JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDRAULIC ENGINEERING

Characterization and Modeling of watershed Processes using SWAT and GIS in Gumara Watershed, Upper Blue Nile, Ethiopia

A thesis 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

By

Marye Shiferaw Bogale

November, 2015

Jimma, Ethiopia

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November, 2015

Jimma, Ethiopia

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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APPROVAL PAGE

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ABSTRACT

Soil erosion and Land degradation is a major problem throughout the Blue Nile Basin, Ethiopian highlands. Poor land use practices and improper management systems have significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. Gumara watershed is located in the south Gondar zone, North West part of Ethiopia in Amhara Regional State. There is fast growing population and the density of livestock in the basin and also lack of awareness of the watershed management strategies and agricultural practices. The main objective of the study is to Characterize and Modeling of Gumara Watershed Processes with respect to Watershed management and Agricultural practices and also delineate the sub-watershed. The area of river basin was discretized into 7 sub- basins using Soil and Water Assessment Tool (SWAT) interface of the model. The semi-automated Sequential Uncertainty Fitting (SUFI2) calibration process built in SWAT calibration and uncertainty program (SWAT-CUP) were used to calibrate the model parameters using time series of flow and sediment load data of 2004 to 2010 and validated with the observed data from years 2011 to 2014. Model performance on monthly time step reviled that (R^2= 0.90, NSE = 0.84, PBIAS = 29.3 and RSR = 0.41) and (R^2= 0.84, NSE = 0.71, PBIAS = 38.9 and RSR = 0.54) for flow calibration and validation, respectively. Similarly SWAT-CUP (SUFI2) performed well with (R^2= 0.86, NSE = 0.71, PBIAS = 46.4 and RSR = 0.53) and (R^2= 0.85, NSE = 0.65, PBIAS = 52.9 and RSR = 0.59) for Sediment calibration and validation respectively. This calibrated model was used to predict sediment yield, identify spatial distribution of sediment, and to test the potential of watershed management interventions in reducing sediment load. In this research, two mitigation measures to reduce the sediment inflowing to the Lake Tana from Gumara watershed, these were: (i) Applying area enclosure (afforestation) or Land-Use Redesign of any land use on steep slope (greater than 30%) in the whole Gumara watershed and (ii) Implementation of Parallel terrace (stone bund) in the agricultural HRUs of potential sub basins. The Soil and Water Assessment Tool (SWAT) was used to model soil erosion, identify soil erosion prone areas and assess the impact on BMPs on sediment reduction. Use of terrace in the agricultural HRUs and afforestation of steep slope areas reduced sediment yield (SYLD) inflowing to the Lake Tana from Gumara by 32% and 24%, respectively.

***Key Words**:* SWAT; SWAT-CUP; SUFI2; Calibration; Validation; Gumara Watershed

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ACRONYMS

ANSWERS	Areal Non-point Source Watershed Environmental Resources Simulation
Arc SWAT	SWAT Integrated With ArcGIS
ARS	Agricultural Research Service
BASINS	Better Assessment Science Integrating Point and Non-point Sources
BCEOM	French Engineering Consultant
BMPs	Best Management Practices
CREAMS	Chemical, Runoff, and Erosion from Agricultural Management System
DEM	Digital Elevation Model
DEW02	Dew Point Temperature Calculator
DMC	Double Mass Curve
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
EPIC	Erosion Productivity Impact Calculator
FAO	Food and Agricultural Organization of the United States
GIS	Geographical Information System
GLEAMS	Groundwater Loading Effects of Agricultural Management System
GPS	Global Positioning System
HBV	Hydrological Bayraans Vattenbalans-avediling
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HRU	Hydrologic Response Unit
ILWIS	Integrated Land and Water Information System
IWTC	International Water Technology Conference
KW	Kinematic Wave theory
LS	Slope Length
LU	Land Use
m.a.s.l	Mean at sea level
Max.	Maximum
MCM	Million Cubic Meter
Mgt	Management in SWAT Data base

Min.	Minimum
MoARD	Ministry of Agricultural Resource Development
MoWIE	Ministry Of Water, Irrigation and Energy
MUSLE	Modified Universal Soil Loss Equation
NGOs	Non-Governmental Organization
NMSA	National Metrological Services Agency
NSE	Nash Sutcliff Efficiency
PBIAS	Mean Relative Bias (Percent Bias)
PD	Probability Distributed
RMSE	Root Mean Square Error
RSR	RMSE – Observations Standard Deviation Ratio
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation System
SUFI2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
SYLD	Sediment Yield
U.S.	United States
USDA	United States Department of Agriculture
USDA – ARS	United States Development of Agriculture - Agriculture Research Service
USGS	United States Geographic Survey
USPED	United Stream Power based Erosion Deposition
UTM	Universal Transverse Mercator
WATBAL	Water Balance Model
WEPP	Water Erosion Prediction Project
WHAT	Web Based Hydrograph Analysis Tool
WWDSE	Water Works Design and Supervision Enterprise
WXGEN	Statistical Weather Generators file for SWAT

CHAPTER 1

INTRODUCTION

1.1 Background

Erosion, transportation and deposition of sediment in a watershed are natural processes which are intimately connected with the hydrologic processes. Soil and water conservation in watershed is important parameters affecting the success and economy of many water resources development activities in a basin (K Subramanya, 2008).

A watershed is defined as any surface area from which runoff resulting from rainfall is collected and drained through a common confluence point. The term is synonymous with drainage basin or catchment area (Lakew et al., 2005). It is a hydrologic unit that has been described and used both as a bio-physical unit and as a socio-economic unit for planning and implementing resource management activities (Solomon et al., 2013). The bio-physical unit in a watershed includes its water, soil, and vegetation. While, the socioeconomic unit includes people, their farming system (including livestock) and interactions with land resources, coping strategies, social and economic activities and cultural aspects (Temesgen, 2015).

A watershed is a land unit which drains into a stream system and includes a major part of the natural resources. From these resources, water is of vital importance; the development of a nation is intimately connected with its water resources. Watershed management deals with all land resources, such as forest lands, range lands, areas destroyed by erosion, or others that can serve as protection areas. Like other kinds of management, watershed management needs the sophisticated tools which have been developed in recent decades, Remote Sensing and Geographic Information Systems (GIS) have an important contribution to make (Mohamed, 2015).

Watershed characteristics which may be mostly readily compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type and cover, which includes land use. Many methods are used to estimate the runoff from a watershed. The Curve Number and Rational Methods are versatile and widely used procedure for runoff estimation. These method includes several important properties of the watershed namely soils permeability, land use and antecedent soil water conditions which are taken into consideration (IWTC, 13 2009).

Watershed models are mathematical representations of watershed processes and affected socioeconomic and environmental systems. They have become a fundamental and integrated element of any engineering project or management practice that is deemed to alter diverse natural processes. Models help us gain insights into hydrological, ecological, biological, environmental, hydro geochemical and socioeconomic aspects of watersheds (Singh and Woolhiser, 2002),

There are numerous watershed models, having various levels of sophistication and providing diverse types of information, but all watershed models share one common characteristic, that is, they are all simplifications of actual watershed processes (Wurbs and James, 2002). Another common characteristic of all models is that they require data, or observations, in order for their parameters (i.e., equation coefficients) to be estimated accurately. The process of adjusting model parameters to obtain a good match between model output and real-world observations is called calibration. Additionally, an independent set of observations should be used to test, or verify, the calibrated model in order to evaluate the expected accuracy of model results. If the expected accuracy is not acceptable, additional data should be gathered, or a simpler model may be warranted. Although these steps of calibration and verification may be costly and time-consuming, they are critical to ensuring accurate results and fostering confidence in predicted outcomes (Wurbs and James, 2002).

There are two points to remember as we discuss models the first point is models are a type of tool, and are used in combination with many other assessment techniques. And the second point is that models are a reflection of our understanding of watershed systems.

The Soil and Water Assessment Tool (SWAT) has been applied to watersheds throughout the world (Arnold and Fohrer, 2005). In most cases, the prediction accuracy was satisfactory to obtain working knowledge of the hydrologic system and the processes occurring in the watersheds. One of the shortcomings of SWAT has been an inability to model flow and transport from one position in the landscape to a lower position prior to entry into the stream. The model utilizes a Hydrologic Response Unit (HRU) concept which combines a unique combination of land use and soil type within a defined sub basin.

The purpose of this study was to determine the spatial variability of sediment load, to identify critical micro watersheds, to evaluate various mitigation scenarios in reducing sediment yield and recommend high impact watershed management interventions using a physically based and spatially distributed SWAT (Soil and Water Assessment Tool) model.

1.2 Statement of the Problem

Soil erosion and land degradation is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. This is becoming the fast growing population and the density of livestock in the basin, lack of awareness of the watershed management strategies and agricultural practices, there is pressure on the land resources, resulting in forest clearing and overgrazing (Epherem,2011).

The rapidly increasing population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use rights (grazing and woody biomass resources), cultivation of marginal and steep lands, overgrazing, and other social, economic and political factors have been the driving force to a series of soil erosion in the basin in general and in Gumara watershed in particular (BCEOM, 1998; MoARD, 2004); (Mequanint and Sileshi, 2009).

Gumara sub-basin is the tributaries of Lake Tana and it feeds the Lake, which is the biggest lake in Ethiopia. Lake Tana is the key socio-economic focal point in the area. It is used for hydropower generation, irrigation, recreation, fishing and navigation. However, due to lack of characterization and modeling of watershed processes, poor watershed management and Agricultural practices, the water level in the lake fluctuates. Inundation of the flood plains bordering Lake Tana is a yearly recurrent phenomenon. On the other hand, water level drop is also observed in some periods of the year and navigation of the boats is hampered to different islands in the lake.

1.3 Objectives of the Study

From the background information and problem of statement the following general and specific research objectives are formulated for thesis work.

1.3.1 General Objective

The general objective of this study is to characterize and model watershed processes with respect to watershed management strategies and agricultural practices of Gumara Watershed.

1.3.2 The Specific Objectives

- ❖ To determine soil erosion and land degradation of the catchment using SWAT model based on different scenario simulation.
- ❖ To estimate erosion hazard of sub- watersheds using distributed physically based model (SWAT) and GIS.
- ❖ To develop watershed management strategies and solution for the present as well as the future scenarios.

1.4 Research Questions

The relevant research questions addressed in this proposal are:

1. Which Sub basins of the watershed need more prioritizations for management practices?
2. Which mitigation measure is best to reduce sediment yield?

1.5 Scope of the Study

The study covers at four woredas (Estie, Farta, Fogera and Dera). The study will cover characterizing and modeling of watershed processes for Gumara watershed using SWAT and GIS software, formulated two scenarios of soil erosion mitigation measures to contribute in the sustainable use of Lake Tana, by promoting best management practices in the Gumara watershed.

1.6 Significance of the Study

The purpose of this study is to determine the characterization and modeling of watershed, to identify critical micro watersheds and evaluate various conservation scenarios based on the simulation result of a physically based and spatially distributed SWAT (Soil and Water Assessment Tool) model. To assess the characterization and modeling on watershed processes, it is important to have an understanding of the dominant characteristics of watershed and the hydrological processes of the watershed. Understanding the dominant characteristics of watershed is essential indicator for resource base analysis and development of effective and appropriate response strategies for watershed management of the country in general and at the study area in particular.

This study will provide a good input at times of planning for future watershed management strategies aimed at foreseeing their future development and impacts. The study will help government policy makers, development organizations, and NGOs to formulate appropriate policies, design effective evaluation and development programs. Here, the ultimate beneficiaries of the study are primarily the poor rural community.

Hence, this study will have a paramount importance in giving an insight on the vulnerability of Gumara watershed and Lake Tana to characterize, modeling of watershed and develop best management practices.

1.7 Organization of the Thesis

The thesis is organized in five chapters: Chapter 1 is an introduction chapter where the background, statement of the problem, objectives, research question, scope of the study and significant of the study are discussed. In Chapter 2, watershed characterization, hydrological modeling, soil erosion and sediment yield of watershed, soil erosion model and sediment yield modeling. Study area description, study design, Hydrological model selection, data collection, temporal data collection and analysis, spatial data analysis, SWAT model input and set up of model, use of SWAT model for watershed intervention impact analysis and scenario development and implementations are elaborated in Chapter 3. Chapter 4 describes result and discussion part, Hydrological model performance assessment, flow sensitivity, flow calibration, flow validation, sediment yield simulation, sediment sensitivity analysis, sediment yield calibration, sediment yield validation, spatial distribution of sediment yield in Gumara watershed and use of SWAT model for watershed intervention impact analysis. Finally, in Chapter 5 presents conclusions and recommendations based on the results of the models and the data used for this study. In addition to this References and Appendixes are attached at the end.

CHAPTER 2

LITERATURE REVIEW

2.1 Watershed Characterization

The Watershed Characterization is a documentation of various aspects of a watershed for the purpose of obtaining a general understanding of its features and functions and provides an overview of the watersheds fundamental natural characteristics such as topography, soils, hydrology, etc; and human characteristics such as population, land use, and water uses/systems (Amended Proposed Assessment Report, 2011).

Watershed Characterization is a relative comparison of areas with in a larger study area or watershed that are better suited for management actions to support ecological function and processes. To characterize the watershed different factors that were taken into consideration may be broadly grouped on the basis of their inter relationship with one another. The natural resources which are taken into consideration are slope, geomorphology, soil and land use cover. The monitoring of natural resources is a must because the improper and inhuman use has resulted in degradation of these. Although, the natural resources comprise all the parameters that affect the watershed, among the factors that influence the watershed, slope, geomorphology, soil and land use play significant role (Binay Kumar and Uday Kumar, volume 1, No 4, 2011).

In Ethiopia land degradation in the form of soil erosion and declining fertility is serious challenge to agricultural productivity and economic growth (Mulugeta, 2004). Several studies have shown that extensive areas of the highlands have high rates of erosion. In the mid-1980s it was estimated that 4% of the highlands (2 million ha) had been so seriously eroded that it could not support cultivation, while another 52% had suffered moderate or serious degradation (Wood, 1990; Ktivaruger et al., 1996).

2.2 Hydrological Modeling

Hydrologic models are simplified; conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. Two major types of hydrologic models can be distinguished. The first one is Stochastic Model, these models are black box systems based on data and using mathematical and statistical concepts to link a certain input to the model output. The second type is Process-Based Models; these models try to represent the physical processes observed in the real world. These models are known as deterministic hydrology models. Deterministic hydrology models can be subdivided into single-event models and continuous simulation models.

Abeyou (2008) has carried out water balance of Lake Tana and in his study a conceptual hydrological model known as HBV has been applied to estimate the water balance components of the Lake. It is used for regionalization techniques to transfer parameters from gauged catchments to ungauged catchments. Evaporation from the Lake surface was estimated using Penman combination equation. The mean annual flow of the Gumara catchment is 1229Mm^3. And also tested the physical catchment characteristics while calculating flow in unguaged catchments.

Shimeles (2008) has tested the performance of SWAT in the northern highlands of Ethiopia for modeling of hydrology and sediment yield. The main objective of his study was to test and examine the influence of topography, land use, soil and climatic conditions on stream flows, sediment yield and soil erosion, modeling of four tributaries (Gumara, Rib, Gilgel Abbay and Megech) of Lake Tana and also found SWAT model gives good agreement with observed and simulated flows.

Sirak (2008) has used conceptual hydrological model known as SWAT has to estimate the water balance components of the Lake, used regionalization techniques to transfer parameters from gauged catchments to ungauged catchments. Evaporation from the Lake surface was estimated using penman combination equation and also found that the mean annual flow of the Gumara catchment is 1323Mm^3.

Yohanes (2007) has used WATBAL and SCS model for water resources potential assessment in the Lake Tana basin. The rainfall on the Lake surface was estimated using spatial interpolation of inverse distance weighted techniques. And also found that the mean annual flow of Gumara catchment is 1388.84MCM.

2.2.1 Hydrological Model

Hydrological model is a mathematical model used to simulate river or stream flow and calculate water quality calculations. These models generally came in to use in the 1960s and 1970s when demand for numerical forecasting of water quality was driven by environmental legislations in the United States and United Kingdom.

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The one objective of the watershed hydrologic modeling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena. The other objective is for hydrologic prediction (Tadele, 2007).

Characterization of the specified watershed was continued by adapting a hydrological model under limited data conditions. The application of the model involved model setup, sensitivity analysis, calibration, and uncertainty analysis. The performance of the model was evaluated by comparing the simulated flow hydrograph with the observed hydrograph visually.

Types of Hydrological Model

Lumped models: provide a unique output for the whole watershed. They do not provide any information regarding the spatial behavior of the outputs. The whole catchment is assumed to be homogeneous and all the potential variations are lumped (averaged) together. Thus, the degree of accuracy of the model is expected to vary with the degree of non-homogeneity of the catchment (Zerihun, 2011).

Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 2000). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin (Tensay, 2011).

Distributed models: Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

2.2.2 SWAT Model

The SWAT model is developed and supported by the USDA/ARS. It is a physically based watershed-scale continuous time-scale model, which operates on a daily time step. The SWAT model delineates a watershed, and sub-divides that watershed in to sub-basins. The major components of SWAT include hydrology, Water supply, Water quality, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The robust application of SWAT model has extended all over the world because of its diversified application.

The SWAT model needs several data inputs to represent watershed conditions which include: digital elevation model (DEM), land use land cover, soils, climate data. The SWAT model development was influenced by other models like CREAMS (Knisel, 1980), GLEAMS (Leonard et al., 1987), and EPIC (Williams et al., 1984; Neitsch et al., 2002).

SWAT is recognized by the Environmental Protection Agency (EPA) and has been incorporated into the EPA's BASINS (Better Assessment Science Integrating Point and Non-point Source) (Di Luzio et al. 2002a). [BASINS is a multipurpose environmental analysis software system developed by the EPA for performing watershed and water quality studies on various regional and local scales.]. In order to optimally calibrate the model parameters, especially for large-scale modeling, an auto-calibration routine has been added to SWAT (Eckhardt and Arnold, 2001); hence, SWAT will be used in this study to simulate evaluation characterization and modeling of watershed.

2.2.3 Overview of SWAT 2009 model

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model 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 (Arnold et al., 1998, 2000; Neitsch et al., 2001). It can also be used to simulate water and soil loss in agriculturally dominated small watersheds. In the SWAT model, the modeling or estimation of flow, sediment or nutrient transport of the watershed is done by dividing the watershed into sub basins and the land areas in the sub basins are also sub-divided again into one or more land units, possessing similar land use, soil type and applied management strategies. These similar land units in land use, management and soil attributes are called Hydrologic Response Units (HRUs). The HRUs are helpful for a better estimation of the loadings (flow, sediment, pollutants) from the sub basins.

The Arc SWAT 2009 extension of Arc GIS 9.3 is a graphical user interface for the SWAT model (Arnold et al., 1998). To create a SWAT dataset, the interface will need to access Arc GIS compatible raster (GRIDs) and vector datasets (shape files or feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the model.

2.2.4 GIS for Hydrologic Modeling

GIS is a special type of information system in which the data source is a database of spatially distributed features and procedures to collect, store, retrieve, analyze, and display geographic data. In other words, a key element of the information used by utilities is its location relative to other geographic features and objects It combines spatial locations with their corresponding various information.(Weizhe An, 2007).

The ArcGIS system is a powerful integrated suite of GIS applications capable of performing advanced mapping, data management and geoprocessing of spatial data. The three applications in the ArcGIS suite are: Arc Catalog used for the organization and management of all GIS data, Arc Map is used for all map based tasks including Cartography, Map analysis and editing. Arc Toolbox this contains large number of GIS tools for geoprocessing and file conversion.

2.3 Soil erosion and Sediment yield of a Watershed

Erosion takes place in the entire watershed including the channels. During a rainfall event, when rain drops impact on a soil surface, the kinetic energy of the drops breaks the soil aggregates and detaches the particles in the impact area. The detached particles are transported by surface run off.

Erosion takes place in various modes, which can be classified as follows: Inter-Rill Erosion in this the detached particles due to raindrop impact are transported over small distances in surface flow of shallow depth without formation of elementary channels called rills. The mode of transport is essentially sheet flow and the inter-rill erosion from this mode is known as sheet erosion.

2.3.1 Factors affecting soil erosion

Several factors influence soil erosion; which include rainfall erosivity, soil erodibility, topography, land cover and management factors (Wischmeier and Smith, 1978). The soil particles of major interest are in the silt and clay ranges. Rainfall characteristics play a major role in determining sediment yield in the upland phase. Major factors affecting the yield in this phase are: soil characteristics, climate, vegetation, topography and human activities.

Erosivity

Climatic erosivity includes drop size, distribution and intensity of rain, amount and frequency of rainfall, run-off amount and velocity, and wind velocity. One of main climatic factor affecting soil erosion is rain fall. Erosivity is the potential capacity of rainfall to cause erosion and it depends essentially on the intensity, duration and frequency of rainfall.

Soil Erodibility (K – Factor) Layer

Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the Soil erodibility factor (K). Soil erodibility factor (K) in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic matter and chemical content of the soil.

Support practice factor (P)

Conservation support practice factor, P by definition is the ratio of soil loss from any conservation support practice to that with up and downslope tillage. It is used to evaluate the effect of contour tillage strip cropping, subsurface drainage.

The support practices considered in this study for cultivated land includes contour plaguing, strip cropping, bunds, fanyajuu, drainage systems and others. On non-cultivated land support practices considered includes hillside terraces, check dams and other practices that result in storage of moisture and reduction of runoff.

Even though, it is more suited for small-scale erosion hazard assessment mapping than regional or basin-wide, Hurni gives parameters for different land management practices on cultivated land. Studies conducted by Hurni (1985) have found P values for various support practices and land use cover. Hurni used P value range between zero and one. This means the P value indicates reduced erosion potential, with a range between 0 to 1 because of farming practices or soil and water conservation measures**.** With no erosion control practice, P is equal to one. The farming practices increasing erosion instead of reducing are ploughing in the direction of up and down slope with equivalent P value of one, which is the worst case scenario.

Slope Length (LS – Factor) Layer

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and is considered by the slope length factor (L). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978).

Land Use/Land Cover (C – Factor) Layer

This factor measures the combined effect of all the interrelated cover and management variables including vegetation plant spacing, the quality of growth tillage practices, land use residues (Wischmeier and Smith, 1978).

The C- factor is used within the RUSLE to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans (USDA-ARS, 2001). The crop cover factor C measures the combined effect of all the interrelated cover and management variables (Wischmeier and Smith, 1978).

Upland erosion by water may occur in three stages, which follow one another in time and to some extent in space. The first stage is sheet erosion which may be idealized as the removal by any means of a sheet of sediment of uniform thickness over an entire area.

The second stage is rill erosion which is the development of small channels of runoff concentration (Young and Mutcher, 1969c; Podmore and Merva, 1971). The rill form due to natural areal variation in the erosion resistance of the soil and small variations in elevation and slope. These are easily obliterated by normal agricultural tillage practices. The third stage is gully erosion. The flows from rills concentrate in gullies which are relatively permanent topographic features.

2.3.2 Erosion Control Measures

Upstream soil and water conservation measures in catchments can have positive impact both upstream in terms of less erosion and higher crop yields, but also downstream by less sediment flow into reservoirs and increased groundwater recharge (J.E. Hunink et al 2012).

Agricultural conservation practices, often called best management practices or BMPs, are widely used as effective measures for preventing or minimizing pollution from nonpoint sources within agricultural watersheds (Arnold et al, 2007).

Various control measures that can be adopted to reduce erosion and transportation of eroded products in the catchment are dealt under the specialized interdisciplinary practice known as Soil Conservation technology. After a thorough study of the catchment area, soil and water conservation practices best suited for each sub watershed of the catchment have to be established by the specialists in the area of soil and water conservation. In a general sense, the soil conservation practices involve components such as

- ❖ Terraces, strip cropping and contour bunding to retard overland flow and hence reduction in sheet erosion.
- ❖ Check dams, to reduce sediment inflow into the stream

- ❖ Vegetal covers, grassed waterways and afforestation to reduce runoff rates and hence to reduce erosion. (Source: K Subramanya (2008).

Once the spatial location of sources of sediment in the Gumara watershed is known, best management practices (BMPs) that can minimize erosion and sediment transport are selected and evaluated.

Agronomic or vegetative measures and Physical (engineering measures) are the two commonly used soil and water conservation practices (Hurni, 1983, Donald et al, 1984; BCEOM, 1998; WWDSE, 2007)

2.4 Soil Erosion Model

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster, 1988). The major forces originate from raindrop impact and flowing water. The mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by (Wischmeier & Smith, 1978) in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots. 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 Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley,1989) and Unit Stream Power - based Erosion Deposition (USPED) are based on the USLE and represent an improvement of the former. In 1996, when the U.S. Department of Agriculture (USDA, 1972) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new calculation procedure to calculate the cover vegetation factor, and the revision of the length and gradient of slope .

The use of the USLE and its derivatives is limited to the estimation of gross erosion, and lacks the capability to compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS. USDA developed the Water Erosion Prediction Project (WEPP) model (Flanagan & Nearing, 1995) to replace the USLE family of models and expand the capabilities for erosion prediction in a variety of landscapes and settings. This model is a physically based, distributed parameter, single - event simulation erosion prediction model. Processes within the model include erosion, sediment transport and deposition across the landscape and in channel via a transport equation.

2.5 Sediment Yield Modeling

Scientific management of soil and water resources on watershed basis is very important in order to plan sustainable uses of these resources and to arrest erosion and sedimentation problems. This requires however, understanding basic processes of soil erosion and the driving forces affecting soil erosion in a watershed.

Modeling soil erosion and sediment transport of a watershed can be used for three basic reasons (Jain and Kothyari, 2000, Solomon.M, 2010).

- To assess soil loss for conservation planning and regulation. Application of watershed models can provide a quantitative and consistent approach to estimate soil erosion and sediment yield under the conditions of applications of different management practices or changes in land use.
- To understand erosion processes and their interactions and for setting research priorities
- Physically based models can predict where and when erosion is occurring, thus helping to target efforts to reduce erosion.

Erosion modeling is based on understanding the physical laws of landscape processes that occur in the natural environment. Erosion models can provide a better understanding of natural phenomena such as transport and deposition of sediment by overland flow and allow for reasonable prediction and forecasting.

Many hydrological and soil erosion models are developed to describe the hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of sediments (Sleshi.B et al, 2009).

A number of sediment yield models have been developed to address wide ranging soil and water resources problems. Williams(1981) classified the models in the following three broad categories on the basis of soil and water problems to be solved: (1) erosion control planning, (2) water resource planning and design, (3) water quality modeling. The complexity of a model is usually dictated by the nature of problem intended to solve. Some problems require simple models, whereas others may require complex models.

For an effective targeting of Best Management Practices the identification of Critical Source Areas within watersheds is crucial. Watershed models like SWAT (Soil and Water Assessment Tool) are valuable tools that allow for the identification of Critical Source Areas in large watersheds and for the assessment of the effectiveness of Best Management Practices without time-consuming and costly field experiments.

CHAPTER 3

METHODOLOGY

3.1 Study Area Description

3.1.1 Location of the study area

The study area is found in North West part of Ethiopia in Amhara Regional State, south Gondar Zone (Figure 3.1). The watershed covers partly four woredas (administrative units) namely, farta, Fogera, Dera, Estie. It is situated in the south east of Lake Tana, and it has a latitude and longitude of 11 ^{0} 51’27.97” N, 37 ^{0} 37’51.21” E.

Gumara watershed is highly cultivated region in Ethiopia highlands around 50 km from Bahir Dar. It has 1278 km^2 watershed area draining to Lake Tana. Elevation of the Gumara watershed ranges from 1797 to 3708 meters above sea level. It has 21 tributaries and the total length of the river is 99.6 km (Ephrem, 2011). Figure 3.1 shows the location of Gumara catchment.

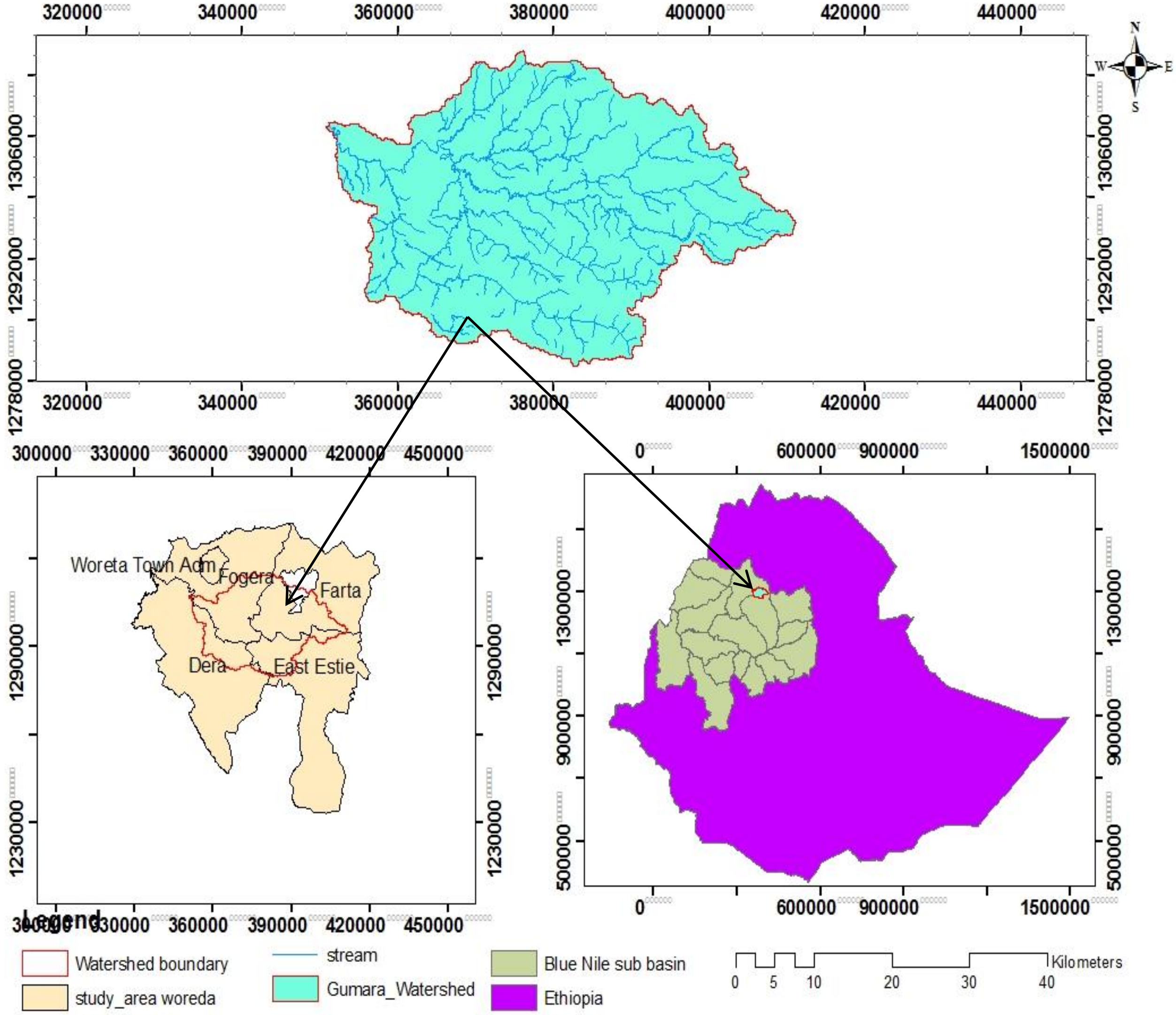


Figure 3.1: Location of the study area

3.1.2 Climate of the Study Area

The annual climate of Gumara watershed can be divided in to rainy and dry season. The rainy season may be divided into a major rainy season from June through September. The dry season occurs between January, February and December. As shown in Figure 3-2, the long-term average annual rainfall (1994 - 2014) of the four stations near Gumara watershed shows an average of 114.5 mm and long term average maximum and minimum temperature of the four stations (Bahir Dar, Debretabor, Mekane eyesus & Woreta) 25.12 ^{o}C and 9.99 ^{o}C respectively.

