JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

HYDRAULICS ENGINEERING MSC PROGRAM

HYDROLOGICAL RESPONSES TO LAND USE AND LAND COVER CHANGES OF RIBB RIVER 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 MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

BY

TSEDALU AYELE

November, 2015

Jimma, Ethiopia

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BY

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November, 2015

Jimma, Ethiopia

Declaration

I, the undersigned, declare that this thesis:

Hydrological responses to land use/land cover changes of Ribb river watershed, upper Blue Nile, Ethiopia is my original work, and it has not been presented for a degree in Jimma University or any other university and that all source of materials used for the thesis have been fully acknowledged.

Name Signature Date

Tsedalu Ayele………………… /……………………….…/………………

This thesis has been submitted for examination with my approval as university supervisor

Name Signature Date

1, …………………………………….…/……………………………./…………….

Chair man

2, ……………………………………./……………………………/……………

Principal advisor

3,……………………………………./…………………………...../……………

Co-advisor

4, ……………………………………./…………………………..../……..........

Internal examiner

5, …………………………………../…………………….…./………………

External examiner

ABSTRACT

The main objective of this study is to assess the impact of land cover changes on the hydrology of Ribb river basin. Specifically, the study analyzed the present land covers that have taken place in the catchment and its effect on the hydrological responses of the catchment. Land cover change scenarios were used to determine the potential effect that will happen on the catchment hydrology. The Soil and Water Assessment Tool (SWAT2009) model was used to investigate the impact of land cover change on hydrological responses of the study area. The model was set up using readily available spatial and temporal data, and calibrated against measured discharge and sediment concentration. Sensitivity analysis result shown SCN curve number (CN), Soil Evaporation Compensation Factor (ESCO), Soil Depth (m) (Sol_Z), Threshold water depth in the shallow aquifer for flow (GWQMN), Base flow alpha factor (Alpha_Bf), (REVAPMN) and Soil Available Water Capacity (SOL_AWC) were found the most influential parameters affecting flow and USLE equation support practice (USLE_P),Linear parameter for maximum sediment yield (SPCON), Exponential parameter for maximum sediment yield in channel sediment routing (SPEXP),Cropping practice factor (USLE_C),channel cover factor (CH_COV1),channel erodiability factor (CH_ERODMO) were the most sensitive parameters affecting sediment yield of the catchment respectively. The model was calibrated from 1996-2008 and validated from 2009-2014 for both flow and sediment at Ribb river gauging station. The performance of the model was evaluated on the basis of performance rating criteria, graphical method, water balance, coefficient of determination (R^2) and Nash Sutcliff efficiency (NSE). The R^2 and NSE values for the catchment were (0.79, 0.78) for flow calibration, (0.7, 0.68) for flow validation, (0.77, 0.71) for sediment calibration and (0.72, 0.72) for sediment validation respectively. Three land use/cover change scenarios were developed to analyze the impact of land use/cover changes to the hydrological regime. Base scenario: current land use practices has cultivated land, grass land, shrub and bush land, forest land, built up area and water body, scenario1: shrub and bush lands completely changed to forest land and scenario2: Grass land changed to cultivated land. The result for different land use scenarios show that: conversion of shrub land to forest area reduced surface runoff, reduced the amount of sediment transported out and increase base flow but conversion of grass land in to cultivated land areas increased surface runoff during wet seasons and reduced base flow during the dry seasons and also as the peak flow increases it is suspected of carrying more sediment.. In general, from the result of land use scenario, the changes in stream flow characteristics could be related to the change of the land use.

Key words: *SWAT, LULCC, SUFI-2, Ribb, stream flow, sediment yield, hydrological modeling, water balance, model calibration, validation*

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LIST OF ABBREVIATION

AMC	Antecedent Moisture Condition
UTM	Universal Transverse Mercator
CSA	Central Statistical Agency
CN	Curve Number
DEM	Digital Elevation Model
ESCO	Soil evaporation compensation factor
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
GPS	Geographical Positioning System
HEC-HMS	Hydraulic Engineering Centre- Hydrologic Modeling System
HRU	Hydrological Response Unit
IWRM	integrated water Resource management
LULCC	Land Use Land Cover Change
MOWIE	Ministry Of Water Irrigation and Energy
NMSA	National Metrological Service Agency
NSE	Nash Sutcliff Efficiency
PET	Potential Evapotranspiration
R^2	Coefficient of Determination
SRTM	Suttele Radar Topography Mission
SCS	Soil Conservation System
SUFI2	sequential uncertainty fitting-2
SWAT_CUP	Soil and Water Assessment Tool Calibration Uncertainty Program
SWAT	Soil and Water Assessment Tool
USDA-ARS	United States Department of Agriculture-Agriculture Research Service

CHAPTER ONE

INTRODUCTION

1.1. Background

Water resources are the basic renewable natural resources that are essential for development of any society. Ethiopia has a huge potential of water resources and arable land. Although the country has abundant water resources and arable land, food insecurity due to the occurrence of frequent droughts and famines is one of the main challenges (MoWR, 2007). Watershed degradation in Ethiopia in general and Amhara National Regional State in particular threatens the livelihood of millions of people and constrains the ability of the country/region to develop a healthy agricultural and natural resource base. Lead to inappropriate cultivation practices, forest removal, and grazing intensities that, in the extreme case, leave a barren land that yields unwanted sediment and damaging floods to downstream communities. The poor land use practices, improper management systems and lack of appropriate soil and water conservation measures have been major causes of soil erosion and land degradation problems in the country.

Land use land cover change (LULCC) can be major threat to biodiversity as a result of the destruction of the natural vegetation and the fragmentation or isolation of natural areas (Verburg, 2006). It is one of the main human induced activities altering the hydrological system. Understanding the impacts of diverse environmental changes and quantifying the effect of LULCC on hydrological dynamics of a catchment is one of the challenges in recent hydrological researches.

LULCC are resulted in significant changes, especially in the developing countries which have agriculture based economics and rapidly increasing populations. LULCC are caused by a number of natural and human driving forces. Natural effects such as, climate changes are only over a long period of time, whereas human activity can dramatically alter hydrological and watershed processes (Meyer and Turner, 1994).

LULCC have direct impact on the amount of evaporation, groundwater infiltration and overland flow that occurs during and after precipitation events (Mustard & Fisher, 2004). In short term destructive land use change may affect the hydrological cycle either through increasing water yield or through diminishing or even eliminating low flow in some circumferences.

Therefore, understanding how LULCC influence on the hydrologic condition of the watershed is needed for planners to formulate policies, to minimize the undesirable effects of future land cover changes for sustainable management of resources. Among thus, quantifying LULC changes within a catchment is an important component of monitoring watershed quality. Therefore, estimating and understanding the impact of LULCC on stream flow is important to accurately assess the type and direction of changes occurring within the catchment. Although the empirical knowledge of land use is obvious; it is difficult to quantify these consequences. Different methodologies have been implemented in attempt to fill deficiencies of knowledge, but no general and creditable model has been established yet to predict the impact of LULCC on stream flow.

One of the main aims of this study is to quantify and identify the scale and impact of land use/cover change on the watershed hydrological responses. It is important to understand the hydrology of the watershed particularly the physical processes occurring and the controlling factors within the watersheds. Studying the hydrological processes reacting to changes in land cover give valuable insights how the river flow will respond to these changes. River flow is known to be an integrated indicator of the entire watershed processes. Besides the projection of watershed hydrology on different land use/cover dynamics, are used to prioritize options for water resources planning and management for future watershed management.

The study was conducted for the Ribb basin, Northern Ethiopia, which is highly prone to changes imposing impact on hydrological processes. Excessive land degradation due to increasing population density within the watershed have created environmental changes, economic and social effects, all resulting in degradation of raw water in the basin. Hence, understanding the impact of land use/cover change enhances the water users and managers to allocate and use the available water resources in supporting the dominant agriculture based economic and social developments. It is also used to implement techniques that control water yields, sediment yield including rainfall, temperature and stream flows and, finally, to optimize the resources.

The semi-distributed Soil and Water Assessment Tool (SWAT2009) is a hydrologic simulation model integrated with ArcGIS is used in this study. The SWAT model is calibrated and validated for the catchment after the sensitive parameters were identified through sensitivity analysis. Then the hydrological response to LULCC is evaluated the SWAT model.

1.2. Statement of the Problem

Land use/cover change is an important characteristic in the runoff process that affects infiltration, interception, erosion, and evapotranspiration. This changes cause different problem in existing hydrological conditions. Change in land use type of certain area like increasing the percentage of impervious will increase volume of surface runoff, decrease time of concentration which makes several distractions by generating higher amount of runoff as well as decrease the amount of water percolated in to the ground. This in turn decreases the amount of water to be recharged in to the ground, and finally imbalances over all hydrological condition of catchment. Such and other issues should be assessed deeply to know how land uses affect different hydrological process.

To balance LULC effect with hydrology, study should be conducted which can give knowledge on how the relation of land use/cover with hydrological process was in past periods as well as to predict what will be the future hydrology of a catchment. By changing the land use which results increasing knowledge of different decision makers how land use can affect certain catchment in order to take mitigation and remedial measure for particular problem.

The areas suffered from serious flooding in the past years caused damages to houses, various infrastructures as well as cause for loss of human lives and affects socio economic activities. Therefore, a strong need is identified for the hydrological techniques and tools that can assess the likely effect of land cover changes on the hydrologic response of a catchment. Such techniques and tools can provide information that will be used for water resources management at a watershed level, and enables local government body to plan the possible problem solving project through future development progress for appropriate measure.

Having the above mentioned and other related problems, it is vital to understand the impact of LULC change on hydrology of Ribb River watershed.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this study is to analyze the impacts of land use land cover change on hydrology of Ribb River watershed, upper Blue Nile.

1.3.2. Specific objectives

In order to achieve the main objective of the study, the following specific objectives are set.

- To develop land use/land cover map of the Ribb catchment.
- To calibrate and validate stream flow and sediment yield and evaluate the performance of the hydrological (SWAT) model.
- To assess the response of stream flow and sediment yield of the catchment to the changes in land use land cover.

1.4. Research Questions

To address the above objectives, the following research questions are designed.

1. What was the land use/land cover map in Ribb catchment?
2. How well can SWAT model simulate stream flow and sediment yield in the watershed?
3. How does the hydrology of Ribb catchment respond to land use and land cover change?

1.5. Significances of the study

This study will attempt to check the performances and suitability of the SWAT model for analyzing the impact of LULCC in the Ribb catchment. Understanding the types and impacts of LULCC will be used as a base for policy maker to formulate and develop effective and appropriate response strategies for sustainable management of resources in the country in general and at the study area in particular. Moreover, this study evaluated the LULCC impact on hydrological process in Ribb watershed; and finally recommended the way forward to minimize the undesirable effects of future land use/cover change.

The study output will be disseminated in the form of publications and will be presented at seminars and conferences that can give further information for other researchers.

1.6. Scope of the study

The scope of this study will be limited to analyze the impact of land use/land cover change effect on hydrological process as well as land use change on soil erosion in the Ribb catchment. The study will not consider the impact of climate change on the water resources of the catchment.

CHAPTER TWO

LITERATURE REVIEW

2.1. Land Use and Land Cover Change: Definitions and Concepts

The International Geosphere-Biosphere Program, The International Human Dimension Program and the Land Use/Land Cover Change project have referred to land use and land cover change' as follows (IGBP-IHDP, 1999). Land cover refers to the physical and biophysical characteristics of Earth's surface and immediate, captured in the distribution of vegetation, water, desert, ice and other physical features of the land, including those created solely by human activities e.g., settlements. Land use refers to the intended use or management of the land cover type by human beings. Thus, land use involves both the manner in which the biophysical attributes of land are manipulated and intent underlining that manipulation (the purpose for which the land is used e.g., agriculture, grazing, etc), which are changes that affect the character of the land cover without changing its overall classification.

LULCC is always caused by multiple interacting factors originating from different levels of organization of the coupled human environment systems. It is the result of complex interactions between several biophysical and socio-economic conditions which may occur at various temporal and spatial scales. The mix of driving forces of LULCC varies in time and space, according to specific human-environment conditions. Understanding the underlying LULCC drivers is an important input for planning and decision making (kassa, 2009 by siting Xiuwan, 2002) as a source.

Quite often the study of LULCC is necessitated by the need to know, in quantitative terms, the nature, the extent and the rate at which these changes advance and the problems or impacts they cause. Furthermore, some studies tried to comprehend the effect of changes in upstream land use and land cover which resulted alterations in the movement of water and water availability at the downstream. Increased consciousness of these impacts enhanced their estimating, forecasting and modeling at the regional scales. However, quantifying impacts of LULCC and management practices at a watershed scale is still complex because of the inherent variability and complex interactions among the different factors. Thus, in order to provide foundations for effective management of natural resources, an understanding must be built on the variability in time and space of the resources and role of human cultures and institutions in bringing those variations (Thomas, 2001).

Comprehensive knowledge of LULCC is useful for reconstructing past land use/land cover changes and for predicting future changes, and thus it may help in elaborating sustainable management practices aimed at preserving essential landscape functions. The primary drivers of LULCC and their interrelationship with the hydrological regimes has to be identified to develop projections of future land use and to plan management decision outcomes under a range of economic, environmental, and social scenarios.

Currently, improved understanding of processes of LULCC has led to a shift from a view condemning human impact on the environment as leading factor for the deterioration of earth's system processes. As a result, general statements about impacts of LULCC and land/water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002).

2.2. Previous Studies and Approaches

Most of our understanding of LULCC has built up from individual case studies, using both remote sensing and ground-based data, and we will continue to rely on case studies as a means to gain required knowledge. Studies that have been carried out at different parts of Ethiopia indicated that agriculture lands have been expanded at the expense of natural vegetation, including forests and shrub lands.

