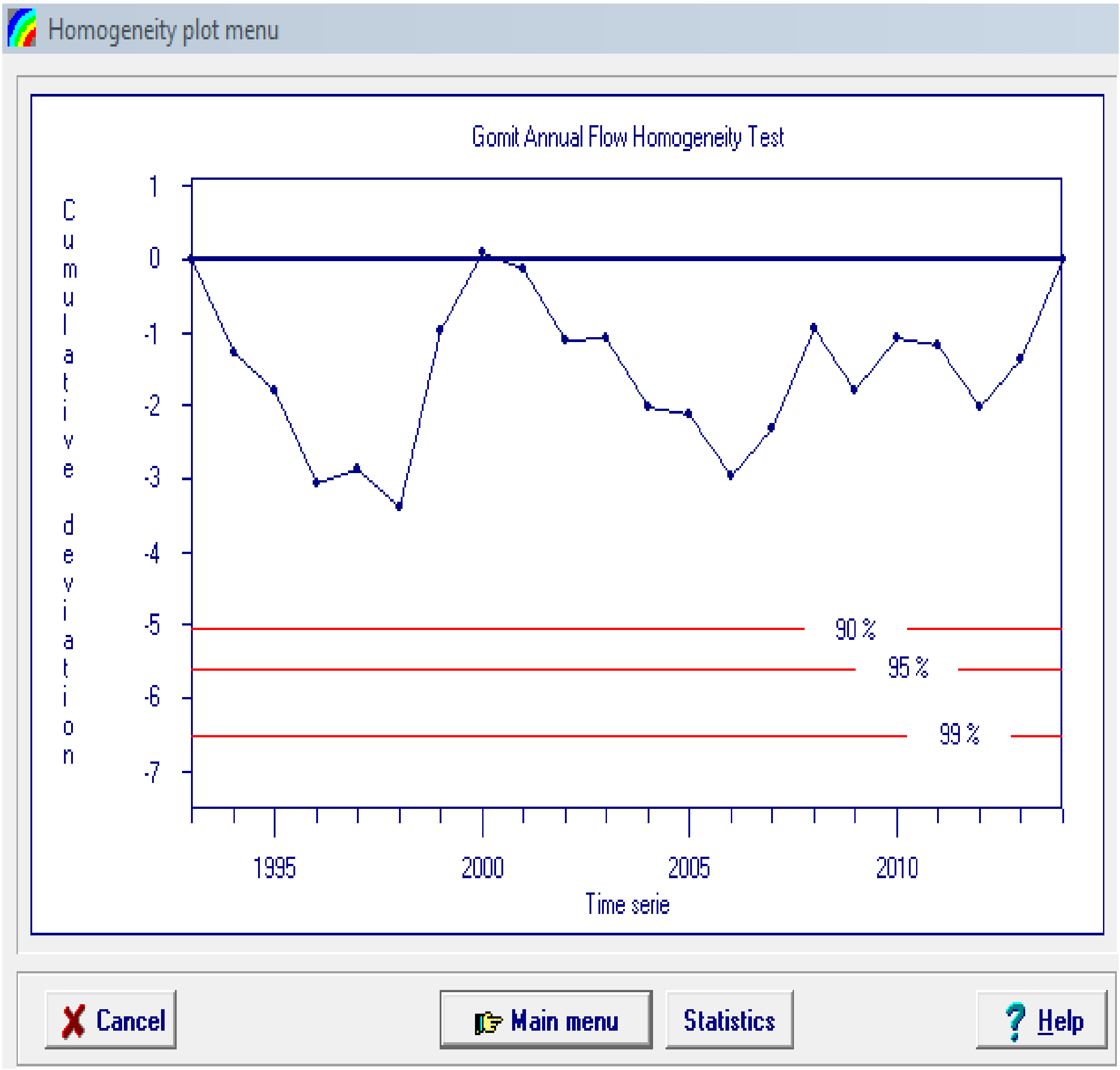

Figure 3.18 Cumulative Deviation of Annual Flow at Gomit station

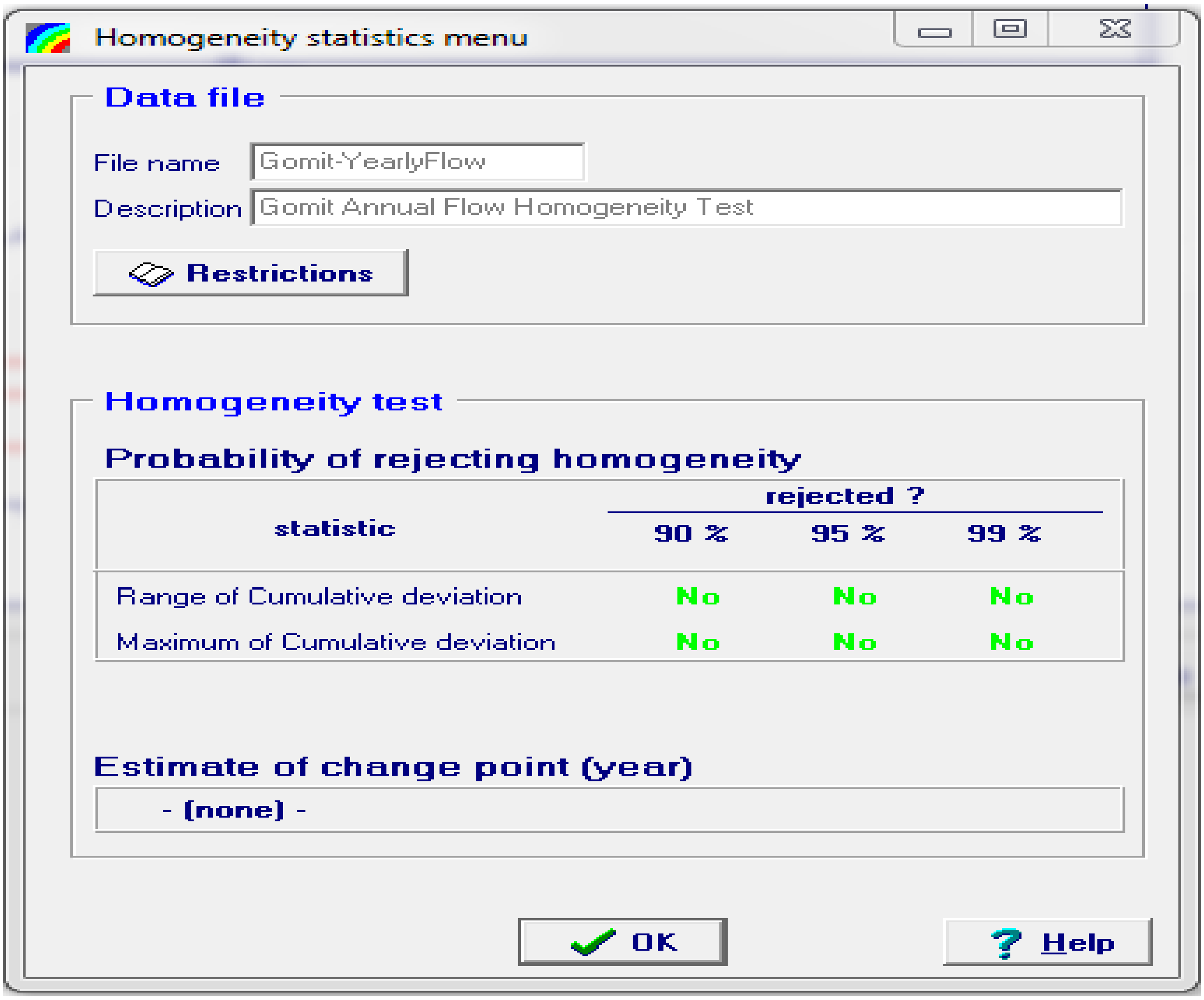

Figure 3.19 Probability of Rejecting Homogeneity Annual Flow at Gomit station

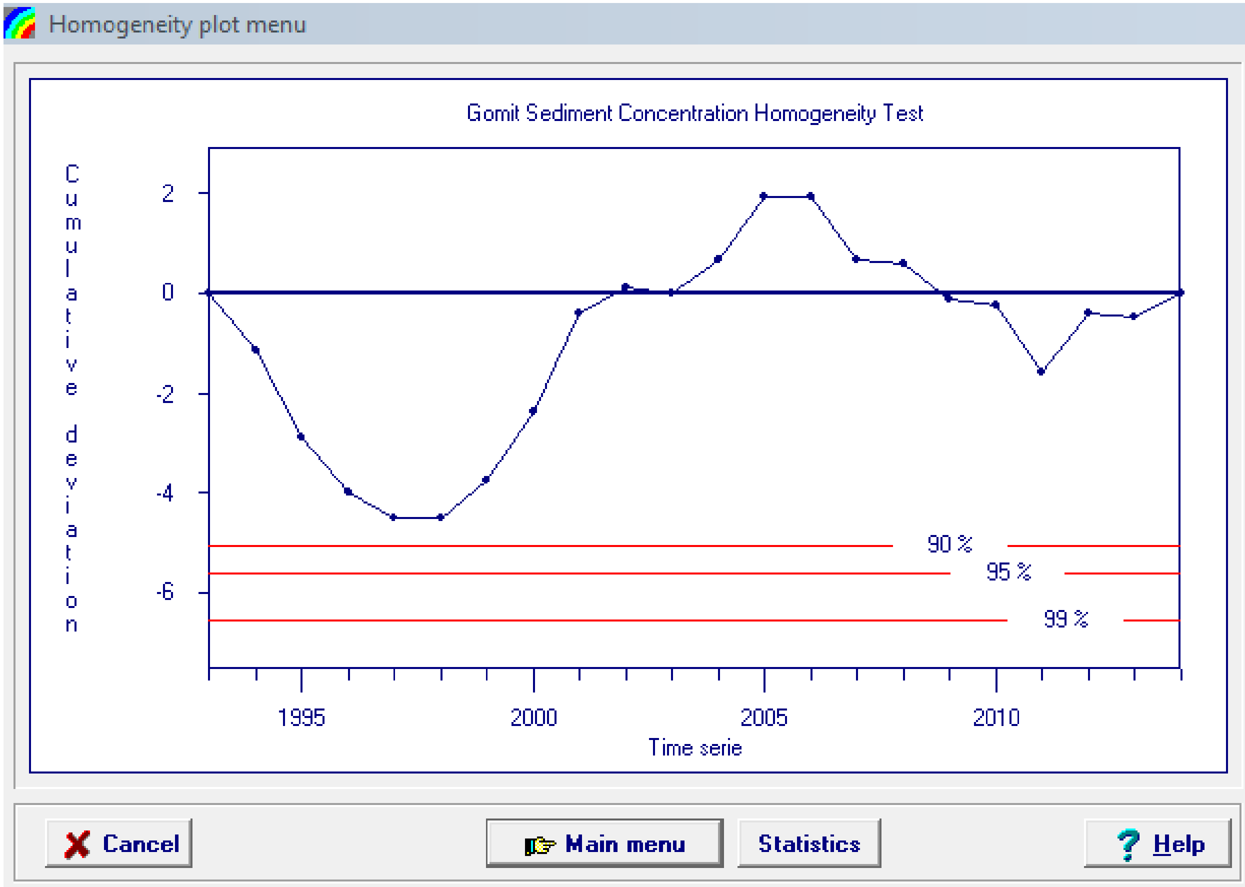

Figure 3.20 Cumulative Deviation of Sediment Concentration at Gomit station

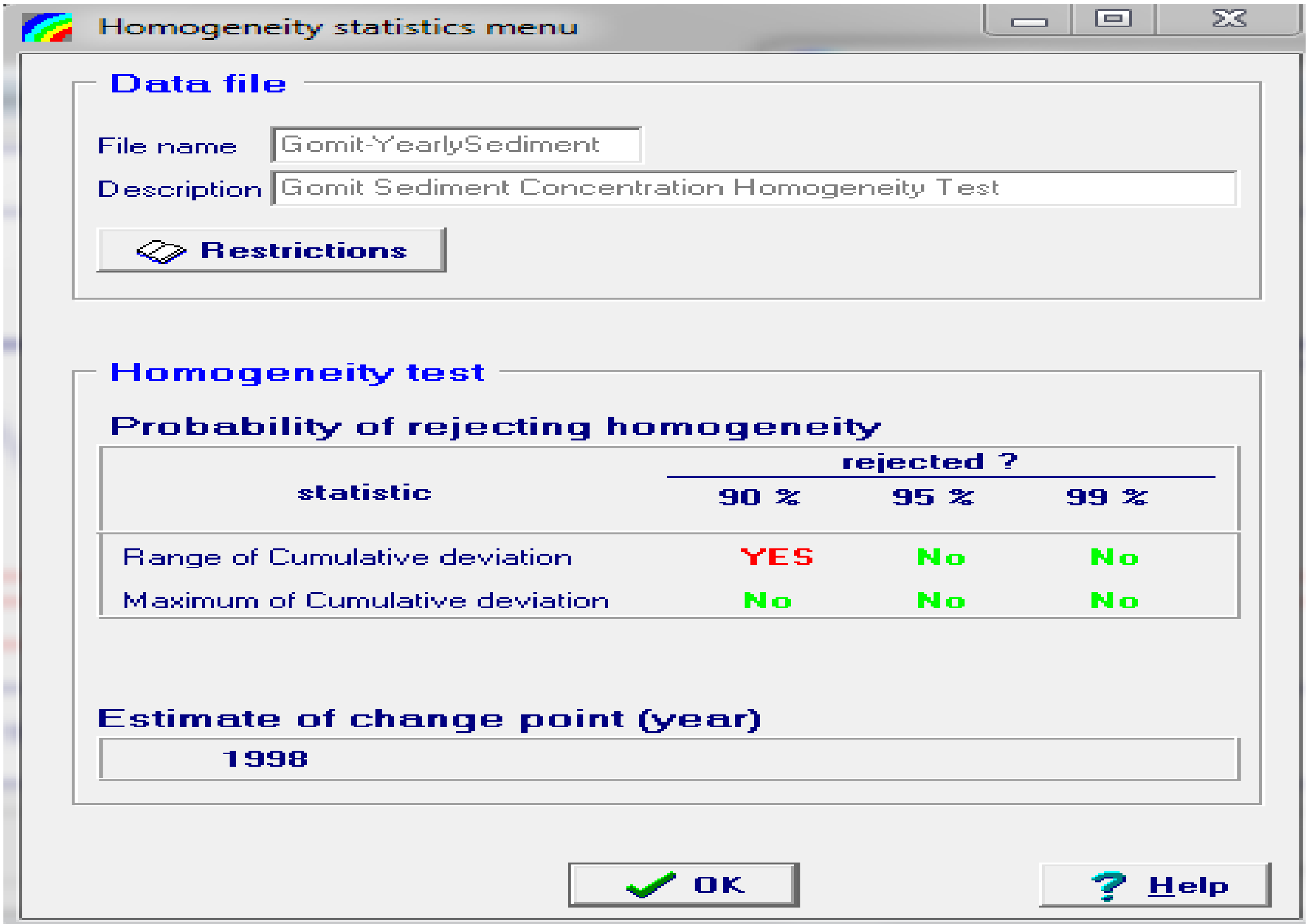

Figure 3.21 Probability of Rejecting Sediment concentration at Gomit Station

3.16 Surface Runoff

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration (Solomon, 2005). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating the surface runoff: the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) or the Green &Ampt infiltration method (Green and Ampt, 1911). The Green and Ampt method needs sub-daily time step rainfall which made it difficult to be used for this study due to unavailability of sub-daily rainfall data. Therefore, the SCS curve number method was adopted for this study.