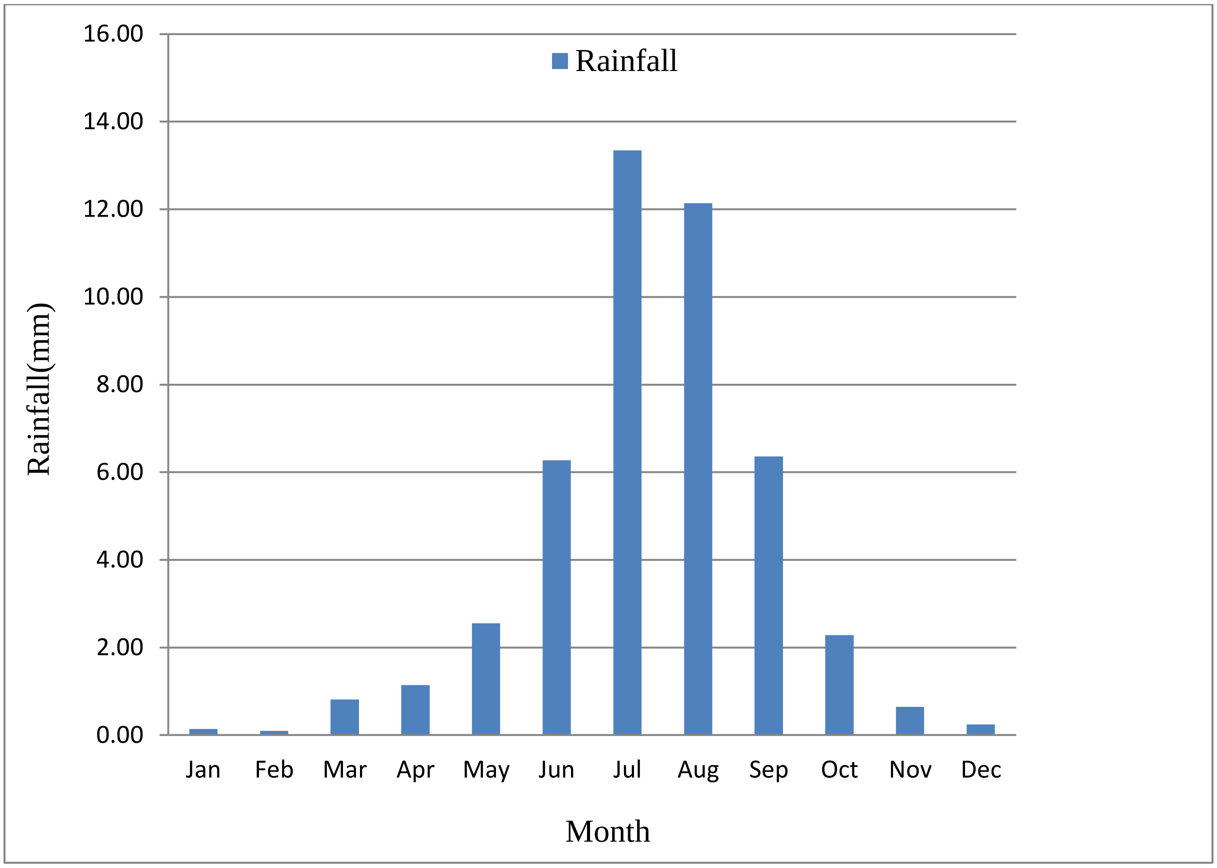


Figure 3-2: Long term Mean Monthly Rain fall distribution of Gumara watershed (1994-2014).

3.1.3 Topography

The slope sliced based on FAO slope classes namely 0 - 2, 2 - 10, 10 - 15, 15 - 30 and more than 30 percent slope. The elevations of the study area vary from 1800m to 4100m above mean sea level and majority of the watershed area are from 1800m – 2055m above mean sea level.

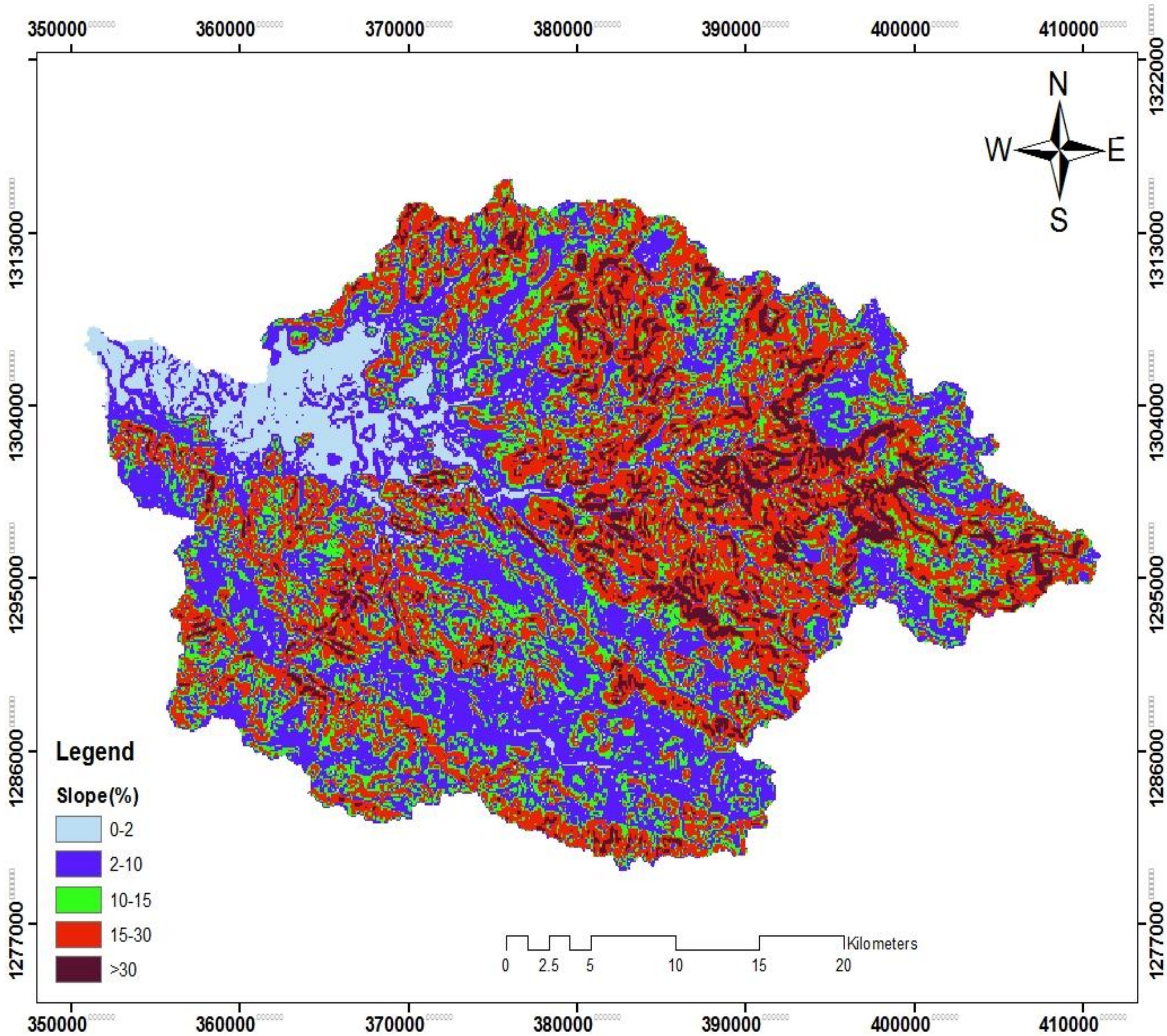


Figure 3.3: Elevation of the Gumara watershed (Study area)

3.2 Study Design /Study Procedure/

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

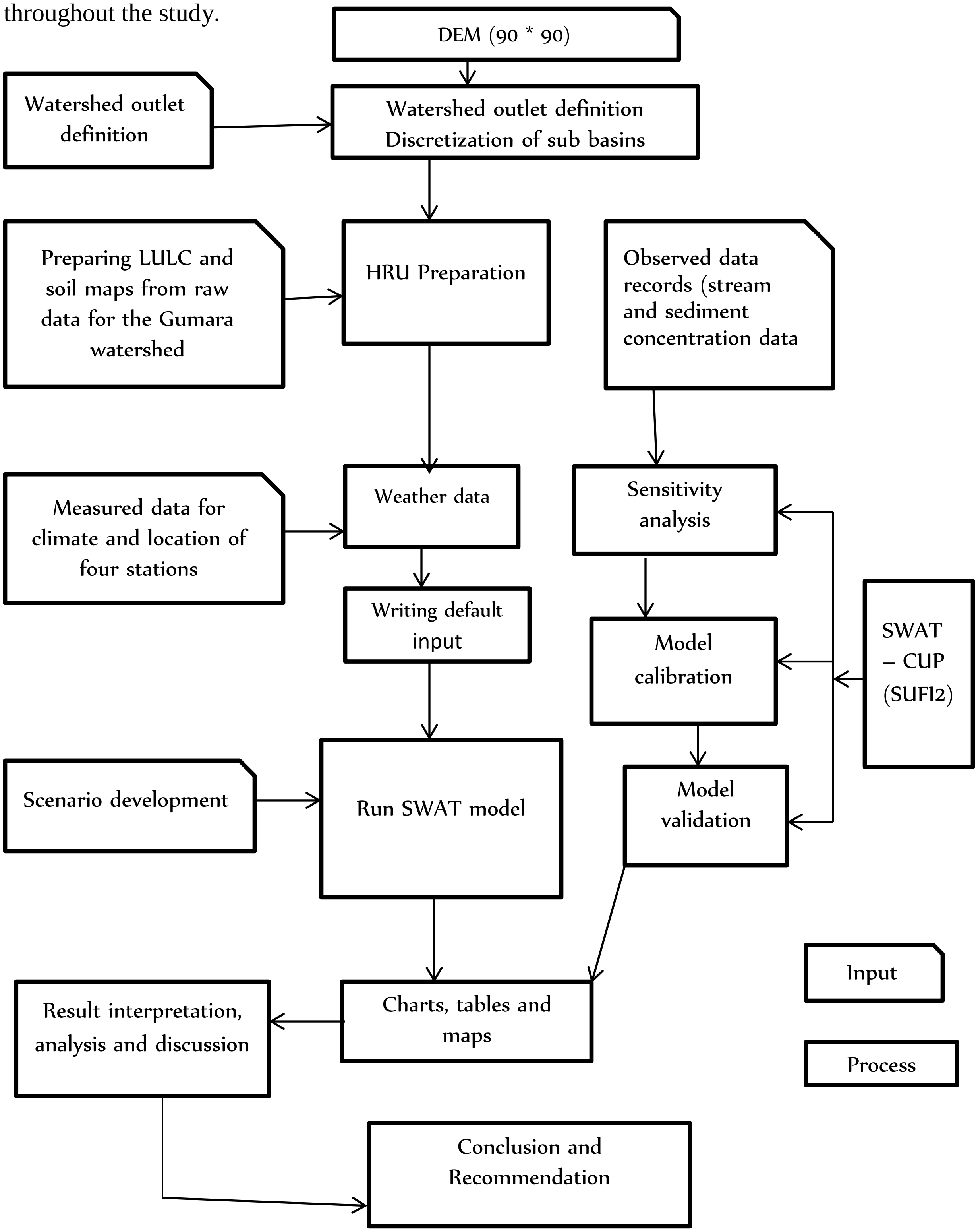


Figure 3.4 Flow chart of the methodology /study design/

3.3 Hydrological Model Selection

Hydrological models are mathematical formulations which determine the runoff signal which leaves a watershed basin from the rainfall signal received by this basin. They provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources. Such hydrological models are also used as means of extrapolating from those available measurements in both space and time into the future to assess the likely impact of future hydrological change. Changes in global climate are believed to have significant impacts on local hydrological regimes, such as in stream flows which support aquatic ecosystem, navigation, hydropower, irrigation system, etc. In addition to the possible changes in total volume of flow, there may also be significant changes in frequency and severity of floods and droughts.

Many comprehensive spatially distributed hydrologic models have been developed in the past decade due to advances in hydrologic sciences, Geographical Information System (GIS), and remote sensing. Among the many hydrologic models developed in the past decade, the Soil and Water Assessment Tool (SWAT) selected, developed by (Arnold, 1998) has been used extensively by researchers. This is because SWAT:

- It is readily and freely available
- It is physically based, spatially distributed
- uses readily available inputs for weather, soil, land use, and topography
- Allows considerable spatial detail for basin scale modeling, and
- It is capable of simulating change in catchment characteristics using different scenarios and confirms the result spatially.

3.4 Data Collection

The necessary data that was collected and used from MoWIE and NMSA were utilized to attain the objectives in this paper. The main input data needed for this study involves temporal data and spatial data. The temporal data consists of Metrological (precipitation, maximum and minimum temperature, relative humidity, wind speed, Sunshine hour), Daily River discharge, and sediment yield concentration or sediment load data are collected from NMSA and MoWIE respectively. The spatial data mainly consists of digital elevation model (DEM), land use/cover and Soil map of the study area.

Models and software's used for develop watershed management strategies and solution for the present as well as the future scenario in the study area was Arc GIS 9.3 extension of SWAT model that is Arc SWAT 2009. The other software used in this study was Arc GIS 9.3. It was used for input preparation of SWAT model, to extend the Arc SWAT model and to prepare the Thiessen polygon of the metrological stations in the watershed.

3.5. Temporal data collection and Analysis

National Meteorological Service Agency (NMSA) classified meteorological stations into four each identified by a code. Code one stations (primary stations) are stations at which observation such as rainfall, relative humidity, maximum and minimum temperature, wind speed and sunshine duration were taken every three hour. For stations categorized under code two (synoptic stations) are those in which observation such as measuring rainfall, relative humidity, maximum and minimum temperature, wind speed and sunshine duration were taken every 24 hours. Stations under code three (ordinary stations) are those only daily rainfall and daily maximum and minimum temperatures are observed. The rest which are categorized under station code four are recording only daily rainfall amount.

SWAT requires daily meteorological data that could either be read from a measured data set or be generated by a weather generator model. In this study, there are a total of four metrological stations in and around the study area named as Debre Tabor, Bahir dar, Woreta, and Mekane Eyesus station which are owned by NMSA. From the first two stations (Type II) daily metrological data such as precipitation, maximum and minimum temperature, relative humidity, wind speed and daily sunshine hours were collected but from the remaining two stations daily precipitation and maximum and minimum temperature data were collected for the period of 1994 - 2014. In addition, Debre Tabor station has used as weather generator station to fill the gaps due to missing data.

3.5.1 Estimation of Missing Data

Before beginning any hydrological analysis it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers, (Vedula, 2005). Generally, data should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques.

Estimation of missing data is one of the most important tasks required in many hydrological modeling studies. There are many methods and studies already developed to estimate the missing data, such as simple average (Station Average), linear or multiple regression, normal-ratio, coefficient of correlation, and inverse distance weighting method are commonly used to fill the missing records (Gomez, 2007).

The method used to fill data gaps in this study was the "Station Average Method". In Station Average Method, the missing record is computed as the simple average of the values at the nearby gauges. Mc Cuen (1998) recommends using this method only when the annual precipitation value at each of the neighboring gauges differs by less than 10% from that for the gauge with missing data; hence, the Station Average method is given by:

$$P_x = \frac{1}{Z}(P_1 + P_2 + P_3 + \ldots\ldots\ldots\ldots + P_z) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where: Px = the missing precipitation record

P1, P2, P3, ------------, Pz = Precipitation records at the neighboring stations

Z = Number of neighboring stations

If the annual precipitations vary considerably by more than 10%, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighboring stations by the ratios of normal annual precipitations.

Table 3.1: Location and percentage of missing values in the daily rainfall records

Station	Lat.	Long.	Elevation	Period of data	Missing data (%)	Class
Bahir Dar	11.6027	37.322	1827	1994 - 2014	8.579	1
Debretabor	11.8666	37.9954	2612	1994 - 2014	2.738	1
Woreta	11.92225	37.6958	1819	1994 - 2014	5.398	3
Mekane eyesus	11.6076	38.05422	2374	1994 - 2014	17.199	3

The average mean method is adopted to fill missing air temperature data. After filling both rainfall and Minimum and Maximum air temperature daily 21 year's data and their consistency and homogeneity were checked by double mass curve and RAINBOW software respectively.

3.5.2 Homogeneity

One of the methods to check homogeneity of the selected stations in the watershed is the RAINBOW software. 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).

For this study RAINBOW software was used to check the homogeneity of data which is based on the cumulative deviation from the mean.The following figure shows the homogeinity test of rainfall data for Debretabor station.Like Debretabor rainfall station,the homoginity test for the rest of the rainfall stations was done and all of the stations are homogeneious (see the Appendix).

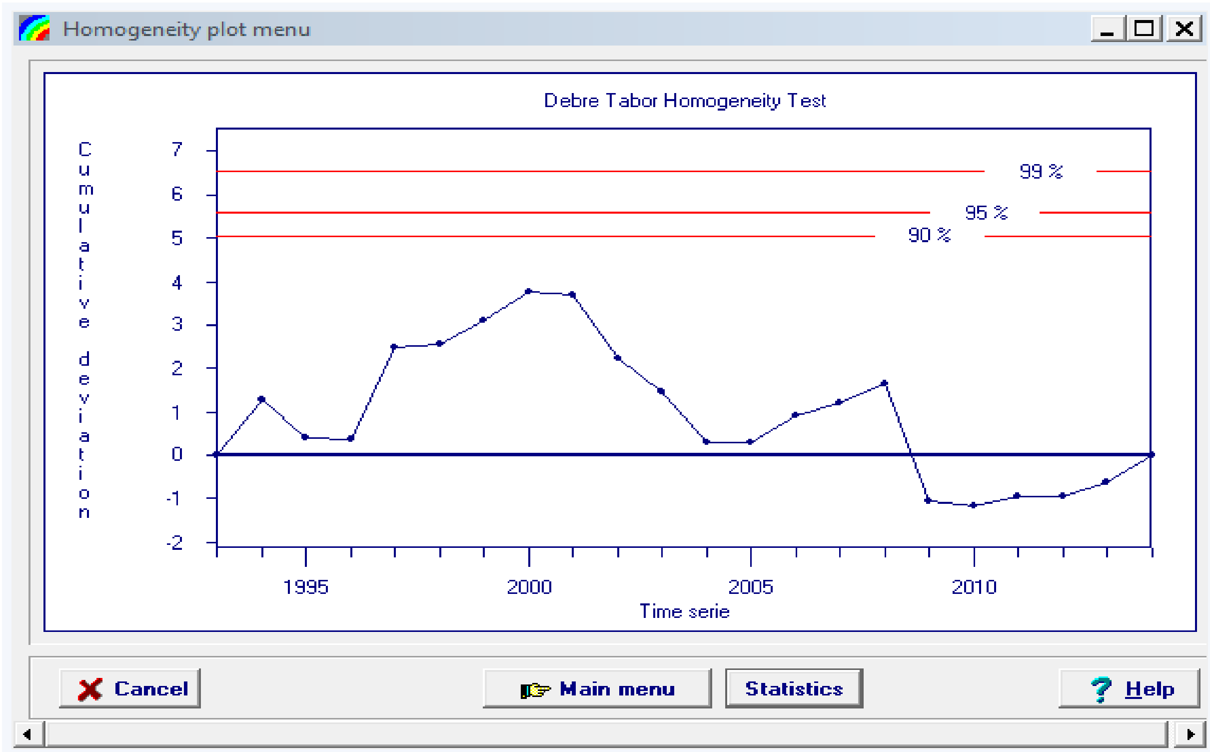


Figure3.5: cumulative deviation of annual rainfall at Debretabor station

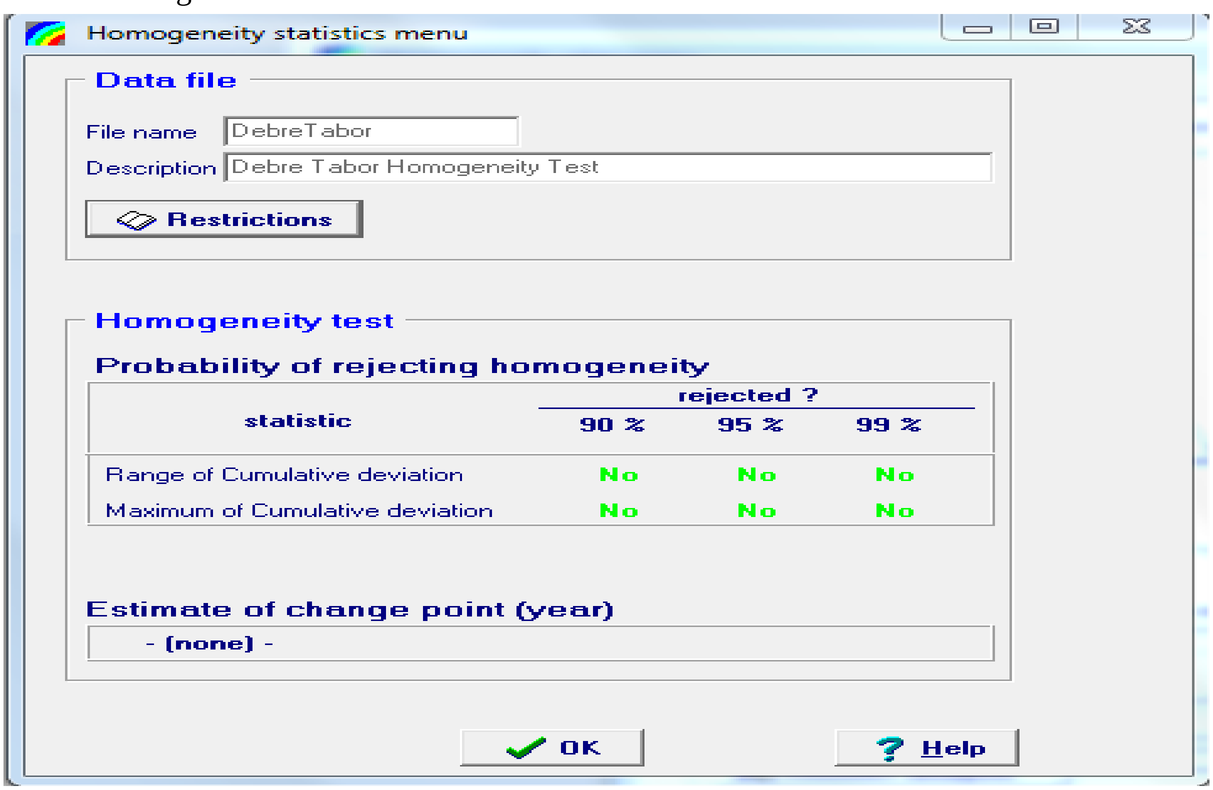


Figure 3.6: Probability of rejecting homogeneity of annual rainfall at Debre Tabor Station

3.5.3 Consistency Test of Data

Estimating missing precipitation is one problem that hydrologists need to address. A second problem occurs when the catchment rainfall at rain gages is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record.

To overcome the problem, in consistency a technique most widely applied called double mass curve is used. The double mass curve is used to check the consistency of many kinds of hydrologic data by comparing data for a single station with that of a pattern composed of the data from several other stations in the area. The double mass curve can be used to adjust inconsistent precipitation data.

Consistency of precipitation data from individual stations used in this study was checked using a double mass analysis and any of the stations used in this study have not undergone a significance change during the base line period (1994-2014) of the study below Figure 3.7.

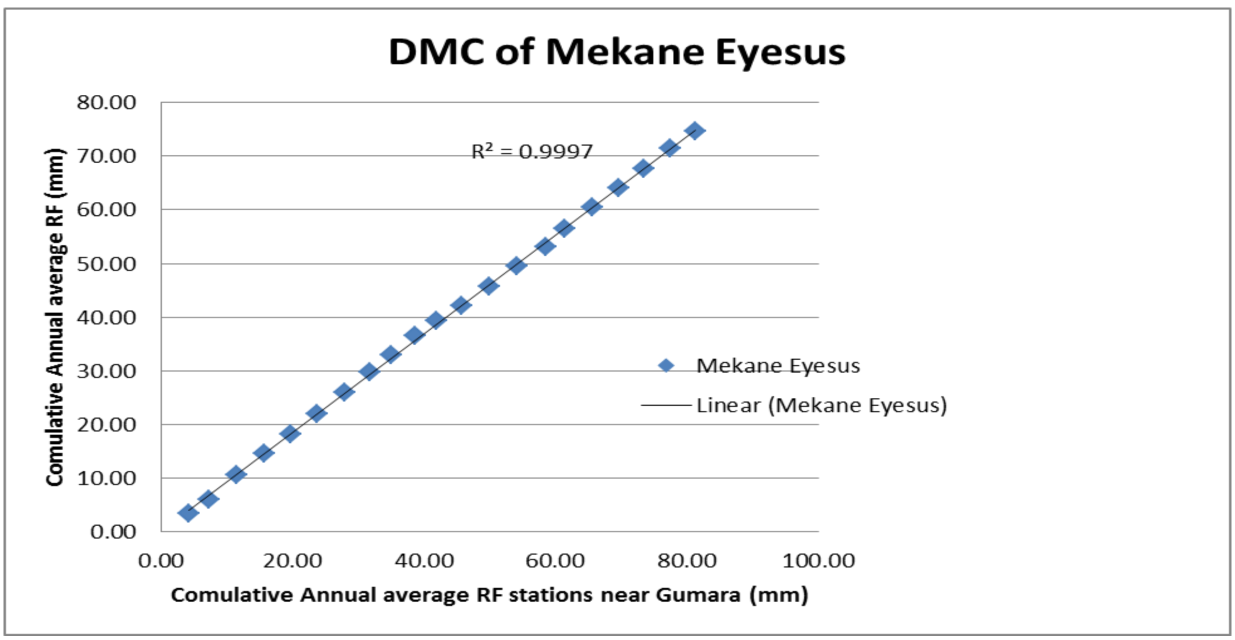


Figure 3.7: DMC of Mekane Eyesus station showing high data consistency

The double mass curve analysis was done for all rainfall stations as similar to Mekane Eyesus rainfall station which showns below the Appendix Figure 7 - 10.

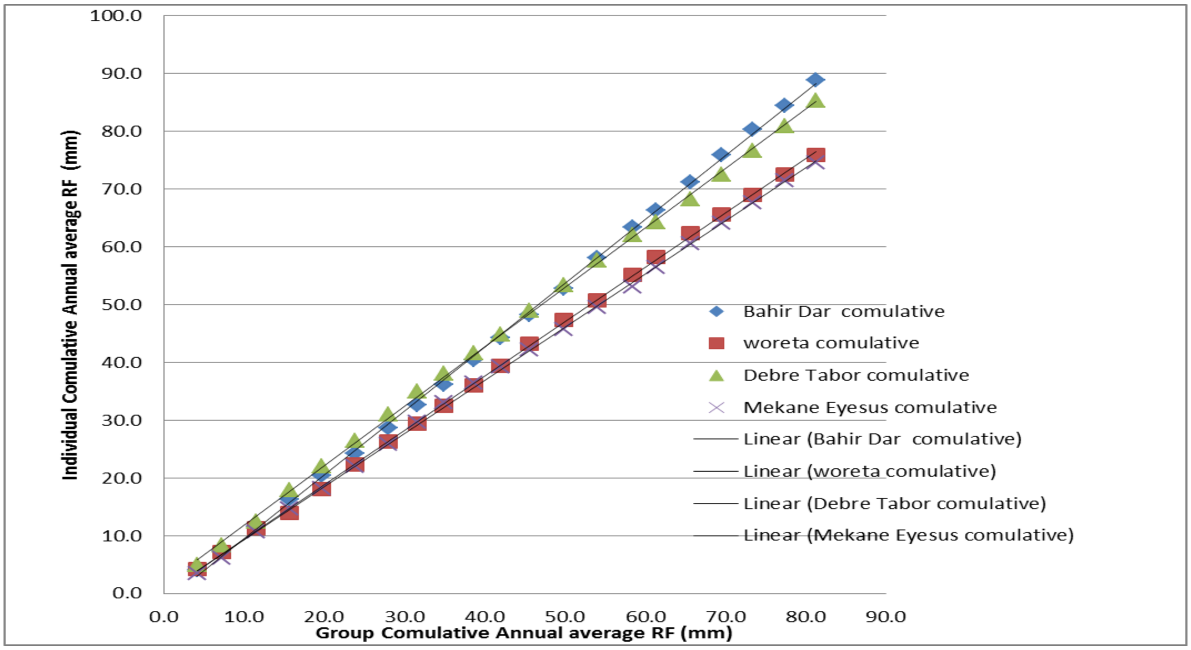


Figure 3.8: Double mass curve of all the stations in and around Gumara catchment.