Ephrem (2011) developed effects of watershed characteristics on river flow for the case of Ribb and Gumara catchment. The objective of the study was to examine the influence of the characteristics of Ribb catchment on the flow of Ribb River in the upper Blue Nile basin. ILWIS model was used for detail evaluation of the physical watershed characteristics for both watersheds. The effects of physical catchment characteristics were analyzed and characteristics which have high differences (Rainfall and soil) were identified. Soil and Water

Assessment Tool (SWAT) has been applied for evaluation of physical watershed characteristics with significant differences. The model was calibrated and validated over the gauged upper reaches of catchments of Rib and Gumara. The performance of the model was evaluated on the basis of performance rating criteria, coefficient of determination, Nash Sutcliff efficiency, and volumetric error. The author conclude that The physical catchment characteristics which have high differences (Rainfall and Soil) in the two watersheds were evaluated and tested by creating different scenarios in the calibrated and validated models and the result shows soil has a great effect in lower annual flow of Ribb watershed followed by rainfall.

Setegn et al., 2008 developed hydrological model for Lake Tana basin. SWAT 2005 model was used to examine the effect of land use, soil, topography and climatic conditions on stream flow. Soil evaporation compensation factor ESCO and SCS curve number II were found to be the most sensitive parameters for the sub basins. The authors concluded the successful application of SWAT 2005 model to Lake Tana sub basins for the study of hydrological water balance.

Assefa et *al.,* 2008 developed flood forecasting and early warning model for Lake Tana sub basin. The study aimed to set up flood forecasting model for Gumara and Ribb catchments and verify the accuracy. The rainfall-runoff model was integrated with HEC-HMS for Gumara and Rib using soil moisture accounting model to model soil loss, Clark unit hydrograph for direct runoff, linear reservoir model for base flow and Muskingum–Cunge routing model components. Flows above and below 63 m3/s were classified as high and low flow ranges respectively for Gumara watershed. It was noted that simulated stream flow were higher than observed value for validation period; and seasonality, spatial variability of rainfall, soil/land use heterogeneity were identified to be possible sources of error in the hydrological modeling. The authors concluded that HEC-HMS continuous hydrologic simulation has good performance for hydrological modeling in Gumara watershed. Further recommendation was provided to use GIS for model parameterization. This was assumed to improve the result since the soil moisture accounting parameters used in HEC-HMS models were derived from general guide lines that refer soil and land use map of the area sited by Tewodros (2012).

Yohannes (2007) assessed water resource potential for Lake Tana basin based on remote sensing data. The research aimed improving hydrological description of Lake Tana basin and thus contributes towards integrated water Resource management (IWRM). The study makes the use of remote sensing techniques for hydrologic components of water balance estimation. Satellite derived parameters have been used for evaporation estimation, satellite based rainfall estimates have been validated with recorded data and land cover information has been obtained from moderate resolution optical images. Penman-Monteith method for evapotranspiration estimation, HEC-HMS for flood hydrograph (SCS and SWAT curve number) and soil water balance method for runoff estimation were used in the study. The authors presented that major impact of land use/land cover change on runoff estimation in Lake Tana basin need to be carefully identified. The authors concluded the goodness of soil water balance method for un-gauged catchment for runoff estimation in Lake Tana sub basin.

In many parts of the highlands of Ethiopia, agriculture has gradually expanded from gently sloping land into the steeper slopes of the neighboring mountains. According to many literatures, population that has been steadily increased at a growth rate of 2 to 3% per year during the past five decades is the major cause of this expansion. In some areas, expansions of cultivation, commonly into steeper slopes and marginal areas, may have been done without appropriate soil and water conservation measures. Despite this increase, the agricultural productivity is lagging behind the population growth rate.

The impact of population growth on the environment and poverty are not simple and one directional (Bewket, 2004). Basically, the complex relationship between human development and the environment is what causes land degradation, in which the use and management of the natural resources is a central issue.

However, most of the empirical evidences indicated that land use/land cover changes and socioeconomic dynamics have a strong relationship; as population increases the need for cultivated land; grazing land and fuel wood will increases. Settlement areas also increase to meet the growing demand for food and energy. Thus, population pressure, lack of awareness and weak management are considered as the major causes for the deforestation and degradation of natural resources in Ethiopia.

2.3. Interaction of Land Use and Land Cover Changes and Hydrology

Land use changes and their associated effects are known to impact the hydrology of the catchment area (Chiwa, 2008). The relationship between land use and hydrology is of greater interest worldwide as it can provide advice for management actions in order to avoid or minimize the negative effects of specific land use activities on the hydrology of a certain region. However, there are still uncertainties on the impact of specific land use practices to different processes of the hydrological cycle due to the complexity and specificity of characteristics of each catchment. Much of the present understanding of land use effects on hydrology is derived from controlled experiments and manipulations of the land surface coupled with observations of hydrological processes, commonly precipitation as inputs and stream flow as outputs (Macuacua, 2011).

The land use and land cover type can affect both the infiltration and runoff amount by following the falling of precipitation. Both surface runoff and ground water flow are significantly affected by types of land cover (Abebe, 2005). Surface runoff and Ground water flow are the two components of the stream flow. Surface runoff is mostly contributed directly from rainfall, whereas ground water flow is contributed from infiltrated water. However, the source of stream flow is mostly from surface runoff during the wet months, whereas during the dry months the stream flow is from the ground water.

2.4. Application of Remote Sensing on LULCC

Remote Sensing (RS) is defined as the science of obtaining information about an object, area, or phenomenon through the analysis of data acquiring by a device that is not contact with the object, area, or phenomenon under investigation (Bawahidi, 2005). It provides a large amount of data about the earth surface for detailed analysis and change detection with the help of sensors. Most of the data inputs to the hydrological model (SWAT) are directly or indirectly extracted from remotely sensed data. Some of the important data used in the hydrological modeling that are obtained from remote sensing includes digital elevation model (DEM) and land cover maps. Some of the application of remote sensing technology in mapping and studying of the land use/land cover changes are: map and classify the land use and land cover; assess the spatial arrangement of land use and land cover; allow analysis of time-series images used to analyze landscape history; report and analyze results of inventories including inputs to Geographic Information System (GIS) and provide a basis for model building. Land use and land cover is changing rapidly in most parts of the world. In such situation, accurate and meaningful data is highly essential for planning and decision making. Remote sensing is particularly attractive for the land cover data among the different sources. Stefanov et al., 2001 reported that in 1970's satellite remote sensing techniques have started to be used as a modern tool to detect and monitor land cover change at various scales with useful results. William et al., 1991 showed that the information of land use and land cover change which is extracted from remotely sensed data is vital for updating land cover maps and management monitoring of natural resource phenomena on earth surface. The importance of land cover mapping is to show the land cover changes in the watershed area and to divide the land use and land cover in different classes of land use and land cover. For this purpose, remotely sensed imagery play a great role in obtaining information on both temporal and spatial distribution of watershed areas and changes over time (Atasoy et al., 2006). To monitor the rapid changes of land cover, to classify the types of land cover, and to obtain timely land cover information, multi temporal remotely sensed images are considered effective data sources.

2.5 Hydrologic Cycle

From the time the earth was formed, water has been endlessly circulating in various reservoirs in the ocean, sky, and soil. This unending circulation of the Earth's moisture is called the water cycle or hydrologic cycle figure (2.1). As with all cycles, the hydrologic cycle is ongoing and continuous, with no specific start or end point; however, by far, the greatest reservoir of water is the ocean, covering about three fourth of the Earth's surface. Water from the oceans evaporates into the atmosphere. The atmosphere then releases this water vapor primarily as precipitation in the form of rain, snow, sleet, or hail. During precipitation, some of the moisture evaporates back to the atmosphere before reaching the ground, some water is intercepted by vegetation, a portion infiltrates to the ground, and the remainder flows off the land into lakes, rivers, or back to the ocean. Groundwater is part of this continuous cycle as water evaporates, forms clouds, and returns to earth as precipitation. The processes in the hydrologic cycle are described as follows:

Precipitation: is the process by which water, in the form of rain, snow, sleet, and hail, falls from the atmosphere to the Earth's surface.

Evaporation: is the return of water from bare soil or/and open bodies of water (mainly the ocean surface) to the atmosphere.

Transpiration: is the transfer of water to the atmosphere through the stomata of vegetation.

Runoff: is the over land flow of water or rainfall that does not soak into the soil.

Infiltration: is the flow of water through the soil surface into a porous medium under the gravity action and the pressure effects.

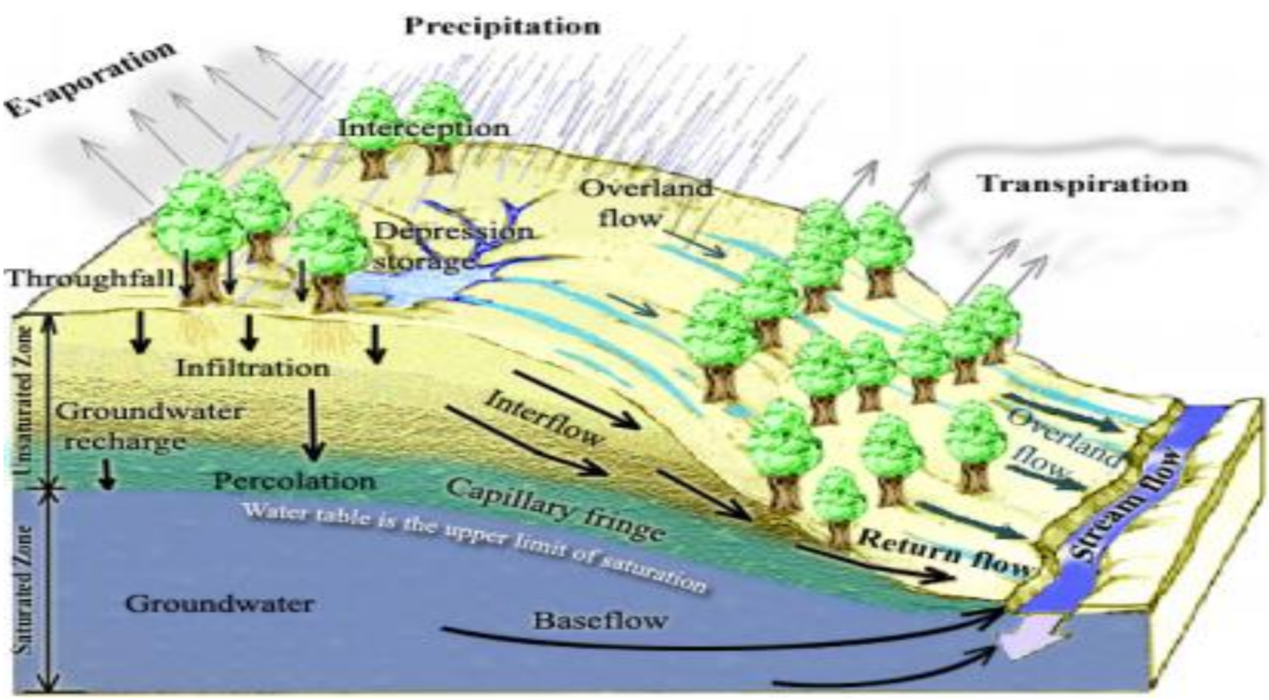

Figure 2. 1 Hydrologic Cycle (source David G, 2003)

2.6 Hydrological Models

A hydrologic model is an approximation of the actual system, with a structure that is a set of equations linking measured inputs and output variables (Chow *et al.*, 1988). Hydrologic models can be categorized two broad classes. (1) Physically-based models that are based on solving governing equations such as conservation of mass and momentum equations. (2) Conceptual models that use simple mathematical equations to describe the main hydrologic processes such as evapotranspiration, surface storage, percolation, snowmelt, base flow, and runoff. The next classification is deterministic and stochastic hydrological models. The deterministic hydrological model as it is the most commonly used modeling approach in hydrology, it can be further classified as lumped, and semi distributed and distributed models (Aghakouchak, 2010 and Nethanet, 2013).

1. Lumped models. Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models.
2. 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 amount of (often unavailable) data. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.
3. Semi-distributed models. Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-

based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT, HEC-HMS, HBV are considered as semi-distributed models.

Generally for this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models. Therefore, three selected semi-distributed models were reviewed Table (2.1).

Table 2. 1 Description of three selected semi-distributed hydrological models

Description	SWAT	HEC-HMS	HBV
Model type	Semi-distributed Physically-based	Semi-distributed Physically-based	Semi-distributed Conceptual model
Model Objective	Predict the impact of land management practices on water and sediment	Simulate the rainfall runoff process of watershed	Simulate rainfall runoff process and floods
Spatial scale	Medium +	Flexible	Flexible
Process Modeled	Continuous	Continuous & event	Continuous & event
Cost	Public domain	Public domain	Public domain

(Source Cunderlik et al., 2003)

2.6.1 SWAT Model

The SWAT (Soil and Water Assessment Tool) watershed model is one of the most recent models developed at the USDA-ARS (Arnold et *al.,* 1998) during the early 1970's. SWAT is a potential distributed parameter and continuous time hydrological model capable of modeling watershed hydrology, irrigation and water transfer, lateral flow, ground water and detailed lake water quality components. It is semi-distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch et al; 2005).

The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed.

In SWAT model, the impacts of spatial heterogeneity in topography, land use, soil and other watershed characteristics on hydrology are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics. The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch, et al, 2005). Major hydrologic processes that can be simulated by the this model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998). Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of study area

3.1.1 Location

The study area, Ribb river watershed is located to the east of Lake Tana, South Gondar Zone in Amhara Region and drains to Lake Tana which is the largest lake of Ethiopia. It is located at a distance of 625km north of Addis Ababa (60km from Bahir Dar town, capital city of the Amhara Region) and has a total drainage area of about 1272 km^2. The length of the main river is about 129.7 km. Geographical coordinate of the area is 12° 35' North and 41° 25' East and 13° 54'N and 35° E. figure (3.1) below shows the main river basin of Ethiopia and the study area map.