The general equation for the SCS curve number method is expressed by equation below:

$$Qsurf = \frac{(Rd-Ia)2}{(Rd-Ia+S)} \qquad \text{3.3}$$

Where, Q*surf* = the accumulated runoff or rainfall excess (mm), *Rd = is* the rainfall depth for the day (mm water),

Ia= is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water),

S= is retention parameter (mm water).

This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as:

$$S = 25.4(\frac{1000}{CN} - 10) \quad \text{……3.4}$$

Where, *CN* is the curve number for the day and its value is the function of land use practice, soil permeability and soil hydrologic group.

The initial abstraction, *Ia*, is commonly approximated as 0.2*S* and equation 3.5 becomes:

$$Qsurf = \frac{(Rd-0.2S)2}{(Rd+0.8S)} \quad \text{……3.5}$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified in to four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively

3.17 Sediment transport

Sediment transport in the channel network is a function of two processes i.e. deposition and degradation. SWAT model compute both of the two processes.

$$Sed_{deg} = (Conc_{sed, ch, mx} - Conc_{sed, ch, i}) * V_{ch} * K_{ch} * C_{ch} \quad \text{……3.6}$$

$$Sed_{dep} = (Conc_{sed, ch, i} - Concmx) * V_{ch} \quad \text{……3.7}$$

Where

Sed_{deg} is the amount of sediment re-entered in the reach segment (metric tons)

$Conc_{sed, ch, i}$ is the amount of initial sediment concentration in the reach (kg/l)

$Conc_{sed, ch, mx}$ is the maximum concentration of sediment that can be transported by the water ton/m3

K_{ch} is the channel erodibility factor (cm/hr)

C_{ch} is the channel cover factor, V_{ch} is the volume of water in the reach segment (m3) and

Sed_{dep} is the amount of sediment deposited in the reach (metric tons). After calculating degradation and deposition the final amount of sediment in the reach and amount of sediment out of the reach is calculated with the following equations.

$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg}$……………………………………………3.8

$Sed_{out} = Sed_{ch} * (V_{out}/V)$…………………………………………………..........3.9

Where;

Sed_{ch} =amount of suspended sediment (metric tons)

Sed_{chi} = amount of suspended sediment in the reach (metric tons)

Sed_{deg} = amount of sediment re-entered in the reach segment (metric tons)

Sed_{out} = amount of sediment transported out of the reach (metric tons)

V_{out} = the volume of out flow (m3)

Vch = volume of water in the reach (m3)

3.18 Sediment Transport Equations by Using MUSLE

The improved equations developed based on the USLE model are such as the Modified Universal Soil Loss Equation (MUSLE) by J.R. Williams (Williams, 1975),

The RUSLE assumes that detachment and deposition are controlled by the sediment content of the flow (Pitt, 2007). The Modified Universal soil lose equation (Williams, 1975) is;

$Sed = 118*(Qsurf* q\ p_{eak*}Arhu)^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG$…………………3.10

Where Sed is the sediment yield on a given day in metric tons, Qsurf is the surface runoff from the watershed in mm/ha, q peak is the peak runoff rate in cubic meter per second, Ahru is the area of HRU, K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE land cover and management factor, P_{USLE} is the USLE support practice factor, L_{SULE} is the USLE topographic factor, and CFRG is the coarse fragment factor.

3.19 Sediment rating curve

Measured stream flow and sediment data can generate sediment load in continuous time step which is known as sediment rating curve. The measured suspended sediment concentration data used for sediment rating graph preparation. Sediment rating curve was the relationship between River discharge and sediment concentration load (Clarke, 1994). It’s basically used to estimate the sediment load being transported by the river. The graph of sediment rating curve is plotted as average sediment concentration as a function average discharge over a given time. The relationship was written as:

$S = aQ^b$…………………………………………………………………….…3.11

Where S= Sediment load in ton/day

Q= Discharge in m^3/s, b and a are regression constants To convert sediment concentration into sediment load the following equation should be applied:

S= 86.40*Q*C ………………………………………………………………3.12

Where S= sediment load in ton/day

Q= flow of a stream m^3/s

C= sediment concentration (mg/l) and 86.4 is conversion factor.

After calculating the sediment load the relationship between continuous measured flow and sediment load graph is constructed.

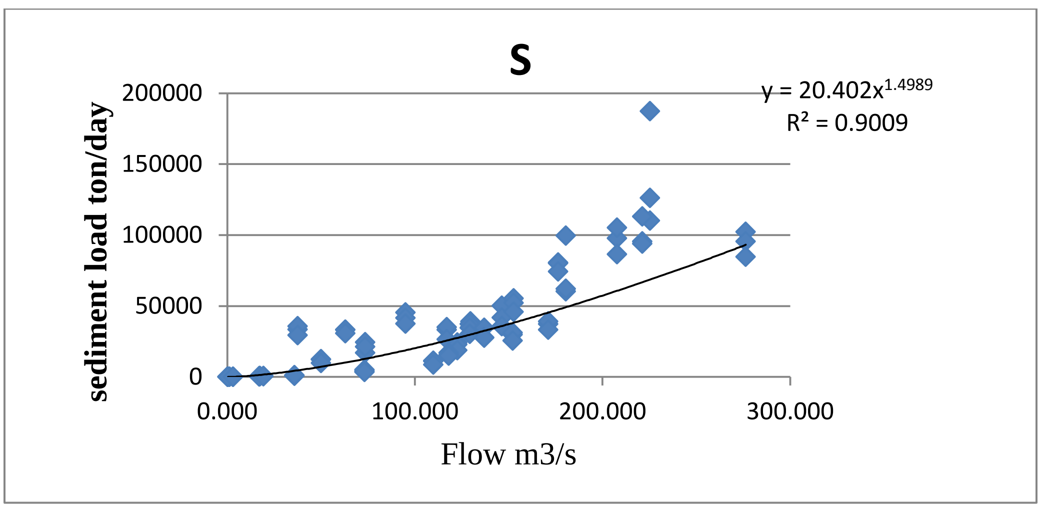

Figure3.22 Sediment Rating Curve of the Study Area

3.20 Inputs of SWAT Model

3.20.1 Digital Elevation Model (DEM)

DEM defines /describes the elevation of any point in a given watershed at special resolutions. A resolution of 90m by 90m DEM has been taken from Ministry of Water and Energy (MOWE). It is used to delineate the watershed area of the study.

3.20.2 Soil data

The soil data has been obtained mainly from MoWIE, Abay Basin and Major soils of the World CD-ROM FAO, (2002).

The soil data is required for SWAT model to analyze the major soil distribution in the catchment area and reclassify them according to SWAT code.

3.20.3 Land use/ Land cover data

Land use map of the study was obtained from Ministry of Water and Energy (MoWIE). SWAT defines the land use identified by four letter coding system and this codes are linked to SWAT land use database.

3.20.4 Daily weather data

Daily weather data, such as Rain fall, temperature of maximum and minimum, wind speed, relative humidity and solar radiation data for 21 year period which is (1994-2014) were obtained from Ministry of Meteorological Service Agency (MSMA). This daily weather data are used by SWAT weather generator to generate the missing data of weather parameter.

3.20.5 Monthly Flow and Sediment data

This data was obtained from Ministry of Water Irrigation and Energy. Monthly stream flow and sediment yield recorded data are used for calibration and validation of the model.

3.21 Parameterization of the model

3.21.1 Catchment Delineation

The SWAT model can be applied with different spatial discretization schemes; however most users apply it in a semi distributed way which is preferable by users - with Arc GIS interface (Diluzio et al., 2002; Diluzio et al., 2004). The catchment was delineated by the following steps in Arc SWAT and it includes DEM set-up, stream definition, outlet and inlet definition, and calculation of sub basin parameters. The study area was manually delineated by masking around the study area.

Watershed delineation is required to provide a boundary of the watershed. SWAT uses Arc Hydro algorithm for watershed delineation. The watershed delineation carries out advanced GIS functions to aid the user in segmenting watersheds in to several 'hydrologically' connected sub watersheds for use in watershed modeling in SWAT.

There are two methods for watershed delineation in SWAT model, one is the DEM-based method, which is based on the DEM of the study area and the other is the pre-defined method in which users can define the reaches and sub basins manually. Most of the researchers use the first method at present, which has high precision only in the area with certain terrain slope .During watershed delineation flow direction and flow accumulation process is done.

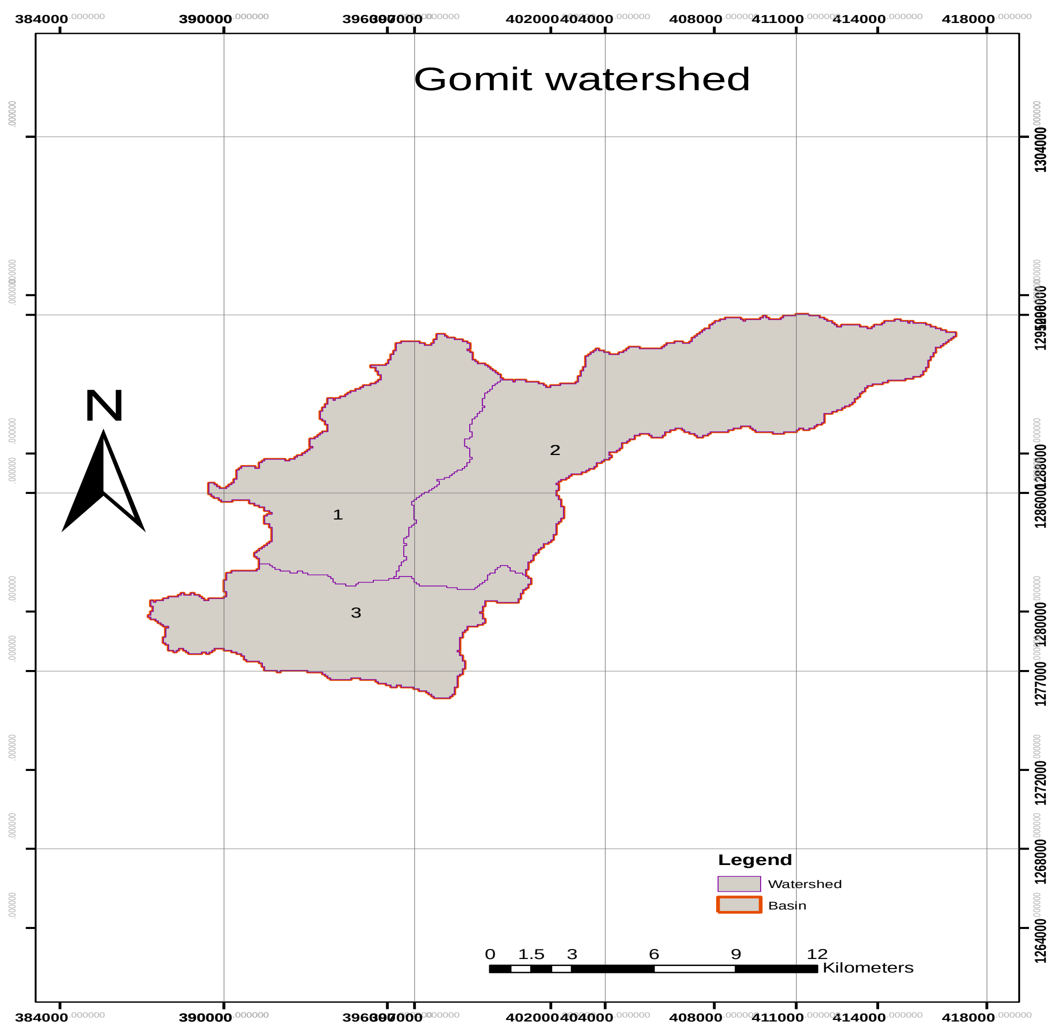

Figure 3.23 Watershed and sub basins of study area

3.21.2 Hydrological Response Unit Analysis

Hydrological response units are areas within a watershed that respond hydrologically similarly to given input. It is a means to representing the spatial heterogeneity of a watershed. With the introduction of hydrologic response unit (HRU), it is possible to expect similar hydrologic behavior in each unit, which can be modeled easily. Plenty of hydrological models use HRU as unit response for a sub basin.

3.21.3 Land use, Soil and Slope Definition

The Land Use, Soil and Slope Definition option in the HRU Analysis menu allows the user to specify the land use, soil and slope themes that will be used for modeling using SWAT and Non-Point Source Model (NPSM). These themes are then used to determine the hydrologic response unit (HRU) distribution in each sub-watershed. Both NPSM and SWAT require land use data to determine the area of each land category to be simulated within each sub basin. In addition to land use information, SWAT relies on soil data to determine the range of hydrologic characteristics found within each sub basin. Land Use, Soil and Slope Definition option guides the user through the process of specifying the data to be used in the simulation and for ensuring that those data are in the appropriate format. In particular, the option allows the user to select and use soil data that are in either shape or grid format. Shape files are automatically converted to grid, the format required by ArcGIS to calculate land use and soil distributions within the sub basins of interest.

3.21.4 Sensitivity analysis

After the SWAT model for Gomit river watershed was compiled using SWAT CUP interface, a stream flow sensitivity analysis was performed on model parameters. These were done to identify the influential parameters on the modeled stream flow. It is essential to identify sensitive parameters for a model to avoid problems known as over parameterization (van Griensven et al., 2005).

After a thorough preprocessing of the required input for SWAT model, flow simulation is performed for recording periods. Then it can be used for sensitivity analysis of hydrologic parameters and for calibration of the model. The sensitivity analysis is made using a built-in SWAT CUP sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven, 2005). The sensitivity analysis was performed for a period of 1997-2009, see table3.2.

Table 3.2 Sensitivity classes for SWAT model

Class	Index(I)	Sensitivity
1	$0.00 \leq I < 0.05$	Small to Negligible
2	$0.05 \leq I < 0.02$	Medium
3	$0.02 \leq I<1$	High
4	$I \geq 1$	Very high

Source (Lenhart et al. 2002)

3.21.5 Model Calibration

Calibration is the process by which a model is adjusted to make its predictions agree with observed data. Model calibration generally reduces uncertainty. Complex models often have many parameters, each with a range of values that may be equally valid. SWAT CUP (SUIF2) was used to calibrate both flow and sediment. Careful selection of a single value within the appropriate range may improve model predictions. Furthermore, calibration requires observed data, which may not be available. In the absence of observed data, calibration is not an option. However, portions of a model may be calibrated while others may not.