3.5.4 Estimation of Areal Precipitation

For analyses involving areas larger than a few square miles, it may be necessary to make estimates of average rainfall depths over sub watershed areas since a rain gauge records rainfall at a geographical point. To convert the point rainfall values of these stations into an avrage value of over a catchment the following methods are in use(i) Arithmetic Mean, (ii) Thiessen Polygon, (iii) Isohyetal, (iv) Grid Point, (v) Percent Normal,(vi) Hypsometric, etc. are available for estimating average precipitation over a drainage basin, (Shaw, 1988).

For this study thiessen-polygon method was used, due to its simplicity and the average rainfall over the catchment. Because Thiessen polygon is graphical technique which calculates station weights based on the relative area of each station in the Thiessen polygon network. The individual weights are multiplied by the station observation and the values are summed to obtain the real average precipitation. The advantage of this method is stations out of the catchment may also be used for assigning weights of marginal stations within the catchment. It is calculated in the following formula (Richard, 1998).

According to Thiessen polygon, the average rainfall, R_{areal} over the area can be computed from:

$$R_{areal} = \sum_{i=1}^{N} \frac{Ri\,Ai}{At} \quad \text{OR} = \frac{R_1A_1 + R_2A_2 + R_3A_3 --- + R_NA_N}{A_1 + A_2 + A_3 ----- + A_N} \text{---------------} (3.2)$$

Where:

R_{areal} = is a real potential precipitation of the catchment.

A_i = is the polygon area of station i.

R_i = is the rainfall at station i.

N = is the number of stations in the watershed.

A_t = is total catchment area.

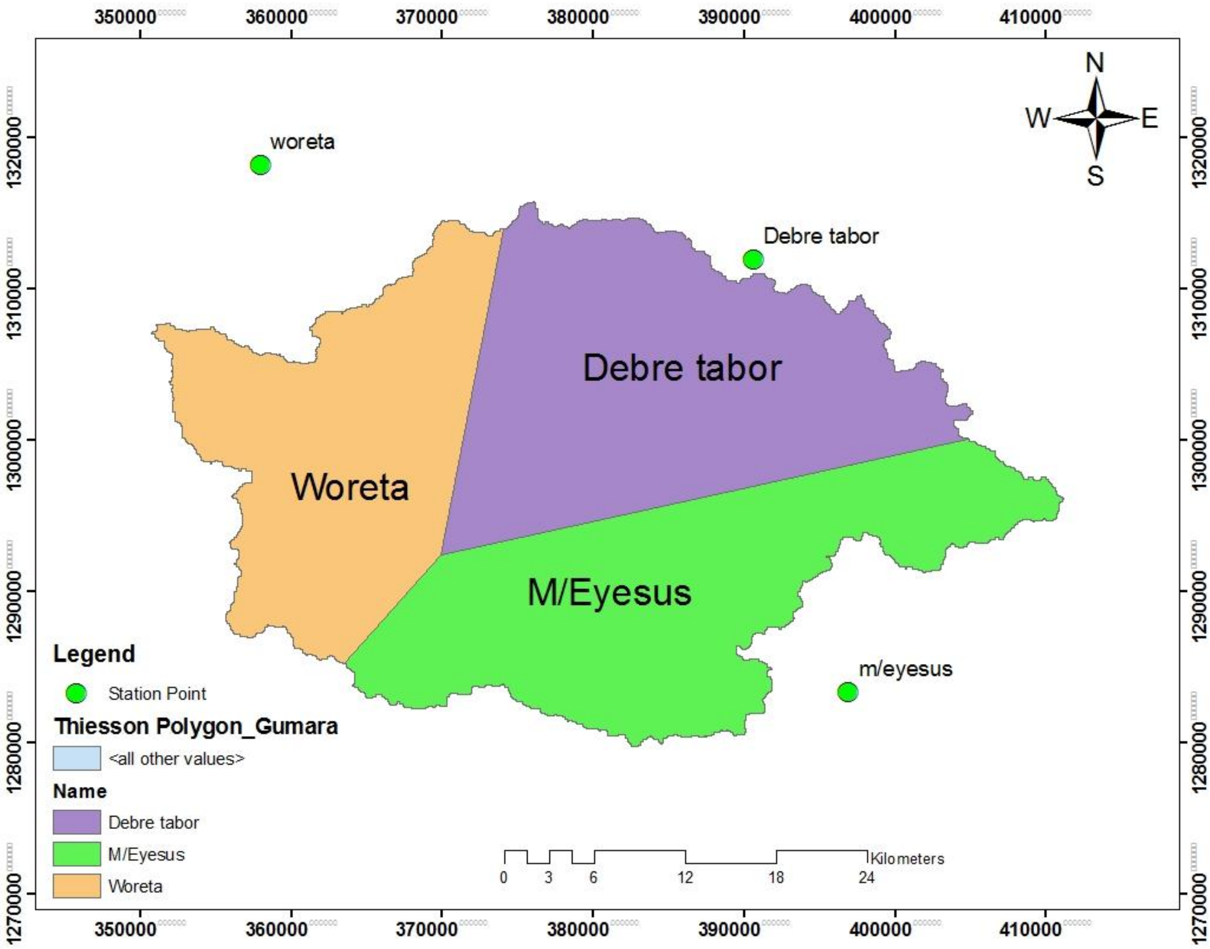


Figure 3.9: Thiessen polygon map of Rainfall station for Gumara catchment

From the four rainfall stations located around the Gumara catchment, Bahir Dar station was excluded due to its enormous data gaps and the station was also excluded because it found out of the range of Thiessen polygon for areal rainfall determination**.**

Table 3.2: Weights of RF stations assigned for the whole Gumara catchment Based on Thiessen polygon technique

Stations	Area (Km^2)	Weight (%)
Debretabor	477	37.32
Woreta	361	28.25
Mekane Eyesus	440	34.43
Total Area (Km^2)	1278	100

Table 3.3: Station location and their respective length of records

No_	Station name	Period of records(years)	Elevation (m.a.s.l)	Lat. (Deg. and Min)	Long. (Deg. and Min)	Mean Annual Rainfall(mm)
1	Bahir Dar	21	1827	11.6027	37.322	1546.13
2	Debretabor	21	2612	11.8666	37.9954	1484.06
3	Woreta	21	1819	11.92225	37.6958	1321.16
4	Mekane Eyesus	21	2374	11.6076	38.054	1297.58

Table 3.4: Location of Gumara gauging station

Gage name	Period of record Years	Catchment Area Km2	Location		Mean Annual Max. Discharge
			Lat.	Long.	
Gumara	2001 - 2014	1278	11.833	37.63	53.75

3.5.5 Flow Data Filling and Consistency

The daily discharge of the study area is collected from the MoWIE .Unlike the daily metheorological data, the daily discharge data has limitted data composition for the considered stations to represent the study area. Regression analysis was used to fill the missing flow data and to extend those short lengths recorded data by using satisfactory correlation Coefficient for the common data period of neighboring station and use linear interpolation between the last value before the gap and the first value after it or same day average method was used to fill the gap of data for which hydrometric stations that have not satisfactory correlation from any of the neighboring stations. Consistency and homoginity test of flow data is analyzed by DMC and Rainbow software.

During the study period (2001 - 2014) the long- term average monthly discharge of Gumara, which have maximum in the month of August whereas March and April are usually the months of lowest flow.

3.5.6 Sediment rating curve preparation

Sediment measurement in the Gumara River was taken by MoWIE at Gumara gauge station was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step, the relationship known as sediment rating curve. The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load and the general relationship can be written as:

$$S = aQ^b \quad \ldots\ldots \quad (3.3)$$

Where: S = sediment load in ton/day,

Q = the discharge in m^3/s and

a & b = regression constants.

Hence the measured value that was collected from the MoWIE, hydrology office was sediment concentration; so that the first work was convert this value into sediment load by the following formula:

$$S = 86.4*Q*C \quad \ldots\ldots \quad (3.4)$$

Where: S = sediment load in (ton/day),

Q = flow of the stream (m3/S).

C = sediment concentration (kg/m^3) and

86.4 = conversion factor.

After calculated the sediment load the next step was making the relation between the Continuous (daily time step) measured flow in m^3/s and the measured sediment load (ton/day). The relation between the flow and sediment load with R^2 of 0.9009 % was (Figure 3.10):

$$S = 20.402 * Q^{1.4989} \quad \ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

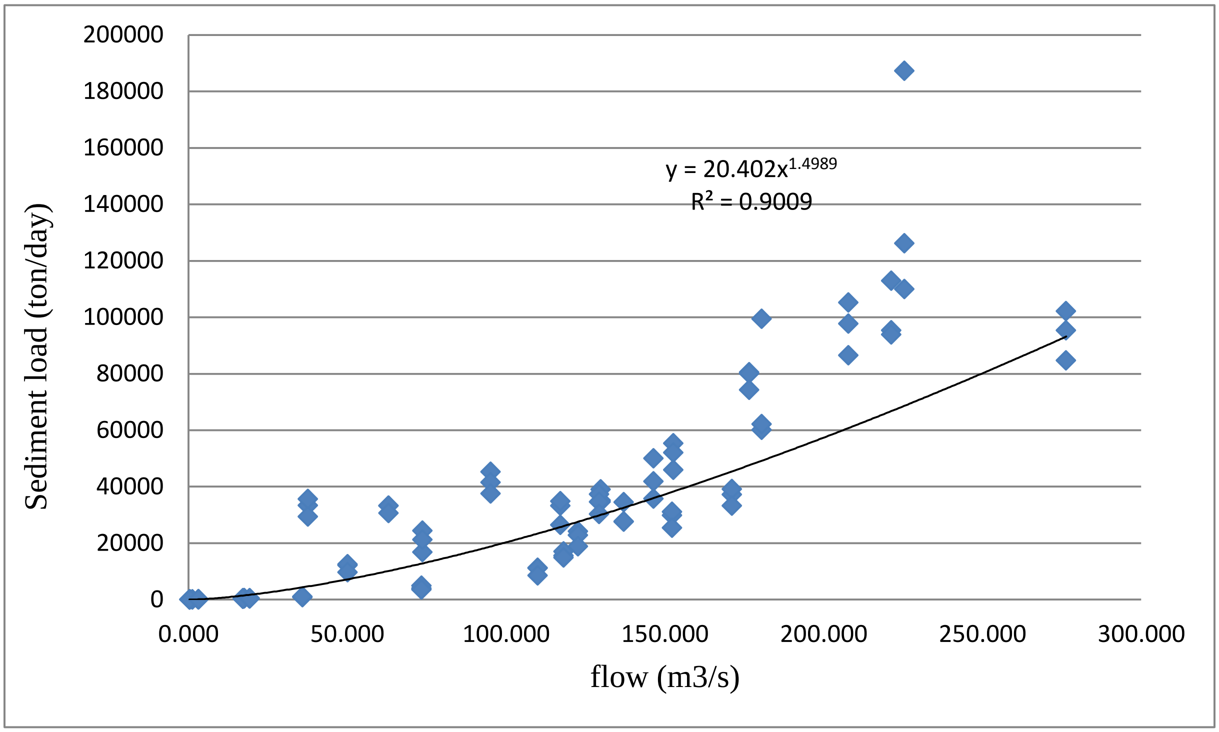


Figure 3.10: Sediment rating curve of Gumara River at Gumara gauge near Bahir dar.

3.6 Spatial Data Analysis

3.6.1 Digital Elevation Model

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A Digital Elevation Model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a Digital Terrain Model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. In this study DEM which is 90 by 90 meter resolution was collected from the federal Ministry of Water,Irrigation and Energy (MoWIE). DEM was used to extract the watershed characteristics of a catchment using open source GIS. Digital elevation model is one of the essential inputs required by SWAT to delineate the watershed in to a number of sub watershed or sub basins.

DEM was used to analyze the drainage pattern of the land surface terrain, sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length and width were derived from the DEM.

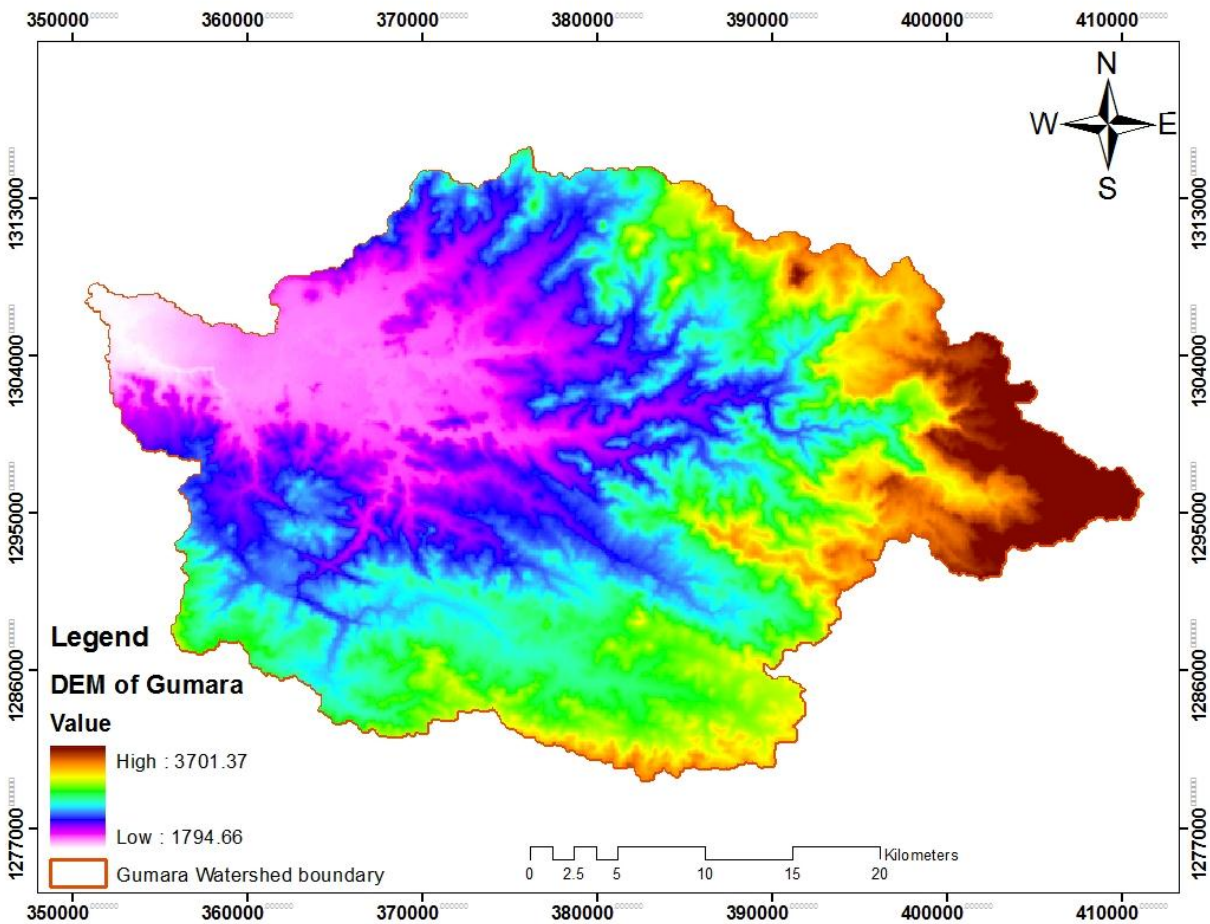


Figure 3.11: Digital Elevation Model (DEM) of the Gumara Watershed

3.6.2 Soil Data

The watershed is characterized by five major dominant soil groups. Chromic Luvisols, Eutric Fluvisols, Eutric Leptosols, Eutric Vertisols, Haplic Luvisols and Urban. Soil data is the other imputes required by SWAT's soil data base and statistical modeling which influences the runoff generation of a catchment. The physical property of the soil in each horizon governs the movement of water and air through the soil profile. It has a majoir impact on cycling of water in hydrologic response unit (HRU), and used to determine water budjet for the soil profile, daily runoff and erossion.

For this study a soil data of major soil groups of study watersheds were collected from MoWIE GIS department. Major soil groups and land use types are indicated in result section.

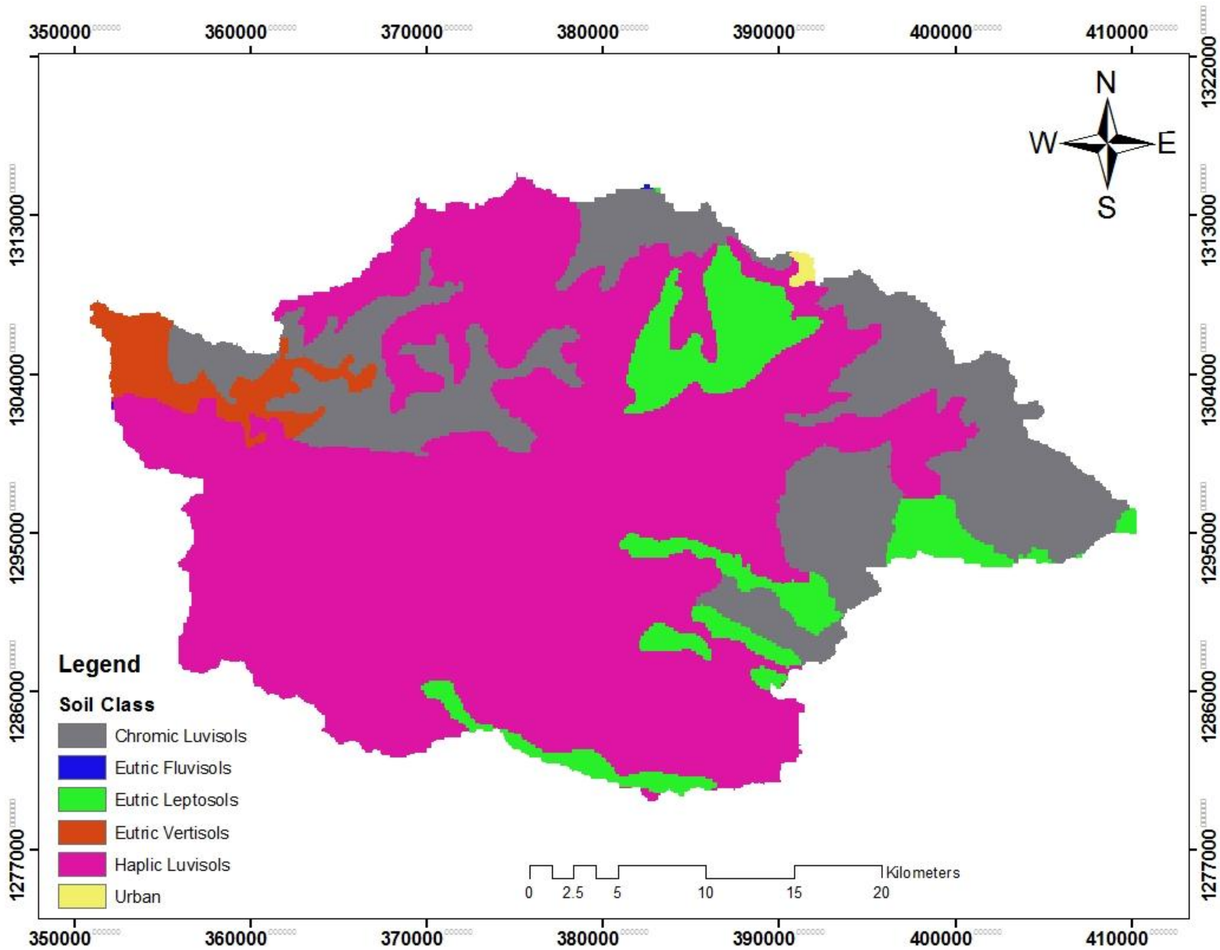


Figure 3.12: Soil Map of Gumara Watershed

Table 3.5: Major Soil Groups of Gumara watershed

Major Soil Group	Area (km^2)	% of Total Area
Chromic Luvisols	304	23.79
Eutric Fluvisols	1	0.08
Eutric Leptosols	119	9.31

Eutric Vertisols	38	2.97
Haplic Luvisols	813	63.62
Urban	3	0.23
Total	1278	100.00

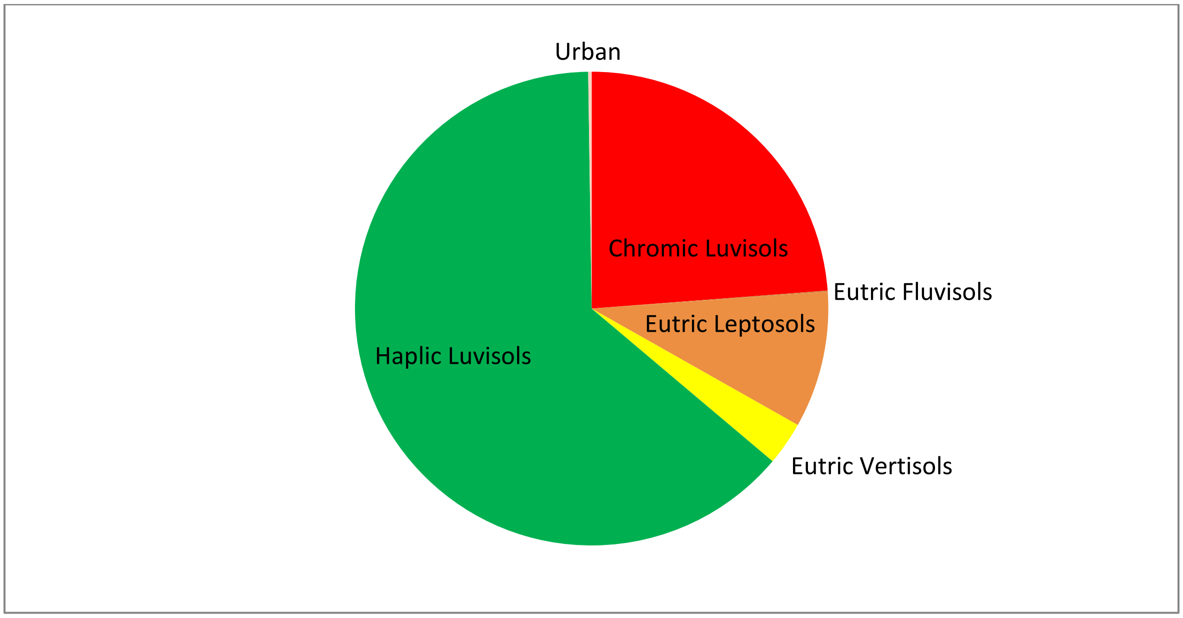


Figure 3.13: Pie charts show the proportions of the Major soil group of the Gumara Catchment.

Table 3.6: Soil parameters used in SWAT

Name	Description
NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrologic group (A,B,C,D)
SOLZMX	Maximum rooting depth of soil profile
ANION_EXCL	Fraction of porosity from which an ions are Exchanged
SOIL_CRK	Crack volume potential of soil
TEXTURE	Texture of soil layers (optional)
SOIL_Z	Depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of the soil layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Clay content

SILT	Silt content
SAND	Sand content
ROCK	Rock fragment content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility (K) factor

3.6.3 Land Use Data

The land use types of Gumara watershed in Figure (3.14) is classified as Bare land, Cultivation, Natural forest, Plantation forest, Grass Land, Water bodies, Shrub land and Wood Land. In the entire watershed resource-intensive economic activities often precipitate environmental degradation. The land use map of the study area was obtained from MoWIE. Land use is one of the most important factors that affect runoff, evapo-transpiration and surface erosion in a watershed.

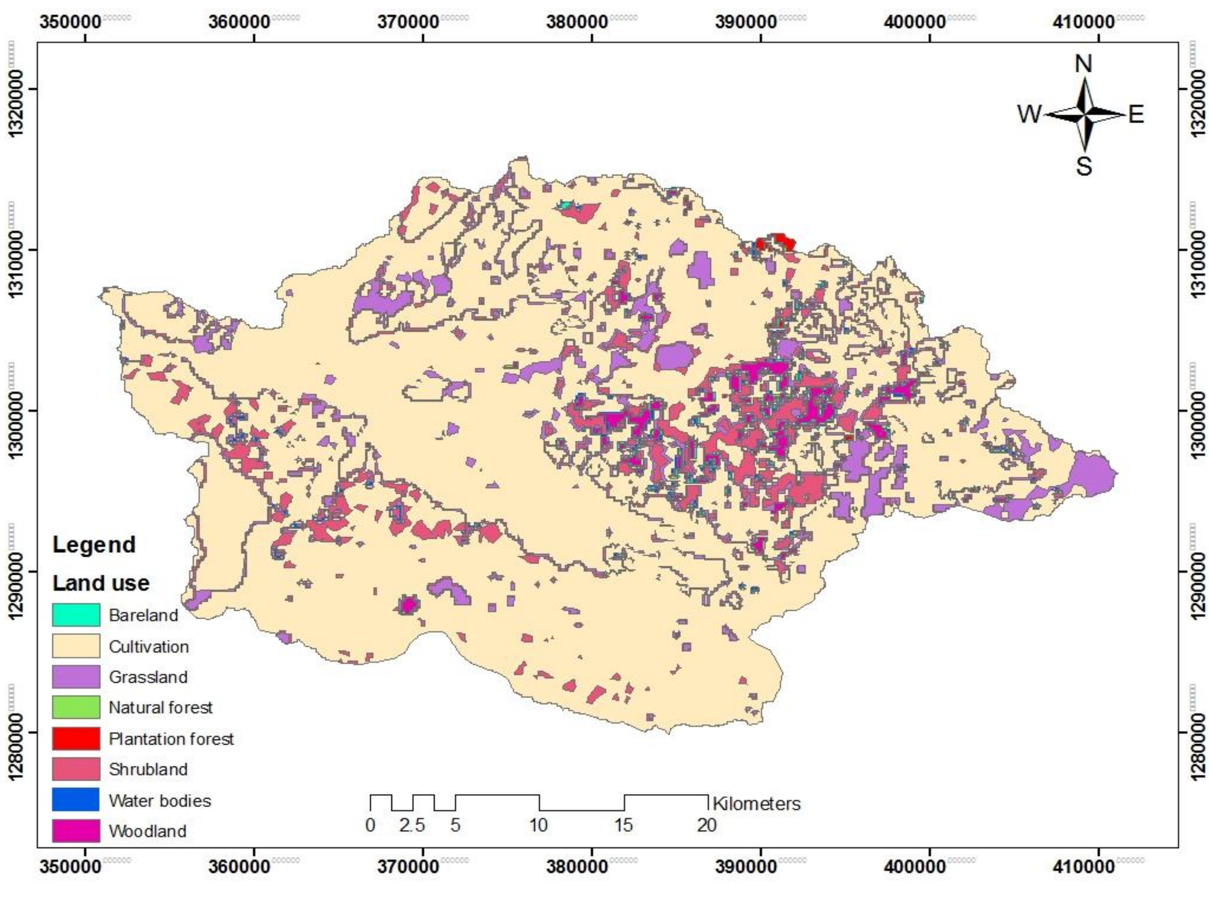


Figure 3.14: Land use map of Gumara watershed

Table 3.7: Original land use/land cover types redefined according to the SWAT code

Original land use	Redefined Land use according to the SWAT Database	SWAT_Code	Area (Km2)	% of Total Area
Bare land	Range-Brush	RNGB	8	0.63
Cultivation	Agricultural Land-Close-grown	AGRC	986	77.15
Grassland	Range-Grasses	RNGE	117	9.15
Natural forest	Forest-Mixed	FRST	4	0.31
Plantation forest	Forest-Mixed	FRST	2	0.16
Shrub land	Range-Brush	RNGB	103	8.06
Water bodies	Water	WATR	5	0.39
Woodland	Forest-Mixed	FRST	19	1.49

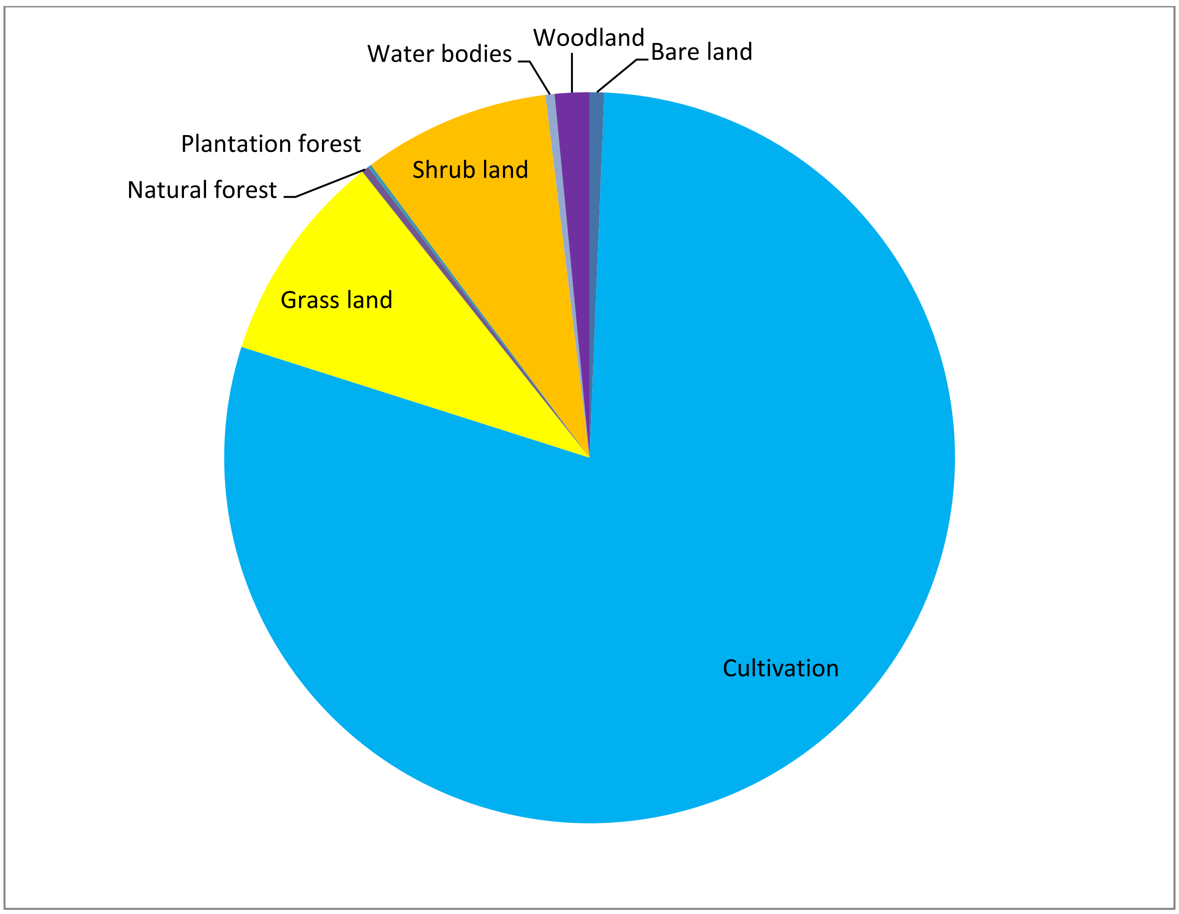


Figure 3.15: Pie chart shows the proportions of the Land use of the Gumara Catchment.