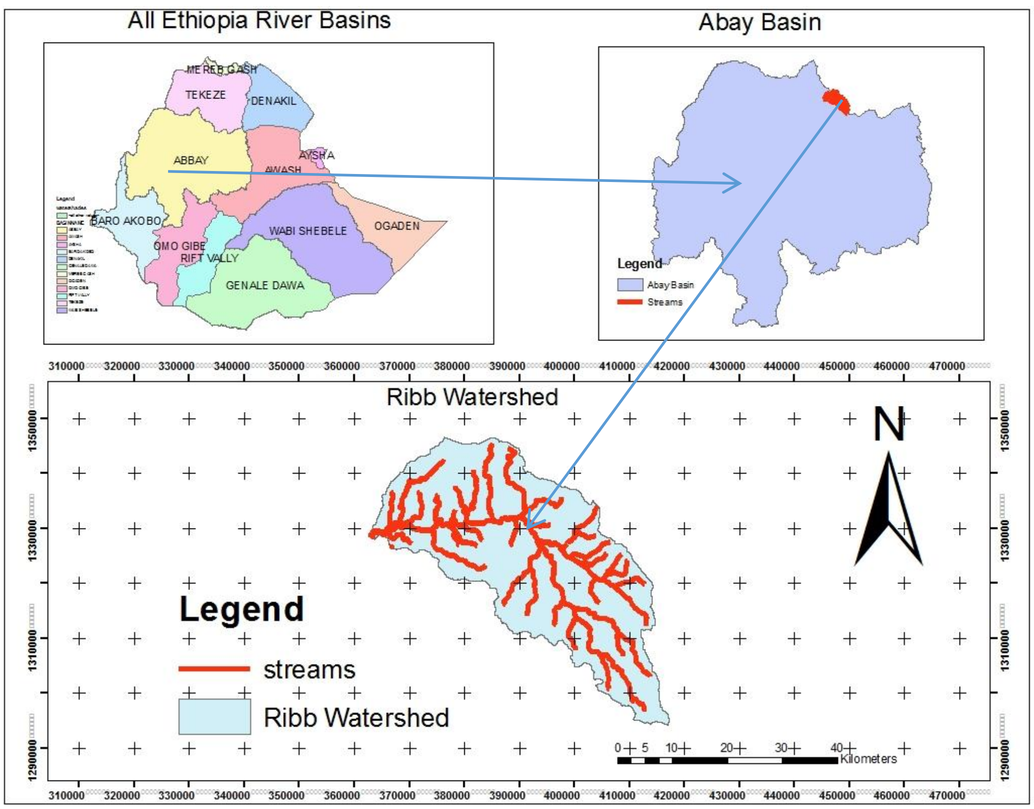

Figure 3. 1 The major river basin of Ethiopia and the study area map

3.1.2 Topography and Slope

The major landform in the watershed include flat, gentle slopping to undulating and rolling hills and mountains and the elevation in the watershed ranges from 1797masl near lake tana to almost 4108masl in the upper ridge. The slope of the watershed is determined from the topographic map with dominantly hilly plains, rolling plains and steep sloped mountains ranges. Slope classes from 0 – 5% cover 24% of the total watershed area while 5 - 20% slope classes, covers 48% and slope class above 20 % which is characterized with very steep slopes on mountains and hills, cover 28% of the watershed.

3.1.3 Geology

Ribb basin which is a sub basin of Lake Tana basin is dominated by a huge volcano system named as Guna mountain shield volcano. It corresponds to the eruptive events that occurred during the early Miocene to Pliocene period and classified in the shield group basalt. The common rock type for this material is basalt with large amount of interbeded lava, volcanic ash and other acidic rocks such as rhyolite and trachyte with rare ignimbrites. Agglomerates and paleo-soils are also common. The other smaller volcanoes located in northern part of the basin are also considered having been active during the same geological period as Guna volcano. The lava flow from the northern source is toward south whereas lava from Guna in this basin is toward north. Here the river follows the area of confluence. This is clearly indicated by the sudden change of the river direction from South to North. Probably this change is the result of blocking of the river by the hard basaltic flows from north side. At the end of the Ribb River (near Lake Tana), the area is completely overlain by recent flood materials, which are mainly covered by silt to clayey deposits (MoWR, 2002).

3.1.4 Soils

Geology, climate and vegetation have been the major soil forming entitles active in the watershed area. Luvisols soil formed in the south to north through south-west (large belt crossing from north-east west and west-north) of the watershed from the basaltic rock cap are deep, well structured, inherently well drained and relatively productive agricultural soil. The second large group of soil in the watershed is Leptosols on the eastern reach with some at the middle and very small on the southern part. This soil is on hill slopes partly on continued hard rocks and partly gravels. The soil is limited in depth having calcareous material or cemented layer within 30 to 40cm depth. There are small pockets of vertisols particularly on hills and mountains tops and fluvisols in valleys along rivers and streams particularly around the proposed dam/reservoir site.

The major soils of the watershed are therefore Chromic Luvisols (39.57%), Eutric Leptosols (36.46%), and Eutric fluvisols (23.83%) in their respective area coverage with small pockets of vertisols on the hill tops and river and streams‟ valleys and Chromic Luvisols as small pockets in different parts. The soils seem to have derived from basalts and tuffs. They are brownish to reddish in color, clay to clay loam and sandy to sandy loam in texture, well drained but very shallow on steep slopes (MoWR, 2002). The Luvisols, fluvisols and vertisols have good inherent fertility and agricultural productivity, although those Leptosols on the mountain ranges and hillsides are severely eroded and further prone to soil erosion. The soil erosion on the hillside slopes and sedimentation at the valleys have already taken place because of intensive annual crop cultivation without soil erosion protection measures (MoWR, 2002).

3.1.5 Climate

Based on the agro climatic classification of Ethiopia, Ribb watershed is characterized with High wurch (on southern edges), Wet dega and Wet Woyna Dega (northern area) agro-climatic zones, with altitude ranges from 1797masl to 4108 masl in the upper ridge (southern edge). The watershed area represents humid, with moderately cool to high frost, agro-climate. Generally, the rainfall pattern in the watershed is unimodal. The mean annual precipitation is about 1511mm with the minimum monthly rainfall of 1mm in January and maximum 411mm in July. Dependable rainfall varies from less than 13mm during the dry season to 80 to 275mm/month during the period of June to July/August, equivalent to 40-80% of the average values. The mean annual temperature is about 20.4^0C while mean minimum temperature is 19^0C in December and monthly maximum temperature is 23^0C in May. Humidity values vary between 70% in December and 88% in August. Average daily sunshine hours are 8.1. Wind speed is reportedly low minimizing, Potential evapotranspiration values between 95mm in December and 140mm in April. In general, a year in the area is divided into two seasons: a rainy season (Kiremt), which occurs from May to September and a dry season (Bega) from October to April. Seasonal variations are four namely, winter (rainy season), summer (dry season), autumn (Small rain), and spring (a spell between rainy and dry season) where dry conditions with high rate off evapotranspiration occur.

3.1.6 Hydrology

The Ribb River, which is a major tributary to Lake Tana, originates at mainly Guna Mountain at the elevation of 4108masl. It collects water from number of streams, within the watershed area. Some of the major tributary stream includes Hamusit, which collects surface runoff from the eastern parts and Kolay, which collects from western parts. The river flows generally in a westerly direction and empties into Lake Tana. The upper section of the valley runs to the north, following the Guna flows direction, while the downstream runs westwards to join Lake Tana, probably because it was blocked by the hard basaltic flows coming from the North (MoWR, 2007).

3.1.7 Land Use/Land Cover

The farming system in the watershed is mixed with dominantly oxen plough cereal crop production and livestock rearing, which is centuries old system. Accordingly, the major land use types in the watershed include cultivated, grazing, very spares and patches of shrub/bushes, plantations, settlement and miscellaneous lands.

It is well understood that Vegetation in a watershed plays multiple effects that include intercepting raindrops, reducing surface runoff, and there by control erosion, maintain soil fertility and maintain the microclimates. It also helps to enrich ground water sources. Nevertheless, in this watershed, the vegetation cover is very scant. There is no natural dense vegetation cover. Only patches of spare and open trees, bush/shrubs exist in hillsides, along rivers‟ courses and pocket areas. Economically and ecologically important indigenous trees are almost disappeared because of the use of tree resources for different socio-economic and socio-cultural needs at the rate of beyond its regenerative capacity. The sparse patches of bushes exist particularly in the northern reach hills and natural big trees around churches and on the southern mountain (mount Guna) range while man made plantations along main roads, towns and rural homesteads. The central part, all across east to west edges, is absolutely denuded of vegetation cover except only very sparse on farm trees here and there observed (MoWR, 2002).

3.2. Materials Used

For proper implementation of the study, some equipment, materials and software are required for data collection, processing and evaluation. Some of the software and materials required for this study include;

- Arc-GIS 9.3 to obtain hydrological and physical parameters and spatial information of the catchments of the study area.
- Soil and Water Assessment Tool (SWAT2009) software
- SRTM 90m resolution DEM data is used as an input data for Arc-GIS software for catchment delineation and estimation of catchment characteristic
- Hydrological data(Daily Discharge) and sediment concentration
- Meteorological data (Precipitation, Maximum Temperature. Minimum Temperature, Solar Radiation, Wind Speed and Sunshine)
- GPS
- Land use/land cover data
- Soil data
- Dew02
- SWAT_CUP
- Excel spread sheet for pre and post processing etc.,

3.3 Data Collection

Different methods of data collection were used for collecting necessary data, materials and information by using two major categories of data gathering techniques such as field of primary data and gathering secondary data. The required hydro-meteorological data, DEM, land use map, soil map were obtained from different organizations which are presented below**.**

3.3.1 Digital Elevation Model (DEM)

Spatial input data a Digital Elevation Model (DEM) gives the elevation, slope and defines the location of the streams network in a basin. Digital Elevation Model is one of the essential inputs required by SWAT to delineate the watershed in to number of sub watershed or sub basins. The DEM is used to analyze the drainage pattern of the watershed, stream lengths, and widths of channel within the watershed. The raw DEM was processed and projected using Arc GIS 9.3. A DEM used in this study obtained from Ministry of Water, Irrigation and Energy (MoWR, 2015).

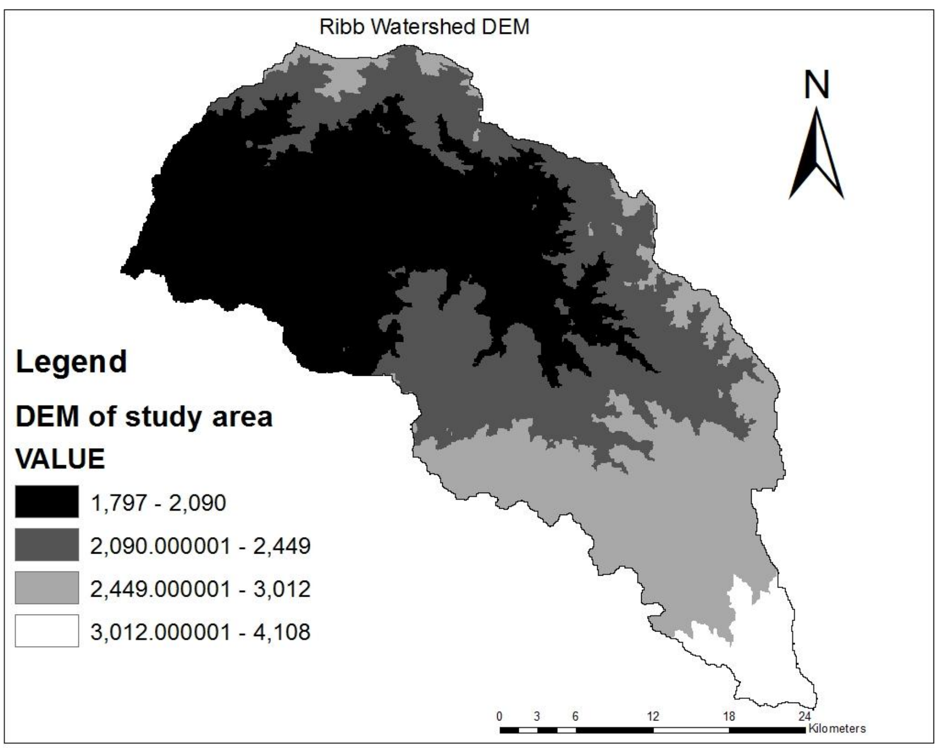

Figure 3. 2 DEM of study area

3.3.2 Land Use/Land Cover Map

The land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a catchment. The land use/land cover map gives the spatial extent and classification of the various land use/land cover classes of the study area. The land use land cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and the storage in the soil layers. The Land use data were obtained from ministry of water, irrigation and energy of Ethiopia.

3.3.3 Soil Data

The soil data as required by Arc SWAT to predict the stream flow and sediment yield should include the relevant inputs concerning catchment's soil physical and chemical properties. First the shape file format of soil type distribution through the catchment was collected from Ministry of Water, Irrigation and Energy (MoWR,2015). Major soil of study area include Chromic Luvisols, Eutric Fluvisols, Eutric Leptisols,Haplic Nitisols and Urban**.** Using this shape file, soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type were extracted from major Soils of the world database (FAO, 1995) and Digital soil map of the world database. Figure (3.3) the major soil types of the study area.