The graphical and statistical approaches were used to evaluate the SWAT model performance a number of times until the acceptable values were obtained for surface runoff and base flow independently. The flow calibration procedure made by SWAT developers in Santhi et al. (2001) and Neitsch et al. (2005) was carefully followed. SWAT developers assumed an acceptable calibration for hydrology at R2 >0.6 and *E*NS >0.5 (Santhi et al., 2001; Moriasi et al., 2007). Calibration of sediment yield was performed after calibration of flow within the given time step. Like flow calibration, sediment yield calibration was done based on sensitive parameters. The time of modeling for calibration and validations are:

- Flow calibration period was (2000-2009)
- Flow validation period was (2010-2014), similarly sediment yield calibration and validation periods are listed below with the given time step.
- Sediment calibration period (2000-2009)
- Sediment validation period (2010-2014)

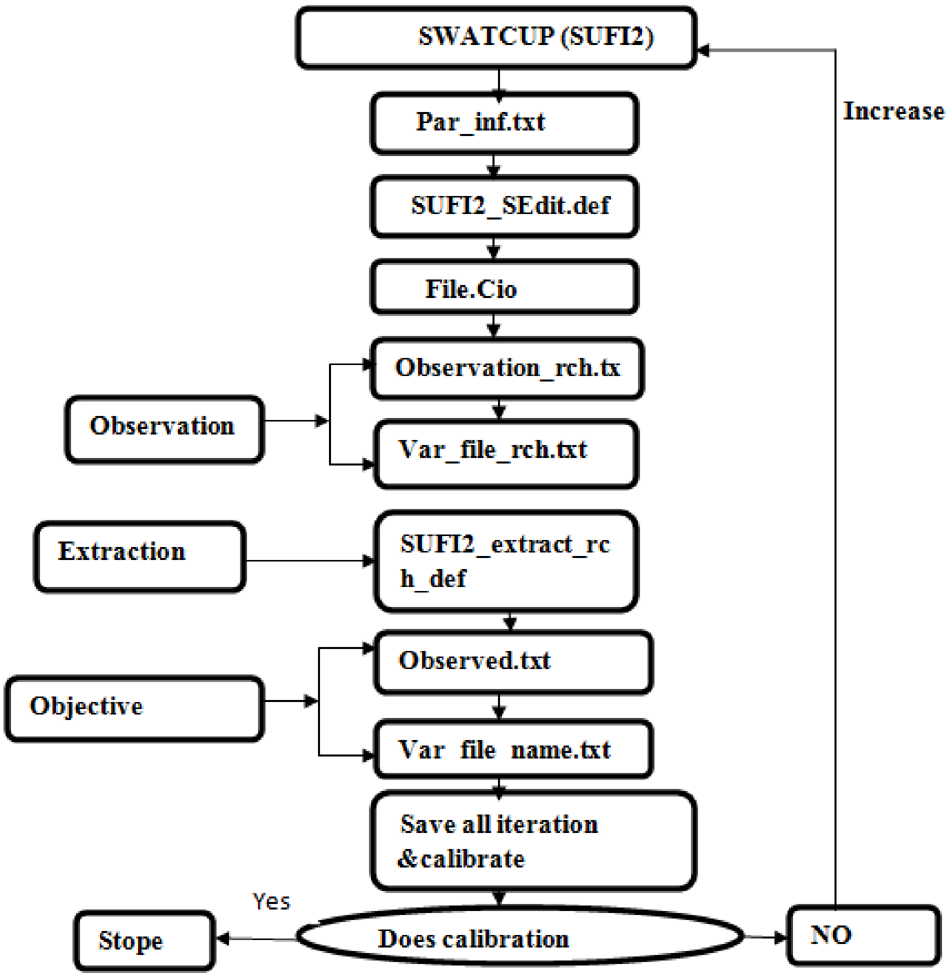

Figure 3.24 Calibration procedures for flow and sediment

3.21.6 Model Validation

Validation is a process of proving the performance of model. Validation is carried out for time periods different from calibration period, but without any further adjustment of calibrated parameters.

3.22 Model performance evaluation

To evaluate how well the model represented actual conditions within the watershed, its performance was evaluated using qualitative and quantitative measures involving both graphical comparisons and statistical analyses. Mean, standard deviation, coefficient of determination (R2) and Nash-Sutcliffe modeling efficiency (NSE) (Nash and Sutcliffe, 1970) are common statistical methods used to evaluate model predicted flow during calibration and validation. NSE describes the proportion of variance between the observed values and those accounted for by the model.

It is calculated as:

$$R^2 = \sum_{n=1}^{\infty} \frac{\sum_{i=1}^{n}(Oi-\bar{O})^2(P-\bar{P})^2}{\sum_{i=1}^{n}(Oi-\bar{O})^2 \sum_{i=1}^{n}(Pi-\bar{O})^2} \qquad \ldots 3.14$$

$$E_{NS} = \sum_{n=1}^{\infty} \frac{\sum_{i=1}^{n}(Oi-\bar{O})^2 \sum_{i=1}^{n}(Pi-\bar{P})^2}{\sum_{i=1}^{n}(Oi-\bar{O})^2} \qquad \ldots 3.15$$

Where Pi and *O*i are predicted and observed values at each comparison point I; *O* is the arithmetic mean of the observed values, and n is the number of observations during the simulated period. Possible NSE values range from -∞ to 1.0 (1 inclusive). A value of 1 means that modeled results match perfectly with recorded data. There is no official performance rating for common watershed modeling statistics. However, An NSE value greater than 0.75 can be considered very good; between 0.65 and 0.75 can be considered good while a value between 0.5 and 0.65 is considered only satisfactory (Moriasi et al., 2007).

3.23 SWAT based watershed management intervention scenarios

Watershed management intervention provides best management practice (BMPs) to reduce sediment transport and soil erosion. Performing of all the activities of sensitivity analysis calibration and validation by using SWAT CUP, identification and prioritize of the eroded sub basins was essential. Based on the prioritized of the potential intervention areas, different conservation scenarios were applied to compare the resulting sediment yield with the existing one. For these study different watershed management scenarios were developed based on the base line condition. Scenarios were developed based on the severity of sediment load, soil erosion hazard and the influencing factors that affect the target area. Also there importance is taken in to account. SWAT model was applied to simulate and analysis scenarios to select the most effective management practice to reduce sediment load and soil erosion.

Table 3.3 Soil erosion classifications based on soil loss rate

Cass	Sediment yield ton/ha/yr	Category
1	0-20	Low
2	20-70	Moderate
3	70-150	Sever
4	≥150	Extreme severe

Source (Hurni, 1983)

The management practice (scenarios) used for this study are briefly described below.

Scenario 0: Base line

Base line scenario shows simulation of existing sediment yield, soil erosion management practice. Generally this scenario was the simulated SWAT model results and it considers the best management practices in the watershed. As the name indicates base line scenarios were a base for the results of the other scenarios.

Scenario 1: Land use/ Land cover Redesign for sediment yield and steep slopes in the watershed

Land use redesign of steep slopes in the catchment of Gomit was done by using GIS, to prepare slope map of the study area. The inputs used for land use redesign were land use and slope shape files. This activity was performed by overlaying of land use and slope shape file. After overlaying of the two intersections is used to redesign slope and land use. Parts of the catchment was changed to plantation when slopes of the land use is steepy (>30%).

Table 3.4 Slope and land forms of the watershed

Slope range	Land forms	Area (ha)	Coverage (%)
0-2	Flat	572.702	2.56
2-10	Gentle slope	4471.218	19.98
10-15	Moderately steep	7097.541	31.71
15-30	Steep slope	7772.881	34.73
>30	Very steep slope	2466.759	11.02

Table3.5 Land use redesign scenario summary

Scenario type	Measures applied	Mechanisms	SWAT coding system
Land use redesign	Land use redesign	land use redesign reduces agricultural land scape	Replacing of existing land use with Afforestation

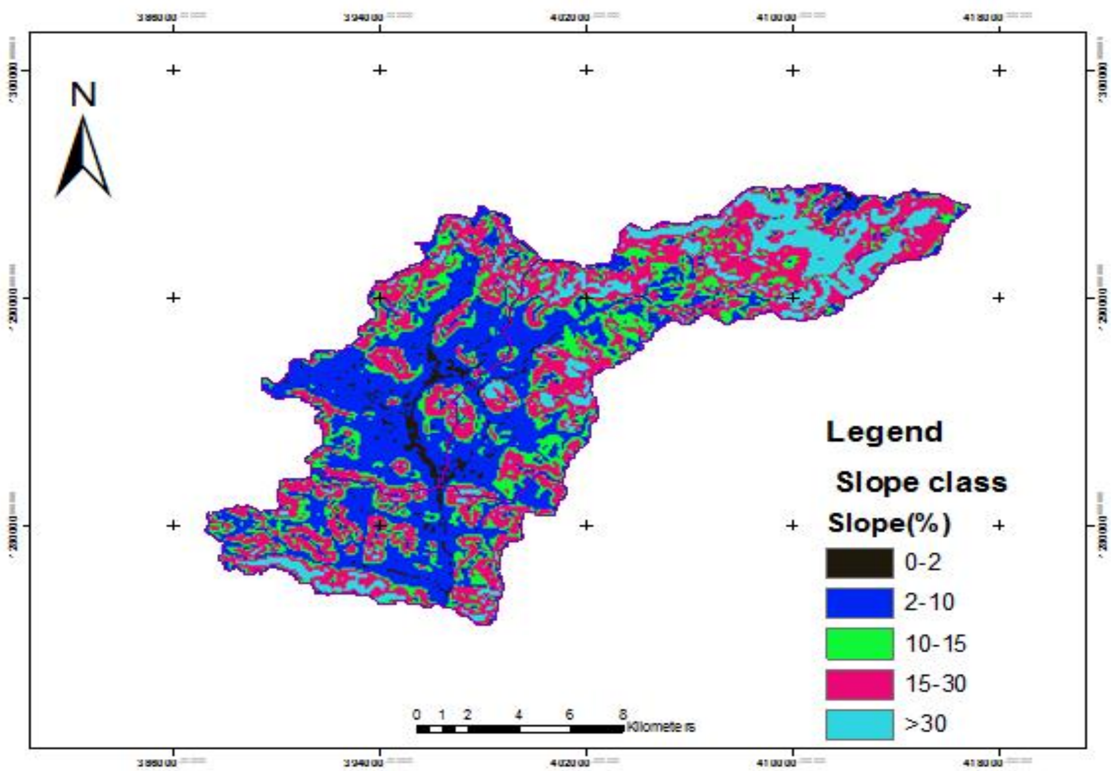

Figure 3.17 Slope class of the watershed

Scenario 2: Terracing activity which is a conservation measure

USLE support practice factors (USLE-P), slope length (SLSUBBSN) and SCS curve number (CN) were adjusted (Arabi et al., 2008). The function of terrace is to reduce soil erosion by dividing the slope length in to smaller length. In SWAT coding system slope length is represented by a parameter SLSUBBSN. It is adjusted using the horizontal interval method for terrace design (Arabi et al., 2008).

Table3.6 Terracing activity scenario summary

Scenario type	Measures applied	Descriptions	SWAT coding system
Terracing activities	Terracing of the land use	Rill or sheet erosion reduction	Minimize USLE_P
		Over land flow reduction	Minimize CN
		Slope gradient reduction	Minimize slope
		Slope length reduction	Minimize terrace slope length

CHAPTER FOUR

4 Results and Discussions

4.1 Land use

Land use land cover of the study area can be categorized as cultivated land, forest land, grass land, shrubs and bush land, built up area and water body.

The information that is obtained in the land use map tells how the different uses of the surface are distributed inside the area under the study. It can be observed from the land use map, that agricultural land occupies (86.91%) of the basin area.

Forest land, grass land, shrub and bush land covers 11.83% of the area. The rest is built up area and water body. The farming system in the watershed is mixed with dominantly oxen plough cereal crop production and livestock rearing.

Table 4.1 Land use/land cover types and its SWAT code

Land use/ land cover type	Land use according to SWAT data base	SWAT code
Built up area	Residential low density	URLD
Cultivated land	Agricultural land-close grown	AGRC
Forest land	Forest mixed	FRST
Grass land	Range-grass	RNGE
Shrub and bush land	Range –brush	RNGB
Water body	Water	WATR

Table 4.2 Land use type and its area coverage

No.	Land use /land cover	Area(ha)	Coverage (%)
1	Built up area	267.376	1.19
2	Cultivated land	19452.78	86.91
3	Forest land	585.64	2.62
4	Grass land	1787.107	7.98
5	Shrub and bush land	274.376	1.23
6	Water body	14.663	0.07

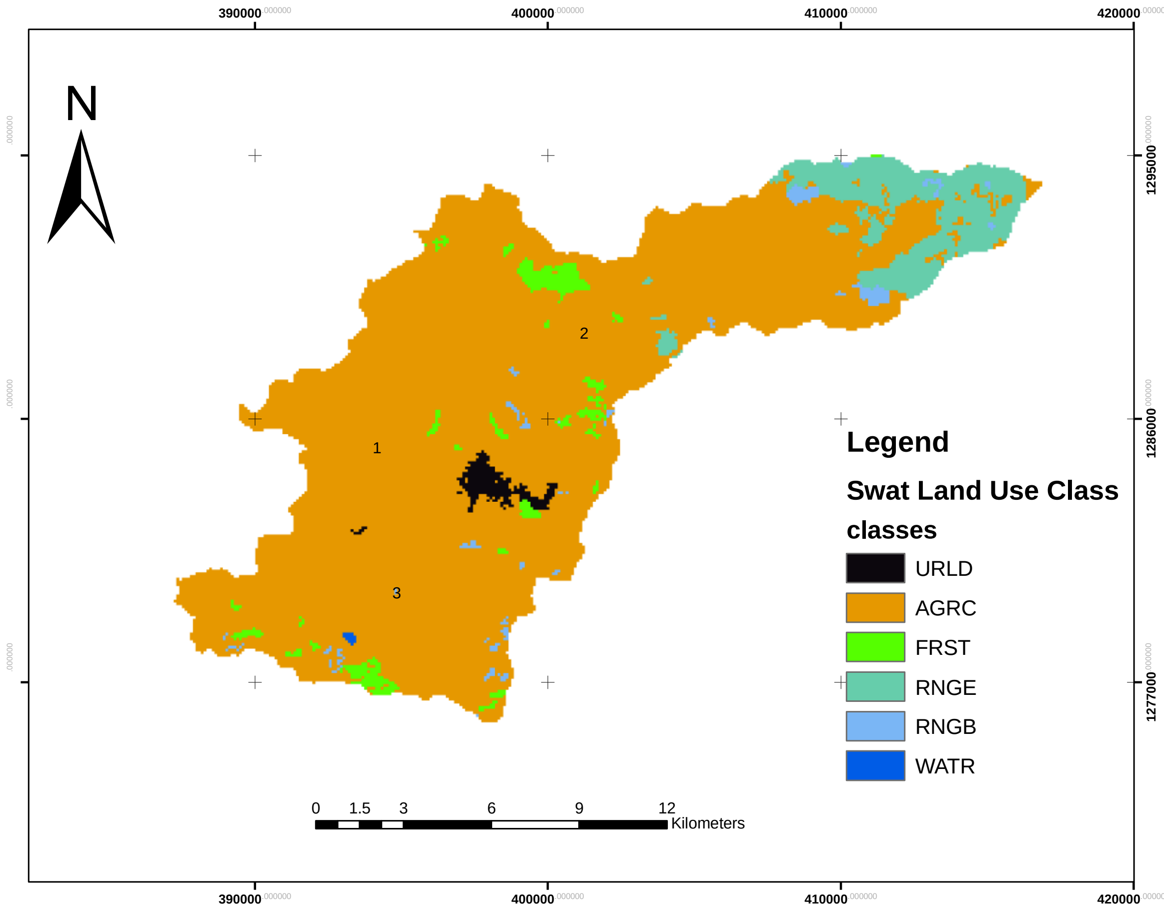

Figure 4.1 Land use class of Gomit watershed

4.2 Soil type

The major soil of the study area covers chromic luvisols (51.23%), Chromic Vertisols (8.04%), Eutric Cambisols (20.56%), Eutric Nitosols (0.26%), Litho sols (5.18%) and Orthic Luvisols (14.73%) in their respective are coverage. Soil erosion on the hill side slopes and sedimentation at the upstream of the Dam already exists, because of intensive annual crop cultivation.