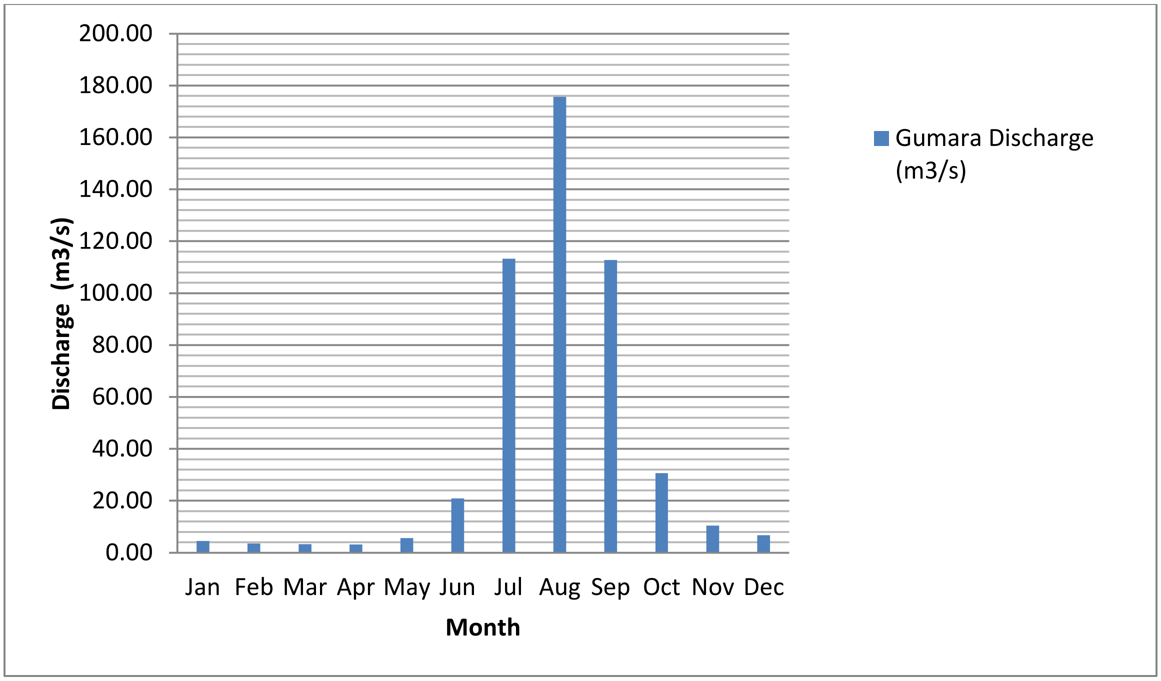


Figure 3.16: Average monthly discharge of Gumara River (2001 - 2014)

3.7 SWAT Model Input and Set up of Model

3.7.1 SWAT Model inputs

DEM

Digital elevation model is one of the essential inputs required by SWAT to delineate the watershed in to a number of sub watershed or sub basins. DEM was used to analyze the drainage pattern of the land surface terrain, sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length and width were derived from the DEM.

Soil data

SWAT model requires different soil textural and physio-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content or different layers of each soil type. These data were obtained mainly from the MoWIE. Major soil types in the watershed are Chromic Luvisols, Eutric Fluvisols, Eutric Leptosols, Eutric Vertisols, Haplic Luvisols, and Urban. The values of different soil parameters (properties) for each soil are listed in Appendix Table 7.

Land use

Land use is one of the most important factors that affect runoff, Evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from MoWIE. The land use / Land cover map scale used during the master plan study were 1:250,000. Land cover/ Plant growth is one of the data base used in SWAT. The model already has predefined SWAT four letter codes for each land cover classification in such a way that the land use/Land cover classification used in the study area were assigned in SWAT database.

Weather Generator

SWAT requires daily metrological data that could either be read from a measured data set or be generated a weather generator model. In this study, the weather variables used for driving the hydrological balance are daily precipitation, minimum and maximum air temperature, relative humidity, wind speed and solar radiation. Before preparation of the weather data metrological stations in the study area were selected based on Thiessen polygon method. The meteorological stations around the study area were Bahir dar, Woreta, Mekane Eyesus, Debretabor stations was included and the Debretabor station selected to be principal station for the weather generator. For the missing data filling all stations were added to the WXGEN with their statistical values.

In this study, the weather data used was considered for a period of 1994-2014. Missing weather data are left as it was in name. dbf format and a negative (-99.0) inserted for missing data. This value tells SWAT to generate weather data for that missed data day. To Generate the data, weather parameters were developed by using the weather parameter calculator WGNMaker and dew point temperature calculator DEW02 (Liersch, 2003). The parameters needed for the weather generators are listed in Appendix Table 11 and statistical values of each station presented in Appendix Table 12.

River Discharge and Sediment yield Data

Daily river discharge values and sediment concentration for Gumara River were obtained from the Hydrology Department of the MoWIE, Ethiopia. These daily river discharges and sediment concentrations at Gumara River were used for model calibration and validation.

3.7.2 SWAT Model Set up

The model setup involved data preparation, Watershed delineation, HRU definition, Parameter sensitivity analysis, calibration, and validation.

3.7.2.1 Data preparation

The SWAT model build up process involves the preparation of the input data. This input data is classified mainly as spatial data (DEM, land use, soil type) and temporal data or weather input data (rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed).

The DEM was used to delineate the watershed and to analyses the drainage patterns of the land surface terrain. The land use / Land cover special data were decalcified in to SWAT land cover/plant types. A user lookup table was created that identified the SWAT code for different categories of Land cover/Land use on the map as per the required format. The soil map is linked with the soil data base which is a soil data base designed to hold data for soils not included in the U.S.

3.7.2.2 Watershed delineation

The watershed delineation process include five major steps, DEM setup, stream delineation, outlet and inlet definition, watershed outlet selection and definition and calculation of sub basin parameters. For the stream definitions the threshold based stream definition option was used to define the minimum size of the sub basins.

3.7.2.3 Hydrologic Response Unit Analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land use and the soil data in a projected shape file format were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed.

The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWATs code for the different categories of land use /land cover was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The second step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 35 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to consideration, 5%, and 10% threshold levels for the land use, and soil were applied, respectively so as to encompass most of spatial details.

The third step in HRU definition is selection of slope classification option (single or multiple) and if multiple slope option is select then defines the range of the slope. For this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified depending up on the FAO (2001) slope classification to five and the range was 0-2%, 2-10%, 10 – 15%, 15 – 30% and above 30%.

Finally, by define the HRUs within a sub-basin complete the HRU setup. For this study the option of multiple HRU was selected and 5%, 10% and 5% were the threshold area of land use, soil and slope in each HRU from the sub-basin values respectively. The reason for taking these threshold values was in order to keep the HRUs to a reasonable and manageable number and also considering computer processing time required. Even though, application of these thresholds eliminates the land uses and soils that covered relatively small areas in the sub-basins it creates a total of 125 HRUs for 7 sub-basins.

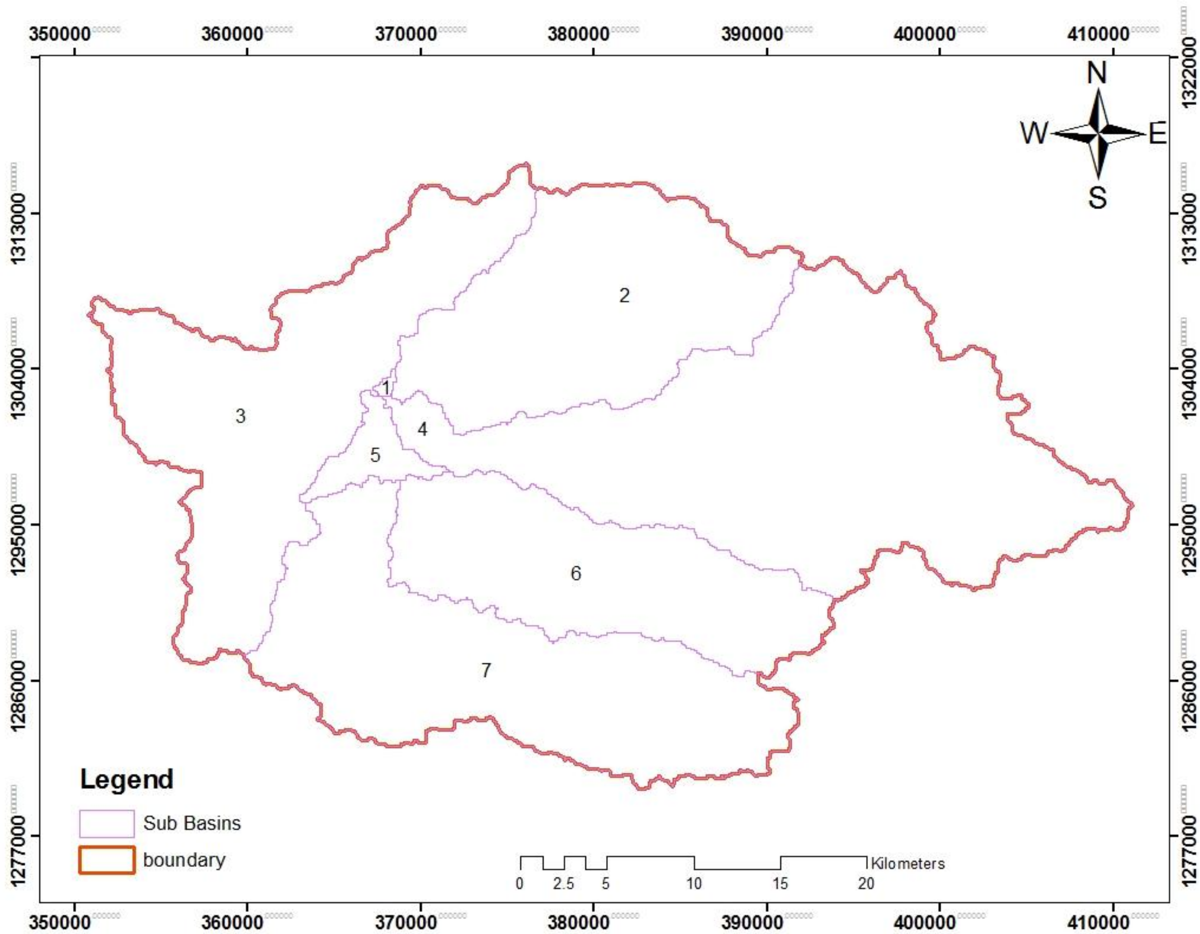


Figure 3.17: The delineated watershed and sub-basins by SWAT model

3.7.2.4 Importing climate data

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle. The climatic variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate dbase format. Due to data availability and quality, daily precipitation, and maximum and minimum temperature in dbase format were the climatic input variables imported together with their weather location. And due to lack of complete weather data we used the penman montith method which uses Temperature, Rainfall, Wind speed and Relative humidity to determine the solar radiation and potential evapotranspiration.

3.7.2.5 Sensitivity Analysis

Sensitivity analysis is a method of identifying the most sensitive parameters that significantly effect on model calibration or on model prediction. Sensitivity analysis describes how model output varies over a range of a given input variable (Dilnesaw, 2006).

According to Lijalem (2006), sensitivity analysis is a method of reducing the number of parameters to be used in calibration step and using the most sensitive parameter largely controlling the behavior of the simulation processes which finally eases calibration and validation processes as well as the time required for it.

Sensitivity analysis is an instrument for the assessment of the input parameters with respect to their impact on model output which is useful for model development, model validation and reduction of uncertainty, which can be classified in to four orders after Len hart et al. 2002. See table below after a complete preprocessing of the required input for SWAT - CUP (SUFI2) model, flow simulation was performed for ten years of recording period of 2001 - 2010. The first three years which was used as a warm up period and the remaining records was used for flow simulation, which then used for sensitivity analysis of hydrologic parameters.

Table 3.8: Sensitivity classes after (Len hart, 2002)

Class	Index	Sensitivity
1	0 <= Index < 0.05	small to negligible
2	0.05 <= Index < 0.2	Medium
3	0.2 <= Index < 1	High
4	Index >= 1	Very high

Based on this classification, sensitive parameters with Index value of medium to very high were selected for calibration. The higher the value of Index, the higher will be the influence on the run off and sediment yield generation.

Following the sensitivity analysis, the SWAT Calibration and Uncertainty Procedures (SWAT-CUP) version 5.1.6 was applied to calibrate, validate, and assess model uncertainty (Abbaspour et al. 2007). The calibration and validation was performed using the SUFI-2 (sequential uncertainty fitting version 2) algorithm, which is a semi-automated inverse modeling procedure for a combined calibration-uncertainty analysis (Abbaspour et al. 2004; 2007).

3.7.2.6 Model Calibration

Calibration is the process whereby model parameter are adjusted to make the model output match with observed data.

There are five calibration approaches widely used by the scientific community. These are the Sequential uncertainty Fitting (SUFI2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), Markov Chain Monte Carlo (MCMC) and Particle Swarm Optimization (Pso). Sequential uncertainty Fitting (SUFI2) is the most widely used in Tana Sub Basin approach. In this study Sequential uncertainty Fitting (SUFI2) was employed to get the best model parameters.

The final model parameters values that were Sequential uncertainty Fitting (SUFI2) calibrated and reached to acceptable value as per the R^2 and NSE were used as initial values for the auto-calibration procedure. The maximum and minimum limits of parameter value were used to keep the output values within a reasonable range.

After calibration, checking the R^2, NSE and RSR values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 and $0.6 \leq$ RSR $\leq 0.7\%$, (Moriasi et al.2007).

The stream flow and sediment calibration was on monthly average time steps. The procedure for calibrating the model for flow and sediment yields is shown in Figure 3.18.

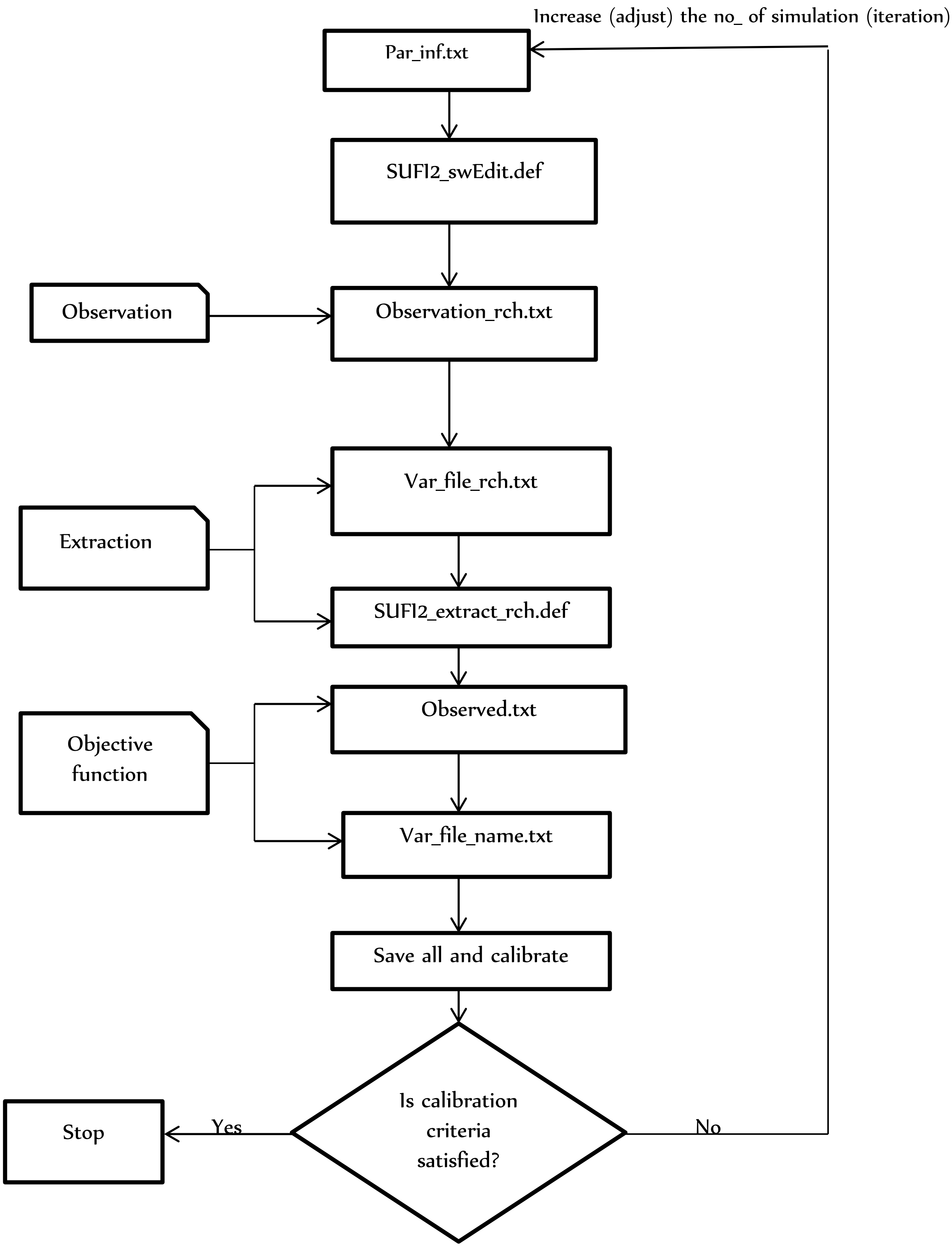


Figure: 3.18. Calibration procedures for flow and sediment yields in the SWAT - CUP (SUFI2)

3.7.2.7 Model Validation

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation period stream flows confirm that the model performs satisfactorily. In this study, data for a period of four years (2011-2014) was used at Gumara watershed to validate and evaluate the model accuracy. The statistical criteria used during the calibration procedure were also followed for model validation.

The statistical criteria (the R^2, NSE and RSR) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits. $R^2 > 0.6$, NSE > 0.5 and $0.6 \leq RSR \leq 0.7$ (Moriasi et al.2007).

Based on the available model input data parameters the time periods of modeling are:

- Flow Calibration period (2001- 2010)
- Flow Validation period (2011- 2014)
- Sediment calibration period (2001- 2010)
- Sediment validation period (2011- 2014)

The first three year of each period used (2001, 2010) and (2001, 2010) is used as a model warm up period and is not fused for model evaluation

3.7.2.8 Model Evaluation

The performance of SWAT-CUP (SUFI2) was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE) were used as measure of the goodness of fit to evaluate model prediction.

The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (NSE) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, NSE is 1. If the NSE is between 0 and 1, it indicates deviations between measured and predicted values. If NSE is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). The R^2 and NSE values are calculated as follows in equations 3.5 and 3.6 respectively.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_m - \bar{Q_m})(Q_s - \bar{Q_s}\right]^2}{\sum_i (Q_m - \bar{Q_m})^2 \sum_i (Q_m - \bar{Q_s})^2} \quad \text{...} \quad (3.6)$$

$$NSE = 1 - \frac{\sum_i^n (Q_s - \bar{Q_s})^2}{\sum_i^n (Q_m - \bar{Q_m})^2} \quad \text{...} \quad (3.7)$$

Percent bias (PBIAS): PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999) and calculated as follows in equation 3.8.

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Q_m - Q_s)^2}{\sum_{i=1}^{n}(Q_m)} * 100\right] \quad \text{...} \quad (3.8)$$

Root mean Square Error Standard Deviation Ratio (RSR): RSR is calculated as the ratio of the Root mean square error (RMSE) and standard deviation of measured data, as follows in equation 3.9.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sqrt{\sum_{i=1}^{n}(Q_m - Q_s)^2}}{\sqrt{\sum_{i=1}^{n}(Q_m - Q_m^-)^2}}\right] \quad \text{.....................................} \quad (3.9)$$

Where: R^2 is the Coefficient of determination

NSE is the Nash Sutcliffe Efficiency

Q_m is the measured discharge,

Qs, is the simulated discharge,

$\bar{Q_m}$ is the average measured discharge,

$\bar{Q_s}$ is the average simulated discharge,

n is the number of observations during the simulation period, PBIAS is mean relative bias,

RSR is Root mean Square Error Standard Deviation Ratio,

RMSE is Root mean square error,

$STDEV_{obs}$ is Standard deviation of measured data

Uncertainty measure: P – Factor and r - Factor

The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). Another measure quantifying the strength of a calibration/uncertainty analysis is the r-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data.

Theoretically, the value for p-factor ranges between 0 and 100%, while that of r-factor ranges between 0 and infinity. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to measured data.

A larger p-factor can be achieved at the expense of a larger r- factor. Hence, often a balance must be reached between the two. When acceptable values of r-factor and p-factor are reached, then the parameter uncertainties are the desired parameter ranges (SWAT - CUP (SUFI 2) 2012 user manual).

Table 3.9: General performance ratings for recommended statistics for a monthly time step (Moriasi et al.2007)

Performance			PBIAS (%)	
Rating	RSR	NSE	Stream flow	Sediment
Very good	0.00≤ RSR ≤0.50	0.75 ≤ NSE ≤ 1.00	PBIAS < ±10	PBIAS<±15
Good	0.50≤RSR≤0.60	0.65 ≤ NSE ≤ 0.75	±10 ≤ PBIAS ≤ ±15	±15≤PBIAS≤±30
Satisfactory	0.60≤RSR≤0.70	0.50≤NSE≤0.65	±15≤PBIAS≤±25	±30≤PBIAS≤±55
Unsatisfactory	RSR > 0.70	NSE≤0.50	PBIAS ≥ ±25	PBIAS ≥ ±55

3.8 Use of SWAT Model for Watershed Intervention Impact Analysis

After the SWAT - CUP (SUFI2) model had been calibrated and validated successfully, it was then used to identify and prioritize erosion-hotspot sub-catchments for introducing appropriate management strategies.

Because of the spatial variability of erosion severity and the difficulty in implementing conservation measures to all areas, identification of sites that require prior intervention will be necessary. After potential areas of intervention were prioritized, some conservation scenarios were applied, and the resulting sediment yield was compared with the existing/baseline condition.

In addition, data were interpreted in relation to standards (soil loss severity classes, soil loss tolerance) for the study catchment condition. GIS maps in ArcGIS 9.3 were also developed to display the magnitude and spatial variability of model outputs for the sub-basins in the study area.

Table 3.10: Classification of soil erosion based on soil loss rate

Class	Sediment yield (tons/ha/year	Category
1	0 - 20	Low
2	20 - 70	Moderate
3	70 - 150	Severe
4	$\geq$ 150	extreme severe

Source (Betrie et al. 2011)

Different scenarios were developed based on the current (baseline) condition of the study catchment. When developing the scenarios, the severity of the erosion rate/sediment yield losses (hotspot areas), and the most strongly influencing (sensitive) factors and their relevance were considered. Scenario simulation and analysis can be used to select the most effective strategies for reducing soil degradation. The details of the scenarios (management strategies) developed in this study are described below.

3.8.1 Scenario Development and Implementations

Scenario 1: Baseline scenario (existing condition)

This scenario was a simulation of current sediment yield of (existing) Gumara watershed including existing condition of soil erosion and management practices. This scenario is essentially the calibrated SWAT model and accounted for the BMPs will be in use in the watershed. The baseline scenario was used as a benchmark against which the results of the other scenarios were rated.

Scenario 2: LUC-redesign targeting 'steep slope' and sediment potential sub basins

(FAO, 1986) classifies land slopes of a watershed in to six classes and recommends corresponding ways of usage and management of the land where land area of 30 % is essential to be covered by forest. Accordingly Gumara watershed (whose 7.6% of the total watershed is greater than 30 % or steep slope) as can be seen in table 3.11, is assumed to be covered by afforestation/plantation forest.

For this scenario, any land use on steep slopes (greater than 30%) part of the watershed was changed in to plantation forest/ afforestation.

In the redesign of LUC of steep slopes of Gumara watershed, the role of GIS software was vital. It was used to prepare slope map of the watershed. Land use and slope shape files were overlaid and by intersecting, that was possible to know focus slope and the corresponding land uses. For this scenario, 97.25 km^2 areas are enclosed.

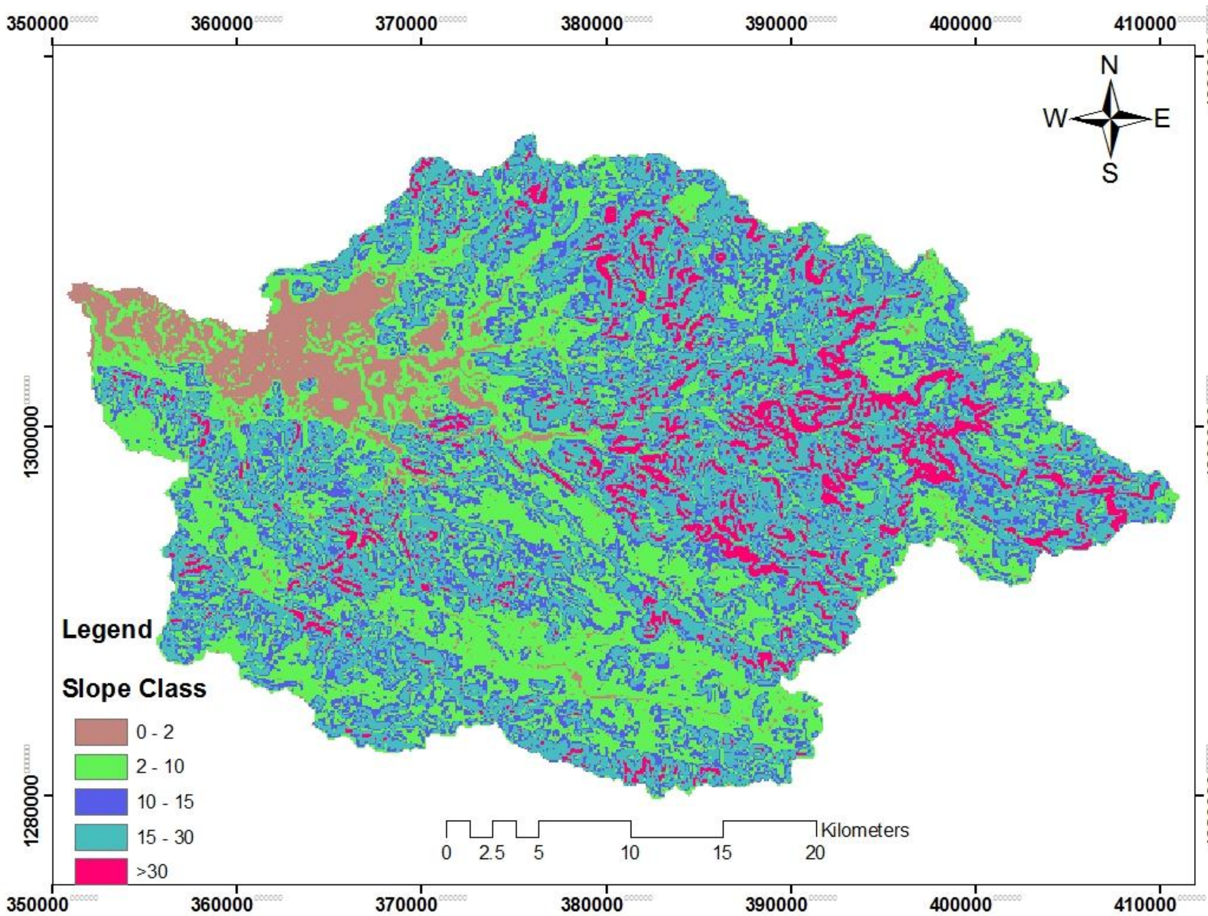


Figure 3.19: Slope map (%) of Gumara watershed

Table 3.11: Attributes of the slope map

Slope (%)	Description	Area (km^2)	Area Coverage (%)
0 – 2	Flat	86.52	6.79
2 – 10	Sloping	432.47	33.95
10 – 15	Moderately Steep	253.24	19.88
15 – 30	Steep	405.18	31.81
>30	Very Steep	96.51	7.58

Scenario 2: Parallel terraces/conservation measures

In a Watershed vulnerable to erosion, there is a need for conservation measures such as terraces that reduce further soil degradation, reduce the surface runoff by encouraging more infiltration, reduce the slope, reduce slope length and thus reduce the peak runoff rate as well as reducing the erosive power of runoff. To represent this conservation practice, Slope length (SLSUBBSN), USLE support practice factor (USLE_P), and SCS curve Number (CN) were adjusted (Arabi et al., 2008). Terraces divide the slope length into smaller lengths reducing the sheet and rill erosion. In SWAT, slope length is represented by the parameter SLSUBBSN. SLSUBBSN parameter was adjusted using the horizontal interval method for terrace design (Arabi et al., 2008). The reduced soil loss was factored in by reducing the USLE practice factor, USLE_P in the Modified Universal soil loss equation. USLE_P values for terracing type 1 (graded channels sod outlets) in Appendix Table 14 and 15 were used depending on the average slope of the HRU. Implementation of terraces would affect all these processes together and thus all the parameters were adjusted simultaneously for a single simulation run.

Table 3.12: Summary of the scenario development

Scenario ID	Mitigation Measures	Conceptual Model Description and mechanism	SWAT Model Representation
1	Conversion of land use on land to Afforestation (Land use Redesign)	change in land use reducing agricultural land scape	replace current land management file with Afforestation
2	Parallel terracing	Reduce rill- sheet erosion Reduce over land flow Reduce slope gradient Reduce slope length	Decrease USLE_P Decrease CN Decrease slope (s) Decrease SLSBUSN Agricultural HRUs

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Hydrological Model performance assessment

The flow simulation was performed for Gumara catchment at near Bahir Dar hydrometric station. The result of sensitive parameters, calibrated values and the validation result on this catchment were discussed below.