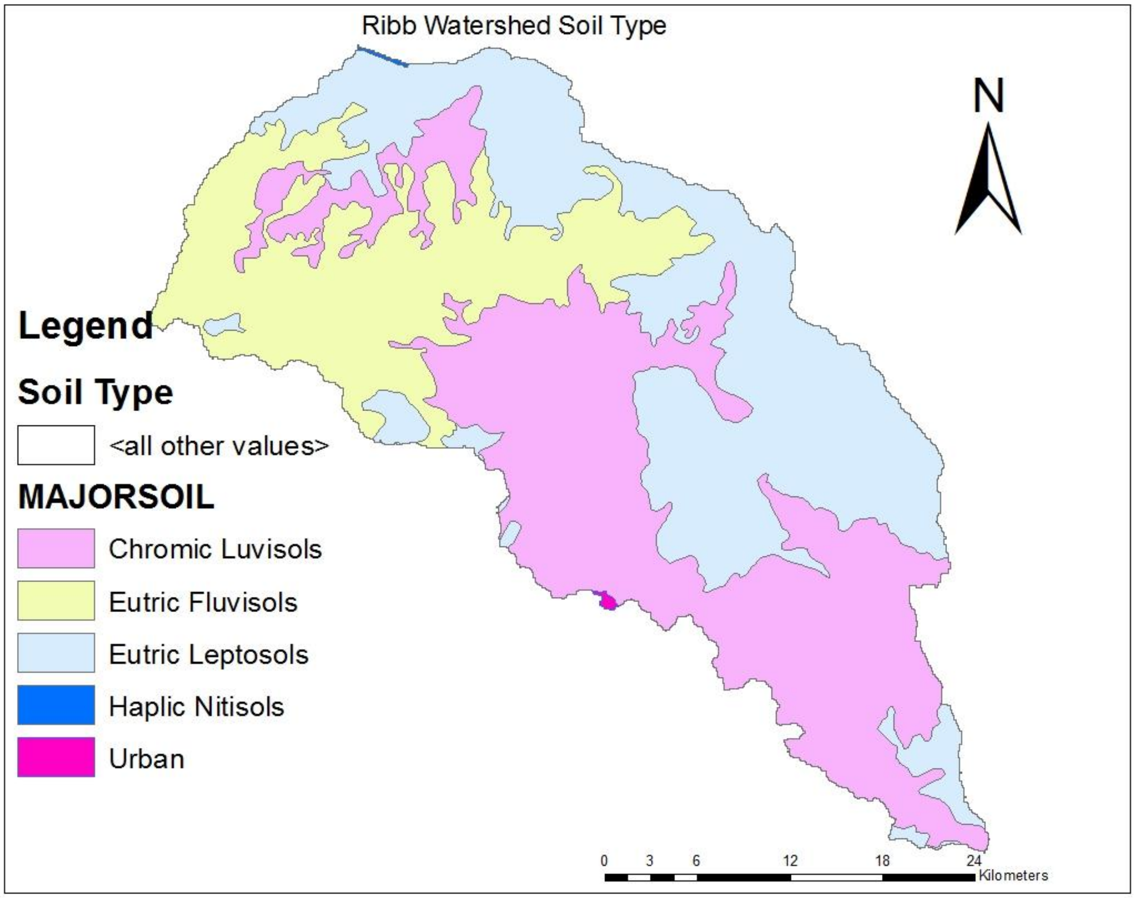

Figure 3. 3 study area soil map

Table 3. 1 major soil types of the study area

S/No	Soil Type	Area	
		Km^2	%
1	Chromic Luvisols	503.5	39.6
2	Eutric Fluvisols	303.3	23.8
3	Eutric Leptisols	463.9	36.5
4	Haplic Nitisols	0.76	0.005
5	Urban	1	0.008

3.3.4 River Discharge and Sediment yield

Daily river discharge values and sediment concentration for Ribb River were obtained from the hydrology department of the Ministry of Water, Irrigation and Energy (MoWR, 2015) Ethiopia. These daily river discharges and sediment concentrations at Ribb River were used for model calibration and validation. River discharge and sediment concentration data was available for one Station in between (Addiszemen and Woreta towns). The station have discharge data from 1994 to 2014, though they have missing data. Table (3.2) gives the summary of the stream flow data and the percentage of missing data.

Table 3. 2 Summary of available flow data with percent of missing

Station name	X-Coordinate	Y-Coordinate	Elevation	Length of data used	Percent of missing data (%)
Ribb	359551	1325931	1798	1994-2014	7.13

3.3.4.1 Rating Curve

The available sediment concentration data was converted to sediment load in order to develop rating curve. Rating curve is the graphical representation of flow versus sediment load. Sediment load is calculated from the discharge and sediment concentration as follows.

$$S = 86.4 * Q * C \quad \text{-----------------------} \quad (3.1)$$

Where: S = sediment load (ton/day)

Q = discharge (m^3/s)

C = sediment concentration (kg/m^3)

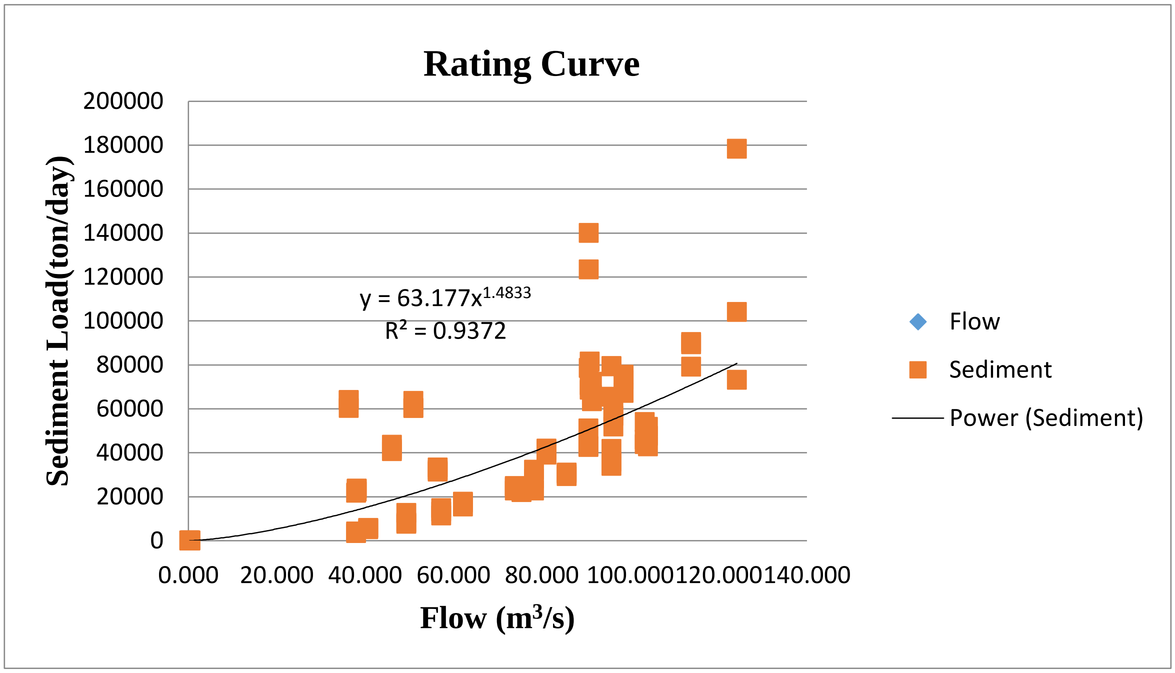

Figure 3. 4 Rating curve of flow versus sediment load

From the above rating curve graph BCEOM (1999) gave the following equation for estimating the daily suspended sediment load.

$$Q_s = 63.177 * Q_d^{1.4833} \text{ -- (3.2)}$$

Where, Q_s = Suspended sediment mass transport rate (ton/day)

Q_d = daily discharge (m3/s)

63.177, 1.4833 was constants obtain from Rating Curve

Based on the above rating curve equation, the monthly suspended sediment loads were estimated at the Ribb gauging station for the period of 1994-2014.

3.3.5 Weather Data

SWAT also needs daily long years of climate data for the simulation of hydrological processes. For this specific study, the necessary climate data were collected from the National Meteorological Services Agency (NMSA). Since there may be few meteorological stations which have relatively long period of records inside the meteorological variables that have been collected like humidity, sunshine hours, and wind speed in addition to rainfall, maximum and minimum temperatures. The number of meteorological variables collected varies from station to station depending on the class of the stations. Some stations contain only rainfall data. The other group includes maximum and minimum temperature in addition to rainfall data. There are also stations which contain variables like humidity, sunshine hours, and wind speed in addition to rainfall, maximum temperature and minimum temperature. The first class station Debretabor which have all components of climatic variables mentioned above were used as weather generator station. Four meteorological stations (Debretabor, Addiszemen,Woreta and Ageregenet) Data of precipitation, maximum and minimum temperatures, sunshine hours, relative humidity, and wind speed were collected within and around the catchment. The collected data ranges in time between (1994-2014), though there were quite a number of missing data. Table (3.3) below shows the stations used for this study including their class and location.

Table 3. 3 station class and location

Name	Class	X-Coordin	Y-Coordinate	Elevation	Meteorological variables
Addiszem	III	366478	1339791	1940	PCP,Tmax,Tmin
Ageregene	III	423633	1304644	3010	PCP,Tmax,Tmin
Debretabo	I	390538	1312044	2612	PCP,Tmax,Tmin,RH,SLR,W
Woreta	III	357996	1318262	1819	Rainfall,Tmax,Tmin

3.3.6 Field Work

A preliminary reconnaissance was conducted in selected Ribb Sub-catchment. During fieldwork, visual observations through transect walks were made along selected routes for the identification of surface features and land use types and key information interviews and group discussions were conducted. The existing situation of the sub-catchment and the general idea of the physical characteristics of the area were visited. Focus group discussion was used to supplement other data sources. This was done through discussions with the communities living in the villages in the sub-catchment. Most of them were elders who are longtime residents of these areas. During the focus group discussion, the objective was to get information on the land use history of the sub catchment, factors contributing to land use change and measures taken to mitigate negative effects. Field work was also conducted for ground truth verification of mapped features by collecting GPS data. The GPS was used to collect coordinates for geo referencing the satellite images, aerial photographs and to verify the accuracy of the classified satellite images. During field work hydro-meteorological gauging stations was observed. The overall flow of a river was assessed at gauging station that captures all the flow from all upper in the sub-catchment. Figure(3.7 a, b, c, d,) shows field observation of the study area.

(a) Gauging station

(b) River flow (c) Uncontrolled/ Overgrazed land leading to land degradation

(d) Deforestation practices for cultivation ultimately leading to severe soil erosion
Figure 3. 5 field observation

3.4 Data Quality Analysis (Control)

3.4.1 DEM, Land use/Land cover and soil map

The DEM, land use/land cover and soil map layers provided spatial information of the study area for the watershed-modeling program. Both land use and soil maps were provided by extracting large dataset land use/cover and soil map obtained from Ministry of Water Resource (MoWR) of Ethiopia after importing them into ArcGIS interface. Similar attribute classes of the two extracted maps that had different names either because of spatial variability or have no distinct difference in terms of hydrological prospect that had been reclassified and renamed before they have been used for further task. By doing this, the same classes have been assigned in the same name and the comparable classes have also been combined in to one name. To arrange all the layers geometrically so as fit to the study area, they were geo-referenced to the corresponding coordinate projection of the study area which is Adindan_UTM_Zone_37N.

3.4.2 Filling Missing Weather Data

Measured precipitation data are important to many problems in hydrologic analysis and design. For gauges that require periodic observation, the failure of the observer to make the necessary visit to the gauge may result in missing data. Vandalism of recording gauges is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the weather data record. There are number of methods for estimating missing data such as, Arithmetic average method, normal ratio method, quadrant method, and inverse distance, weighting method and regression methods. The most common method used to estimate missing rainfall data is Normal Ratio method (Chow et al, 1988). Normal ratio methods are expressed by the following relationship:

$$Px = \frac{Nx}{N}\left(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pn}{Nn}\right) \quad (3.3)$$

Where, P_x =Missing value of precipitation to be computed.

N_x = Average Annual value of rainfall for the station

N_1 ,N_2………N_n= Average Annual value of rainfall for the neighboring station.

P_1,P_2..............P_n= Rainfall of neighboring station during missing period

N= Number of stations used in the computation.

The percentage of Missed data resulting from lack of appropriate records, shifting of station location and processing for each station and data type are shown in table (3.4) below.

Table 3. 4 Percentage of daily data missed

Station name	Class	Data length	Rain Fall	Maximum temperature	Minimum temperature	Relative humidity	Sunshine hour	Wind speed
Addiszemen	III	1994-2014	6.86	9.0	9.45	No data	No data	No data
Ageregenet	III	1994-2014	15.6	6.52	6.15	No data	No data	No data
Debretabor	I	1994-2014	2.72	2.91	3.57	1.77	2.14	1.63
Woreta	III	1994-2014	5.4	11.54	6.76	No data	No data	No data

Thus after filling the missing daily data of 21years weather data, their consistence is checked by double mass curve.

3.4.3 Checking the Consistency of Data

A consistent record is one where the characteristics of the record have not changed with time. Adjusting for gauge consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result from any one of a number of events; specifically, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gauge, changes in land use that make it unreasonable to maintain the gauge at the old location, and where vandalism frequently occurs.

Double-mass-curve analysis is the method that is used to check for an inconsistency in a gauge record. The curve is a plot on arithmetic graph paper of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region.

The method for checking consistency of a hydrological or meteorological record is considered to be an essential tool for taking it for analysis purposes. It is determined by plotting the cumulative values of observed time series of station for which consistency need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x-axis. The station affected by trend or a break in slope of the curve would indicate that conditions have changed that location. The data series, which is inconsistency, will be adjusted to consistent values by proportionality. Therefore, the station to be adjusted for consistency by using the equation:-

$$Si = \frac{\Delta Yi}{\Delta Xi} \qquad (3.4)$$

Where, Si: is the slope of section i,

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

ΔXi: is the change in the cumulative catchment for the sum of the regional gages between the endpoints of sections i.