Table 4.3 Soil class of Gomit watershed

Major soil type	Area(ha)	Coverage (%)
Chromic luvisols	11465.258	51.23
Chromic Vertisols	1800.045	8.04
Eutric cambisols	4600.593	20.56
Eutric Nitosols	57.788	0.26
litho sols	1160.067	5.18
Orthic luvisols	3297351	14.73

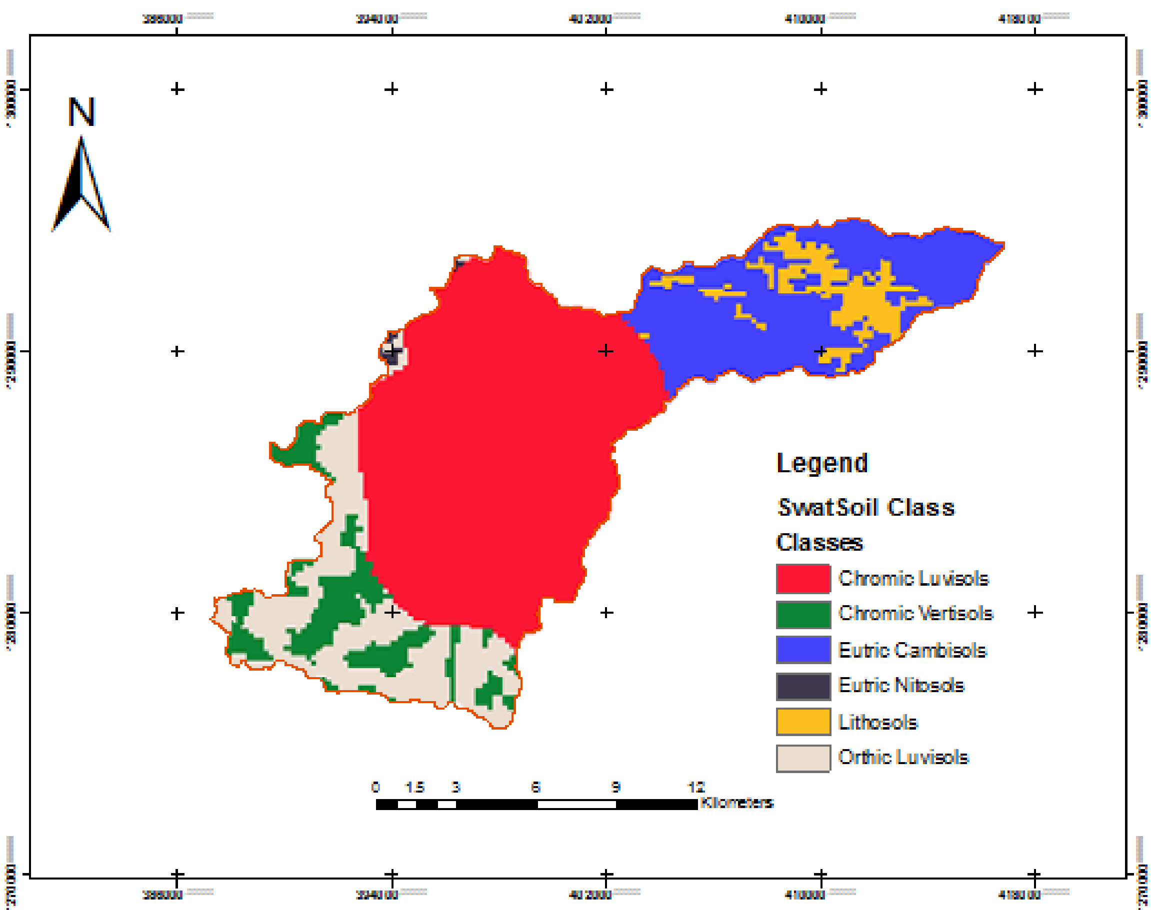

Figure 4.2 Soil type classes of the watershed

4.3 Simulation analysis

After identifications of the sensitive parameter a SWAT model was calibrated and validated on monthly time base to estimate flow and sediment yield of Gomit watershed using a time series of 21 years (1994-

2014). The year starting from (1997-1999) of the modeling period used for ″warm up″. The period starting from 2000-2009 was used for calibration and the validation period was taken from2010-2014. The area of watershed was subdivided in to 3 sub basins. The overlay of land use, soil and slope maps resulted 28 HRUs. The observed flow and sediment yield at the outlet of the watershed were compared with the simulated flow and sediment yield. Based on the calibrated and validated values of R^2 and E_{NS} both observed and simulated stream flow and sediment loads are related, see appendix table 9&10 for validation.

4.4 Sensitivity Analysis of Flow

Flow sensitivity analysis was carried out for a period of 13 years. It includes both warm up and calibration periods.

Table 4.4 Sensitivity analysis of flow

SWAT parameters	Rank	Mean values of parameters	Sensitivity class
Cn2	1	0.233	High
Esco	2	0.231	High
Gwqmn	3	0.159	High
Sol_Awc	4	0.0713	Medium
Revapmn	5	0.049	Medium

4.5 Flow calibration

The performance of the model was evaluated from SWAT simulation runs with model default parameters after this calibration procedures are proceeds. The parameters of the model were calibrated by using SWAT cup and calibration process considers the sensitivity parameters. Values are iterated until good results are obtained between the measured and simulated stream flow. The calibration results of coefficient of determination (R^2) and Nash Sutcliffe efficiency (E_{NS}) are both 0.80.This indicate that the measured and simulated values are related.

Table 4.5 Calibrated Flow Parameters and its value

Parameters Name	File Ext.	Method	Min	Max	Fitted value
CN2	.mgt	r Relative	-25	25	-22.5
ESCO	.bsn	v replace	0	1	0.55
GWQMN	.gw	v replace	-1000	1000	900
SOL_AWC	.sol	r Relative	-25	25	7.5
REVAPMN	.gw	v replace	-100	100	-10

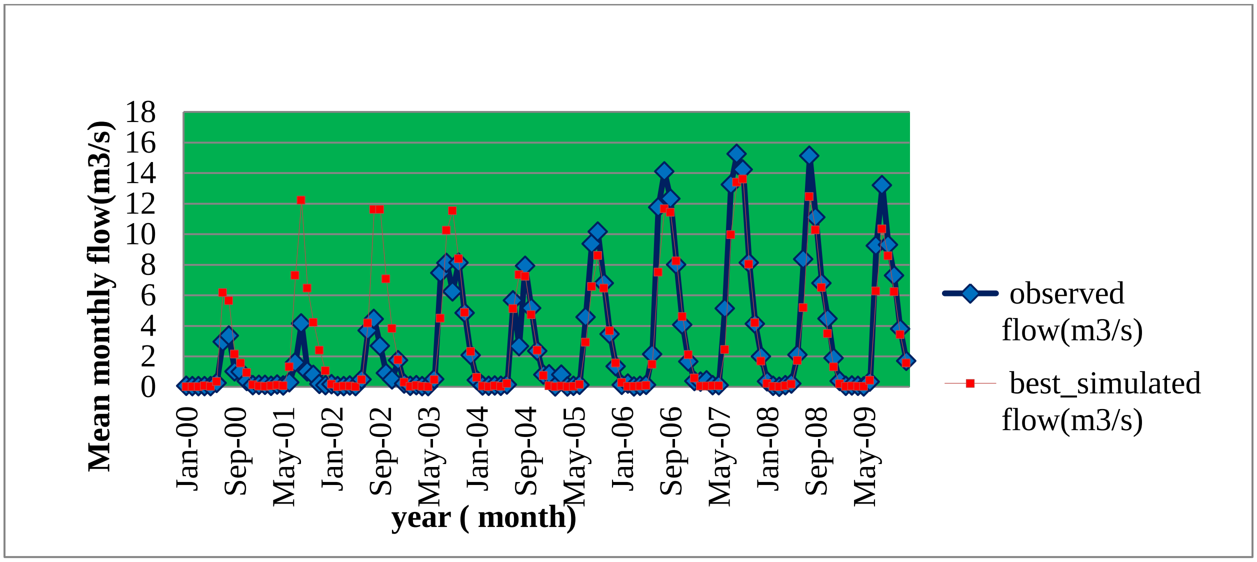

Figure 4.3 Average Monthly Observed and Simulated Calibration Graph during the period (2000-2009)

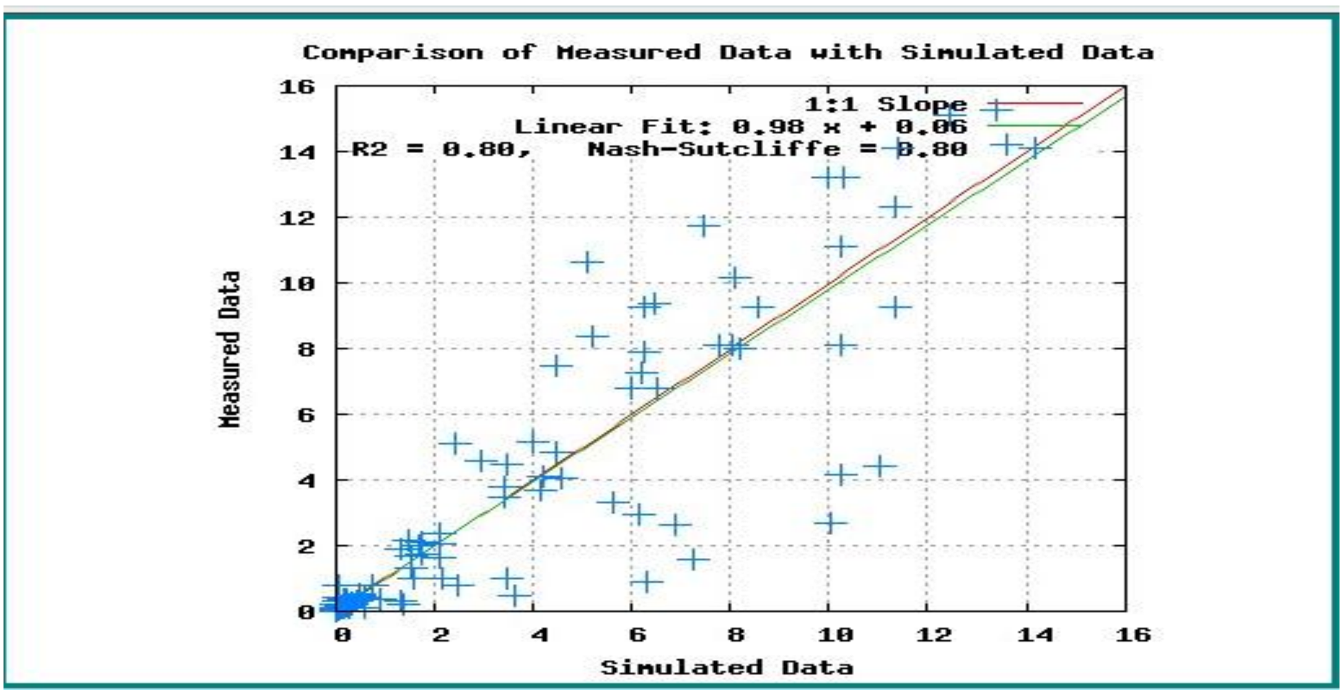

Figure 4.4 Regression fit and Slope fit line of observed Vs simulated monthly flow during calibration period (2000-2009).

4.6 Flow validation

The validation test is carried out from a period of 2010-2014 which is different from calibration periods. Correlation between observed and simulated stream flow during the validation gives coefficient of determination (R^2) 0.86 and Nash Sutcliffe efficiency (E_{NS}) value of 0.84 respectively.

Table.4.6 Calibration and validation of monthly stream flow

Parameters	Calibrated(2000-2009)	Validated(2010-2014)
R2	0.8	0.86
NSE	0.8	0.84
PBIAS	24.5	17.4
RSR	0.45	0.4

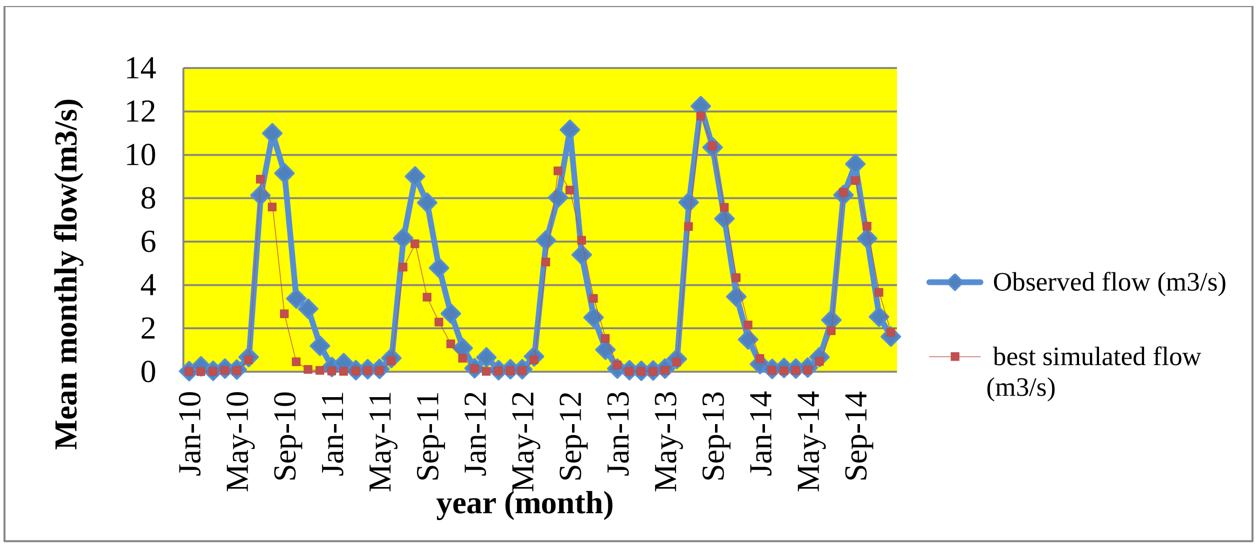

Figure 4.5 Average monthly observed and simulated validation graphs during the period (2010-2014).

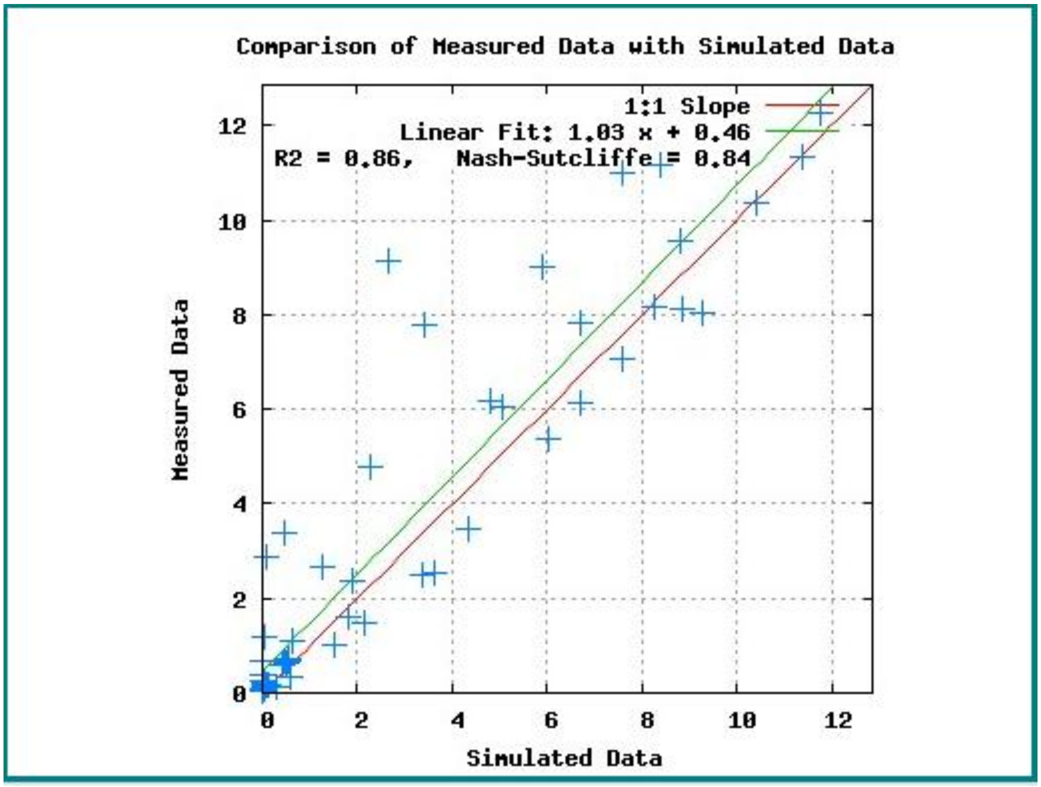

Figure 4.6 Regression fit and Slope fit line of observed Vs simulated monthly flow during validation period (2010-2014).