4.1.1 Flow Sensitivity Analysis

Flow sensitivity analysis was carried out for a period of ten years, which includes both the calibration period (from January 1, 2004 to December 31, 2010) and three year of warm-up period (from January 1, 2001 to December 31, 2003). The first six parameters showed a relatively high sensitivity from the flow parameters and the Initial SCS Curve number (Cn2) was the most sensitive of all (Table 4-1). Threshold depth of water in the shallow aquifer required for return flow to occur (Gwqmn) were Sensitive parameters that mainly influence base flow. The flow was also sensitive to soil properties of the watershed like soil evaporation compensation factor (Esco), base flow alpha factor (Alpha_BF), available water capacity of the soil layer (Sol _ Awc) and depth from soil surface to bottom of the layer (Sol _ Z) of soil depth were sensitive parameters that significantly affect surface runoff.

Table 4-1: Result of sensitive analysis of flow parameters in Gumara watershed using SUFI-2.

Parameter	Parameter Description	Index Value	Category	Rank
R_Cn2.mgt	Initial SCS CN2 value	0.605	High	1
V_Gwqmn.gw	Threshold water depth in the shallow aquifer for flow (mm)	0.448	High	2
V_Esco.hru	Soil evaporation compensation factor	0.445	High	3
V_Alpha_BF.gw	Base flow factor (days)	0.244	High	4
R_Sol_Awc(..)sol	Available water capacity (mm water/mm soil)	0.218	High	5
R_Sol_Z (...).sol	Soil depth (mm)	0.144	Medium	6

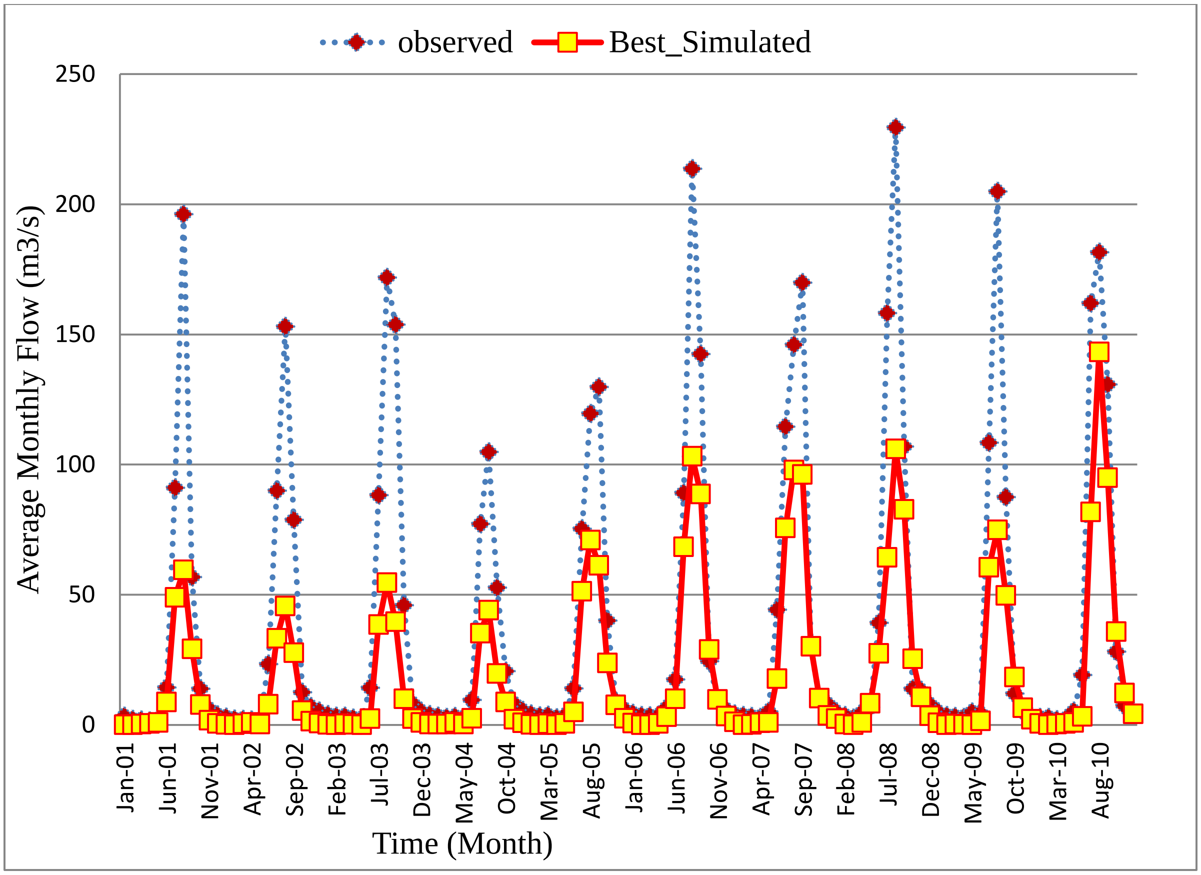


Figure 4.1 Sensitivity analysis results of average monthly Observed and simulated flow hydrograph of Gumara Catchment (2001- 2010) (SUFI2).

4.1.2 Flow Calibration

The calibration processes considered 6 parameters and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The result shows the performance indicator was with the acceptable limits, i.e. $R^2 > 0.6$, NSE > 0.5 (Santhi et al, 2001). But, some the model flow parameters were required adjustment and this adjustment was based on the sensitivity analysis result of flow parameters (Table 4.1).

Flow calibration for the watershed was conducted for the total of ten years (from January 1, 2001 to December 31, 2010) which includes three year, 2001 - 2003, for model initialization (warm up). Therefore, for the model performance in calibration was considered from 2004 to 2010.

Thus, the parameters (Table 4-2) were adjusted further by varied iteratively in their allowable range until satisfactory agreement between measured and simulated stream flow was obtained.

The graphical and statistical approaches were used to evaluate the SWAT – CUP (SUFI2) model performance a number of times, until p – Factor, r – Factor, R^2, NSE, PBIAS, and RSR values reached to 0.08, 0.00, 0.90, 0.84, 29.3 and 0.41 respectively (Figure 4.2). The comparison between the observed and simulated discharge values for Seven years of simulations indicated that there is a Very good agreement between observed and simulated flows.

The final calibrated values were shown in Table 4.2, that the base flow Alpha factor (ALPHA_BF) which is a direct index of groundwater flow response to changes in recharge was adjusted to 0.25. Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) was adjusted to 1250 and soil evaporation compensation factor (ESCO) was increased from the default value and adjusted to 0.85. SCS curve number (CN2) value was adjusted by subtracting -17.5% from the default value, Depth from soil surface to bottom of layer (SOL_Z) and available water capacity of the soil layer (SOL_AWC) were adjusted by subtracting -7.5% and default value -17.5% from the database value that append in the soil properties of the watershed respectively.

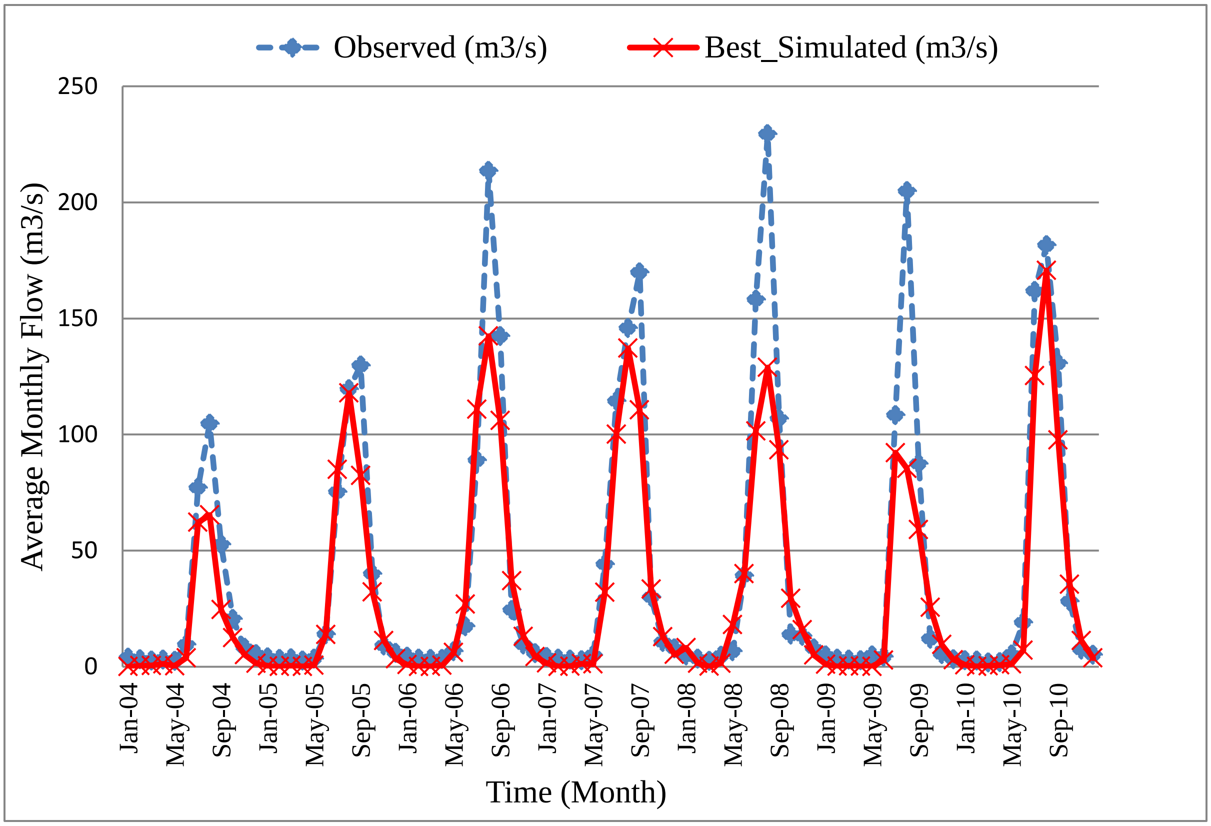


Figure 4.2: Calibration results of average monthly Observed and simulated flow hydrograph of Gumara Catchment (2004- 2010) (SUFI2).

The hydrograph of the calibration period (2004 – 2010) of the observed and simulated flow in monthly mean flow shows (Figure 4.2), the model underestimate some of monthly peak flows of the years; such as August of 2004 and 2006, September of 2007 and August of 2008 and 2009 and also slightly underestimate the peak flows, like September of 2005 and August 2010 of the years monthly mean flows.

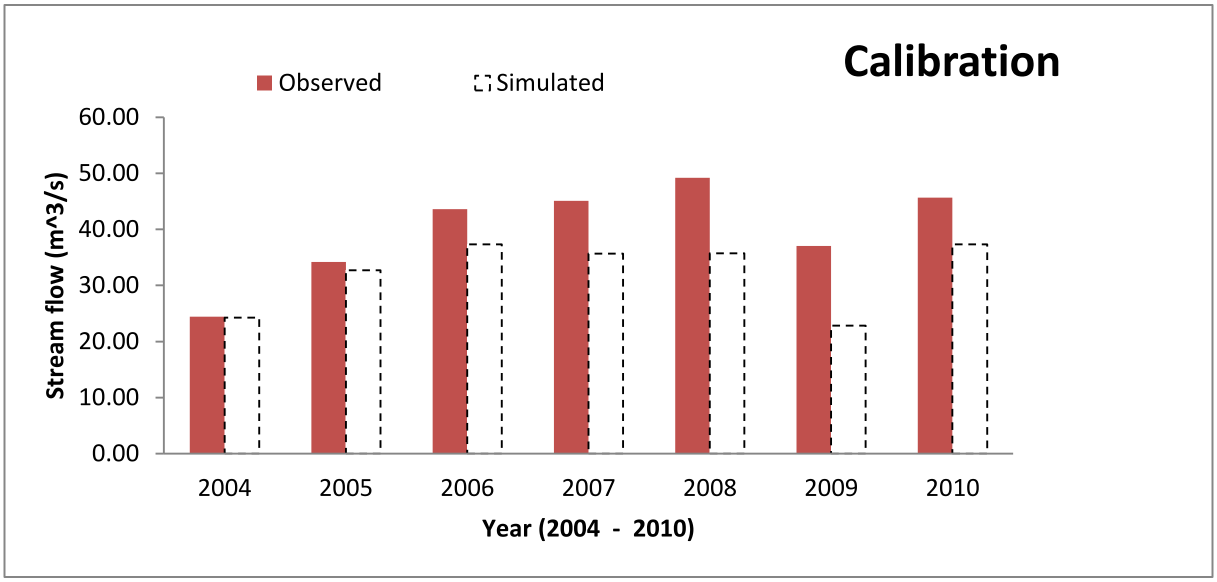


Figure 4.3: Model observed and simulated stream flow during annual Calibration period for Gumara Catchment

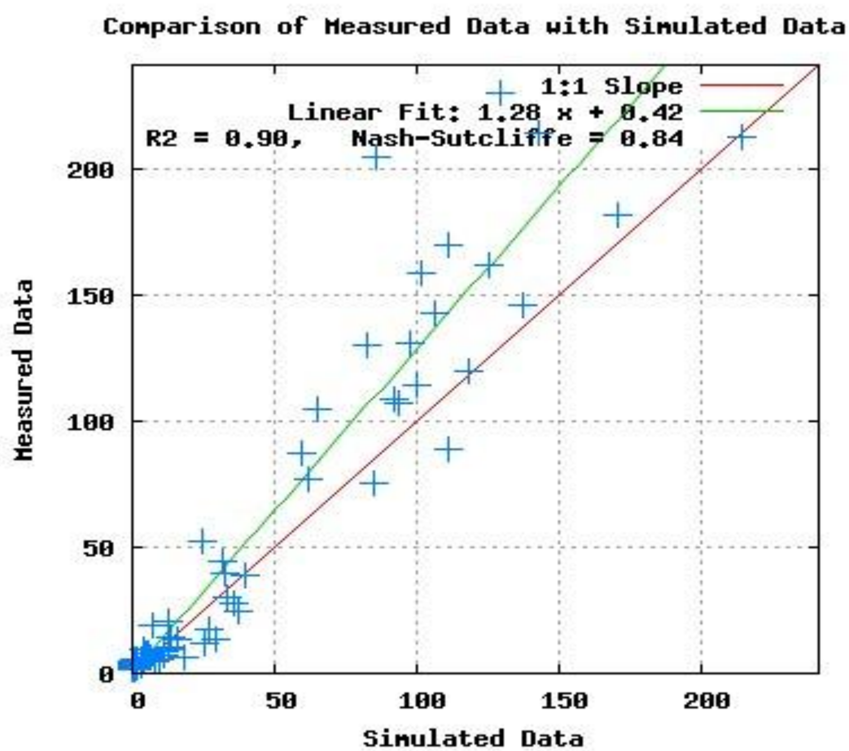


Figure: 4.4: Regression analysis line and 1: 1 fit line of Simulated versus observed monthly flow during calibration period (2004–2010)

Table 4.2: Flow sensitive parameters and fitted values after calibration of Gumara watershed using SUFI-2

No_	Sensitive parameters	Lower bound	Upper bound	Fitted value
1	V_Alpha_BF.gw*	0	1	0.25
2	V_Gwqmn.gw**	0	5000	1250
3	V_Esco.hru	0	1	0.85
4	R_Cn2.mgt***	-25	25	-17.5
5	R_Sol_Z (..).sol	-25	25	-7.5
6	R_Sol_Awc (..).sol	-25	25	-17.5

* The extension (e.g., gw) refers to the SWAT input file where the parameter occurs.

** The qualifier (V_) refers to the substitution (replace) of a parameter by a value from the given range.

*** The qualifier (R_) refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range.

Table: 4.3 Model performance evaluation coefficients for calibration of monthly flow (SUFI2).

	Mean Annual Stream Flow (m3/sec)					
Monthly time step Simulation	Observed	Simulated	R^2	NSE	RSR	PBIAS
Calibration (2004 - 2010)	39.9	30.8	0.90	0.84	0.41	29.3

4.1.3 Flow Validation

The model performance in validation was carried out from 2011 to 2014, without further adjustment of the parameters of flows. Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the coefficient of Determination (R^2) of 0.84, Nash - Sutcliffe simulation efficiency (ENS) of 0.71,Mean Relative bias (PBIAS) of 38.9, p - Factor of 0.08, r - Factor, 0.00 and a Root mean Square error standard deviation ratio (RSR) of the monthly flow was found to be 0.54 (Table 4.4).

The goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the P-factor and r-factor measures. The value for p - factor ranges between 0 and 100%, while that of r – factor ranges between 0 and infinity. A p – factor of 0.08 and r- factor of zero is a simulation that does not exactly corresponds to measured data.

Table: 4.4. Model performance evaluation coefficients for calibration and validation of monthly flow (SUFI2)

Parameters	Calibrated (2004 - 2010	Validation (2011 - 2014
p - Factor	0.08	0.08
r - Factor	0.00	0.00
R^2	0.90	0.84
NSE	0.84	0.71
RSR	0.41	0.54
PBIAS	29.3	38.9

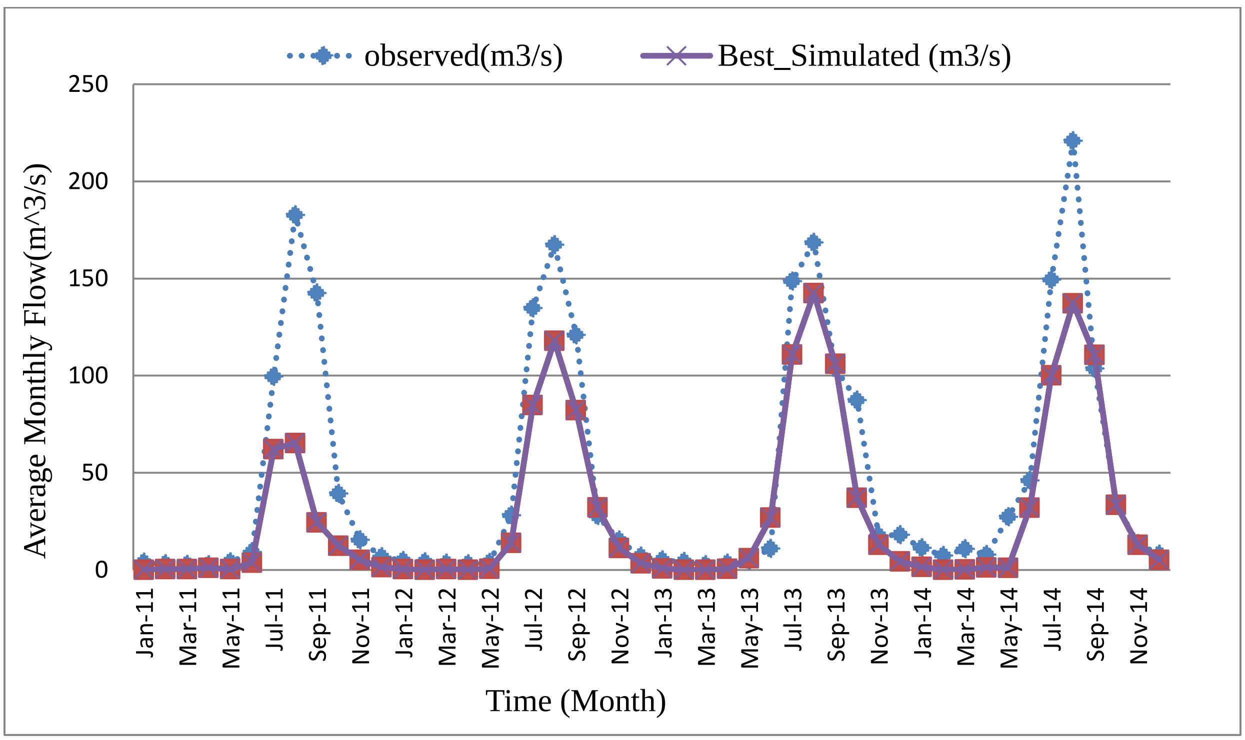


Figure 4.5: Monthly flow validation plot (SUFI2).

The hydrograph of the validation period (2011 – 2014) of the observed and simulated flow in monthly estimation, the model slightly under estimates some of the peak flows of the months, like in the year of August, 2013 and some of the months peak flows were also under estimated by the model in the year of August 2011, August of 2012 and August of 2014 in period of validation period, respectively. (Figure 4.5) This may be resulted from the quality of weather or flow data used as an input to the model. Some of the stations have many missing weather data which were left to be estimated and filled by the model's weather generator. Using estimated data may influence the simulation output. Additionally , mistake in measurement of flow and weather data may be another reason for the slight variation between measured and simulated flows at peak and under discharges.

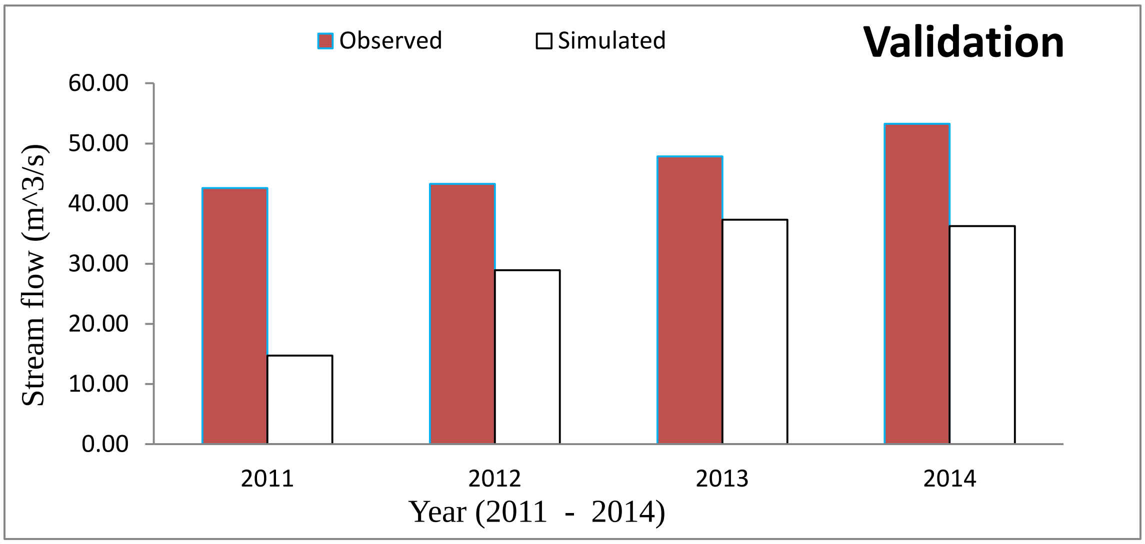


Figure 4.6: Model observed and simulated stream flow during annual validation period for Gumara Catchment.

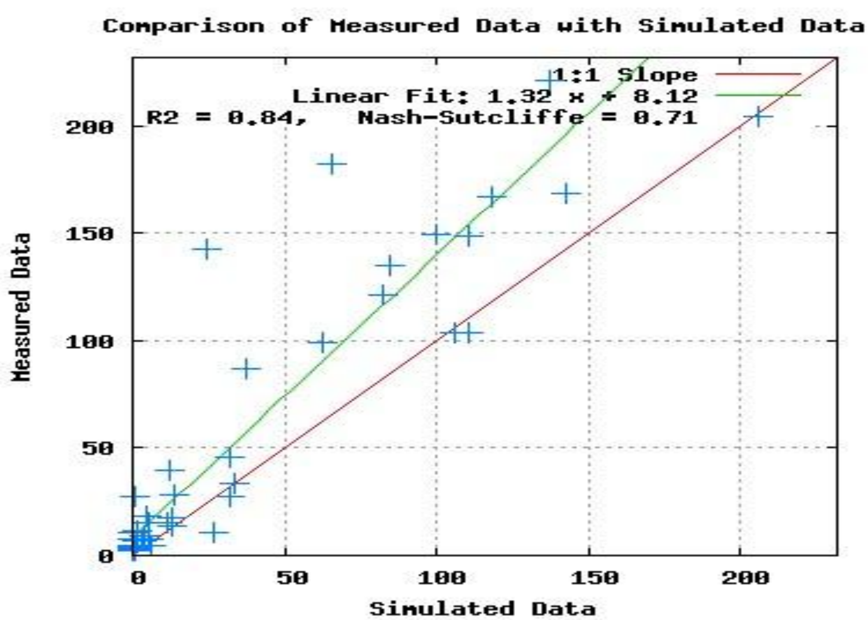


Figure 4.7: Regression analysis line and 1:1 fit line of Simulated versus observed monthly flow during validation period (2011–2014)

4.2 Sediment Yield Simulation

Sediment yield is the amount of sediment transported out of a watershed or sub watershed. This value is used for model calibration and validation because it can be compared against available data sets.

4.2.1 Sediment Yield Sensitivity Analysis

Sensitivity analysis was carried out for sediment to identify parameters that affect sediment yield. SWAT - CUP (SUFI2) model have been used for sensitivity analysis at the Gumara out let sub basin for sediment calibration with the output of six parameters were reported as sensitive in different degree of sensitivity for sediment. These six parameters have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to high of sensitivity class as shown in table 4.5.

Table: 4.5. Result of sensitive Parameters for Sediment yield Gumara watershed using SUFI-2

Parameter	Parameter Description	Index Value	Category	Rank
V_USLE_P.mgt	USLE support Practice factor	62.52	V. High	1
V_CH_COV1.rte	Channel cover factor	0.9	High	2
R_USLE_C(..).plant.dat	USLE cover factor	0.79	High	3
V_SPCON.bsn	Linear factor for channel sediment routing	0.77	High	4
V_SPEXP.bsn	Exponential factor for channel sediment routing	0.39	High	5
V_CH_ERODMO.rte	Channel erodibility factor	0.32	High	6

4.2.2 Sediment Yield Calibration

After sensitivity analysis, the next step was calibrating sediment yield of the watershed. For the years (2001 - 2010) three year, (2001 - 2003) was used for model warm up. So that model was calibrated from 2004 to 2010. The calibration of sediment yield of the Gumara watershed was done based on sediment sensitivity analysis that has identified sensitive parameters and has effect on the simulated result when changed for sediment yield of the watershed (Table 4.6), and by varying iteratively within the allowable ranges of the parameters.

Table: 4.6. Sediment sensitive parameters and fitted values after calibration of Gumara watershed using SUFI-2

No_	Sensitive parameters	Lower bound	Upper bound	Fitted value
1	V_CH_COV1.rte	0	1	0.105
2	V_CH_ERODMO.rte	0	1	0.455
3	V_SPCON.bsn*	0.0001	0.01	0.0038
4	V_SPEXP.bsn**	1	2	1.845
5	R_USLE_C(...).plant.dat***	0	1	0.585
6	V_USLE_P.mgt	0	1	0.995

* The extension (e.g., .bsn) refers to the SWAT input file where the parameter occurs.
** The qualifier (V_) refers to the substitution (replace) of a parameter by a value from the given range.
*** The qualifier (R_) refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range.

After adjustment of all the above parameters, the model is run again with the calibrated parameters. The model was calibrated for sediment by comparing monthly model simulated sediment load against monthly measured sediment load from Gumara near Bahir dar station for the period 2004 to 2010.

The SWAT - CUP (SUFI2) model was found to simulate well on monthly basis of sediment load. Coefficient of determination (R^2) value and Nash - Sutcliffe model efficiency (NSE) statistic computed between the simulated and observed monthly sediment loads for the calibration periods are 0.86 and 0.71 respectively (Table 4.7). Calibration results show that model performance is good with simulation of monthly sediment load.

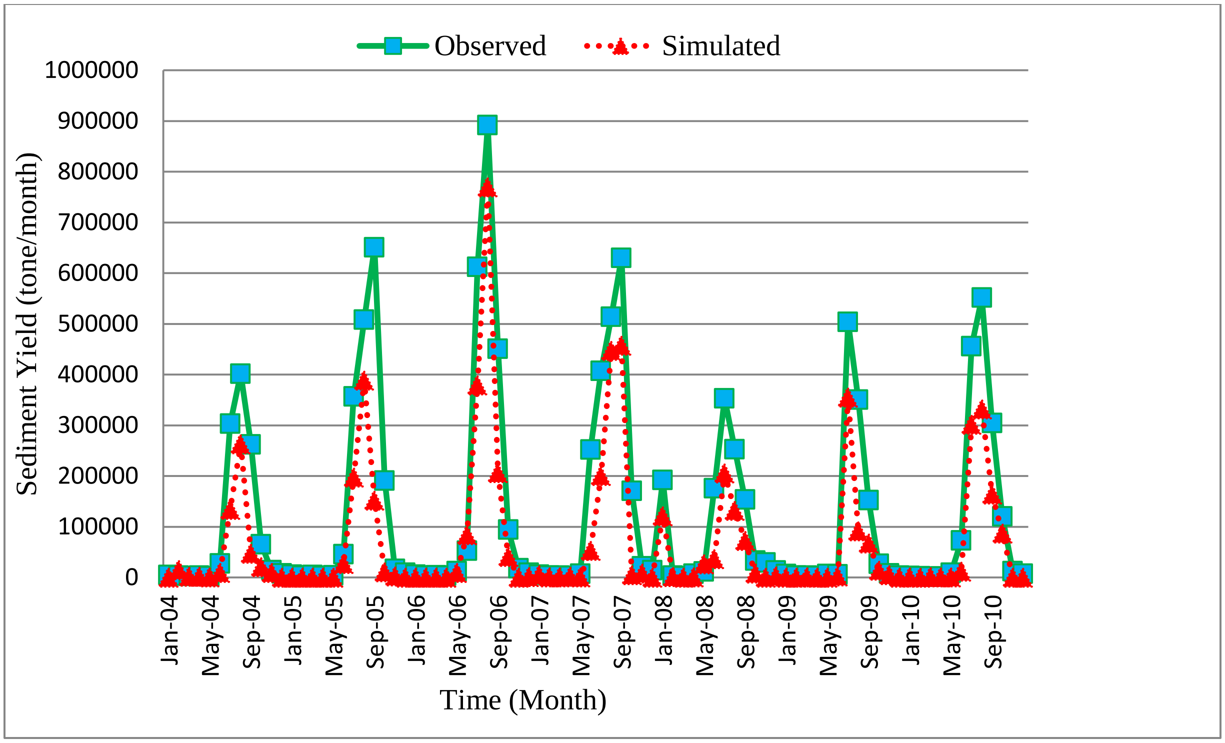


Figure 4.8: Observed and simulated monthly sediment yield in the calibration period (2004-2010) using by (SUFI2).