The double mass curve below shows figure(3.5) four of the stations found in catchment has better correlation as it's shows the plot of cumulative annual rainfall of neighboring stations verses cumulative annual average rainfall of group stations straight lines so that correction for consistency will not be done.

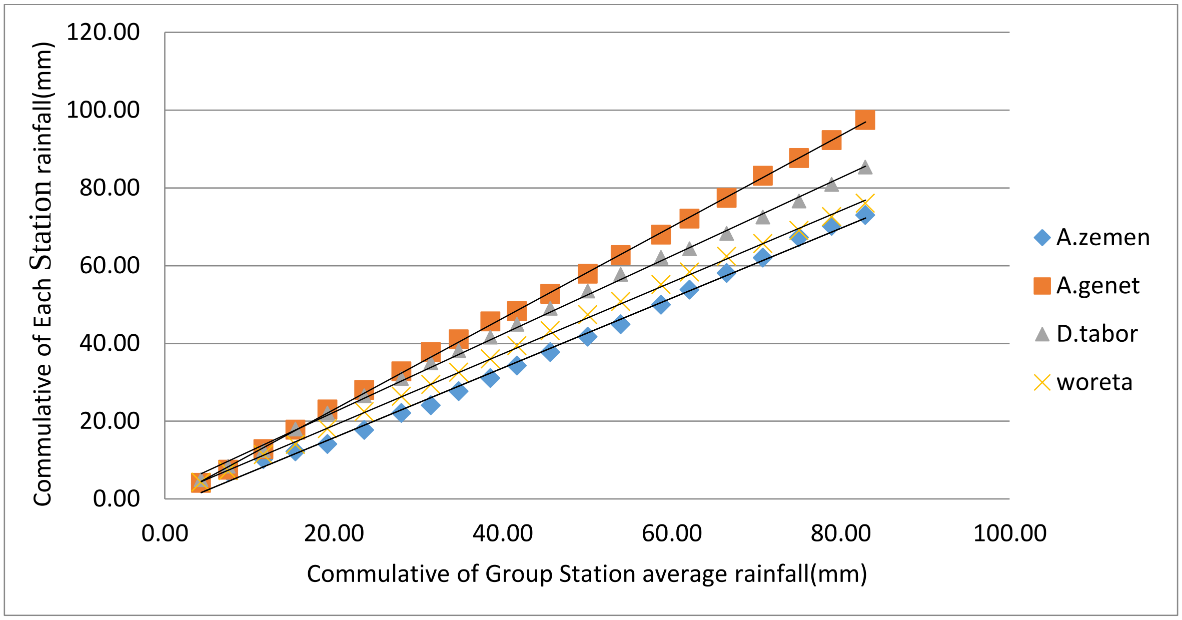

Figure 3. 6 Double Mass Curve plots for consistency check of rainfall average

3.4.4 Estimation of Mean Rainfall

Rain gauge represents only point sampling of the areal distribution of a rainfall. In practice, however, hydrological analysis requires knowledge of the rainfall over an area. Arithmetic average, Isohyetal and Theissen polygon methods are in use to convert the point rainfall values at various stations in to an average value over a catchment. Among those methods Theissen polygon method is used for this study even though the method is depend on a good network of representative rain gauges. The advantage of this method is that easy to understand, allows for the uneven distribution of rain gages and the disadvantage is that it does not take in to account the effect of geographic nature on rainfall. Thiessen polygon method is one way of calculating areal precipitation. The method gives weight to point data in proportion to space between stations. Lines are drawn between adjacent stations on map. The area of each polygon inside the sub basin area is calculated. Figure (3.6) below shows Thiessen polygon of Ribb watershed used as weight of station studies with in that polygon

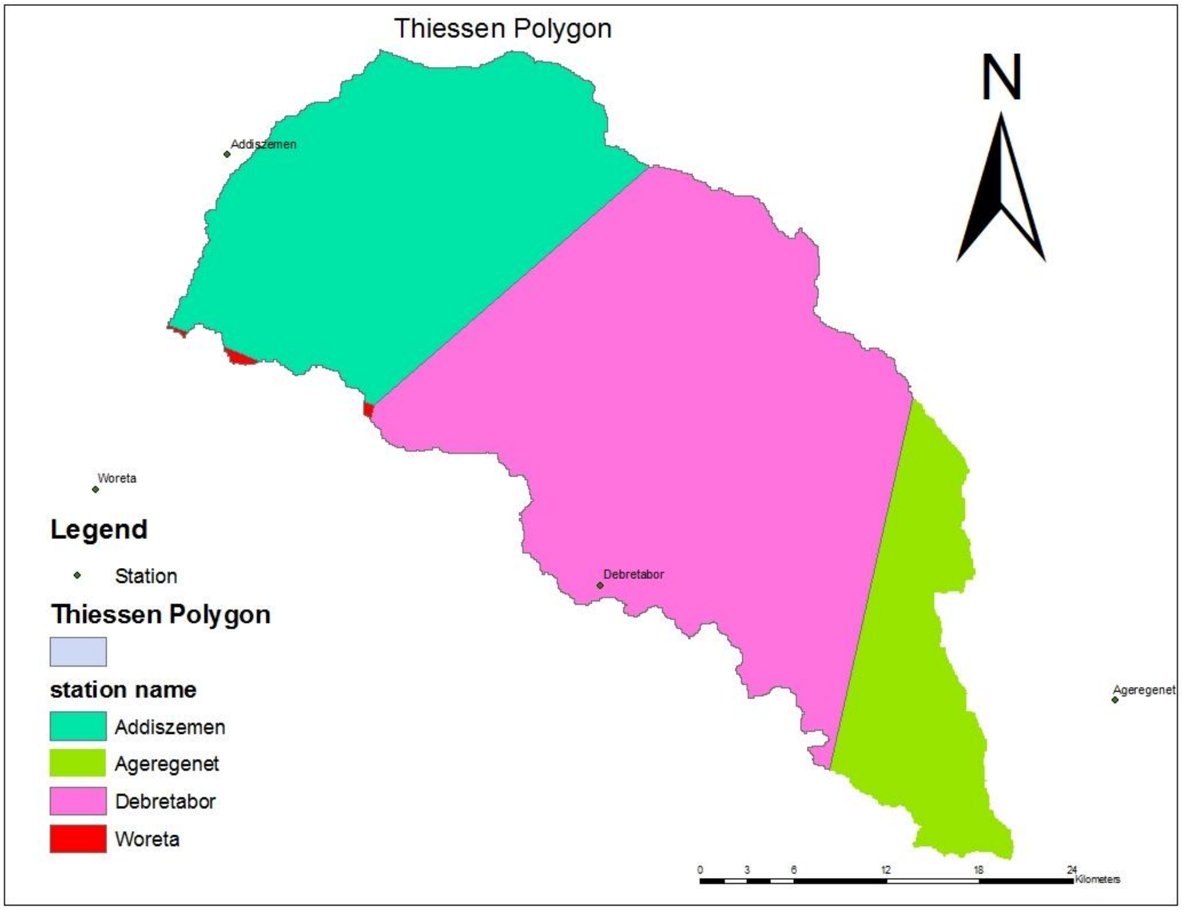

Figure 3. 7 Thiessen polygon of Ribb watershed

Thiessen polygon is drawn by using Arc GIS software. After drawing the polygon, it is necessary to find percentage of area that each rainfall station represents. To determine mean areal rainfall, amount of rainfall at each station multiplied by area of its polygon and the sum of those products is divided by total area of the catchment. Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P_1, P_2, P_3 ... p_n are the rainfalls at the individual stations, and A_1, A_2, A_3 ... A_n are the areas of the polygon surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$P_{avg} = \frac{\sum AiPi}{A_T} \text{------} (3.5)$$

Where, P_{avg} = Areal average rainfall

A_T= total area of the basin

P_1, P_2, P_3 ... p_n are the rainfalls at the individual stations

A_1, A_2, A_3 ... A_n are the areas of the polygon surrounding these stations,

Table (3.5) below is result obtained from Thiessen polygon showing area covered by each station. Aerial depth of precipitation obtained using this method was presented in Table (3.5).From the result the total annual precipitation over the catchment is 1511mm.

Table 3. 5 Thiessen polygon result for meteorological station

Station Name	Area		Mean Annual Rainfall(mm)
	(km^2)	(%)	
Addiszemen	408.87	32.13	1480
Ageregenet	173.14	13.6	1695
Debretabor	688.45	54.1	1484
Woreta	1.94	0.15	1321
Areal average	1272	100	1511

3.5 Hydrological Model Selection Criteria

There are multiple criteria which can be used for choosing the "right" hydrologic model. These criteria are always project-dependent, since every project has its own specific requirements. Among the various selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik *et al.*, 2003):

- Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as long-term sequence of flow?),

- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?),
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),
- Price (Does the investment appear to be worthwhile for the objectives of the project?

Generally, the reasons behind for selecting SWAT model for this study are:

- Physical based model: It is based on readily observed and measured information and it attempts to simulate many hydrological components.
- The model was applied for land use and land cover change impact assessment in different parts of the world.
- It is public domain with for free and online access.
- Its compatibility with ArcGIS interface: for ease of data base management.
- It's easy linkage to sensitivity, calibration and uncertainty analysis tools.
- Its smart and coordinated user groups.

3.6. Description of SWAT Model

SWAT is a basin-scale model designed to simulate hydrologic processes, nutrient cycling, and sediment transport throughout a watershed (White *et al.*, 2009). In order to simulate hydrological processes in a watershed, SWAT divides the watershed in to sub watersheds based upon drainage areas of the tributaries. The sub watersheds are further divided into smaller spatial modeling units known as HRUs, depending on land use and land cover, soil and slope characteristics.

The SWAT hydrological compartment in a watershed consists of a land phase and a water routing phase. The land phase of the hydrological cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub watershed. While the routing phase considers the movement of water, sediment and agricultural chemicals through the channel network to the watershed outlet (Neitsch *et al.*, 2005).

The model has eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch *et al.*, 2005). However, brief description of some of the SWAT computation procedures which are considered in this study are presented under the following subsections.

3.6.1 Water balance equation

The model estimates relevant hydrologic components such as evapotranspiration, surface runoff and peak rate of runoff, groundwater flow and sediment yield for each HRUs unit. SWAT is imbedded in a GIS interface. The hydrologic cycle simulated by SWAT is based on the water balance equation (3.6).

$$S_{wt} = S_{wo} + \sum_{i=1}^{t} (Rday - Q\,surf - Ea - Wseep - Qgw) \quad (3.6)$$

In which, SWt is the final soil water content (mm water),SWo is the initial soil water content in day i (mm water), t is the time (days), Rday is the amount of precipitation in day i (mm water), Qsurf is the amount of surface runoff in day i (mm water), Ea is the amount of evapotranspiration in day i (mm water), Wseep is the amount of water entering the vadose zone from the soil profile in day i (mm water), Qgw is the amount of return flow in day i (mm water)

3.6.2 Surface Runoff Generation

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration (Solomon, 2005). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. To determine the respective amounts of infiltration and surface runoff, SWAT used the popular Curve Number (CN).

To model surface runoff for any given day, the first step that SWAT takes is to assign an initial NRCS Curve Number (CN) for each specific land use and soil combination in the watershed, then calculates upper and lower limits for each CN following a probability function described by the NRCS to account for varying antecedent moisture conditions (AMC). SWAT determines an appropriate CN for each simulated day by using this AMC distribution in conjunction with daily soil moisture values determined by the model (White *et* *al*., 2009). In developing the SCS rainfall-runoff relationship, the total rainfall was separated into three components: direct runoff (Q), actual retention (F), and the initial abstraction (Ia). The retention F was assumed to be a function of the depths of rainfall and runoff and the initial abstraction. The development of the equation yielded:

$$Q = \frac{(P-Ia)^2}{P-Ia+S} \quad \text{------} \quad (3.7)$$

Where, P is the depth of precipitation (mm)

Ia is the initial abstraction (mm)

S is the maximum potential retention (mm)

Q is the depth of direct runoff (mm).

Given Equation (3.7), two unknowns need to be estimated S and Ia. The retention S should be a function of the following five factors: land use, interception, infiltration, depression storage, and antecedent moisture. Empirical evidence resulted in the following equation for estimating the initial abstraction.

$$Ia = 0.2S \quad \text{------} \quad (3.8)$$

If the five factors above affect S, they also affect Ia. Substituting Equation (3.8) into Equation (3.7) yields the following equation, which contains the single unknown S:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{------} \quad (3.9)$$

A curve number is an index that represents the combination of a hydrologic soil group and a land use and treatment class. Empirical analyses suggested that the CN is a function of three factors: soil group (A, B, C and D soils have high, moderate, slow, and very low infiltration rates with low, moderate, high, and very high runoff potential), the cover complex, and antecedent moisture conditions.

$$S = 25.4(1000/CN - 10) \quad \text{------} \quad (3.10)$$

3.6.3 Computation of Evapotranspiration

The combination of two separate processes where by water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET).

Evaporation: is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface (vapour removal).Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

Transpiration: consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata. These are small openings on the plant leaf through which gases and water vapour pass .SWAT2009 offers three methods for estimating PET: the Penman-Monteith , Priestley-Taylor, and Hargreaves model. In this study daily potential evaporation is calculated by using Penman Monteith formula. The Penman Monteith requires radiation, air temperature, air humidity, and wind speed data.

$$ET_O = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \quad (3.11)$$

Where: ETo reference evapotranspiration (mm day-1), Rn net radiation at the crop surface (MJ m day-1), G soil heat flux density (MJ m-2day-1), T mean daily air temperature at 2m height (°C), u2 wind speed at 2m height (m s), es saturation vapour pressure (kPa), ea actual vapour pressure (kPa), es-ea saturation vapour pressure deficit (kPa), Δ slope vapour pressure curve (kPa °C-1),and γ psychrometric constant (kPa °C-1).