4.7 Sediment Yield Sensitivity Analysis

After demonstrating the flow the model is shifted to sediment yield sensitivity analysis, calibration and validation. Sediment yield sensitivity analysis carried out by identifying the parameters that affect the sediment yield. Six sediment parameters are sensitive in different degree of sensitivity. The period of sensitivity analysis, calibration and validations are similar with stream flow.

Table 4.7 Sediment sensitivity parameters

SWAT parameter code	Mean sensitivity index	Rank	sensitivity class
USLE_C	0.552	1	High
SPCON	0.499	2	High
SPEXP	0.202	3	High
USEL_P	0.091	4	High
CH_EROD	0.062	5	High
CH_COV 1	0.051	6	Medium

4.8 Sediment yield Calibration

Sediment yield calibration was performed after sensitivity analysis. Parameters of the model were calibrated by using SWAT cup and the calibration period starts from (2000-2009). Depending up on the sediment sensitivity analysis calibration of sediment yield in the watershed was done by identifying sensitive parameters. Values are iterated until good results are obtained between the measured and simulated sediment yield. The calibration results of coefficient of determination (R^2) 0.80 and Nash Sutcliffe efficiency (E_{NS}) 0.78 respectively.

Table 4.8 Calibrated sediment parameters

Parameter Name	File Ext.	Method	Min	Max	Fitted value
CH_COV1	.rte	r Relative	0	1	0.35
CH_EROD	.rte	v Replace	0	1	0.05
SPCON	.bsn	r Relative	0.0001	0.01	0.000595
SPEXP	.bsn	v Replace	1	2	1.05
USLE_C	.dat	r Relative	-25	25	7.5
USLE_P	.mgt	r Relative	0	1	0.55

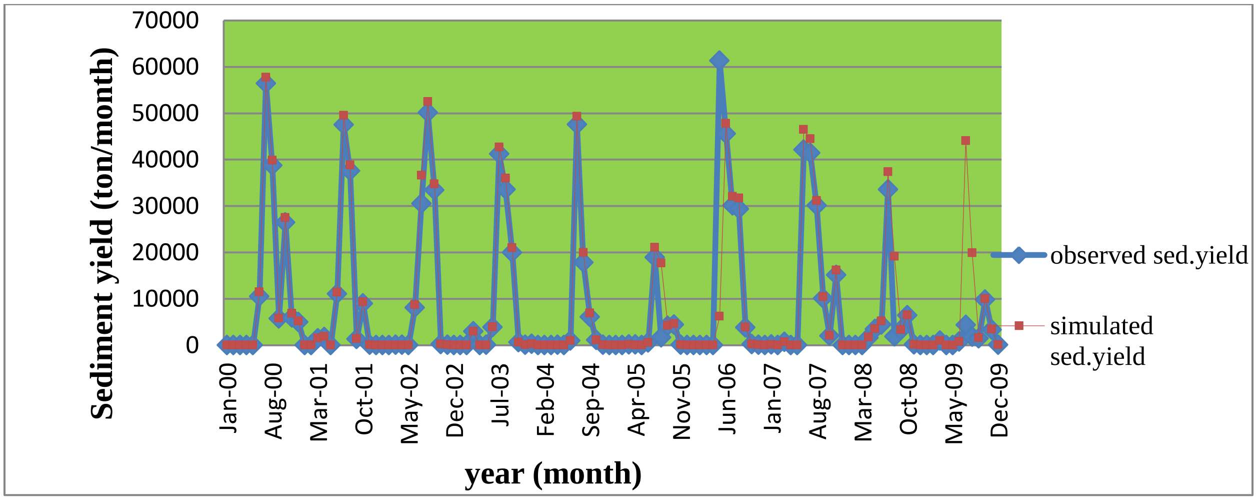

Figure 4.7 Monthly Observed and Simulated Sediment Yield Calibration Graph (2000-2009)

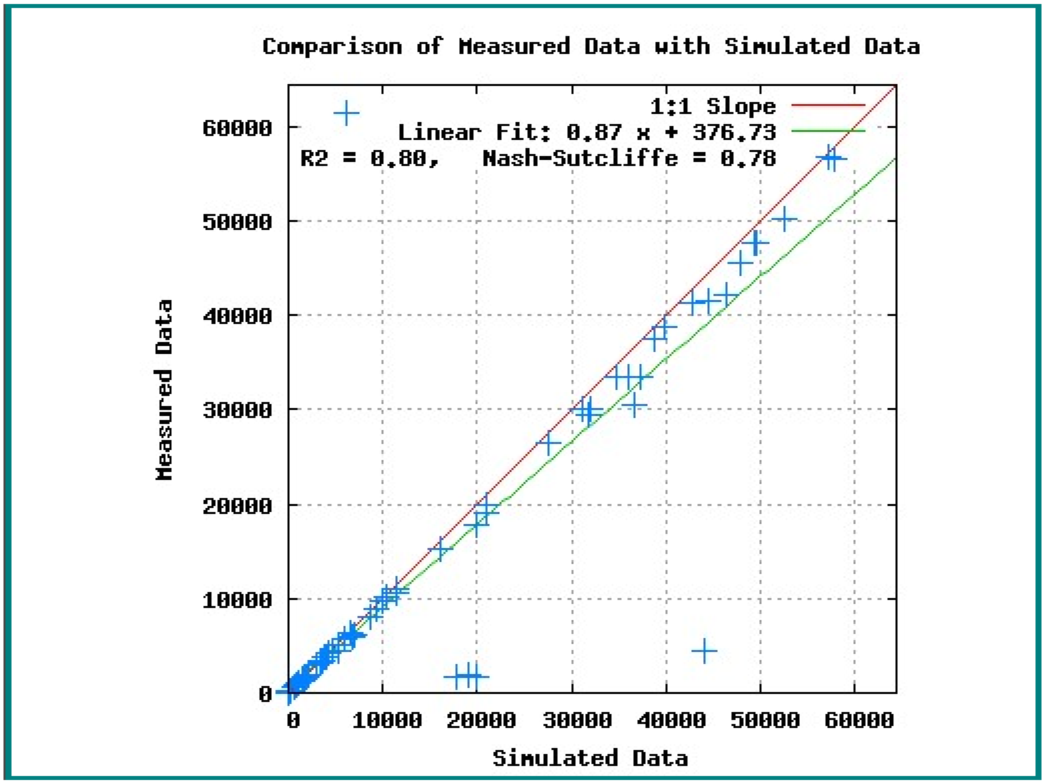

Figure 4.8 Regression analyses fit line and slope fit line of observed and simulated monthly sediment yield (2000-2009)

4.9 Sediment yield validation

After calibration of sediment yield, validation of sediment yield carried out for a period of (2010-2014). Monthly measured and simulated sediment loads are plotted graphically and statistically. The values of coefficient of determination (R^2) and Nash Sutcliffe efficiency (E_{NS}) in the monthly basis of sediment yield determination in the validation period results 0.94 and 0.84 respectively.

Table 4.9 Calibration and validation of sediment yield values

Parameters	Calibrated(2000-2009)	Validated(2010-2014)
R2	0.8	0.94
NSE	0.78	0.84
PBIAS	20.5	34.6
RSR	0.46	0.42

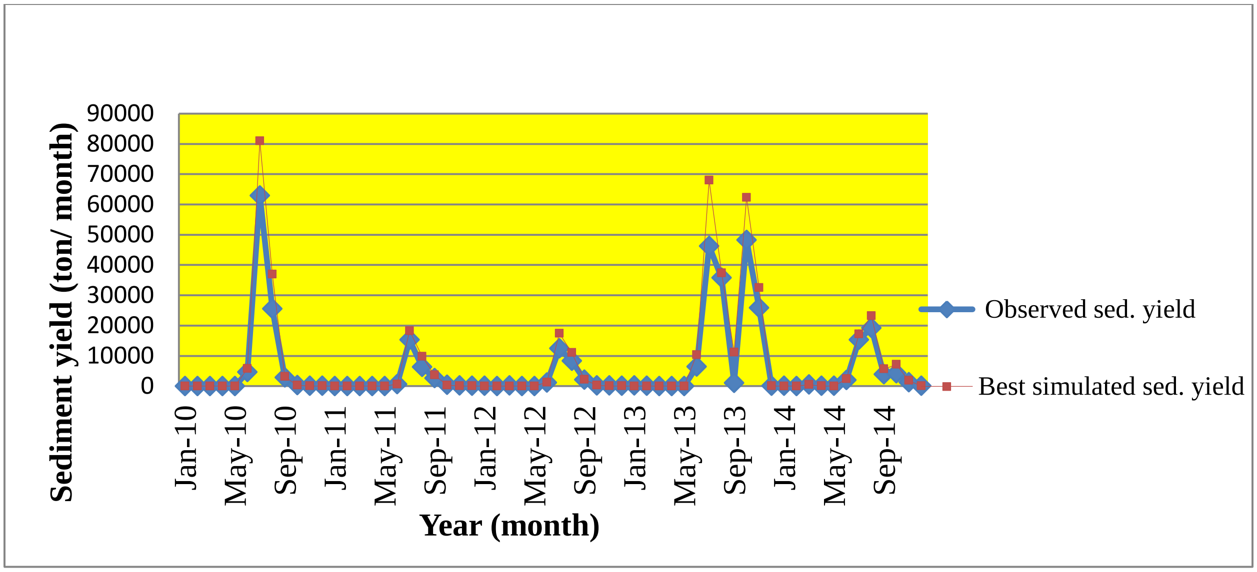

Figure 4.9 Monthly Observed and Simulated Sediment Yield Validation Graph (2010-2014)

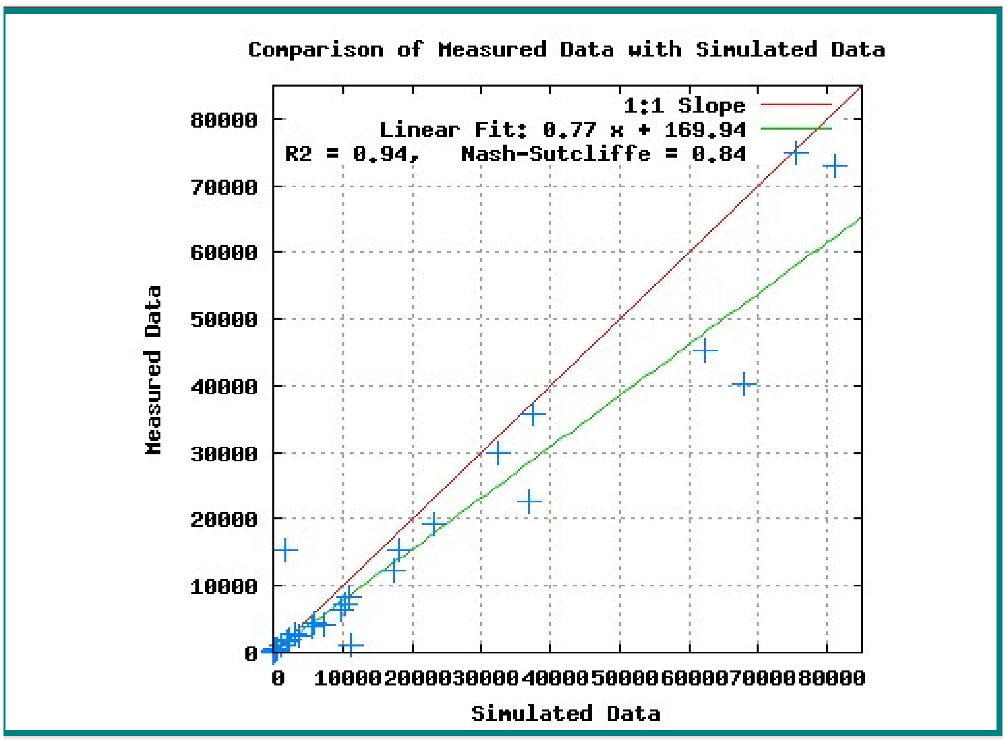

Figure 4.10 Regression analyses fit line and slope fit line of observed and simulated monthly sediment yield (2010-2014)

4.10 Sediment yield in the Sub basin

Sediment source areas were identified after the SWAT model output. Soil erosion and sediment yield within each hydrological response units are calculated by SWAT model for each sub basin. SWAT model calculates soil erosion and sediment yield for each hydrological response units within each sub basins based on the annual sediment classified. Based on this the watershed area reclassified in to three major soil erosion vulnerable area i.e. low, moderate and high soil erosion conditions.

Table 4.10 Sediment yield and its severity in the sub basin

Sub basin	Area (ha)	Sediment yield (ton/ha/yr)	Classes
1	6518.7	36.241	Low
3	10500.78	43.019	Moderate
2	2242.66	65.75	High

Distribution of sediment in the watershed area can be presented in figure 4.11; it helps to identify witch sub basin produce high sediment yield.