The hydrograph of the observed and simulated Sediment load in monthly basis in the calibration period (2004 – 2010) shows the model underestimated of monthly sediment yields of the watershed such as August of 2004, September of 2005 and 2007, July of 2008 and 2009, and August of 2010 respectively; and slightly under estimate the sediment yield of August of 2006 and January of 2008 (Figure 4.8).

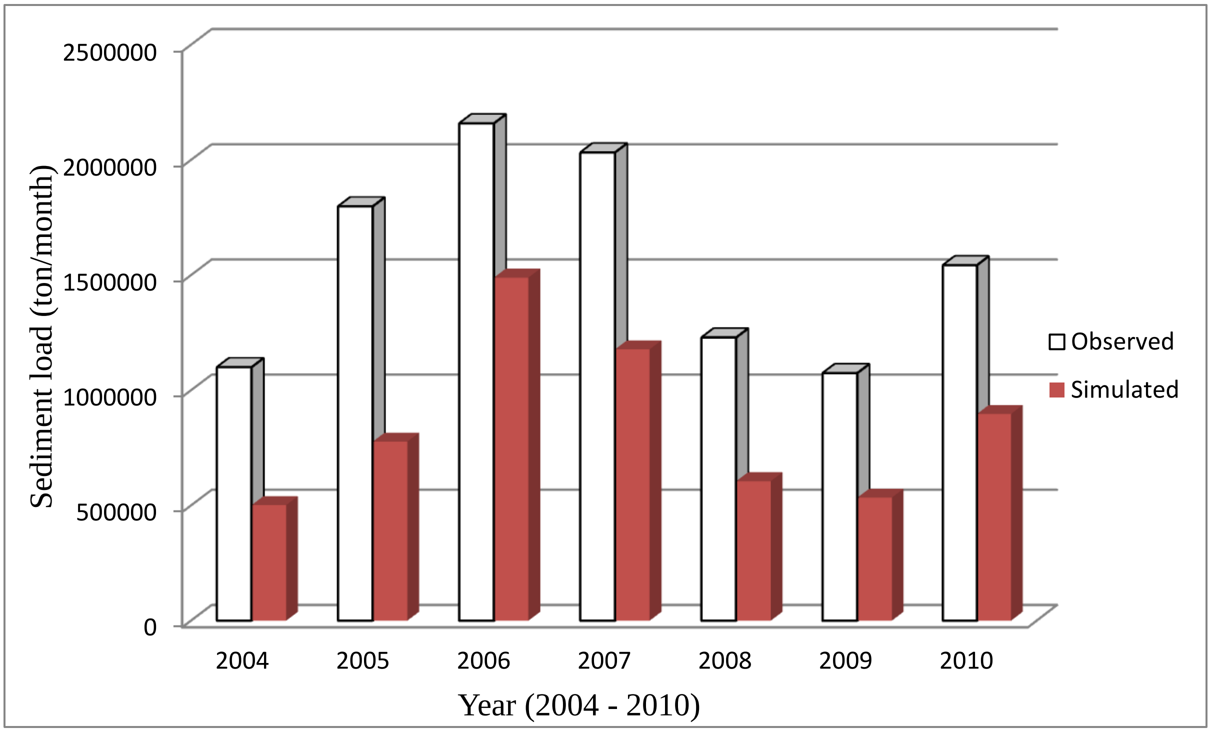


Figure 4.9: Model observed and simulated monthly sediment yield during annual Calibration period for Gumara Catchment

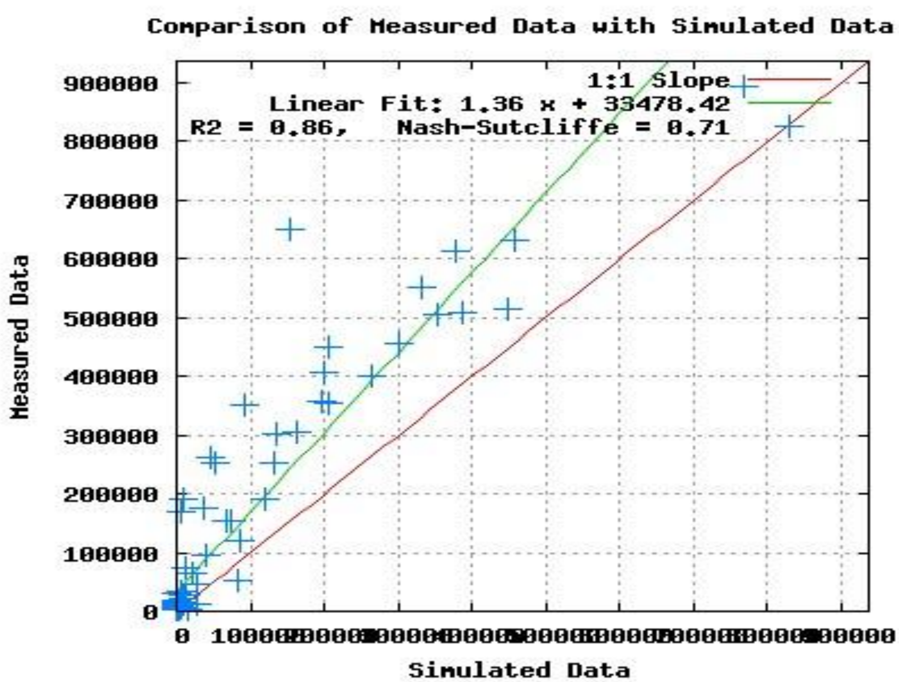


Figure: 4.10: Regression analysis line and 1: 1 fit line of Simulated versus observed sediment during calibration period (2004–2010)

Table: 4.7. Model performance evaluation coefficients for calibration of monthly Sediment yield (SUFI2).

Parameters	p – Factor	r – Factor	R^2	NSE	PBIAS	RSR
Calibration (2004 - 2010)	0.06	0.32	0.86	0.71	46.4	0.53

4.2.3 Sediment yield Validation

After calibration the SWAT - CUP (SUFI2) model was validated to sediment for the period 2011 to 2014 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

Table: 4.8. Model performance evaluation coefficients for validation of monthly Sediment yield (SUFI2).

Parameters	Calibrated (2004 - 2010	Validation (2011 - 2014
p - Factor	0.06	0.08
r - Factor	0.32	0.30
R^2	0.86	0.85
NSE	0.71	0.65
RSR	0.53	0.59
PBIAS	46.4	52.9

The observed and simulated sediment yield in monthly time step of the validation period shows the model underestimate the sediment yields of highly flow time periods, and in low and medium flow periods the model simulation and the observed sediment yield were good fit (Figure 4 -11).

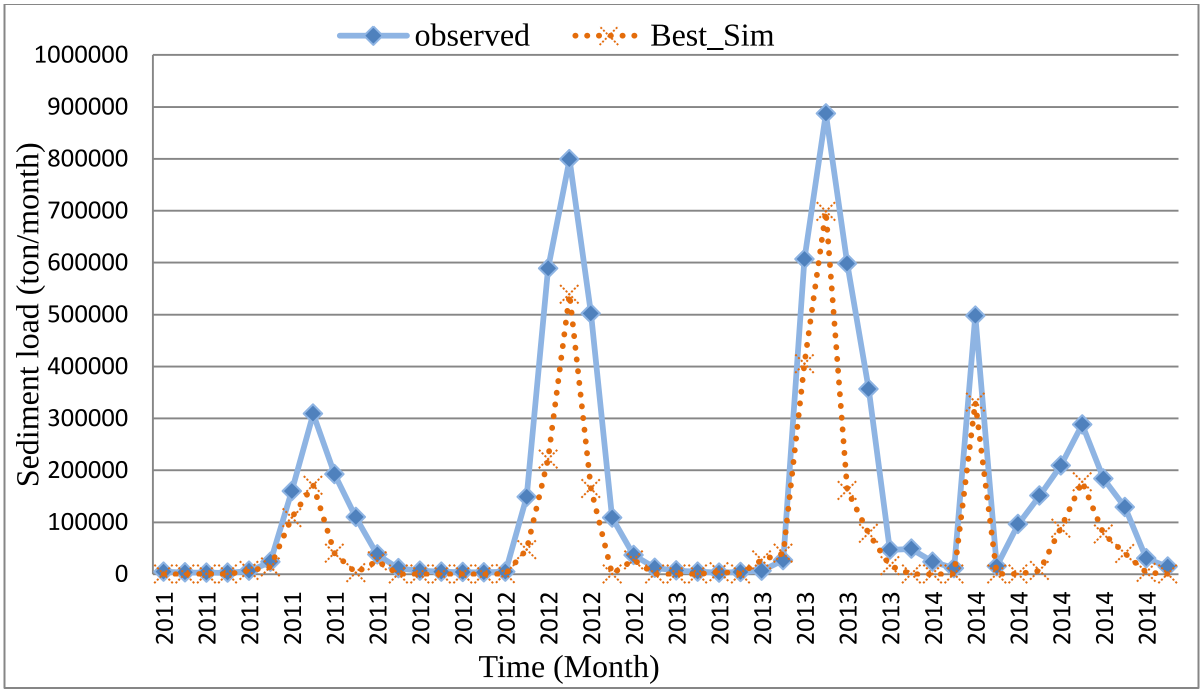


Figure 4.11: Observed and simulated monthly sediment yield in the validation period using by (SUFI2).

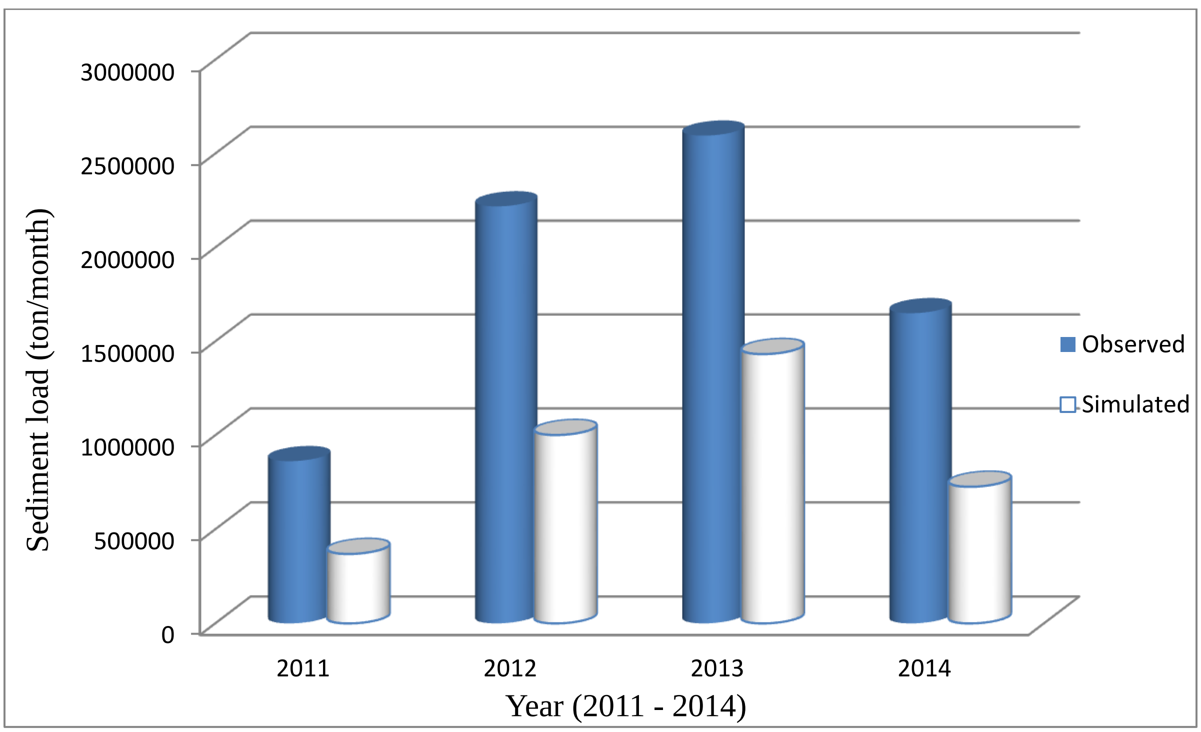


Figure 4.12: Model observed and simulated monthly sediment yield during annual validation period for Gumara Catchment.

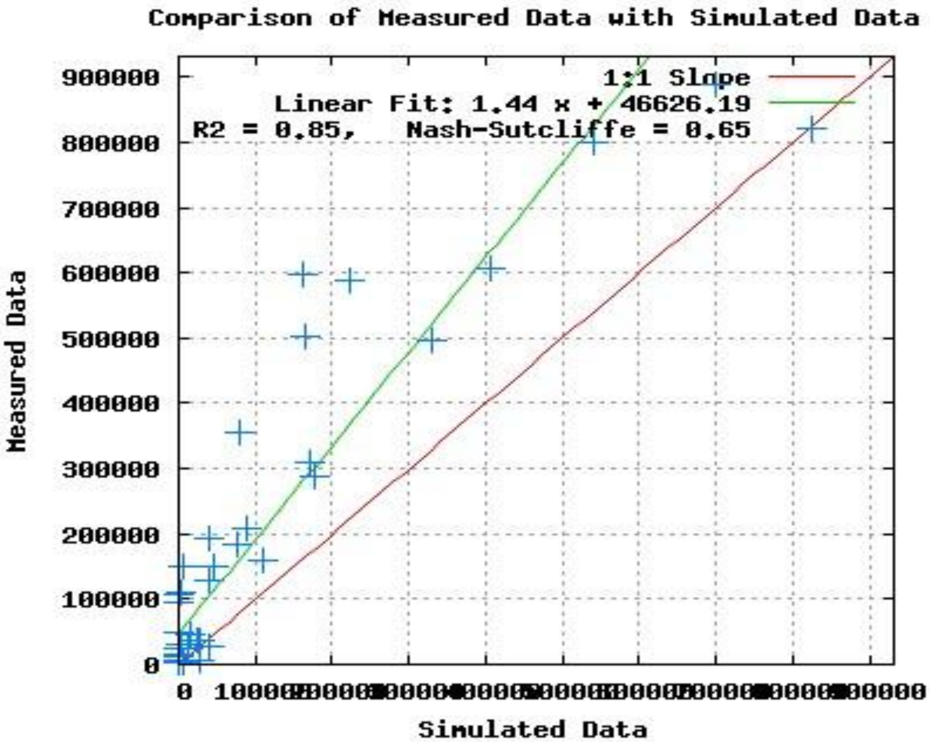


Figure 4.13: Regression analysis line and 1:1 fit line of Simulated versus observed Sediment during validation period (2011–2014).

4.3 Spatial Distribution of Sediment Yield in Gumara Watershed

The assessment of the spatial variability of soil erosion is useful for catchment management planning. The soil erosion prone areas in the Gumara Watershed are shown in Figure. 4.14.

The SWAT model simulation shows that the soil erosion extent varies from negligible erosion to over 150 t/ha. The soil erosion level in the basin classified into low (0–20 t/ha/yr.), moderate (20–70 t/ha/yr.), severe (70–150 t/ha/yr.) and extreme Severe (≥150 t/ha/yr.) categories. The low class represents the erosion extent less than the soil formation rates, which is 22 t/ha/yr.in the Ethiopian highlands (Hurni, 1983). The moderate class represents erosion level less than the average soil loss from cultivated land, which is 72 t/ha/yr.(Hurni, 1985). The extreme class represents one fold higher than the average soil loss and the severe class represents two folds higher than average soil loss. Extreme erosion was dominant in sub basins 3, and 5. Moderate erosion was dominant in sub basins 1, 2, and 4; and low erosion was dominant in sub basins 6, and 7. These results show that the erosion level variations within a sub basin and the basin that is very helpful to prioritize BMPs implementation area. As a result, there have been five principal sub basins (sub basins 1, 2, 3, 4, 5) producing high sediment to Gumara River which are situated in steep and high elevation area whose slope of the watershed below Figure 4.14.

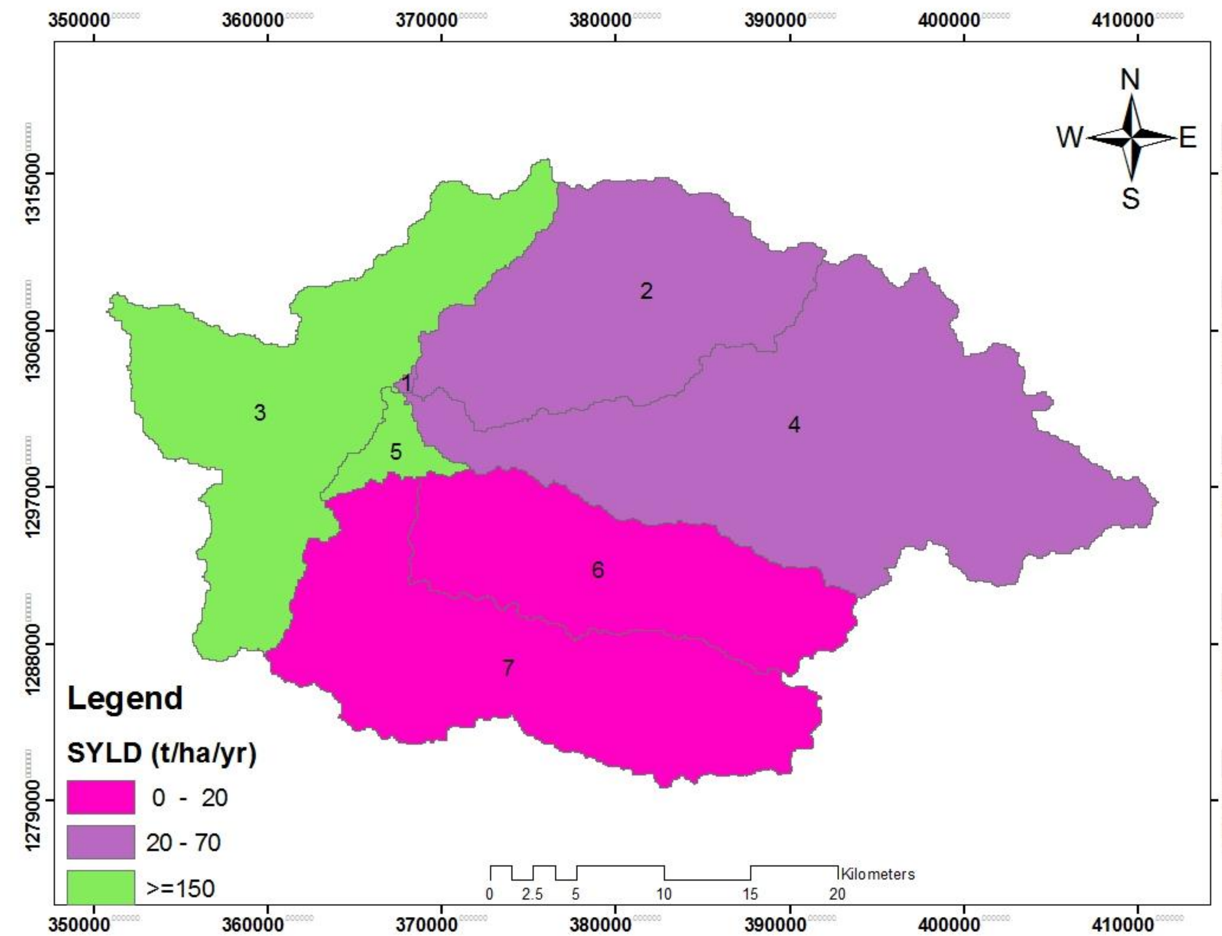


Figure 4.14: Spatial Distribution of SWAT simulated annual sediment yield by sub basin (t/ha/yr.), Number (1-7) are sub basin numbers.

Generally, most of the sediment source areas are located on high slope areas of cultivated fields (especially sub-basins 3 and 5, high sediment yield the reason is high slope) whereas lower slope positions show low amount of sediment lost despite their poor surface cover.

Table 4.9: prioritization of sub basins

Sub basins	Area (Km^2)	SYLD (t/ha/yr.)	Priority level
1	1.08	40.21	#3
2	204.62	30.64	#5
3	248.91	200.32	#1
4	387.26	40.08	#4
5	19.15	191.65	#2

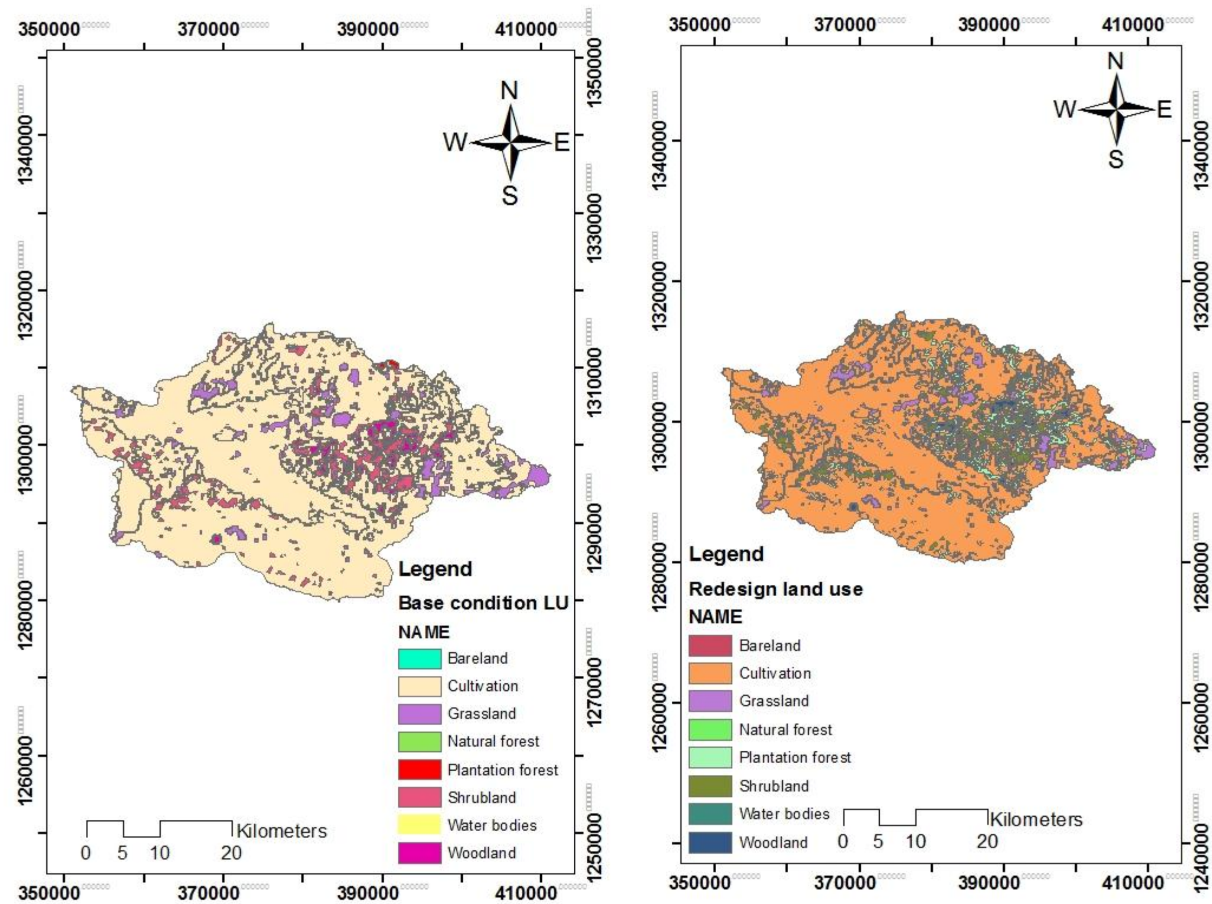
4.4 Use of SWAT Model for Watershed Intervention Impact Analysis

In this study, the SWAT - CUP (SUFI2) model calibrated for flow and sediment at the Gumara station was used to simulate the effect of management and measures on sediment yield in the Gumara watershed.

Two scenarios (other than the one that represents the baseline condition) were developed and simulated by SWAT model for evaluating the most suitable management/conservation measures within the watershed so as to reduce sediment.

Scenario 1: LUC-redesign targeting steep slope & hot-spot areas

The management implication of the direct relation between slope steepness and soil erosion is that conservation practices focused on steep slopes could reduce the rate of soil loss and its downstream delivery. For this scenario, any land use on steep slope areas except of urban and water bodies was changed in to afforestation by Intersecting the land use and slope shape file of the study area on GIS, as can be seen in table 4.10 and figure 4.15. As a result, where there were only 6 km^2 forests (both natural and plantation forest) for the base scenario, redesigning the land use resulted in 97.25 km^2 area of forest (which is about 7.8% of the Gumara watershed). And the prioritized sub basins are located in this steep part of the watershed. Therefore implementation of this scenario can be considered as implemented on these areas.



a). Base condition Land use b). Modified Land Use

Figure 4.15: The existing (Base Condition) and Modified Land use (Land use re design)

Table 4.10: Areas to be enclosed during simulation of scenario two

No_	Land Use	Base Scenario (Km^2)	Modified Land Use (Km^2)
1	Bare Land	8	4.7
2	Cultivation	986	980.29
3	Grass land	117	78
4	Natural forest	4	4
5	Plantation forest	2	93.25
6	Shrub land	103	65.76
7	Water bodies	5	5
8	Woodland	19	13.3

Finally, the model was run using this modified land use and calibrated parameters, and a sediment yield reduction of 32% was achieved as shown in the figure 4.16 below. The reason for decreasing area of above cultivation any land use on steep slopes (greater than 30%) part of the watershed does not use cultivation purpose (ploughing).

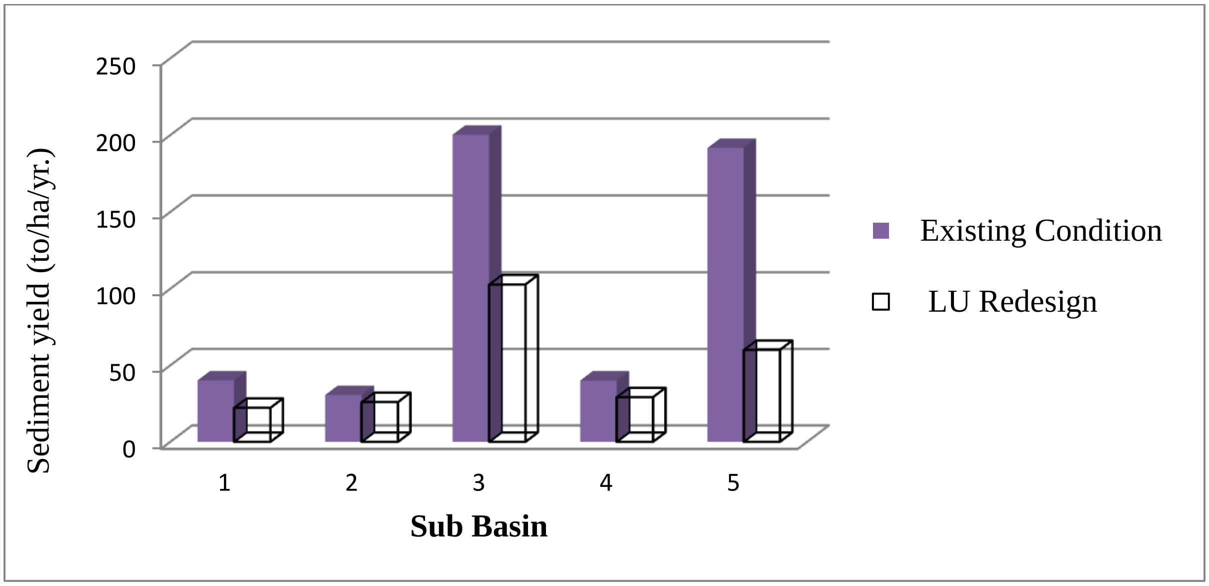


Figure 4.16: Scenario two result

Scenario 3: Parallel Terraces / Conservation measures

A terrace is an embankment within in a field designed to intercept runoff and prevent erosion. It is constructed across slope on a contour. Terracing in SWAT is simulated by adjusting both erosion and runoff parameters. The USLE Practice (TERR_P) factor, the slope length (TERR_SL) and curve number (TERR_CN) are adjusted to simulate the effects of terracing. Appropriate curve number, P factor and slope length values recommended with different authors were used for terraced field (Appendix Table 14 and 15). TERR_SL should be set to a maximum of the distance between terraces. This value varies between 100m where slope ranges from 0-2% and 18m when the slope is greater than 30% slope.

For this scenario, were implemented on 85 agricultural HRUs located in the five potential sub basins. These HRUs have a total area of 35.41km^2. USLE support practice 3 factor (USLE P), curve number (CN) and slope length of the hillside (SLSUBBSN) of 85 agricultural HRUs located in the five targeted potential sub basins are edited with respective slope variation as shown in the Appendix Table 14 and 15.

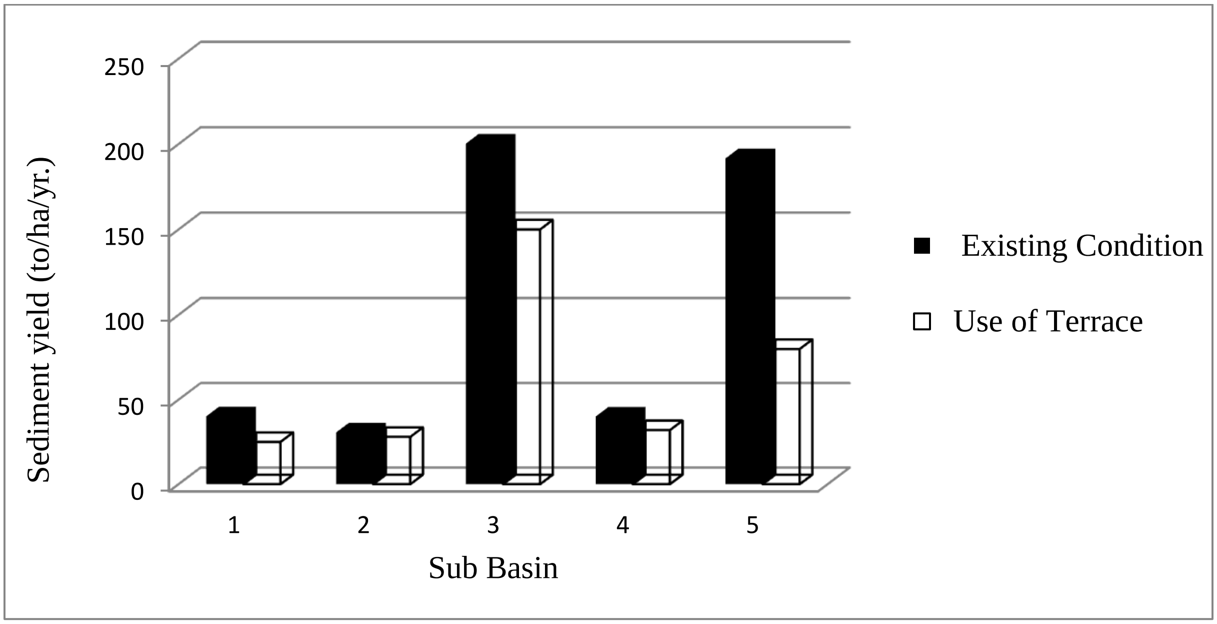


Figure 4.17: Scenario three result

Application of terrace for these potential agricultural HRUs located in potential sub basins helps to reduce SYLD out flowing from the watershed by 24% of the existing condition.