3.6.4 Sediment Transport Equations

SWAT calculates the soil erosion and sediment yield with the Modified Universal Soil Loss Equation (MUSLE), (Williams and Berndt, 1977) equation (3.12).

$$Sed = 11.8(Q_{sur}*q_{peak}*area_{hru})^{0.56}*K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG \quad (3.12)$$

Where sed is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume (mm water/ha),q_{peak} is the peak runoff rate(m3/s), $area_{hru}$ is the area of the hydrological research unit (HRU) (ha), K_{USLE} is the USLE soil erodibility factor((0.013 metric ton m^2 hr/ m^3- metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor. The details of the USLE factors and the descriptions of the different model components can be found in (Neitsch et al., 2005).

ArcSWAT preprocessing into four main steps: Watershed Delineation, Hydrologic Response Unit (HRU) Analysis, Weather Data Definition and SWAT simulation including sensitivity analysis and calibration. In order to understand how each section works with in the modeling process, it is important to understand the conceptual framework of each step, as well as what data are used and how they are integrated into Arc SWAT. Figure (3.8) below shows the flow chart of modeling using arc SWAT.

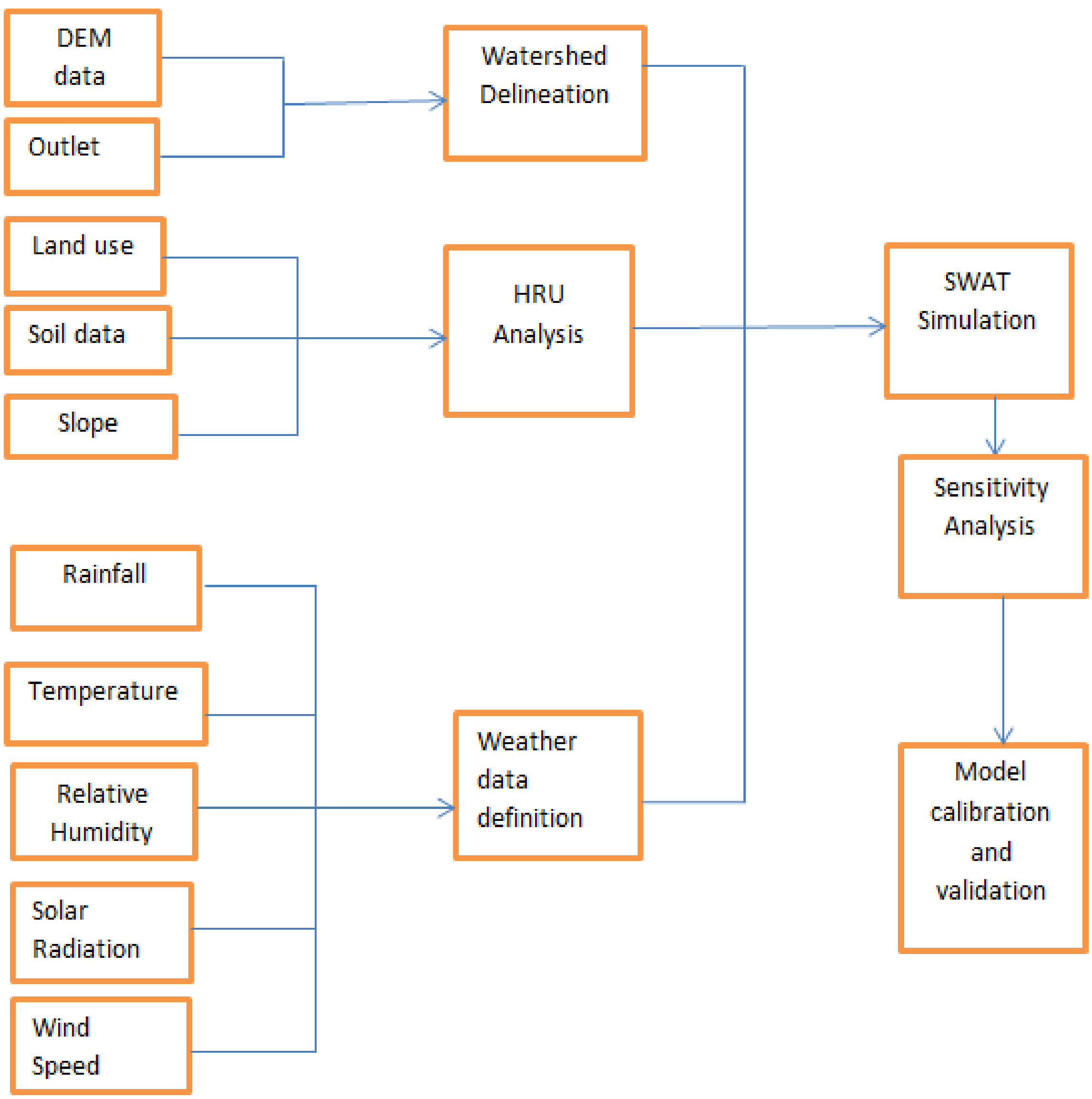

Figure 3. 8 Conceptual frame work showing ARC SWAT Processes

3.7 SWAT CUP

SWAT CUP is an interface that was developed for SWAT. Using this generic interface, any calibration or sensitivity program can easily be linked to SWAT. This is demonstrated by the program links GLUE, Parasol, SUFI2, and MCMC procedures to SWAT. In this particular study, it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration that requires the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model.

3.8 Model Set-Up

3.8.1 Watershed Delineation

As mentioned before, the watershed analysis for the Ribb catchment was performed using ArcSWAT2009. An imported 90 m by 90 m resolution DEM to Arc SWAT work space was used to delineate the watershed of the study area. The stream network and the sub basin outlets were defined. Catchment, the gauge station inside the basin, was manually added and defined as an outlet. The watershed was delineated into 25 sub basin figure(3.9) subsequently; the geomorphic parameters for each sub basin were calculated.

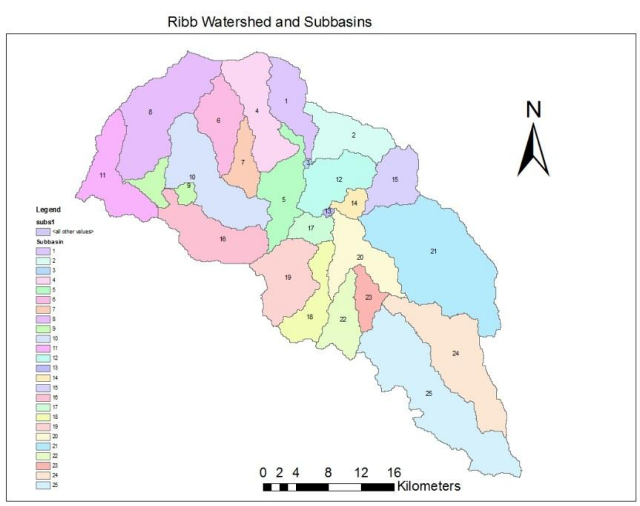

Figure 3. 9 Ribb watershed Sub basins

SWAT model require land use/land cover and soil data in order to determine the area and the hydrologic parameters of each land use and soil category simulated in each sub watershed. The land use/land cover, slope and soil map were imported into the interface and reclassified. Classes which belonged to the same category and had close hydrological properties were combined into six land use/land cover major classes. The very small classes which are far less than 5% percent of the total area were ignored. This was done using Arc Map interface Arc SWAT. Land use, slope and soil were reclassified again in Arc SWAT interface. Current SWAT database has only values of hydrological property parameters of the most common type of land use/land cover classes. Some of the land use land cover classes and their parametric values did not exist in SWAT default data base. It was necessary to replace these classes with land use/land cover classes of the SWAT database which have similar hydrological properties.

Therefore, during reclassification, land use/land cover classes which were not exist in SWAT database substituted by classes which exist in SWAT database and have similar hydrological properties. The soil map of the study area was reclassified according to Arc SWAT requirements. It was reclassified into the most representative classes of the study area. During the reclassifying process there was a problem of obtaining the values of soil parameters that represent physical and chemical properties of each soil class which were used as SWAT input data. Food and Agriculture Organization of the United Nations (FAO) soil classification system which was supported by other additional method was used to determine soil types and properties of each soil class. Partly the values of the parameters of hydrological properties have been determined by studying typical textural characteristics of an existing soil material and estimating their values by referring other similar previous works.

Slope classification was carried out based on the height range of the DEM used during watershed delineation. The slope values were reclassified in percent. It was reclassified in to three classes. In the next step, all the reclassified three maps were overlaid. This procedure helped to determine land use/cover /soil /slope class combination and distribution for the delineated watersheds and each respective sub-watershed. Then, the sub basins were divided into Hydrologic Response Units (HRUs) by assigning the threshold values of land use/cover and soil percentage. While assigning multiple HRUs to each sub basin the thresh hold level should be defined in which the user can specify sensitivities for land use/cover, soil and slope data that will be used to determine the number and kind of HRUs in each watershed. In general the thresh hold level used to eliminate minor land use/land cover in sub basin, minor soil with in a land use/land cover area and minor slope classes with in a soil on specific land use/land cover area. Following minor land use/land cover, soil areas and minor slope classes elimination, the area of remaining land use/covers, soils and slope classes are reapportioned so that 100% of their respective areas are modeled. SWAT2009 threshold value was chosen for soil and land use/land cover for defining the number of HRUs.

3.8.2 HRU Definition

A watershed is subdivided into sub basins based on the number of tributaries. The sizes of watershed and number of sub basins in the watershed vary from place to place. The sizes of sub basins also vary based on the nature of the topographic and the stream network system of an area. The sub basins of the watershed are divided into 183 multiple Hydrologic Response Units (HRUs). The HRUs represent areas with homogeneous land use/cover, management, and soil characteristics. However they have no separate spatial representation in SWAT simulation. The HRU in SWAT are spatially implicit, their exact position on the surface cannot be identified, and the same HRU may cover different locations in a sub basin (Neitsch et al., 2002). Each HRU in a sub watershed is liable for flow, sediment, nutrient, and pesticide loadings that are routed through channels, ponds, and/or reservoirs to the watershed outlet. Detailed descriptions of the model and model components can be found in (Arnold et al., 1998) and (Neitsch et al., 2000).The main part of SWAT analysis can be performed in ArcSWAT2009 interface. Geographical Information System (GIS) is used as an auxiliary and a preprocessor to the SWAT modeling process. ArcGIS 9.3 can be used for managing and processing spatial data which were used as SWAT input data in a project. Spatial data including digital elevation model (DEM), thematic map layers of land use/cover and soil data are necessary data to perform hydrological water balance analysis of a basin in SWAT. The DEM is used to gain the topographical characteristics of an area which are required by SWAT modeling and has direct impact on hydrological cycle. The land use/cover map is used to categorize vegetation types that have impact on the hydrological process of the area. The soil map is used to identify physical and chemical characteristics of various soils that have major role in the hydrological process of an area. Whereas weather data can be entered in SWAT interface following the reclassification of land use/land cover and soil data. It is important for calculating the water balance components in each HRU in the watershed.

The SWAT model requires the creation of Hydrologic Response Units (HRUs), which are the unique combinations of land use, soil and slop type within each sub basin. The land use, soil and slop classifications for the model are slightly different than those used in many readily available datasets and therefore the land use, soil and slop data were reclassified into SWAT land use and soil classes.

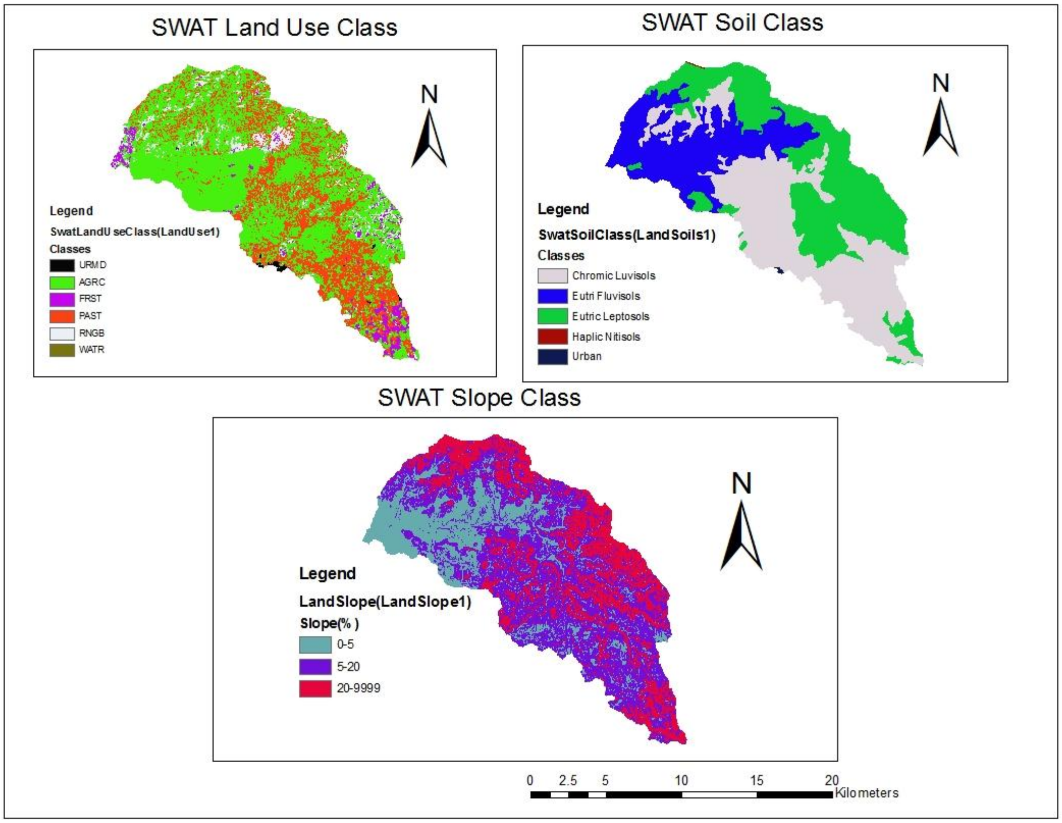

Figure 3. 10 Reclassified land use, soil and slope of rib watershed

3.8.3 Entering Weather Data

Daily time-series of weather data, which includes precipitation and maximum and minimum air temperature data, is required for the SWAT modeling. The climatic stations which were used in the study are called Debretabor, Addiszemen, Woreta, Ageregenet. The periods of the measured weather data, which was obtained from National Meteorology Service Agency of Ethiopia (NMSA), was differ from station to station. From January 1st 1994 to December 31th 2014 including 2 year warm up period was used for SWAT simulation. To deal with the weather data, it should be stored in a specific tabular and supportive file format of Arc SWAT. In this case, they were stored in DBF format which is read by Arc SWAT interface. The geographical coordinate names of the weather stations of the study area were introduced into Arc SWAT database. The data has provided the most representative precipitation and temperature data available. However, some metrological data such as: wind speed, daily sunshine hour and relative humidity data available only at Debretabor station. Even though they were less significant compare to the data which were obtained, they were generated by the model. The elevation of precipitation and temperature gauges were entered. The elevation information help to correctly estimate the amount of rainfall and temperature for a given elevation band in the sub basin.