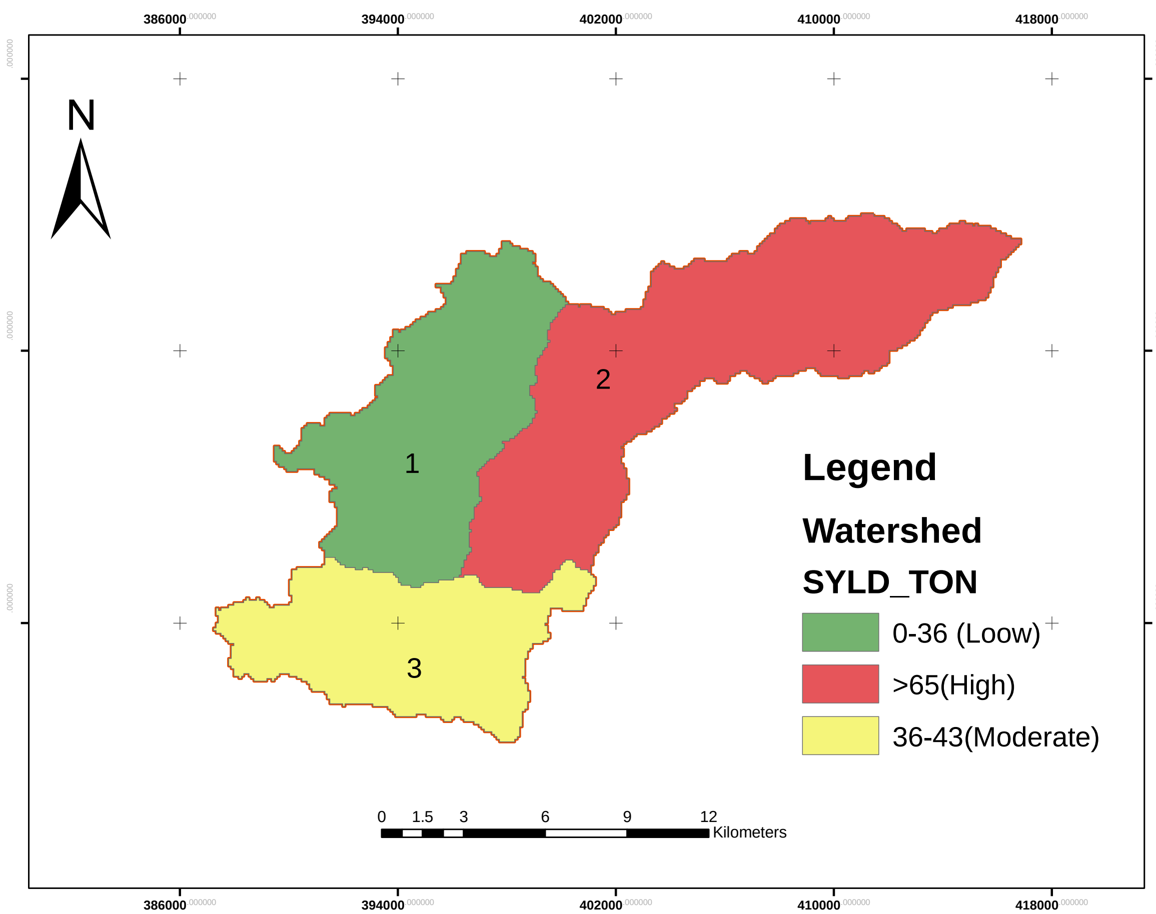

Figure 4.11 SWAT simulated Annual sediment yield of sub basins

The output of SWAT model shows that sub basin 2 produce high potential of soil erosion. Sediment yield in the watershed varies from hydrological response to hydrological response based on land use, soil and slope in each hydrological response units.

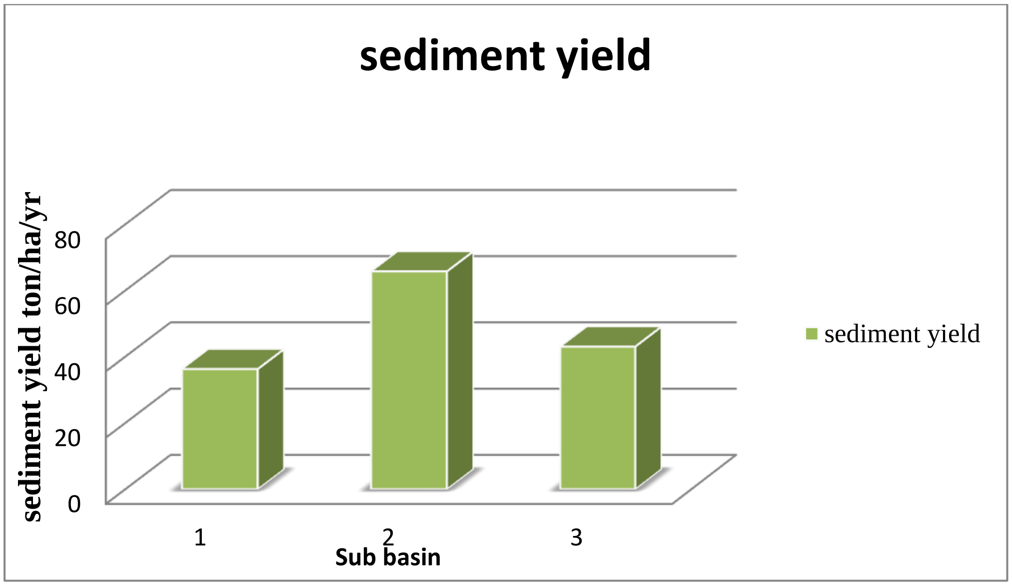

Figure4.12 Simulated annual sediment yield in the watershed

4.11 Watershed management intervention scenario results

The two scenarios i.e land use redesign and terracing activities were simulated by SWAT model to evaluate the most effective conservation measures in the water shed and to minimize soil erosion and sediment load.

Scenario1: land use redesign for steep slopes

In land use redesign scenario except the area of water body and built up areas, all the other land use on steep slope were changed to plantation. The best management practice related to soil erosion and slope steepness reduce the rate of soil erosion and sediment load. Based on the result implementing of this scenario is highly recommended in this watershed.

Table 4.11 Area of the Base scenario and Redesign land use change

Land use type	Base scenario (km2)	Redesign land use(km2)
Built up area	3	3
Cultivated land	194	178
Forest land	6	28
Grass land	18	12
Shrub and bush land	3	2
Water body	0	0

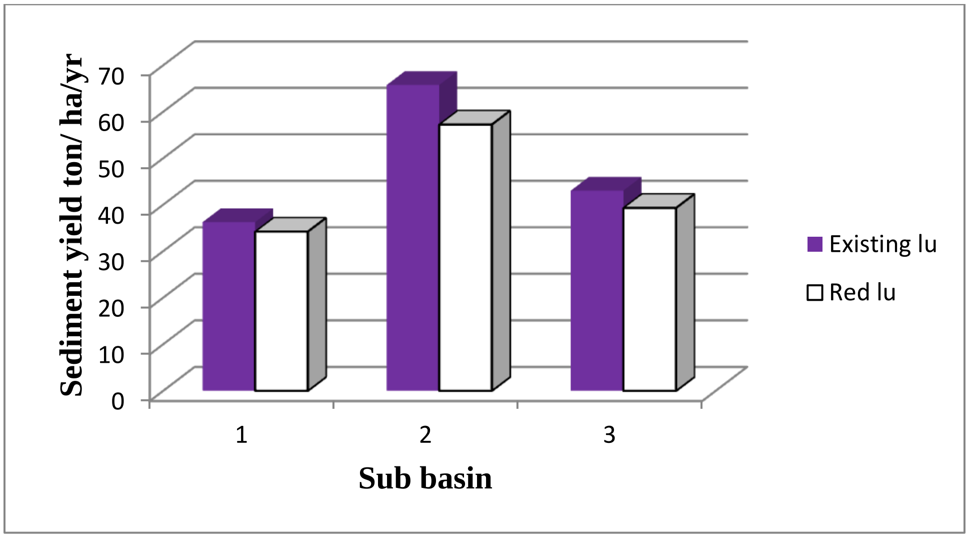

Figure 4.13 Sediment yield compaction of existing and redesigned land use scenario

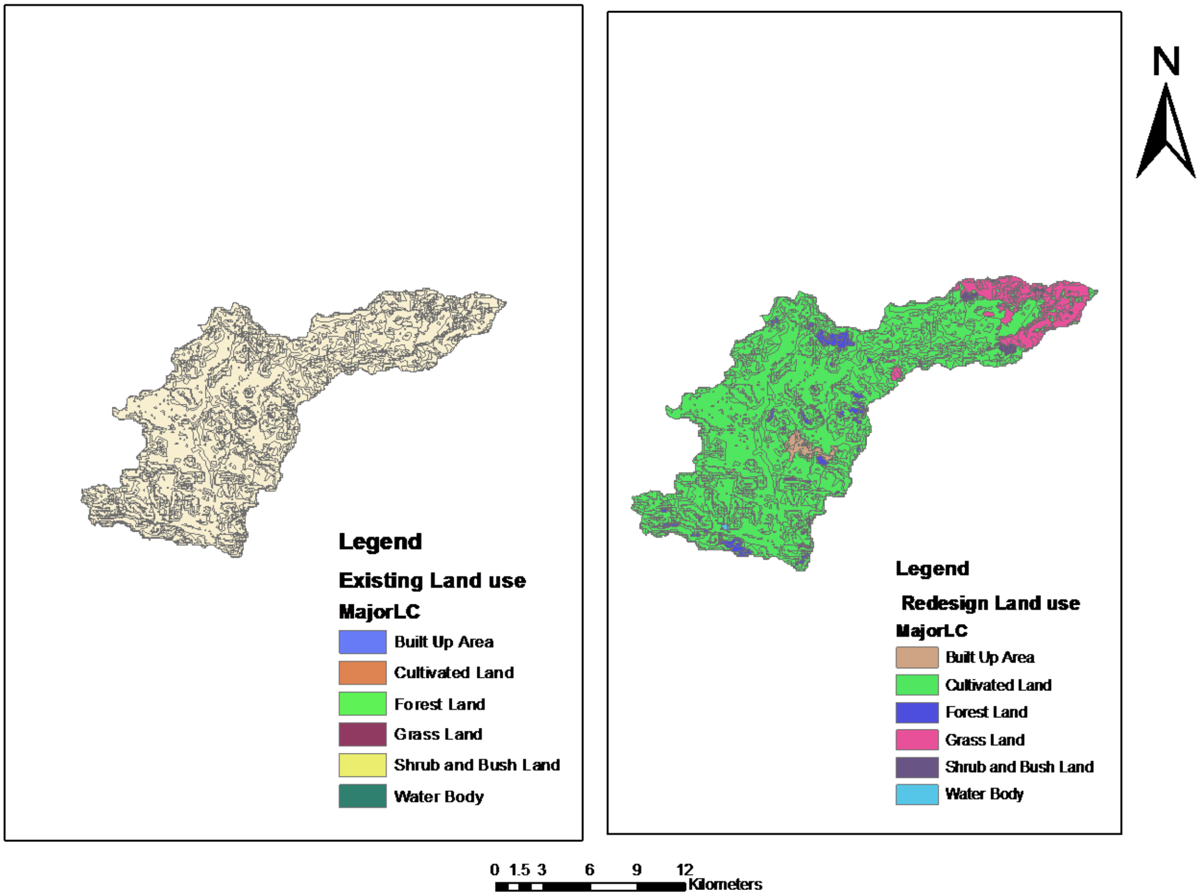

Figure 4.14 Existing and redesign land use map

After doing all the above procedure the model was run by using SWAT model with the redesign land use and calibrated parameters. The modified land use reduces the sediment yield by 7.64% of the existing one. Soil erosion and sediment loads were decreased because of the steep slope (>30) were not used agricultural practice.

Scenario2: Terracing activities

Terracing activity is an agricultural technique for collecting surface runoff water thus increasing infiltration and controlling water erosion. USLE practice (TERR-P), slope length (TERR-CN) and curve number are adjusted to simulate the effect of terrace. Terrace length should be lie with the maximum of distance between terraces. This value varies 0-100m for the slope range 0-2% and 18m when the slope is>30%. The recommended values of curve number, p factor and slope length are used for terraced fields (see appendix table5) the significance of terrace for each agricultural HRUs located in potential sub basins helps to reduce soil erosion and sediment yield.

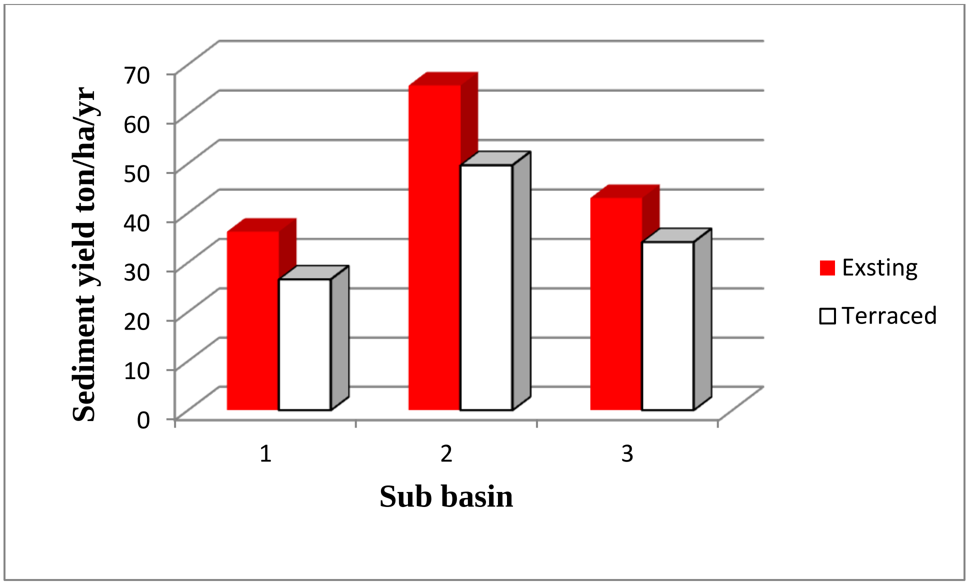

Figure 4.15 Sediment yield comparison of the existing land use with the terraced one

By performing the activities of terracing practice the sediment load in the watershed reduce by 18.03% of the base line conditions.

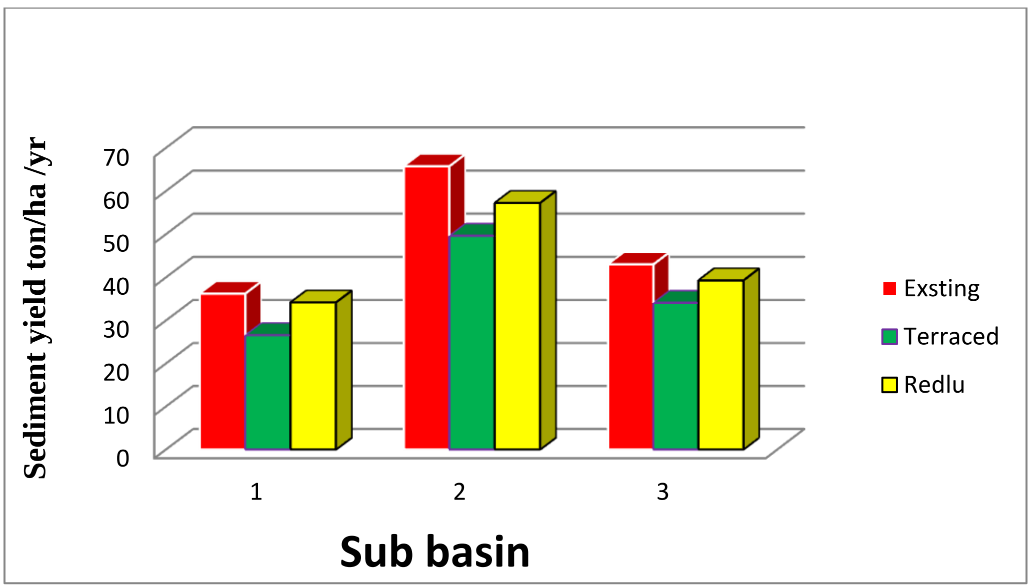

Figure 4.16 Sediment yields of the existing and the two scenarios

CHAPTER FIVE

5 Conclusion and Recommendation

5.1 Conclusion

SWAT model was used to calibrate and validate for stream flow and suspended sediment concentration in the watershed. The result shows that catchment output simulated by SWAT CUP after calibration is comparatively consistent with the measured values. Graphical and statistical analysis was used to evaluate the performance of SWAT model in the study area.