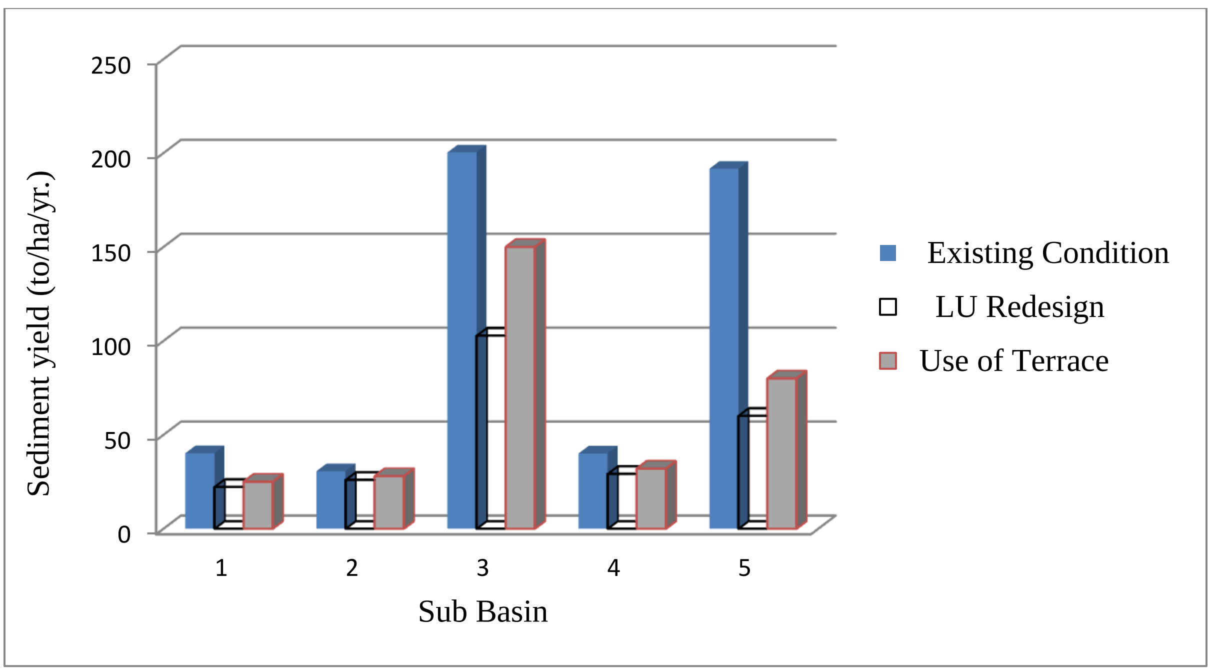


Figure 4.18: The existing and the other two scenarios result

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In the present study, SWAT 2009, a process based partially distributed hydrological model having an interface with Arc GIS software was used for to predict the amount of Sediment Yield from Gumara watershed. In addition to this, to assess and evaluate the spatial variability of sediment yield and identify vulnerable sub watersheds for erosion and sediment yield in the watershed.

- The result from sensitivity analysis of the SWAT – CUP (SUFI2) showed that the flow is most sensitive to the curve number. The other determinant parameters for flow in the watershed are ground water parameters (ALPHA_BF and GWQMN), HRU parameters (ESCO) and the soil properties of the watershed (SOL_Z and SOL_AWC). Thus, for further accuracy of the model a detailed study of the groundwater properties (the groundwater depth, the alpha factor etc) and the soil properties of the watershed are essential. Sediment flow sensitivity analysis result also showed that the sediment loss from the watershed is sensitive to both HRU properties and channel properties.
- The suitability and performance of the SWAT - CUP (SUFI2) was evaluated using calibration and validation statistics. A good agreement between measured and simulated monthly stream flow in the gauging station was demonstrated by correlation coefficient (R^2=0.90), Nash-Sutcliffe model efficiency (NSE=0.84) for calibration period and R^2=0.84, NSE= 0.71 for the validation period were observed. In the calibration period (2004-2010) and in the validation period (2011-2014) by SWAT - CUP (SUFI2) estimation, the statistical model evaluation criteria the result was in the acceptance limit.
- In simulating sediment yield in monthly basis in SWAT – CUP (SUFI2) resulted, R^2 = 0.86 and NSE = 0.71 for calibration period and R^2 = 0.85 and NSE= 0.65 for validation period. In both calibration and validation period by SWAT - CUP (SUFI2) estimation, the statistical model evaluation criteria the result was in the acceptance limit.

- ❖ SWAT performed well in simulating sediment yield on monthly basis at the watershed scale and thus can be used as a planning tool for watershed management. Following calibration and validation of SWAT - CUP (SUFI2) model, two scenario analyses other than the base condition were tested to reduce sediment yield from the watershed. The simulation results of the two scenario analysis (Parallel terrace and afforestation or land use redesign) indicated that implementing these mitigation measures can reduce sediment yield by 24% and 32%.respectively.
- ❖ Terraces are effective for controlling high soil loss. In the Soil and Water Assessment Tool (SWAT), terrace effects are simulated by adjusting the slope length and the USLE P-factor. A process-based algorithm was developed and incorporated into SWAT (version 2009) to simulate the environmental effects of normal and bench terraces at the Hydrological Response Unit level. Implementation of terrace on agricultural HRUs in sediment prone areas helped to reduce the sediment yield by 24% with respect to the existing scenario.

5.2 RECOMMENDATION

- ❖ The result of this study could help different stakeholders to plan and implement appropriate soil and water conservation strategies in the watershed. The calibrated model can be used for further analysis of the effect of climate and land use change as well as to investigate the effect of different management scenarios on stream - flows and sediment yields in the watershed.
- ❖ To minimize the sediment load of the Gumara River, more intensive soil and water conservation works are required. Such a focused effort could noticeably reduce the amount of sediment in the watershed.
- ❖ As a mitigation measure for prevention of severs erosion and conservation mechanism, it is recommended to cover the Steep and very steep area with plantation and control further degradation by erosion. Further study is required in different scenarios to decide a type of coverage and extent of application on different sub basins. And also the high sediment yielding areas should be verified by field measurements.
- ❖ The sediment yield of the Gumara watershed will continue in this manner it will dangerous to the Lake Tana life with respect to their sedimentation and stability of the

Lake. So the responsible bodies must take action in the watershed; like watershed management or any other sediment minimization technique even though it requires further study.

- Model prediction output depends on the quality of input data. The constraints in conducting this research work were lack of continuous measured suspended sediment data. Hence, responsible bodies should give due attention to minimize this problems for well managed water resource application.

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APPENDIX

Appendix – Table

Appendix Table 1: Annual Rainfall at the Surrounding Stations (mm)

Year	Debretabor	M/eyesus	Woreta	Bahir Dar
1994	1794.5	1294.8	1557.7	1498.3
1995	1272.6	932.1	1062.3	1201.1
1996	1480.1	1676.1	1525.9	1550.0
1997	1998.4	1454.7	953.5	1706.7
1998	1505.8	1309.2	1491.5	1512.7
1999	1617.5	1378.0	1570.0	1396.6
2000	1645.6	1412.7	1443.6	1622.1
2001	1470.9	1385.0	1130.9	1401.6
2002	1119.9	1224.1	1142.0	1334.8
2003	1289.3	1252.6	1263.5	1549.5
2004	1198.1	1019.6	1227.6	1399.9
2005	1486.9	1046.0	1403.9	1420.7
2006	1634.5	1304.7	1519.6	1673.6
2007	1554.0	1401.2	1238.6	1956.7
2008	1599.7	1318.2	1585.7	1905.0
2009	814.7	1240.8	1167.1	1087.5
2010	1461.0	1464.7	1473.6	1789.3
2011	1533.2	1297.9	1195.3	1696.2
2012	1489.4	1291.9	1240.5	1618.9
2013	1565.4	1388.9	1297.6	1543.6
2014	1633.8	1155.9	1254.2	1604.9

Appendix Table 2: Annual maximum temperature (^{0}c) of Surrounding Stations

year	Bahir dar	Debretabor	M/eyesus	Woreta
1994	27.32	22.45	25.72	27.12
1995	27.71	22.13	25.76	27.00
1996	27.25	21.49	25.36	27.31
1997	27.79	21.54	26.19	27.33
1998	28.11	22.05	26.52	28.53
1999	28.11	21.98	26.75	28.60
2000	27.84	21.82	26.89	28.01
2001	28.01	22.04	25.97	28.69
2002	28.79	22.84	26.78	29.02
2003	28.70	22.52	27.00	28.50
2004	28.32	22.43	27.12	27.99
2005	28.62	22.60	26.81	27.63
2006	28.47	21.83	26.17	27.87
2007	28.19	22.32	26.06	28.03
2008	28.11	19.84	25.97	27.78
2009	28.92	20.30	26.81	28.91
2010	28.22	21.46	25.81	27.52
2011	28.35	22.10	25.21	27.99
2012	28.75	23.46	26.27	27.88
2013	28.30	23.04	26.01	27.24
2014	28.30	22.80	26.02	24.58

Appendix Table 3: Annual minimum temperature (^{0}c) of Surrounding Stations

Year	Bahir dar	Debretabor	M/eyesus	Woreta
1994	12.86	9.66	8.40	12.26
1995	12.91	9.91	8.29	12.06
1996	12.30	9.62	7.81	12.36
1997	11.66	9.69	8.62	11.94
1998	11.12	9.94	8.60	10.44
1999	10.83	9.39	7.72	9.41
2000	11.80	9.31	7.88	11.01
2001	11.61	9.53	8.42	9.48
2002	11.72	9.36	8.48	12.85
2003	12.02	9.42	8.37	13.32
2004	11.55	9.38	8.21	12.60
2005	10.97	9.38	8.32	12.69
2006	11.34	9.23	8.42	13.07
2007	11.47	9.44	8.72	13.28
2008	11.47	9.52	8.16	13.38
2009	11.74	9.87	8.58	13.79
2010	11.83	8.26	8.79	12.66
2011	11.21	8.77	8.43	14.14
2012	11.07	9.33	8.30	17.33
2013	11.54	9.35	8.49	16.91
2014	11.39	9.57	8.61	12.36

Appendix Table 4: Average annual areal rainfall for the Gumara watersheds in mm

Year	Areal rainfall
1994	1555.58
1995	1095.98
1996	1560.51
1997	1516.08
1998	1434.08
1999	1521.62
2000	1508.36
2001	1345.28
2002	1162.02
2003	1269.37
2004	1144.98
2005	1311.65
2006	1488.50
2007	1412.29
2008	1498.80
2009	1060.96
2010	1465.82
2011	1356.73
2012	1351.10
2013	1428.99
2014	1362.05
Average	1373.84

Appendix Table 5: Annual maximum temperature for the study watersheds (^{0}C)

Year	Areal maximum temperature
1994	24.90
1995	24.76
1996	24.47
1997	24.78
1998	25.42
1999	25.49
2000	25.31
2001	25.27
2002	25.94
2003	25.75
2004	25.61
2005	25.47
2006	25.03
2007	25.22
2008	24.19
2009	24.98
2010	24.67
2011	24.83
2012	25.68
2013	25.25
2014	24.41
Average	25.12

Appendix Table 6: Annual areal minimum temperature for the study watersheds (^{0}C)

Year	Areal minimum temperature
1994	9.96
1995	9.96
1996	9.77
1997	9.96
1998	9.62
1999	8.82
2000	9.30
2001	9.14
2002	10.04
2003	10.16
2004	9.89
2005	9.95
2006	10.04
2007	10.27
2008	10.14
2009	10.53
2010	9.69
2011	10.17
2012	11.24
2013	11.19
2014	10.03
Average	9.99

Appendix Table 7: Soil Parameters of the study area used in the SWAT model

Soil Name	No_ of Layers	Soil hydro.Grp.	SOL_ZMX(mm)	Texture	SOL_Z(mm)	SOL_BD(g/cm^3)	SOL_AWC(mm/mm)	SOL_K(mm/hr.)	SOL_CBN (%)	CLAY (%)	SILT (%)	SAND (%)	SOL_ALB	USLE_K
Chromic Luvisols	1	B	1800	SiL-	200	1.45	0.11	7	0.5	25	31	44	0.13	0.3
	2			CL-	260	1.46	0.11	37.2	0.3	14	66	20	0.13	0.3
	3			CL-	460	1.45	0.1	34.8	0.21	19	59	22	0.13	0.3
	4			CL-	650	1.49	0.1	33.6	0.2	22	56	22	0.13	0.3
	5			C-	950	1.48	0.1	36	0.2	17	57	26	0.13	0.3
	6			C-	1350	1.49	0.1	36	0.12	17	57	26	0.13	0.3
	7			C	1800	1.47	0.1	36	0.1	16	59	25	0.13	0.3
Eutric Fluvisols	1	B	1700	LS-	200	1.1	0.11	25	2	50	34	17	0.13	0.22
	2			LS-	500	1.04	0.11	25	2.3	51	22	27	0.13	0.2
	3			LS-	900	1.05	0.12	25	2.5	39	40	21	0.13	0.2
	4			LS-	1300	1.3	0.95	25	0.2	37	34	29	0.13	0.2
	5			LS	1700	1.04	0.1	60	0.42	59	30	11	0.13	0.2
Eutric Leptosols	1	C	650	C-	200	1.1	0.11	25	2	50	34	17	0.13	0.22
	2			C	650	1.23	0.1	13	1.1	66	14	20	0.13	0.22
Eutric Vertisols	1	D	2422	C-	250	1.08	0.12	6.8	1.7	54	26	21	0	0.09
	2			C-	363	1.27	0.11	4.54	1.37	61	19	21	0	0.09
	3			C-	847	1.28	0.1	5.16	1.41	63	17	20	0	0.09
	4			C-	1029	1.22	0.1	4.24	0.88	63	8	29	0	0.09
	5			C-	1392	1.13	0.1	4.34	1.17	63	9	28	0	0.09
	6			C-	1635	1.1	0.11	4.24	1.24	60	13	27	0	0.09
	7			C	2422	1.1	0.09	4.04	0.34	64	17	20	0	0.09
Haplic Luvisols	1	B	2000	L-	260	1.15	0.12	15.5	1.29	73	20	7.1	0.13	0.2
	2			C-	800	1.25	0.12	16.7	0.6	85	13	2.3	0.13	0.2
	3			C	940	1.25	0.12	11.45	0.08	81	17	1.4	0.13	0.2
Urban	1	D	1500	SIL-SICL-SIC	280	1.13	0.022	6.6	1.49	27	20	24	0.13	0.32
	2				737	1.45	0	10.7	1	38	55	7.5	0	0.5
	3				1500	1.6	0.16	5.33	0.15	45	48	7.4	0	0.49

Appendix Table 8: Mean monthly stream flow of Gumara River at Gumara gauge near Bahir Dar (From 2001 - 2014) (m3/s).

Month	Gumara Discharge (m3/s)
Jan	4.52
Feb	3.47
Mar	3.31
Apr	3.09
May	5.65
Jun	20.94
Jul	113.25
Aug	175.69
Sep	112.82
Oct	30.63
Nov	10.42
Dec	6.78
Average	40.88

Appendix Table 9: Average annual stream flow of Gumara River at Gumara gauge near Bahir Dar (From 2001 - 2014)

Year	Flow
2001	33.04
2002	31.89
2003	42.11
2004	24.64
2005	34.41
2006	43.92
2007	45.32
2008	49.55
2009	37.43
2010	46.10
2011	42.92

2012	43.51
2013	48.38
2014	53.75
Average	41.21

Appendix Table 10: Measured Sediment Concentration at Gumara

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 11: Definition of Weather Generator statistic and probability value

Symbol	Symbol Description
TMPMX	Average or mean daily maximum air temperature for month (^oc). This value is calculated by summing the maximum air temperature for every day in the month for all years of record and dividing by the number of days summed:
TMPMIN	Average or mean daily minimum air temperature for month (^oc). This value is calculated by summing the minimum air temperature for every day in the month for all years of record and dividing by the number of days summed:
TMPSTDMX	Standard deviation for daily maximum air temperature in month (^oc). This parameter quantifies the variability in maximum temperature for each month.
TMPSTDMN	Standard deviation for daily minimum air temperature in month (^oc). This parameter quantifies the variability in minimum temperature for each month.
PCPMM	Average or mean total monthly precipitation (mm H_2O).
PCPSTD	Standard deviation for daily precipitation in month (mm H_2O/day). This parameter quantifies the variability in precipitation for each month.
PCPSKW	Skew coefficient for daily precipitation in month.
DEWPT	Average daily dew point temperature for each month (^Oc) or relative humidity (fraction) can be input. If all twelve months are less than one, the model assumes relative humidity is input. If any month has a value greater than 1.0, the model assumes dew point temperature is input. Dew point temperature is the temperature at which the actual vapor pressure present in the atmosphere is equal to the saturation vapor pressure. This value is calculated by summing the dew point temperature for every day in the month for all years of record and dividing by the number of days summed.
WNDAV	Average daily wind speed in month (m/s). This value is calculated by summing the average or mean wind speed values for every day in the month for all years of record and dividing by the number of days summed.

Appendix Table 12: Weather generator Statistics and probability value of Gumara station

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
TMPMX	22.78	24.39	24.98	24.57	23.83	21.76	18.82	18.85	20.06	21.15	21.7	21.91
TMPMIN	8.13	9.31	10.27	10.93	10.89	10.46	10.04	9.98	9.36	8.45	7.82	7.48
TMPSTDMX	1.41	1.46	2.21	1.96	2.3	2.2	2.01	1.54	1.51	1.53	1.51	1.47
TMPSTDMN	1.24	1.43	1.59	1.84	1.96	1.23	1.21	1.21	1.11	1.36	1.41	1.26
PCPMM	9.33	3.66	32.91	42.82	98.11	175.48	411.76	409.06	199.13	62.34	26.26	13.21
PCPSTD	2.67	1.01	4.35	3.89	8.35	8.1	11.3	12.18	8.75	6.75	3.43	2.6
PCPSKW	15.04	12.26	8.4	4.29	6.19	2.77	1.48	1.73	2.14	8.18	5.11	12.72
PR_W1	0.04	0.04	0.12	0.16	0.23	0.48	0.91	0.76	0.47	0.15	0.08	0.06
PR_W2	0.26	0.31	0.43	0.66	0.66	0.84	0.97	0.95	0.8	0.69	0.46	0.51
PCPD	1.62	1.24	5.38	9.38	12.52	21.38	29.9	29.19	21.71	10.52	3.86	3.43
RAINHHMX	0	0	0	0	0	0	0	0	0	0	0	0
SOLARAV	19.99	21.31	21.4	21.35	20.73	19.15	15.7	16.74	20.04	20.69	19.59	19.51
DEWPT	3.79	3.82	5.41	6.54	8.84	11.32	12.05	11.87	10.89	8.55	6.55	4.91
WNDAV	1.03	1.19	1.19	1.25	1.27	1.16	1.04	1.14	1.03	0.84	0.85	0.93

Appendix Table 13: Sensitivity Ranking for Flow Calibration

No_	Parameter Description	SWAT Parameter Code	Rank	Index value	Category of Sensitivity
1	Base Flow alpha factor (days)	Alpha_BF	4	0.244	High
2	Maximum Potential Leaf Area Index (unit less)	Biomix	19	0.000681	Small
3	Maximum Potential Leaf Area Index (unit less)	Blai	8	0.027	Small
4	Maximum Canopy Index (mm)	Canmx	10	0.0197	Small
5	Effective Channel Hydraulic Conductivity (mm/h)	Ch_K2	12	0.0165	Small
6	Manning coefficient for channel (unit less)	Ch_N2	16	0.0035	Small
7	SCS- CN for moisture condition II (unit less)	Cn2	1	0.605	High
8	Plant evaporation compensation factor (unit less)	Epco	11	0.0166	Small
9	Soil evaporation compensation factor (unit less)	Esco	3	0.445	High
10	Ground water delay (days)	Gw_Delay	13	0.0096	Small
11	Groundwater revaporation coefficient (unit less)	Gw_Revap	7	0.0468	Small
12	aquifer required for return flow to occur (mm)	Gwqmn	2	0.448	High
13	Threshold depth of water in the shallow aquifer required for revaporation to occur (mm)	Revapmn	9	0.0252	Small
14	Snowfall temperature (°C)	Sftmp	27	0	Small
15	Average slope steepness (m/m)	Slope	15	0.0067	Small
16	Average slope length (m)	Slsubbsn	20	0.000341	Small
17	Snowmelt base temperature (°C)	Smfmn	27	0	Small
18	Maximum snowmelt rate (mm/°C/day)	Smfmx	27	0	Small
19	Snowmelt base temperature (°C)	Smtmp	27	0	Small
20	Soil Albedo	Sol_Alb	18	0.00207	Small
21	Available water capacity of the soil layer (mm/mm)	Sol_Awc	5	0.218	High
22	Soil conductivity (mm/h)	Sol_K	14	0.00853	Small
23	Soil depth (mm)	Sol_Z	6	0.144	Medium
24	Surface runoff lag coefficient	Surlag	17	0.00251	Small
25	Snowpack temperature lag factor	Timp	27	0	Small
26	Temperature lapse rate (°C/km)	Tlaps	27	0	Small

Appendix Table 14: USLE_P (*.mgt) or P factor Values and slope length limits for contour farming terraced agricultural fields (SWAT user manual)

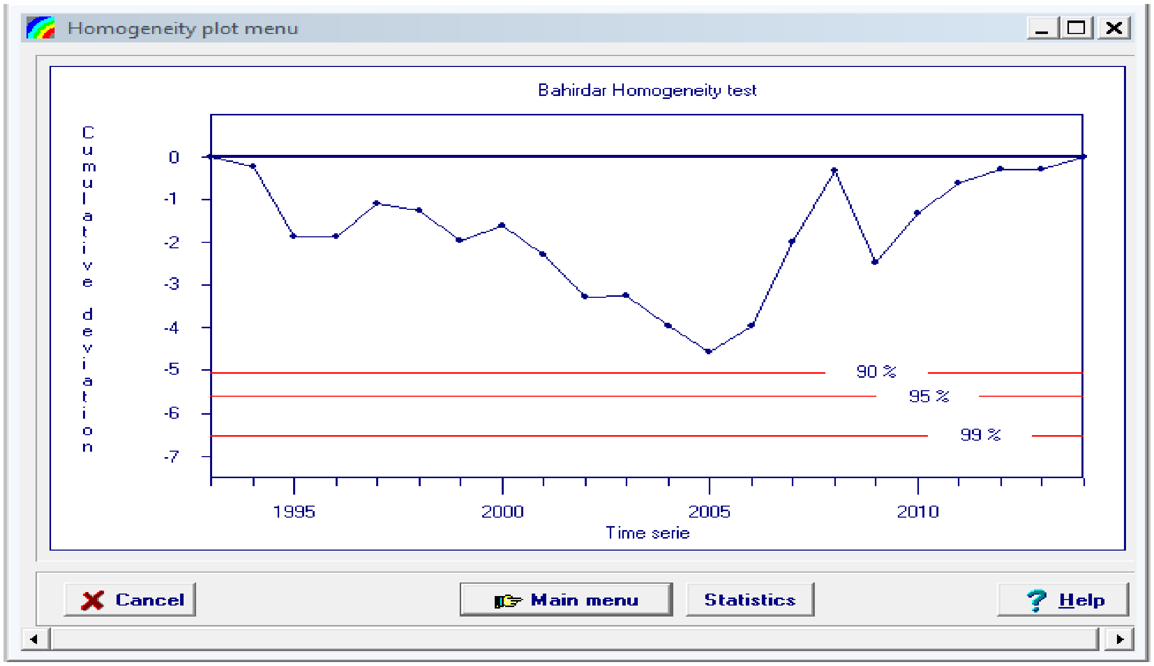
Land slope (%)	Farm Planning		Slope length(m)
	Contour P factor	Strip crop P factor	
1 to 2	0.6	0.3	122
3 to 8	0.5	0.25	76
9 to 12	0.6	0.3	37
13 to 16	0.7	0.35	24
17 to 20	0.8	0.4	18
21 to 25	0.9	0.45	15

Appendix Table 15: CN2 (*.mgt) Initial SCS runoff curve number for moisture condition II (SWAT user manual)

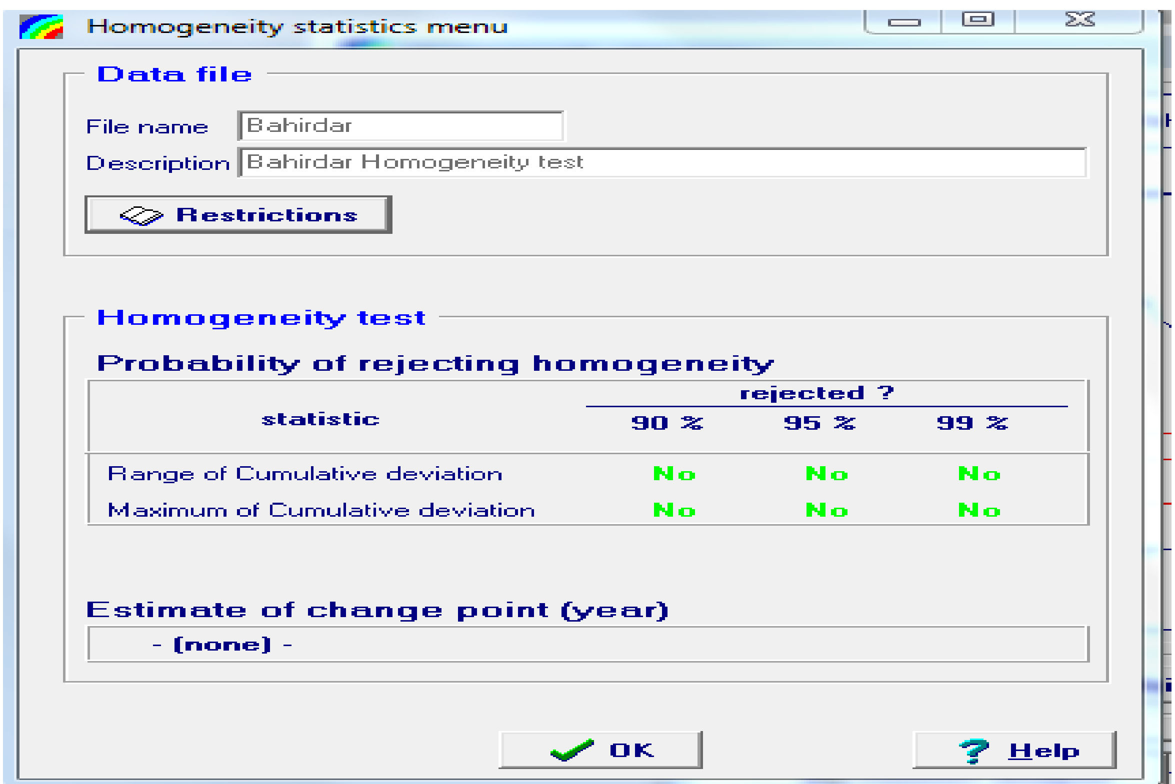
Cover		Hydrologic	Hydrologic Soil Groups			
Land use	Treatment/practice	Condition	A	B	C	D
Row		Poor	66	74	80	82
Crops	Contoured & terraced	Good	62	71	78	81
	Contoured & terraced	Poor	65	73	79	81
	w/residue	Good	61	70	77	80
Small grains	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured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

Urban=D, Chromic Luvisols=B, Eutric Vertisols=D, Haplic Luvisols=C, Eutric Leptosols= C