3.8.4 SWAT Simulation

The database files containing the information needed to generate default input for SWAT model were built. In SWAT, once the default input database files are built, the necessary parameter values can be entered and edited manually. The HRU distribution was also modified whenever it was needed. The soil parameters values of each type of soil were entered. The land use land cover parameters were edited where it was necessary. SWAT simulation run was carried out on the 1994-2014 climate data. Two year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm-up period differ from catchment to catchment. It is mainly depend on the objective of the study. The run output data imported to database and the simulation results were saved in different files of SWAT output. It is used for SWAT model calibration since most of the observations of the watershed's behavior are obtained by measuring these parameters.

3.9 Sensitivity Analysis

There are several parameters which affect a complex hydrological modeling. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in description of both the elements and processes present in the system are some of the reasons. Therefore, optimizing internal parameters of a model is an important task in order to achieve a well representative hydrological model. This kind of task is called model calibration which is usually supported by sensitivity analysis. Sensitivity analysis helps to determine the sensitivity of parameters by comparing the output variance due to input variability. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability. Therefore, the number of parameters that can be involved for calibration will be less in number and influential. It also evaluates the model capacity and helps to understand the behavior of the system being modeled. Sensitivity analysis was performed to determine the influence a set of parameters had on predicting total flow. The analysis was carried out to identify the SWAT hydrologic sensitive parameters by comparing their relative sensitiveness. It was performed on Twenty-seven different SWAT parameters. Then the model parameters used in the sensitivity analysis of stream flow were selected and the method algorithm for analysis was defined. By applying default lower and upper boundary parameter values, the parameters were tested for sensitivity analysis for the simulation of the stream flow. 'Average criteria' options have been selected for 'sensitivity analysis output'. Finally the sensitivity analyses were run for the main Ribb river gauge station. In the analysis, the sensitive parameters of the stream flow of the basin were identified. The parameters, which resulted from the analysis, were ranked according to the magnitudes of response variable sensitivity to each of the model parameters, which divide high and low sensitivities. The method used to determine the dominant hydrological parameters and to reduce the number of model parameters which will be used in calibration. However, parameters that had been not evaluated during sensitivity analysis have to be modified during calibration so that the simulated flow model parameters fit that of the observed stream flow parameters. Modifying parameters other than those identified during sensitivity analysis was carried out with investigating the type of error which occurs in simulated variables.

Therefore, sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Lenhart et al., 2000).

Table 3. 6 parameter sensitivity classes (Lenhart et al., 2000)

Sensitivity class	Index	Sensitivity
I	< 0.05	Small to negligible
II	0.05 =< I =< 0.2	medium
III	0.2 =< I =< 1	High
IV	I > 1	Very high

3.10 Model Calibration and Validation

3.10.1 Model Calibration

The time series of discharge at the outlet of the catchment was used as data for calibration and validation for SWAT model, the model was calibrated using the measured stream flow data from 1994 to 2014 and first the sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity. The parameters were optimized first using the auto calibration tool, then calibration was done by adjusting parameters until the simulated and observed value showed good agreement. In this process, model parameters varied until recorded flow patterns are accurately simulated. Model calibration of SWAT run can be divided in to several steps. Among these, Water balance and stream flow generation are the most important part is also considered. There are three different types of calibration methods:

A: The manual trial-and-error method,

B: Automatic or numerical parameter optimization method; and

C: A combination of both the above methods

For this research work the measured stream flow and sediment yield were calibrated both manually and automatically.

3.10.2 Model Validation

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenario.

3.11 Model Performance Evaluation

To evaluate the model simulation outputs in relative to the observed data, model performance evaluation is necessary. There are various methods to evaluate the model performance during the calibration and validation periods. For this study four methods will be Select to evaluate the goodness-of-fit of model approach, visual hydrographs will be comparing visually, water balance(comparing the cumulative discharges for observed and simulated), coefficient of determination (R^2) and Nash Sutcliffe simulation efficiency (NSE). The determination coefficient (R^2) describes the proportion the variance in measured data by the model. It is the magnitude linear relationship between the observed and the simulated values. R^2 ranges from 0 (which indicates the model is poor) to 1 (which indicates the model is good), with higher values indicating less error variance, The Nash Sutcliffe simulation efficiency (NSE) indicates that how well the plots of observed versus simulated data fits the 1:1 line. The value of NSE and R^2 are computed using the Eqn. (3.13) and (3.14) respectively.

$$R^2 = \frac{\sum(\boldsymbol{Xi-Xav})(\boldsymbol{Yi-Yav})}{\sqrt{\sum(\boldsymbol{Xi-Xav})^2}\sqrt{\sum(\boldsymbol{Yi-Yav})^2}} \quad (3.13)$$

Where, Xi – measured value (m3/s)

Xav – average measured value (m3/s)

Yi – simulated value (m3/s) and

Yav – average simulated value (m3/s)

$$NSE = 1 - \frac{\sum(Xi-Yi)^2}{\sum(Xi-Xav)^2} \quad (3.14)$$

Where, Xi – measured value

Yi – simulated value and

Xav – average observed value

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents and discusses results analyzed in the previous chapter. Results of land use/land cover map and their influences on the stream flow and sediment yield as well as results from land use/land cover change scenarios are also presented and discussed.

4.1 Land Use/Land Cover Map

Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. From the ground truth data obtained during fieldwork and land use/land cover map of 2008, obtained from Ministry of Water, Irrigation and Energy the catchment has various land use/land cover classes. Forest cover, Grass land, Shrub land, of the catchment area was transformed in to agricultural or cultivated land during recent decades. This change could be linked with high population growth.

The reclassification of the land use map was done to represent the land use according to the specific land cover types such as cultivated land, grass land, shrub land, forest land, water body and built up area. The land cover map of 2008 (figure 4.1) shows that about 61.4% of the Ribb catchment was covered by cultivated land, 28.1% by Grass Land, 4% by forest land, 6.1% by shrub and bush land, 0.4% by settlement (Urban) area, and 0.01% by water body.

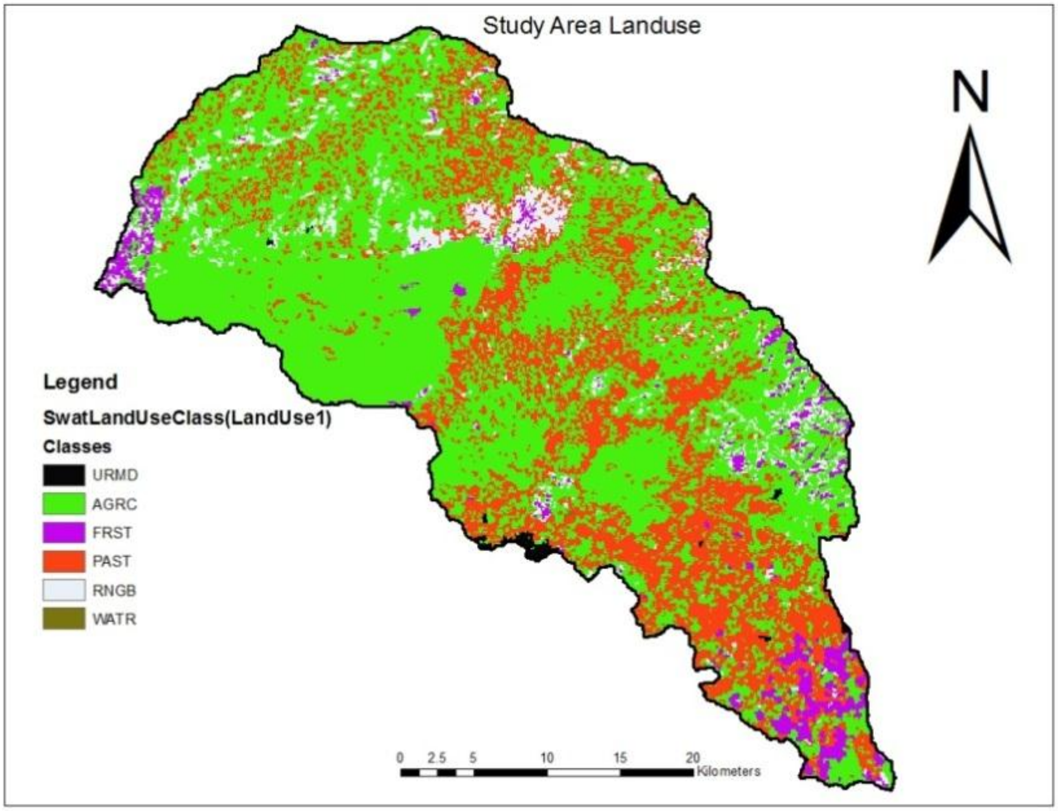

Figure 4. 1 Land use Land cover map of Ribb watershed (2008)

The actual percentages covered by different land use land cover types in the years 2008 are presented in table (4.1) below.

Table 4. 1 Area covered by different land use land cover type

No	Land use type	Area	
		km^2	(%)
1	Cultivated land	781	61.4
2	Grass land	358	28.1
3	Forest land	51	4
4	Shrub and Bush land	78	6.1
5	Water body	0.14	0.01
6	Built up area	5	0.4
	Total	1272.4	100

4.2 Average Monthly Flow Response to Average Monthly Rainfall

The results of the analysis of the mean monthly flow hydrograph for the Ribb River indicates periods of high and low flows corresponding to the long and short rains figure(4.2). The highest peak in Ribb River is observed from July - September. The low flows are experienced during the dry period of February -April.

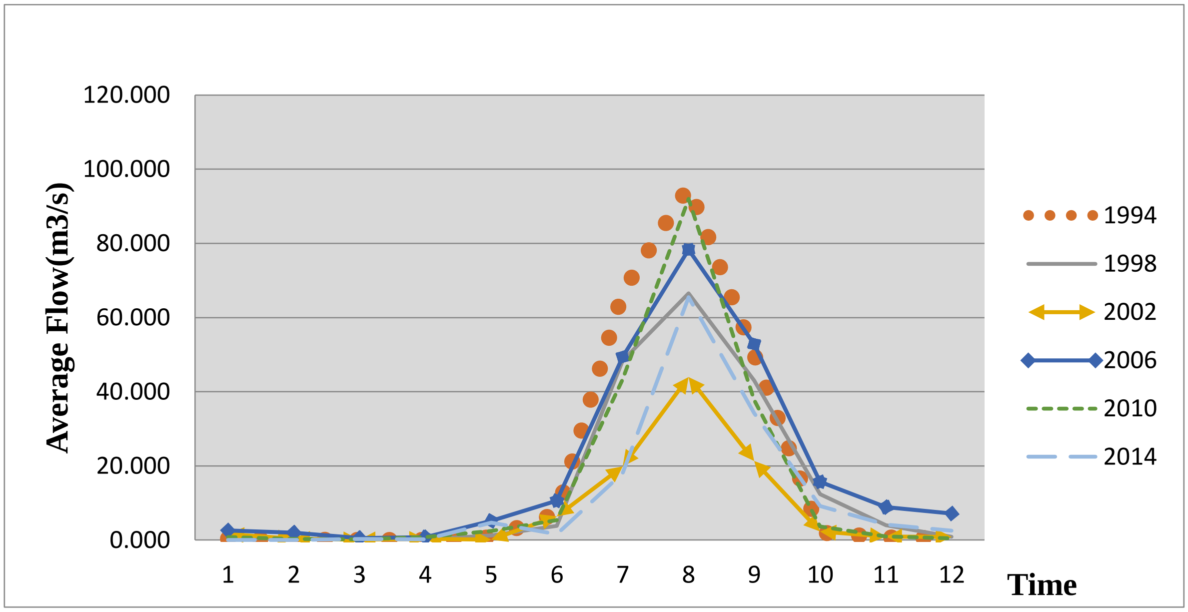

Figure 4. 2 Mean Monthly Flow Hydrograph at Different Periods of Ribb River

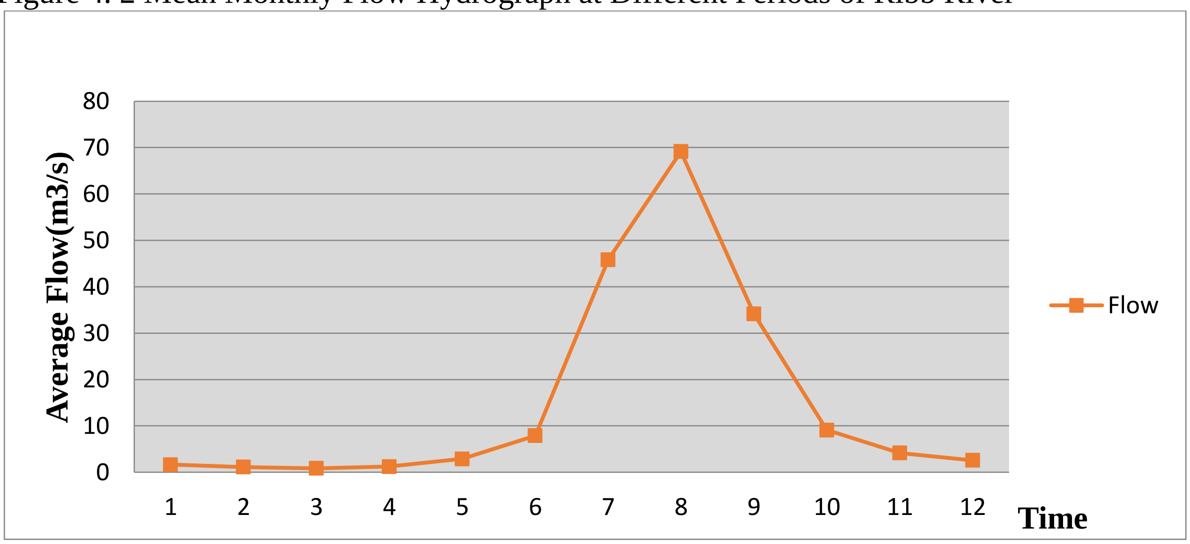

Figure 4. 3 Average Monthly Flow Hydrograph for Ribb River (1994 – 2014)

Figure (4.3) above present the flow hydrograph of the mean monthly flows for Ribb River. The hydrographs start to rise in June (corresponding to the onset of the short rains) and reaches its peak in August (long rain season) and the recession starts with the onset of the dry season in October.