- The SWAT model was calibrated from 2000-2009 and the validation period is 2010-2014 on monthly time basis to demonstrate its applicability for simulating stream flow and sediment yield in the watershed.
- The average monthly observed stream flow and average monthly simulated stream flow were compared using graphical and statistical method. Similarly average monthly observed sediment yield values are compared with average monthly simulated sediment yield values using graphical and statistical methods.
- The results show that good estimation of average monthly stream flow and sediment yields based on the values of coefficient of determination (R2) and Nash Sutcliffe model efficiency (E_{NS}) during the calibration and validation periods.
- The value of coefficient of determination and Nash Sutcliffe efficiencies are 0.80 and 0.80 in calibration, 0.86 and 0.84 in validation for flow analysis. Similarly, the values of R^2 and E_{NS} are 0.80 and 0.78 for calibration, 0.94 and 0.84 for validation in sediment yield analysis.
- This study provides good under stand of SWAT model set up, sensitive parameters that the model output and hydrological response of the catchment.
- CN is the most sensitive parameter which depends up on the management practice and soil parameter.
- SWAT model calibration and validation for Gomit watershed can be used to assess the impact of land use change, climate change and management practices on stream flow and sediment yield in the watershed area.
- Sediment inflows to the Gomit reservoirs are depend on the land use in the reservoirs contributing catchment, particularly high erosive agricultural practices. SWAT model helps to

simulate the effect of terrace by adjusting P-factor, curve number and slope length. The two simulated scenario results indicate that, properly implementing these measures can reduce sediment yield.

5.2 Recommendation

- Based on the result of the study, it could helps different stakeholders to plan and implement appropriate soil and water conservation strategies.
- The calibrated model can be used for further analysis of the impact of different management scenarios, climate and land use change on stream flow and soil erosion.
- Gomit reservoir operators and Provincial Authorities should work together to the Gomit catchment and identifying suitable cultivation practices for each sub basin, such that hill slope erosion is minimized.
- The reservoir should look to preserve its active storage capacity by supporting upland soil conservation practices designed to reduce bulk transport of course and medium size sediments. Once this sediment in the tope set its difficult and expensive to remove.
- To reduce soil erosion and sediment load in the watershed best management practice should required. Based on this result it is highly recommended that ridges, mountains, steep and very steep slopes are covered with Afforestation.

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APPENDIXS

Appendix Table 1: Description of SWAT data base

Data classification	Data description	File format
Geo database table	SWAT data base	Access file
	User soil(attributes of soil texture)	dBase or ASCII
	User Wgn(attribute of metrological station)	
	Land use look up table	
	Soil look up table	
Special data sets	DEM	ESRI grid format
	Land use	ESRI grid format or shape file
	Soil texture	
	User defined watershed	Shape file
Weather data sets	Weather generator data(location of meteorological station)	Dbase
	Daily precipitation data table	Dbase
	Temperature data table	
	Relative humidity data table	
	Solar radiation data table	
	Wind speed data table	

Appendix Table 2 Sensitive analysis result of stream flow in the watershed

SWAT parameters	Rank	Mean values	Sensitivity class
Alpha_Bf	11	0.0213	Small
Biomix	19	0.00154	Small
Blai	7	0.0402	Small
Canmx	10	0.0259	Small
Ch_K2	14	0.00923	Small
Ch_N2	18	0.00161	Small
Cn2	1	0.233	High
Epco	9	0.0296	Small
Esco	2	0.231	High
Gw_Delay	13	0.00933	Small
Gw_Revap	8	0.0388	Small
Gwqmn	3	0.159	High
Revapmn	5	0.049	Medium
Sftmp	27	0	Negligible
Slope	15	0.00766	Small
Slsubbsn	20	0.000256	Small
Smfmn	27	0	Negligible
Smfmx	27	0	Negligible
Smtmp	27	0	Negligible
Sol_Alb	16	0.00457	Small
Sol_Awc	4	0.0713	Medium
Sol_K	12	0.0105	Small
Sol_Z	6	0.0422	Small

Appendix Table 3 soil parameters used in SWAT model for the study area

VALUE	SNAME	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1
1	Lithosols	1	B	500	0.01	0	C	200	1.25	0.11	5	2	50	33	17	5	0.13	0.22
2	Chromic Vertisols	3	D	1200	0	0	SIC	200	1.20	0.08	0.50	2	47	40	13	4	0.13	0.20
							C	700	1.36	0.08	0.30	0.15	58	32	10	5	0.11	0.18
							C	1200	1.36	0.08	0.30	1.0	62	28	10	7	0.11	0.20
3	Orthic Luvisols	3	B	2000	0	0	L	260	1.15	0.12	15.5	1.29	72.7	20.2	7.1	0	0.13	0.2
							C	800	1.25	0.12	16.7	0.6	84.7	13	2.3	0	0.13	0.2
							C	940	1.25	0.12	11.45	0.08	81.2	17.4	1.4	0	0.13	0.2
4	Eutric Nitisols	4	C	2000	0.01	0	C	200	1.1	0.11	4.34	2	50	33	17	5	0.13	0.22
							SiL	900	1.27	0.11	4.54	1.5	23	50	27	0	0.13	0.22
							C	1000	1.28	0.11	5.16	1.3	60	25	15	0	0.13	0.22
							C	2000	1.22	0.11	4.24	0.5	71	20	9	0	0.13	0.22
5	Chromic Luvisols	7	B	1800	0.01	0.01	SiL	200	1.45	0.11	7	0.5	25	31	44	0	0.13	0.3
							CL	260	1.46	0.11	37.2	0.3	14	66	20	0	0.13	0.3
							CL	460	1.45	0.1	34.8	0.21	19	59	22	0	0.13	0.3
							CL	650	1.49	0.1	33.6	0.2	22	56	22	0	0.13	0.3
							C	950	1.48	0.1	36	0.2	17	57	26	0	0.13	0.3
							C	1350	1.49	0.1	36	0.12	17	57	26	0	0.13	0.3
							C	1800	1.47	0.1	36	0.1	16	59	25	0	0.13	0.3
6	Eutric Cambisols	3	B	1400	0	0	C	400	1.10	0.08	2	2	47	28	25	4	0.13	0.23
							C	800	1.36	0.08	0.30	0.15	46	31	23	5	0.11	0.18
							C	1400	1.36	0.08	0.30	1	54	26	20	7	0.11	0.18

Appendix Table 4. Weather generator input data explanation

Input data	Description
STATION	Name of gauging station
WLATITUDE$WLONGTIUDE	Latitude and longitude of weather station in degree
WELEVATION	Weather station elevation in meters
RAIN_YRS	Number of years used
TMPMX	Average maximum daily temperature in a month
TMPMN	Average minimum daily temperature in a month
TMPS TDMX	Standard deviation daily temperature in a month
TMPSTDMN	Standard deviation daily temperature in a month
PCPMM	Average monthly precipitation
PCPSTD	Standard deviation daily precipitation in a month
PCPSKW	Skew coefficient daily precipitation in a month
PR_W1	Probability of wet dray following a dry day
PR_W2	Probability of wet dray following a wet day
PCPD	Average number of daily precipitation in a month
SOLARAV	Average daily solar radiation in a month
DEWPT	Average daily dew point in a month
WINDAV	Average daily wind speed in a month
RINHHMX	Half hour rain fall in a month

Appendix Table 5. P factor Values and slope length limits for contour farming terraced cultivated lands (SWAT input data .mgt)

	Farm Planning		
Land slope (%)	P_{USLE} factor	Strip crop P factor	Slope length(m)
1 to 2	0.6	0.3	122
3 to 8	0.5	0.25	76
9 to 12	0.6	0.3	37
13 to 16	0.7	0.35	24
17 to 20	0.8	0.4	18
21 to 25	0.9	0.45	15

Appendix Table 6. SCS Runoff curve number for soil moisture condition II of agricultural lands (SWAT input data .mgt)

Cover Type		Hydrologic	Hydrologic Soil Groups			
Land use	Treatment/practice	Condition	A	B	C	D
Row		Poor	66	74	80	82
Crops	Contoured & terraced	**Good**	**62**	**71**	**78**	**81**
	Contoured & terraced	Poor	65	73	79	81
	w/residue	Good	616	70	77	80
Small grains	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured & terraced	Poor	60	71	78	81
	w/residue	Good	58	69	77	80
Close	Contoured & terraced	Poor	63	73	80	83
Seeded	or broadcast					
	legumes or rotations	Good	51	67	76	80

Chromic Vertisols D, Chromic Luvisols=B, Eutric Cambisols=B, Chromic Vertisols=B, Eutric Nitosols= C Lithosols B,

Appendix Table. 7 general performance rating for recommended statistics for a monthly time step (Moriasi et al., 2007)

Performance rating	RSR	NSE	PBIAS (%) Stream flow	Sediment	N,p
Very good	0<RSR<0.50	0.75<NSE<1	PBIAS<±10	PBIAS<±15	PBIAS<±25
Good	0.50<RSR<0.60	0.65<NSE<0.75	±10<PBIAS<±15	±15<PBIAS<±30	±25<PBIAS<±40
Satisfactory	0.60<RSR<0.70	0.50<NSE<0.65	±15<PBIAS<±25	±30<PBIAS<±55	±40<PBIAS<±70
Unsatisfactory	RSR>0.70	NSE<0.50	PBIAS>±25	PBIAS>±55	PBIAS>±70

Appendix Table 8. Measured flow and sediment concentration of Gumara which helps to get the sediment concentration of Gomit

Data of sampling	Flow(m3/s)	Sediment Conc. (mg/l)
10-Feb-90	1.283	147.35
10-Feb-90	1.283	185.59
1-Jun-92	0.306	343.13
1-Jun-92	0.306	376.88
1-Jun-92	0.306	385.94
20-Jul-92	37.640	10233.80
20-Jul-92	37.640	10943.00
20-Jul-92	37.640	9028.90
1-May-93	0.450	527.89
1-May-93	0.450	552.96
1-May-93	0.450	529.77
3-Sep-94	35.880	237.85
3-Sep-94	35.880	285.58
3-Sep-94	35.880	337.50
16-Aug-04	117.096	3277.11
16-Aug-04	117.096	3442.98
16-Aug-04	117.096	2604.80
17-Aug-04	207.798	5441.58
17-Aug-04	207.798	5857.37
17-Aug-04	207.798	4815.41
5-Sep-05	95.126	5505.00
5-Sep-05	95.126	5046.32
5-Sep-05	95.126	4565.87
6-Sep-05	146.495	3950.96
6-Sep-05	146.495	3301.84
6-Sep-05	146.495	2817.53

7-Sep-05	152.712	4193.15
7-Sep-05	152.712	3940.53
7-Sep-05	152.712	3477.33
17-Jul-06	50.117	2803.00
17-Jul-06	50.117	2870.83
17-Jul-06	50.117	2221.28
18-Jul-06	62.986	6102.70
18-Jul-06	62.986	6100.78
18-Jul-06	62.986	5632.22
28-Jul-06	73.704	2639.45
28-Jul-06	73.704	3826.76
28-Jul-06	73.704	3326.22
10-Aug-07	129.793	3080.53
10-Aug-07	129.793	3128.22
10-Aug-07	129.793	3474.55
14-Aug-07	122.710	2280.56
14-Aug-07	122.710	2150.88
14-Aug-07	122.710	1773.73
22-Aug-07	73.366	622.50
22-Aug-07	73.366	776.12
22-Aug-07	73.366	545.92
23-Aug-07	129.320	3334.29
23-Aug-07	129.320	3093.94
23-Aug-07	129.320	2704.51
24-Aug-07	152.269	2262.70
24-Aug-07	152.269	2364.17
24-Aug-07	152.269	1931.88
25-Aug-07	180.533	3852.76
25-Aug-07	180.533	6372.96
25-Aug-07	180.533	3982.40
11-Aug-07	118.121	1517.87
11-Aug-07	118.121	1665.63
11-Aug-07	118.121	1458.61
4-Dec-07	3.187	209.14
4-Dec-07	3.187	152.50
4-Dec-07	3.187	142.34
1-Aug-08	225.408	6474.25
1-Aug-08	225.408	9609.84
1-Aug-08	225.408	5645.75
2-Aug-08	176.555	5275.43
2-Aug-08	176.555	5245.38
2-Aug-08	176.555	4864.66
3-Aug-08	221.296	5904.27

3-Aug-08	221.296	4984.27
3-Aug-08	221.296	4909.25
4-Aug-08	171.107	2515.44
4-Aug-08	171.107	2645.21
4-Aug-08	171.107	2249.37
5-Aug-08	276.349	4275.06
5-Aug-08	276.349	3991.67
5-Aug-08	276.349	3546.02
12-Aug-10	110.000	1184.75
12-Aug-10	110.000	1172.35
12-Aug-10	110.000	894.50
20-Aug-10	137.085	2908.29
20-Aug-10	137.085	2325.54
20-Aug-10	137.085	2333.73
10-Oct-11	17.584	293.41
10-Oct-11	17.584	289.47
10-Oct-11	17.584	257.25
11-Oct-11	17.161	280.33
11-Oct-11	17.161	189.75
11-Oct-11	17.161	168.15
12-Oct-11	19.314	274.29
12-Oct-11	19.314	236.67
12-Oct-11	19.314	202.22

Appendix table 9 Monthly observed and simulated flow validation

Month (2010-2014)	Simulated flow m3/s	Observed flow m3/s
1	0.0093	0.0266
2	0.003	0.245
3	0.0139	0.0377
4	0.0498	0.1416
5	0.0324	0.1058
6	0.5352	0.6693
7	8.87	8.127
8	7.586	10.9872
9	2.663	9.1502
10	0.4464	3.376
11	0.1003	2.8945
12	0.0488	1.1895
1	0.0277	0.2201
2	0.0086	0.3985

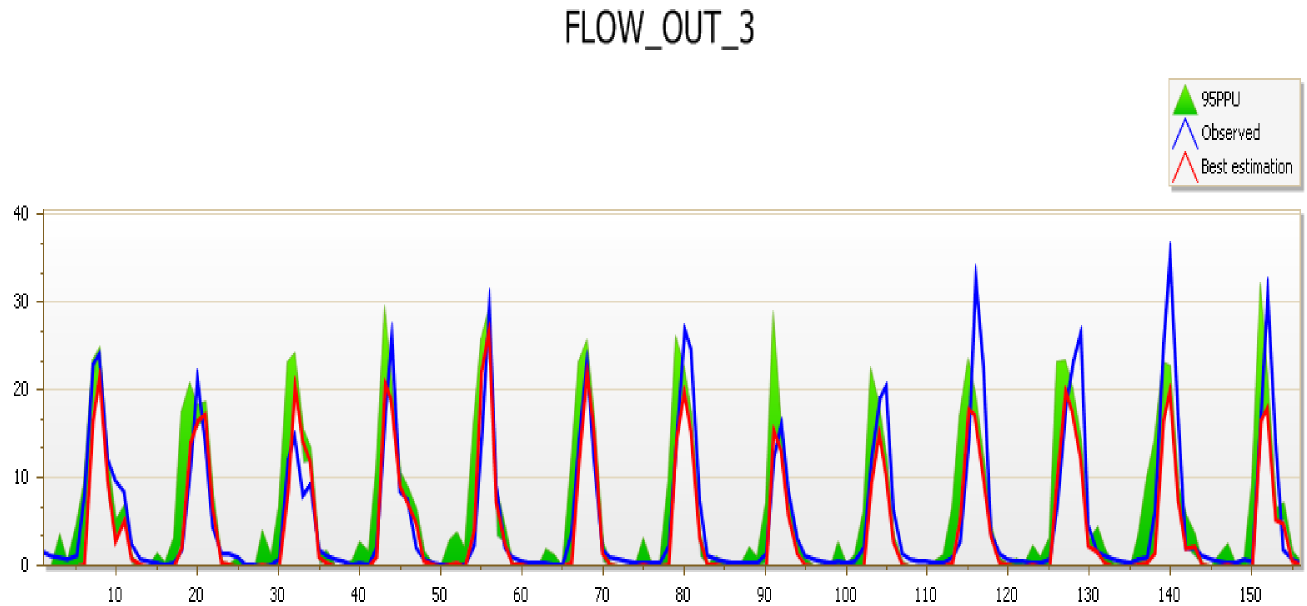
3	0.0259	0.0689
4	0.0385	0.1089
5	0.046	0.1301
6	0.4897	0.6289
7	4.816	6.1586
8	5.894	9.0002
9	3.426	7.7869
10	2.283	4.7896
11	1.281	2.685
12	0.6207	1.0879
1	0.1244	0.1598
2	0.0093	0.6651
3	0.0212	0.0694
4	0.0343	0.1102
5	0.0367	0.1156
6	0.5471	0.7089
7	5.044	6.0487
8	9.256	8.031
9	8.369	11.1586
10	6.046	5.3897
11	3.371	2.4987
12	1.53	1.0158
1	0.3	0.1437
2	0.0175	0.0695
3	0.0093	0.043
4	0.0104	0.057
5	0.0525	0.1455
6	0.4382	0.5786
7	6.688	7.806
8	11.78	12.2453
9	10.4	10.3451
10	7.573	7.063
11	4.336	3.4521
12	2.146	1.4896
1	0.5995	0.3523
2	0.052	0.124
3	0.0429	0.1785
4	0.0509	0.1396
5	0.0693	0.1836
6	0.4717	0.674
7	1.885	2.3882
8	8.264	8.1489
9	8.811	9.5756