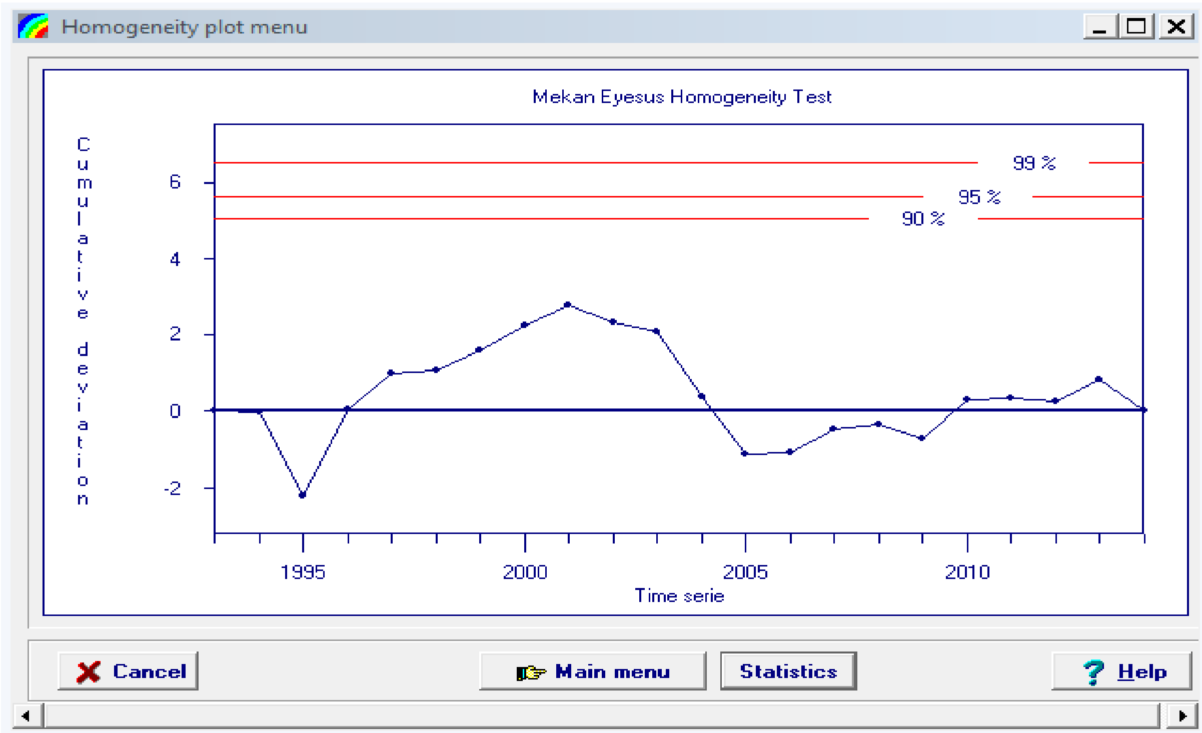
Appendix - Figure



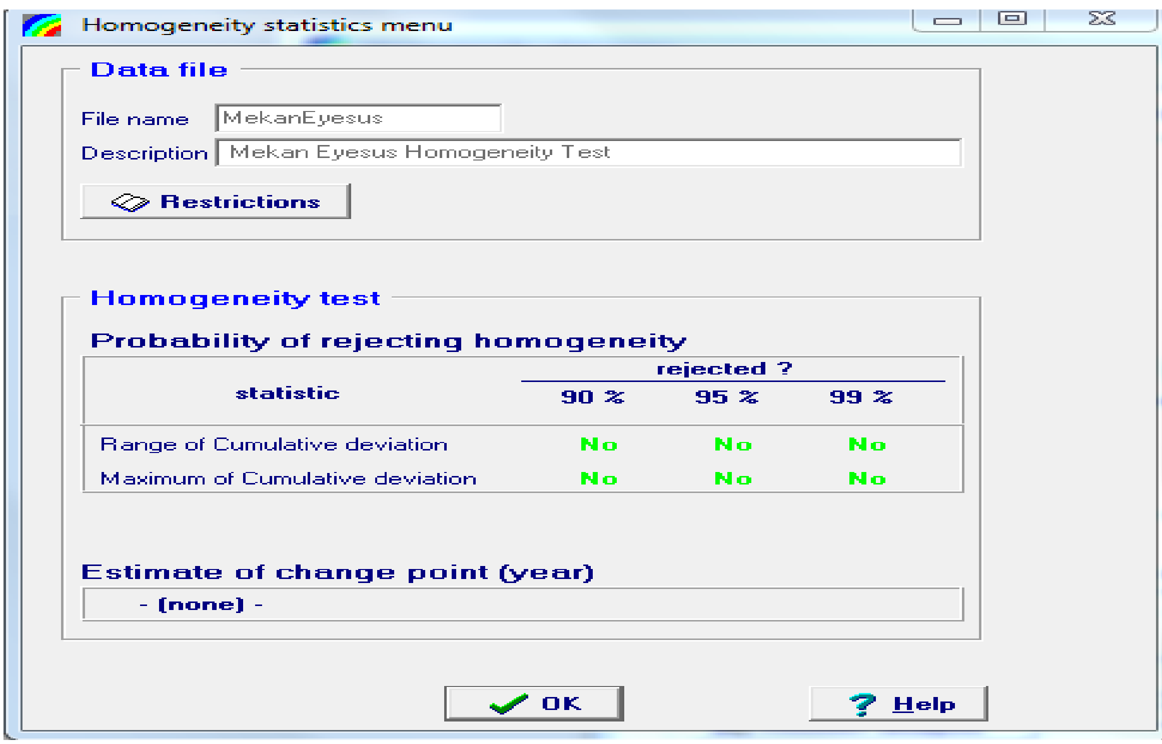
Appendix Figure 1: cumulative deviation of annual rainfall at Bahir dar station



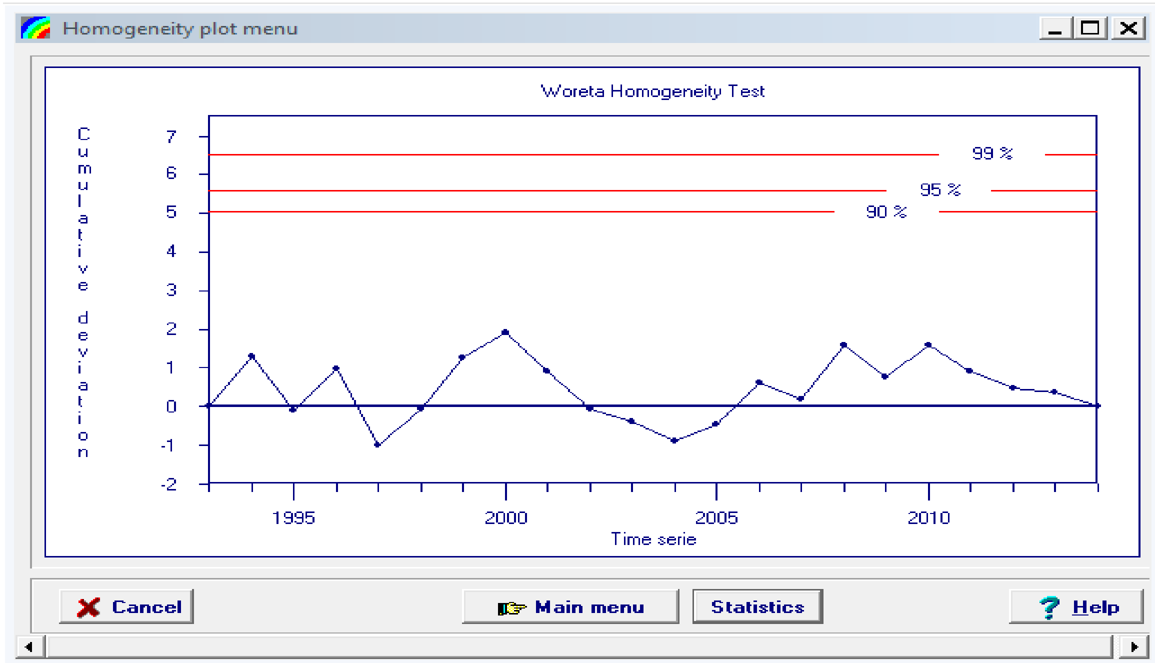
Appendix Figure 2: Probability of rejecting homogeneity of annual rainfall at Bahir dar station



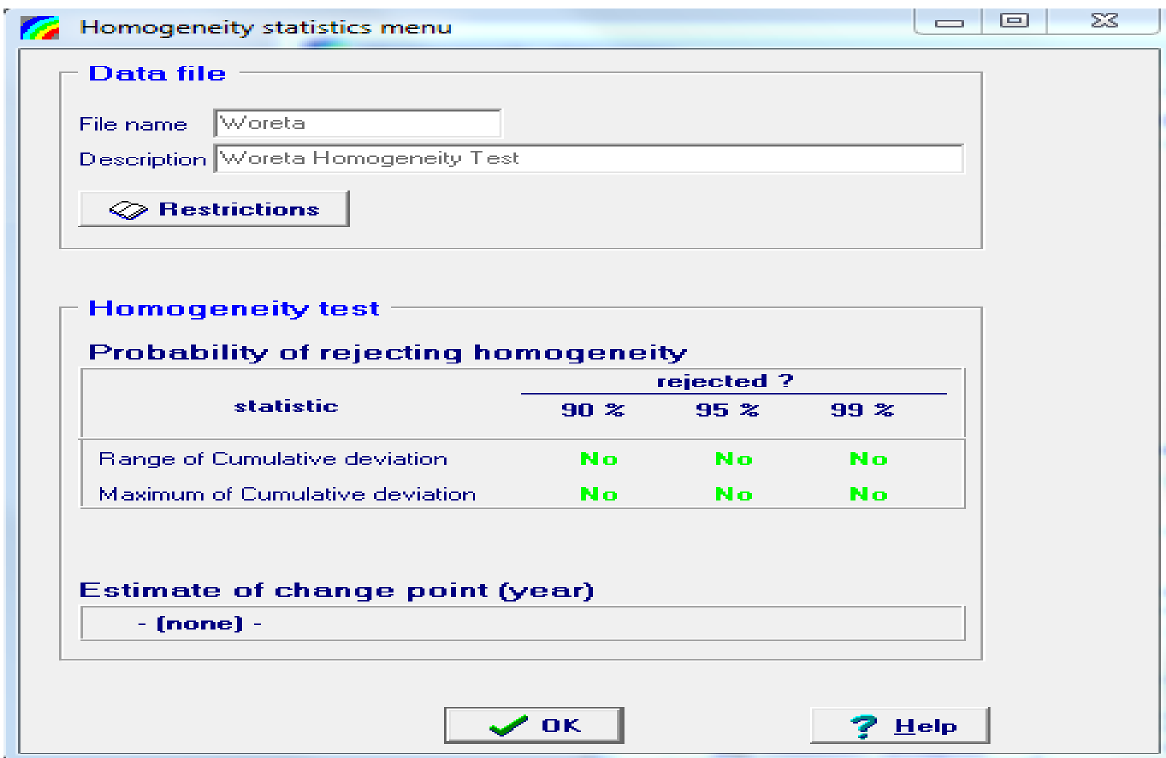
Appendix Figure 3: cumulative deviation of annual rainfall at Mekane Eyesus station



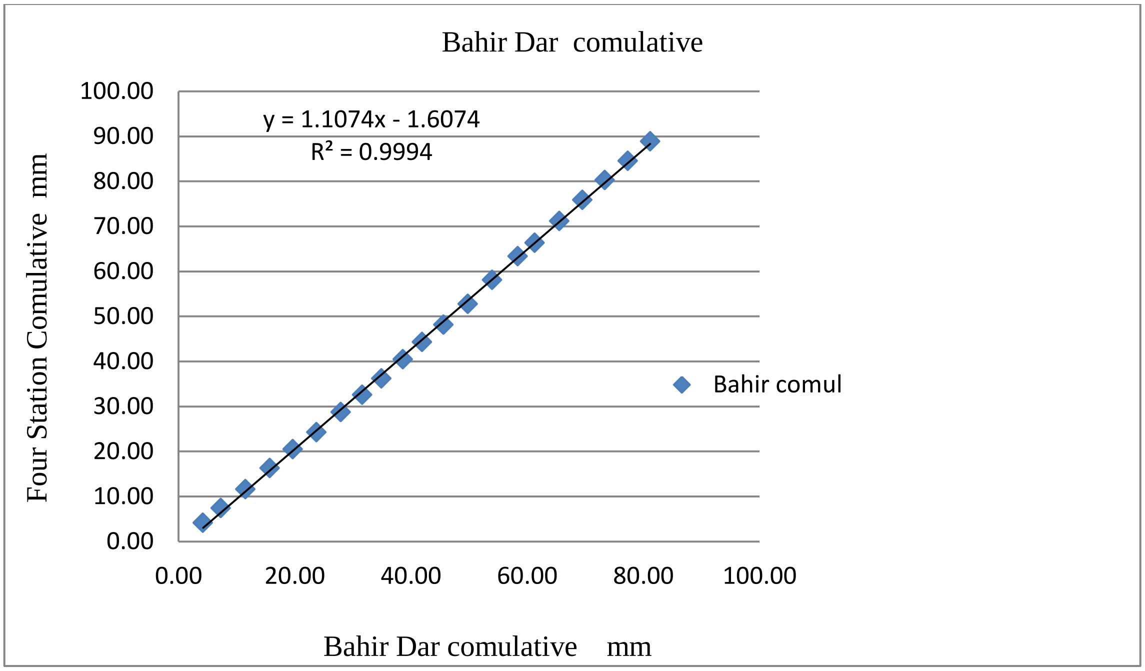
Appendix Figure 4: Probability of rejecting homogeneity of annual rainfall at Mekane Eyesus station



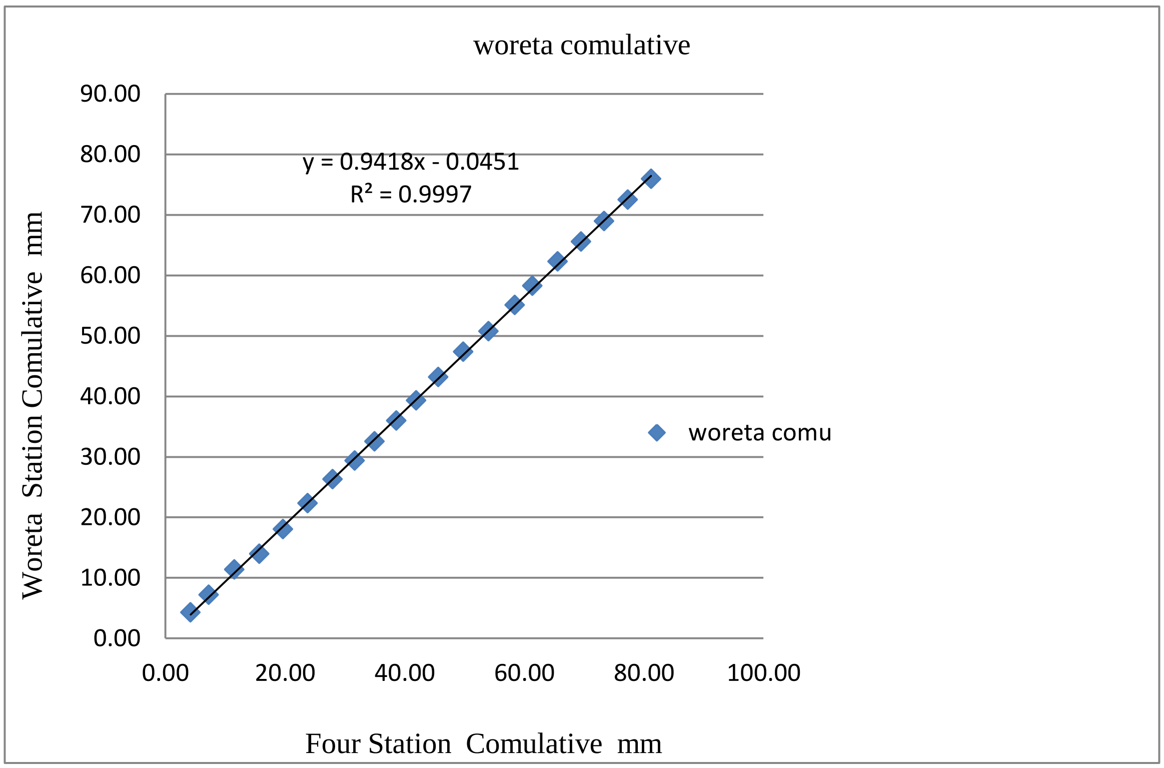
Appendix Figure 5: cumulative deviation of annual rainfall at Woreta station



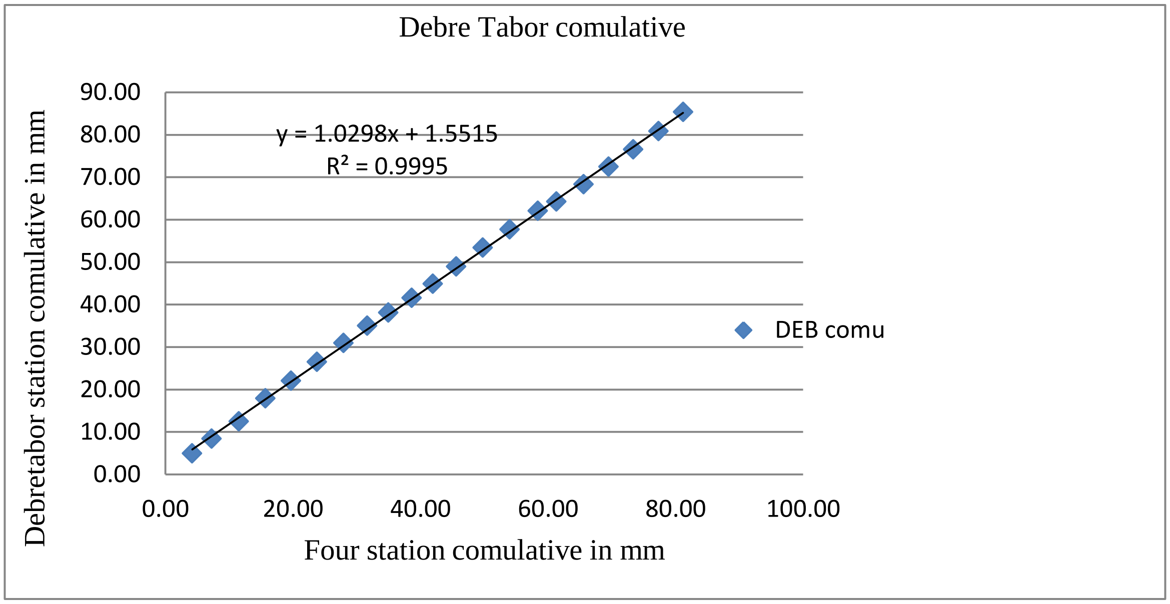
Appendix Figure 6: Probability of rejecting homogeneity of annual rainfall at Woreta station



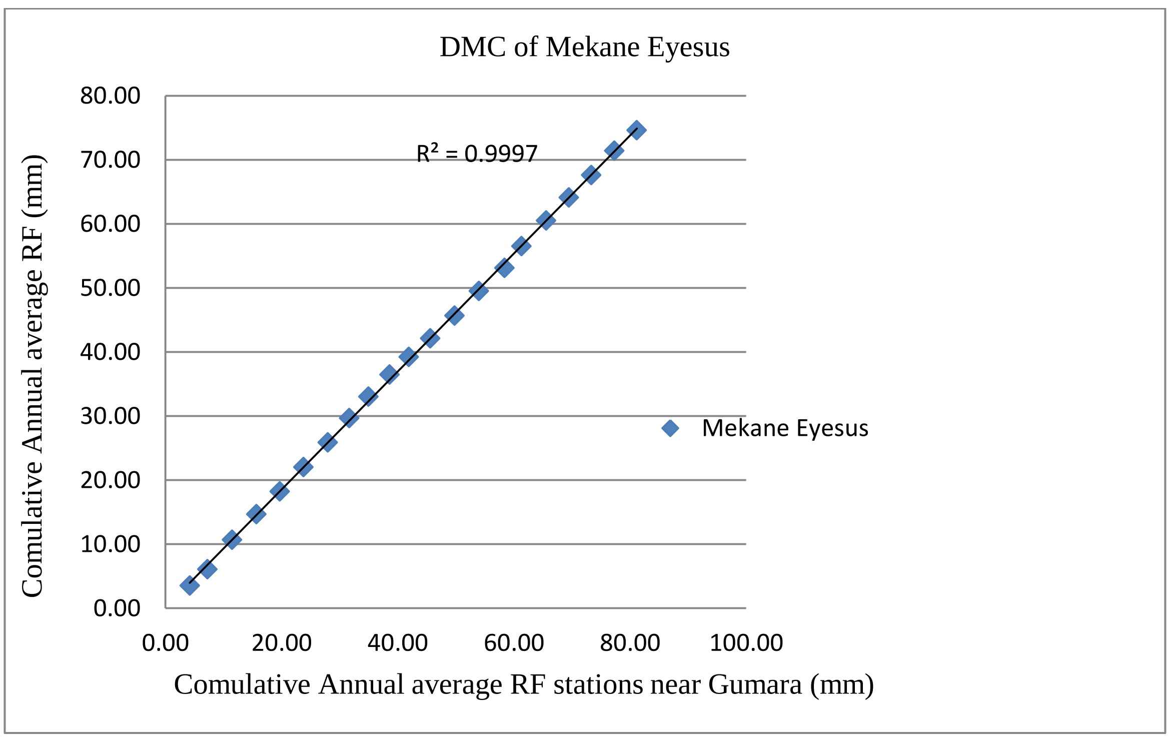
Appendix Figure 7: DMC of Bahir dar station showing high data consistency



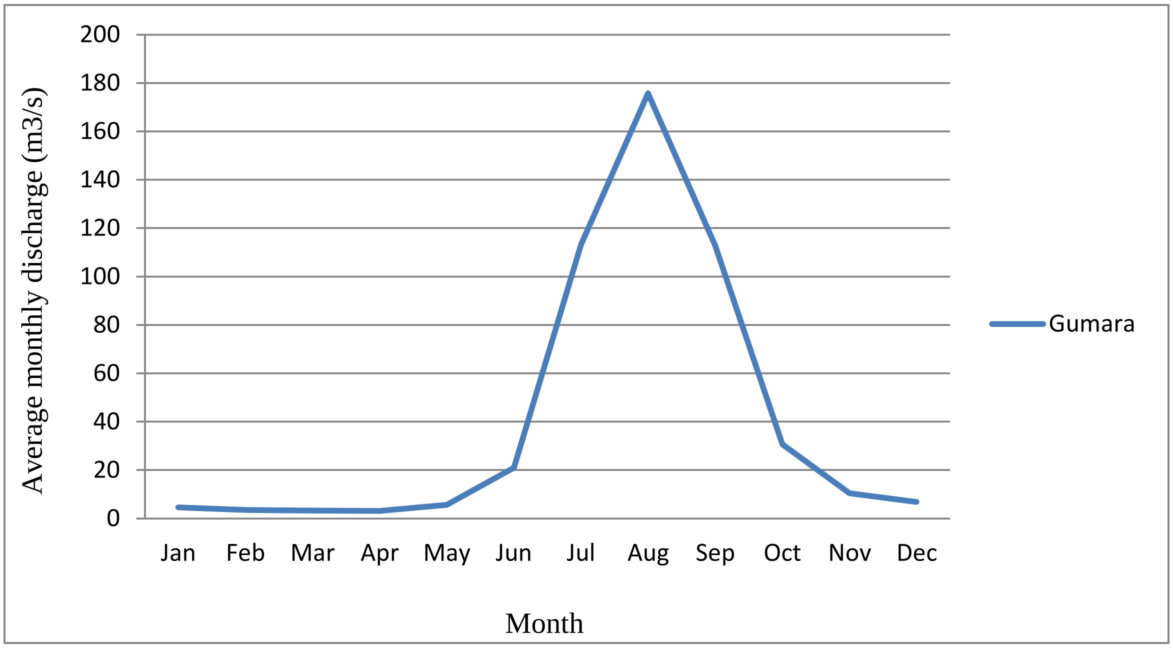
Appendix Figure 8: DMC of Woreta station showing high data consistency



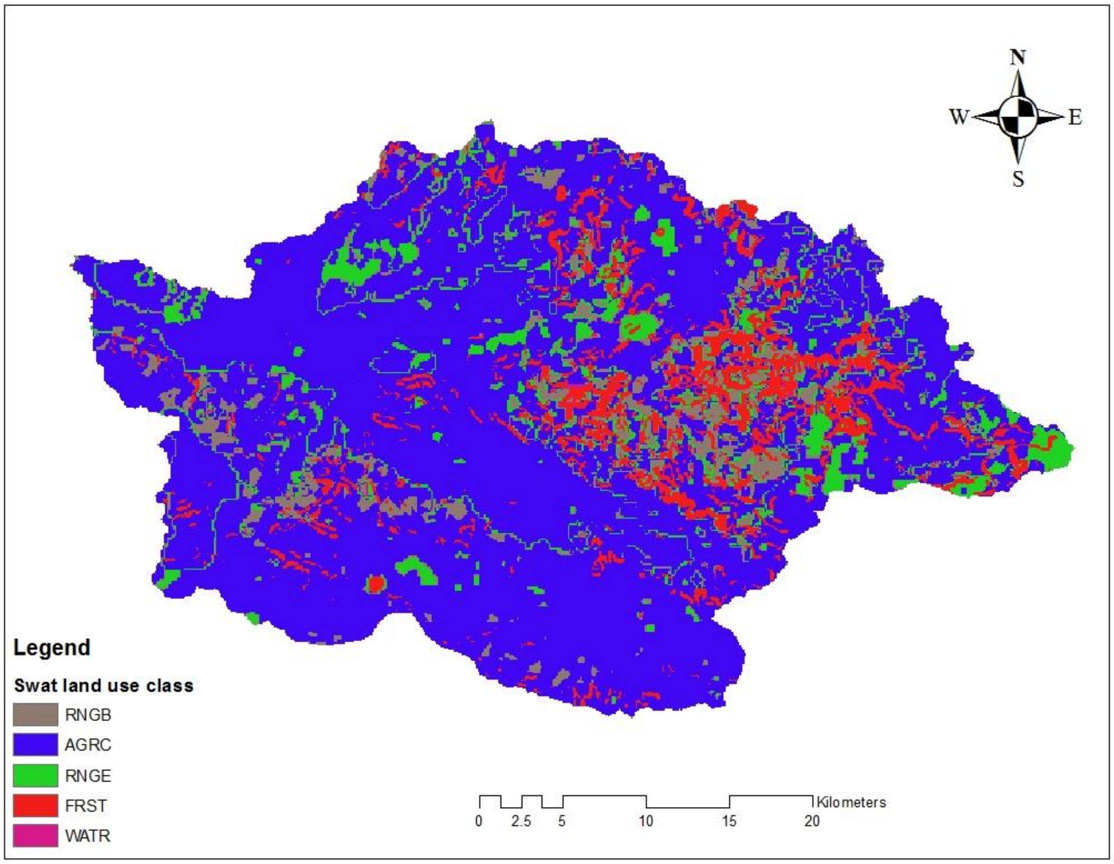
Appendix Figure 9: DMC of Debretabor station showing high data consistency



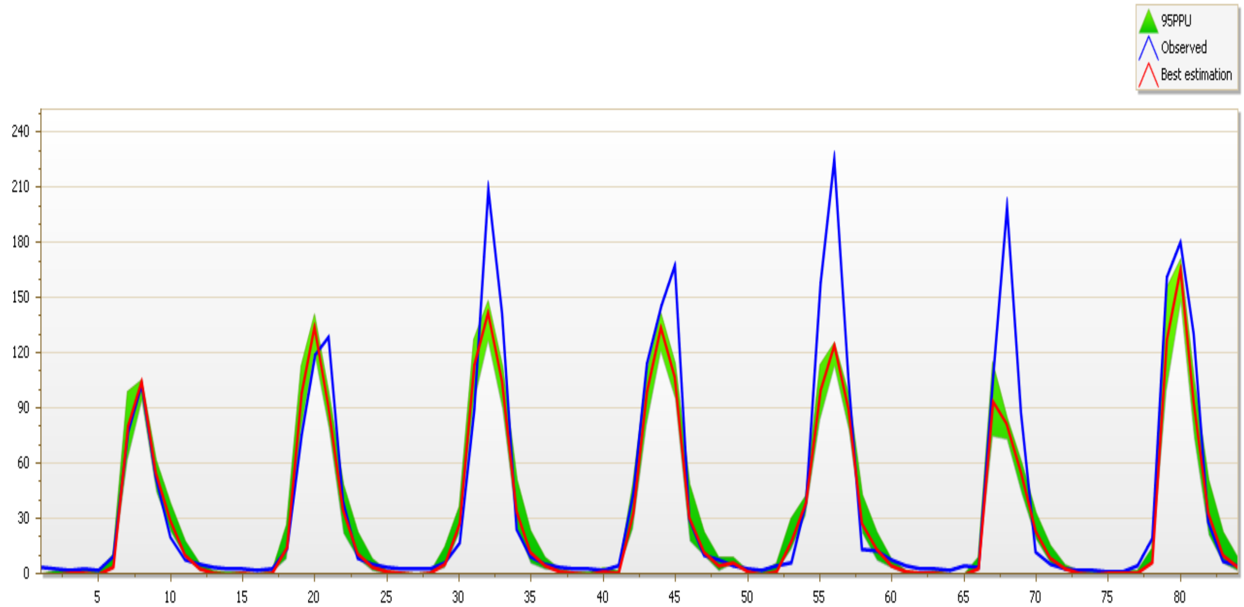
Appendix Figure 10: DMC of Mekane Eyesus station showing high data consistency



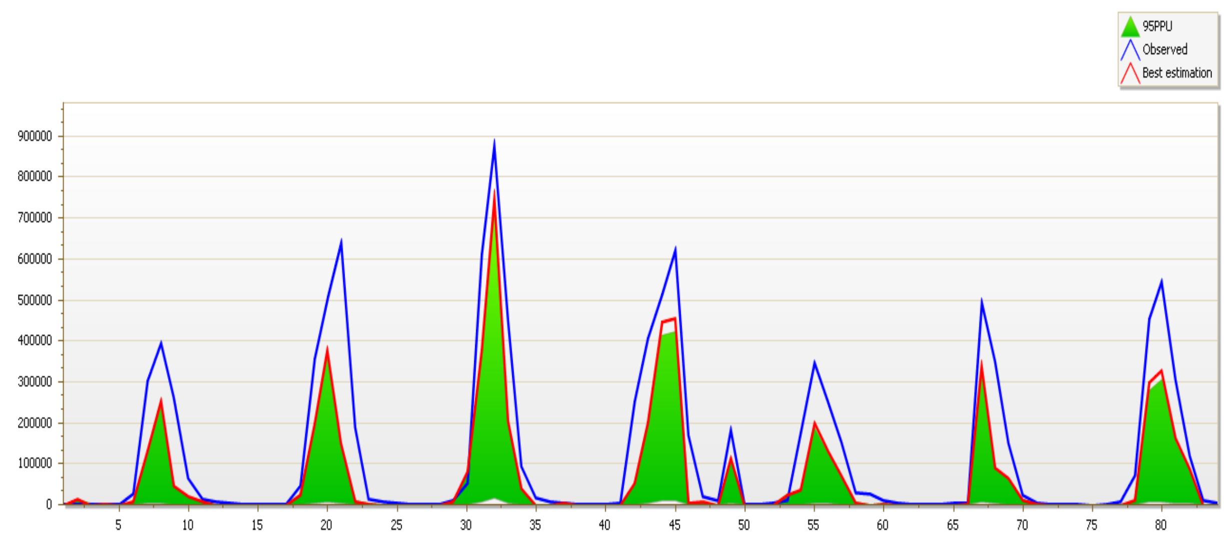
Appendix Figure 11: Average monthly discharge for Gumara near Bahir dar station (m3/sec)



Appendix Figure 12: SWAT-land use classification of the watershed



Appendix Figure 13: First result for calibration of discharge on monthly time step using SWAT-CUP.



Appendix Figure 14: First result for Sediment Calibration on monthly time step using SWAT-CUP (SUFI2).