10	6.706	6.1358
11	3.646	2.5368
12	1.802	1.6189

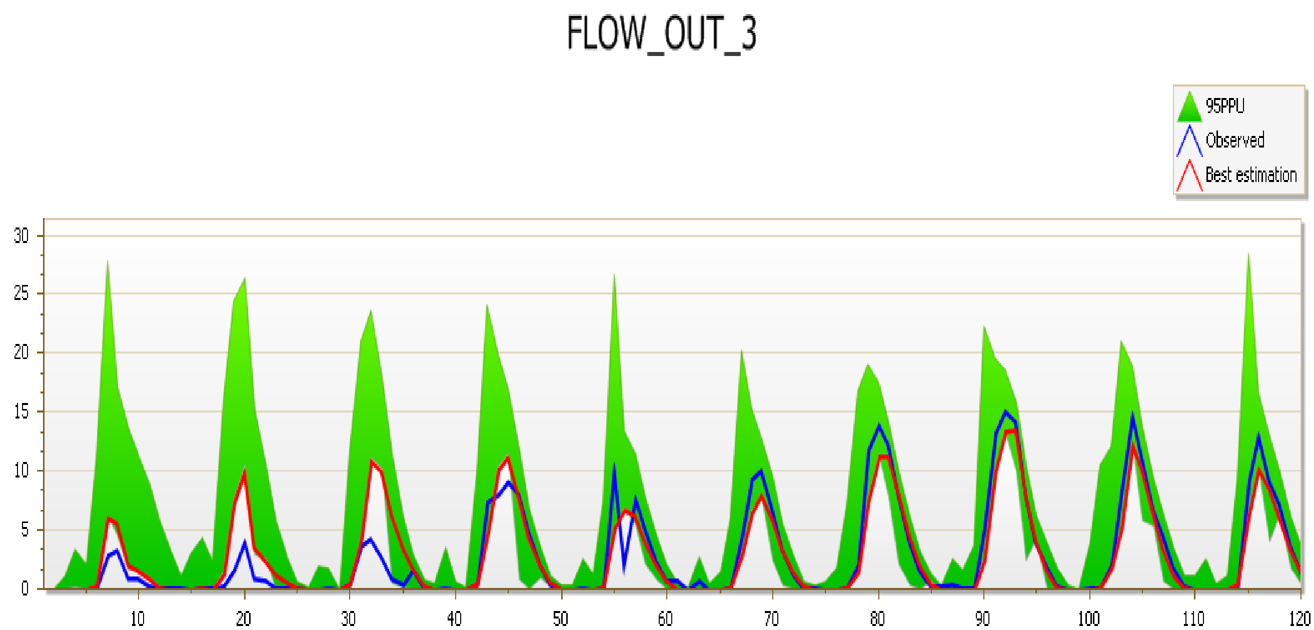
Appendix Table 10 Measured and simulated sediment (ton/month) validation

Month(2010-2014)	Observed sediment ton/month	Simulated sediment ton/month
1	0.24	0
2	0.54	0
3	0.4312	0
4	0.6954	1.348
5	2.1245	0
6	4587.3213	5771
7	72930.2891	80930
8	22578.3691	36930
9	2847.9631	3140
10	256.9847	293.3
11	74.7785	76.01
12	32.8547	33.33
1	5.8564	6.57
2	2.1786	1.708
3	0.9856	1.006
4	0.6874	0.6947
5	0.5698	0.6666
6	650.7125	656.5
7	15284.126	18270
8	6345.4585	9824
9	2589.3679	3651
10	442.6894	315.1
11	182.3647	76.82
12	89.8431	32.93
1	114.1254	6.101
2	9.2154	1.797
3	182.3697	0.9424
4	17.1723	0.6501
5	25.0875	0.5485
6	1089.6346	1246
7	12425.3701	17420
8	8296.3457	11040
9	2089.3794	2216
10	238.9647	262.3
11	180.3258	73.97
12	85.2456	31.15

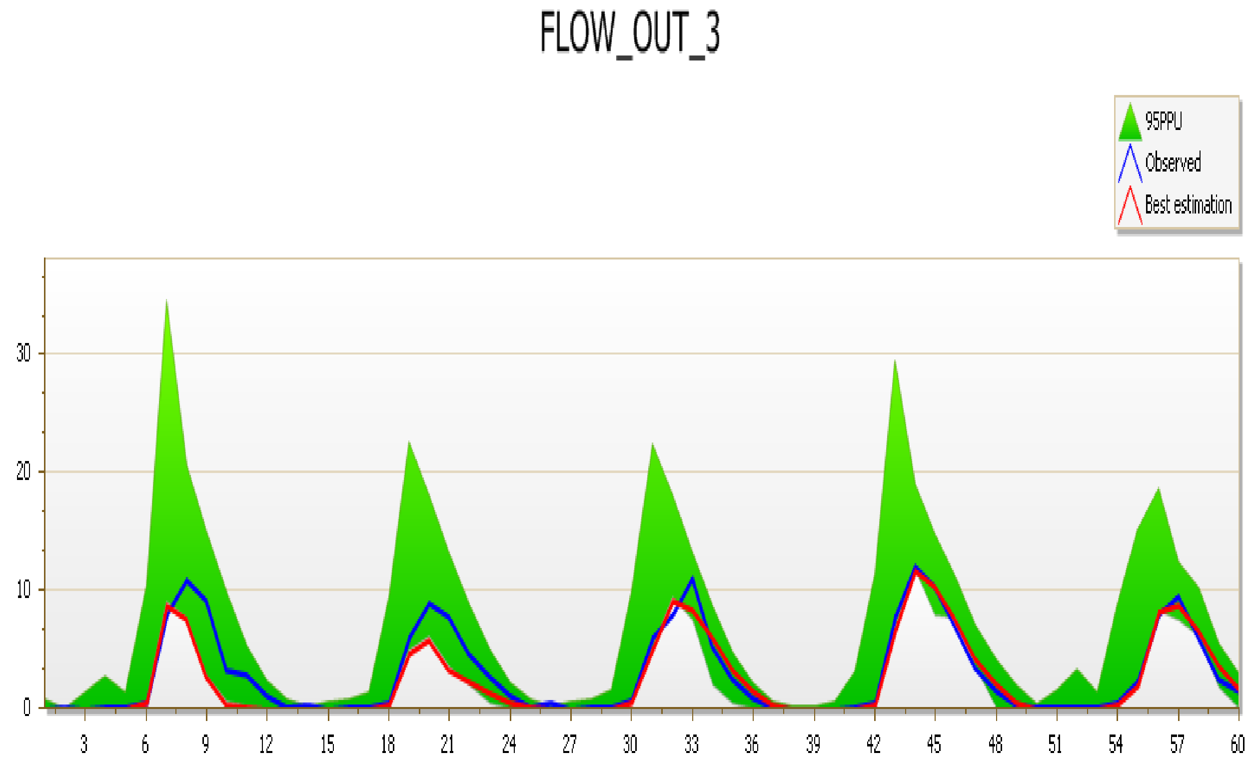
1	150.2136	5.585
2	110.2314	1.681
3	15.8895	0.7492
4	6.8574	0.2522
5	19.4536	1.026
6	7370.9614	10370
7	40258.3672	67930
8	35748.5352	37360
9	1047.3698	11150
10	45228.2344	62280
11	29849.6348	32540
12	101.2546	48.63
1	42.1452	14.31
2	29.3648	3.207
3	455.512	455.5
4	58.33	30.41
5	86.3697	1.406
6	1987.9645	2354
7	15236.9746	1760
8	19230.5684	23220
9	3874.9612	5638
10	4159.6348	7157
11	1602.3894	1834
12	61.3155	30.25



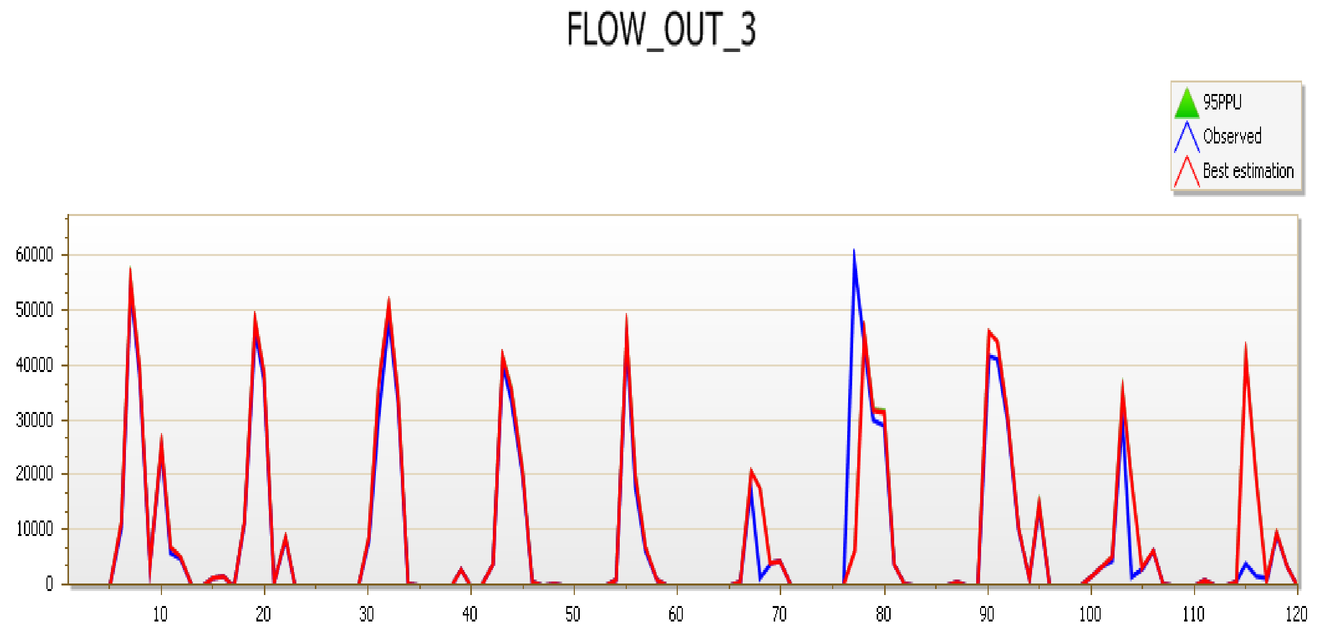
Appendix figure 1 flow sensitivity analysis by using SUFI2



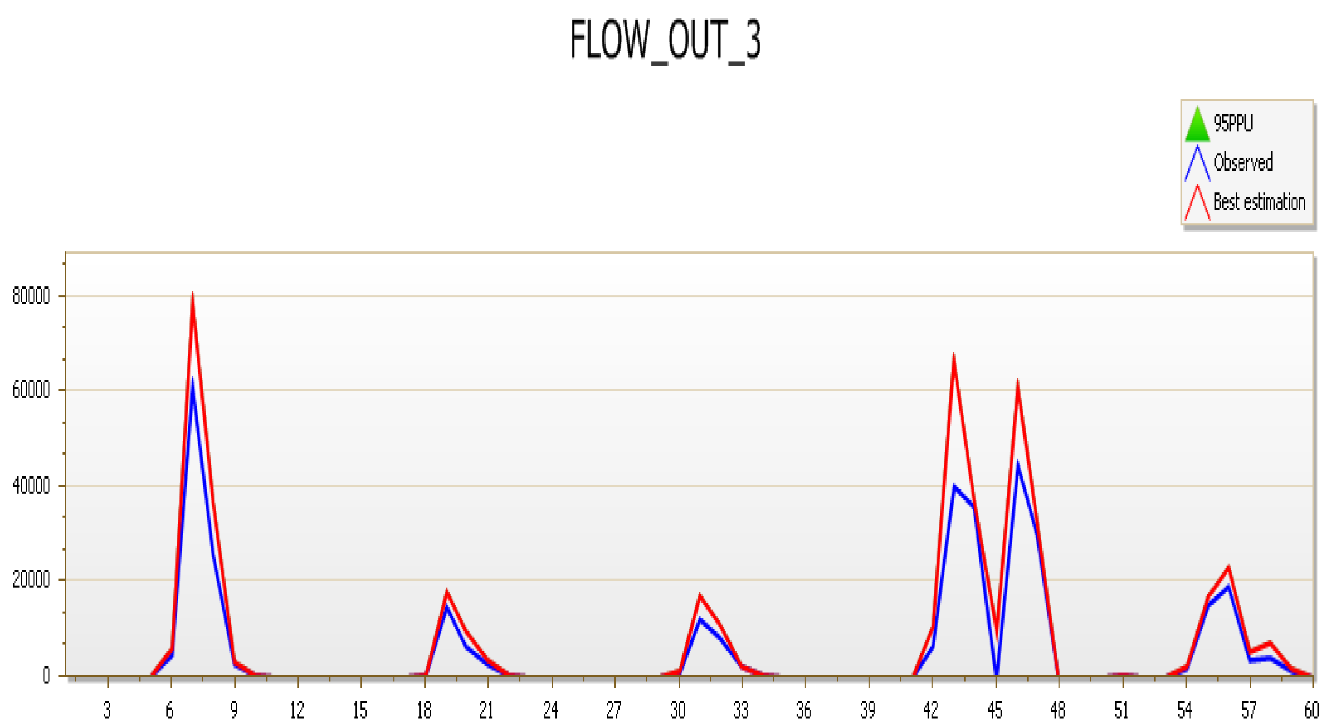
Appendix Figure 2 flow calibration by using SUFI2



Appendix Figure 3 flow validation by using SUFI2



Appendix Figure 4 Sediment calibrations in the monthly time step by using SWAT_CUP



Appendix Figure 5 sediment validations by using SUFI2