Figure (4.4) below presents the mean average monthly variation in rainfall amounts at Addiszemen, Ageregenet, Debretabor and Woreta stations in Ribb catchment. It can be observed from the figure that the catchment experiences unimodal type of rainfall. This rainfall regime corresponds to one rainfall peak which was the long rain season from June to September. Maximum rainfall for all stations is recorded during the months of June-September. The period from October to December usually receives little rainfall and is generally referred to as a transition period between the short and long rains. The seasonal variations further indicate the relatively dry period from January-May with monthly rainfall amounts predominantly below 10 mm.

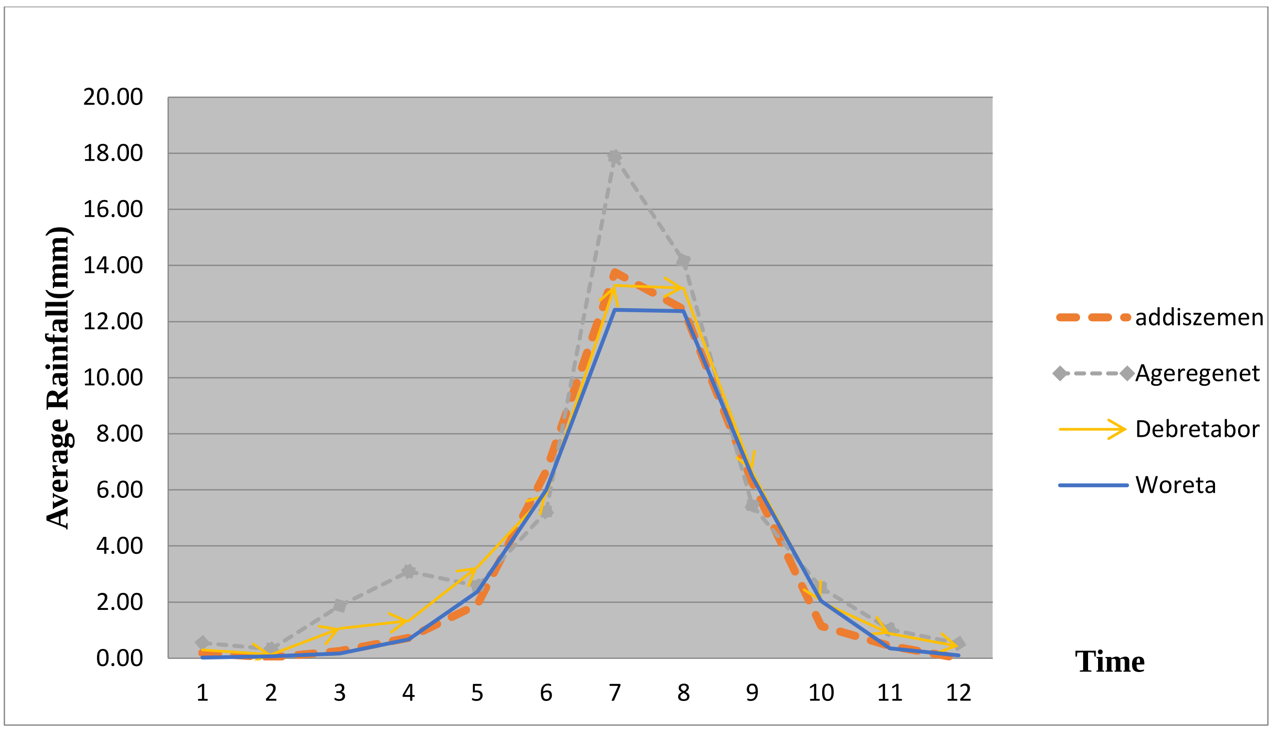

Figure 4. 4 Average Monthly Rainfalls of Stations (1994 – 2014)

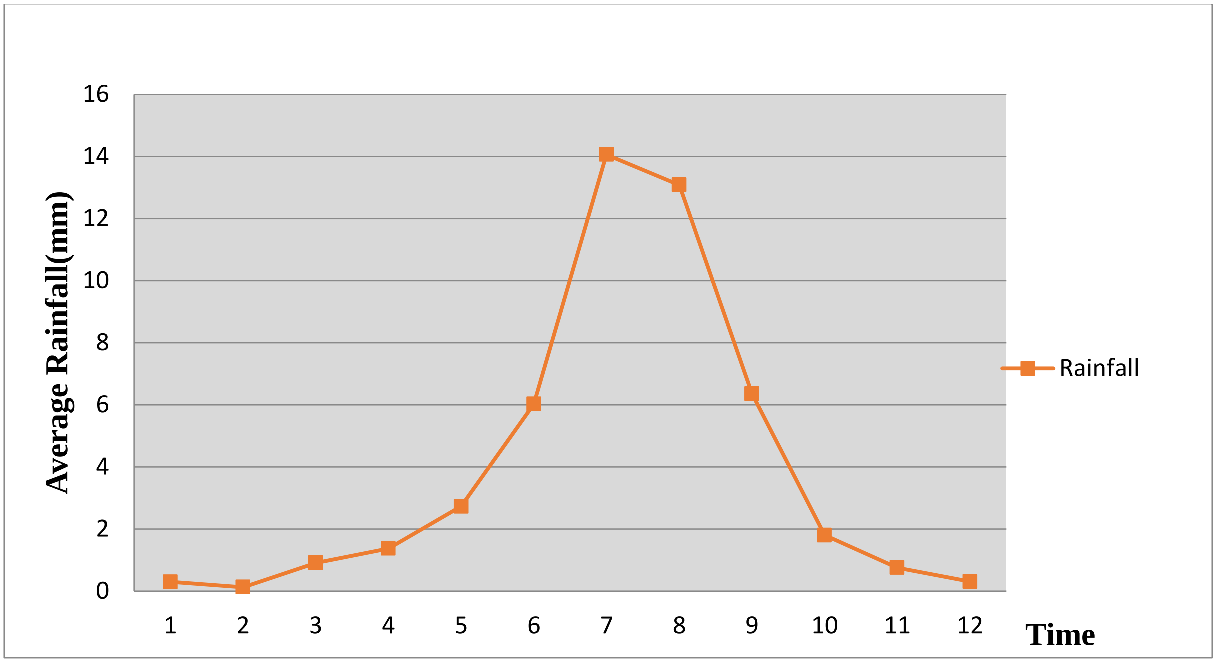

Figure 4. 5 Average Monthly Rainfall for Ribb River watershed (1994 – 2014)

4.3 Flow Sensitivity Analysis

After the SWAT model for Ribb river watershed was run using SWAT interface, a stream flow sensitivity analysis was performed on model parameters. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization (van Griensven et al., 2005). The sensitivity analysis was performed using SWAT interface for a period of 1994-2014. During sensitivity analysis, 270 iterations have been done and 27 parameters were tested for flow sensitivity analysis, but 7 parameters were found to be the most sensitive with their effect on the simulated result when their value is changed and selected for calibration. Curve number II (CN2) was the most sensitive parameter for flow.

Table 4. 2 SWAT parameters selected for flow calibration based on sensitivity analysis

Parameter	Description	Minimum value	Maximum value	Fitted value	sensitivity Rank
CN2	SCN curve number	35	98	40.229	1
SOL_AWC	soil available water capacity	0	1	0.661	2
SOL_Z	Soil Depth	0	3000	1539	3
GWQMN	Threshold water depth in the shallow aquifer for flow	0	5000	1555	4
ESCO	Soil Evaporation Compensation Factor	0	1	0.905	5
REVAPMN		0	500	230.5	6
ALPHA_BF	Base flow alpha factor	0	1	0.623	7

4.4 Stream Flow Calibration Analysis

After the sensitive parameters identification, calibration followed by validation was executed for the significant parameters. The calibration of the model was executed to evaluate the performance of the model simulation using automatic calibration tools embedded in SWAT in addition to manual calibration technique for catchment. Since manual calibration gives a better result on fitting the parameters of simulated and observed flow, it was utilized following to the auto calibration. Initially it was carried out using the most sensitive parameters and the best parameter value which were resulted from sensitivity analysis.

Among the 27 parameters which resulted from sensitivity analysis method SCN curve number (CN), Soil Evaporation Compensation Factor (ESCO), Soil Depth (m) (Sol_Z), Threshold water depth in the shallow aquifer for flow (GWQMN), Base flow alpha factor (Alpha_Bf), (REVAPMN) and Soil Available Water Capacity (SOL_AWC) were found the most influential parameters and were used for further calibration table (4.2).

These were the considerable parameters to fit the data while changing. Most models are provided with default values of the parameters. However, in this case initial values of the model parameters were defined. The minimum and maximum acceptable values were provided based on related pervious works and literatures. The manual calibration was made by varying the values of the sensitive parameters within their permissible values. It was carried out repeatedly by changing one of the more sensitive parameters in the model and then observing the corresponding changes in the simulated flow.

The calibrated parameters are within the range of the suggested values of SWAT. After the calibration result, the model was run and the simulated flow was compared with the observed flow. On (figure 4.6) below showed the hydrographs of the observed and simulated flows from 01 January, 1996 to 31 December 2008 and two year for warm up period for the calibration phase. The calibration period has shown a good agreement between monthly measured and simulated flows (Figure4.6). The Calibration result showed that the coefficient of determinations (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.79 and 0.78 respectively. The Web scatter plot of the values of the measured and the simulated monthly stream flow data have also shown a fair linear correlation between the two data sets. The trend and the magnitude of the two data set values are shown in (Figure 4.7). In addition to the R2 and NSE the efficiency of the model is measured by the water balance which is the cumulative discharge comparison of simulated and observed discharge (Figure4.8) shows 6.4% s under estimated.

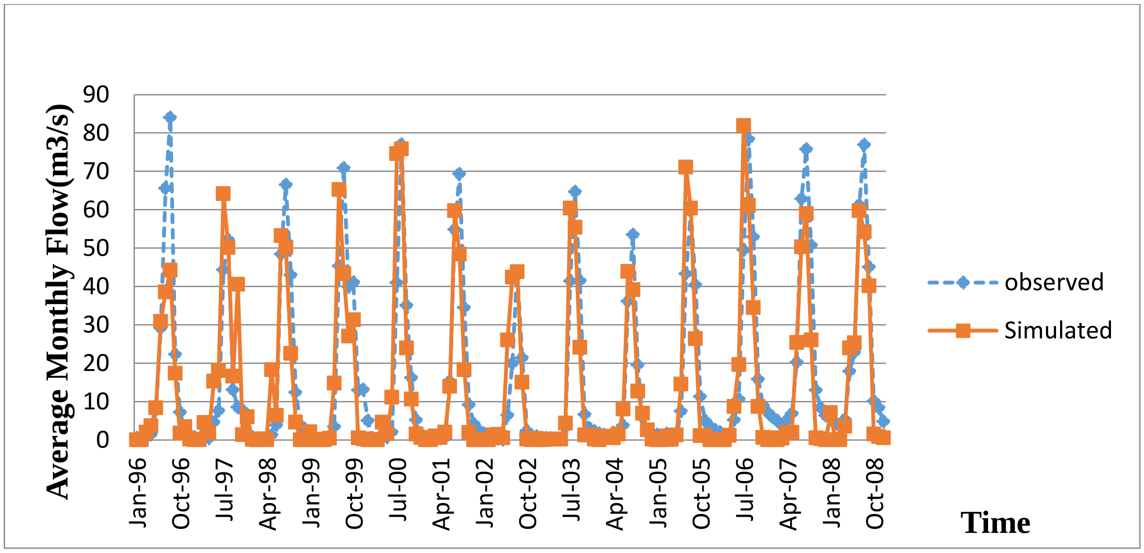

Figure 4. 6 Average Monthly Observed and Simulated Flow Calibration (1996 – 2008)

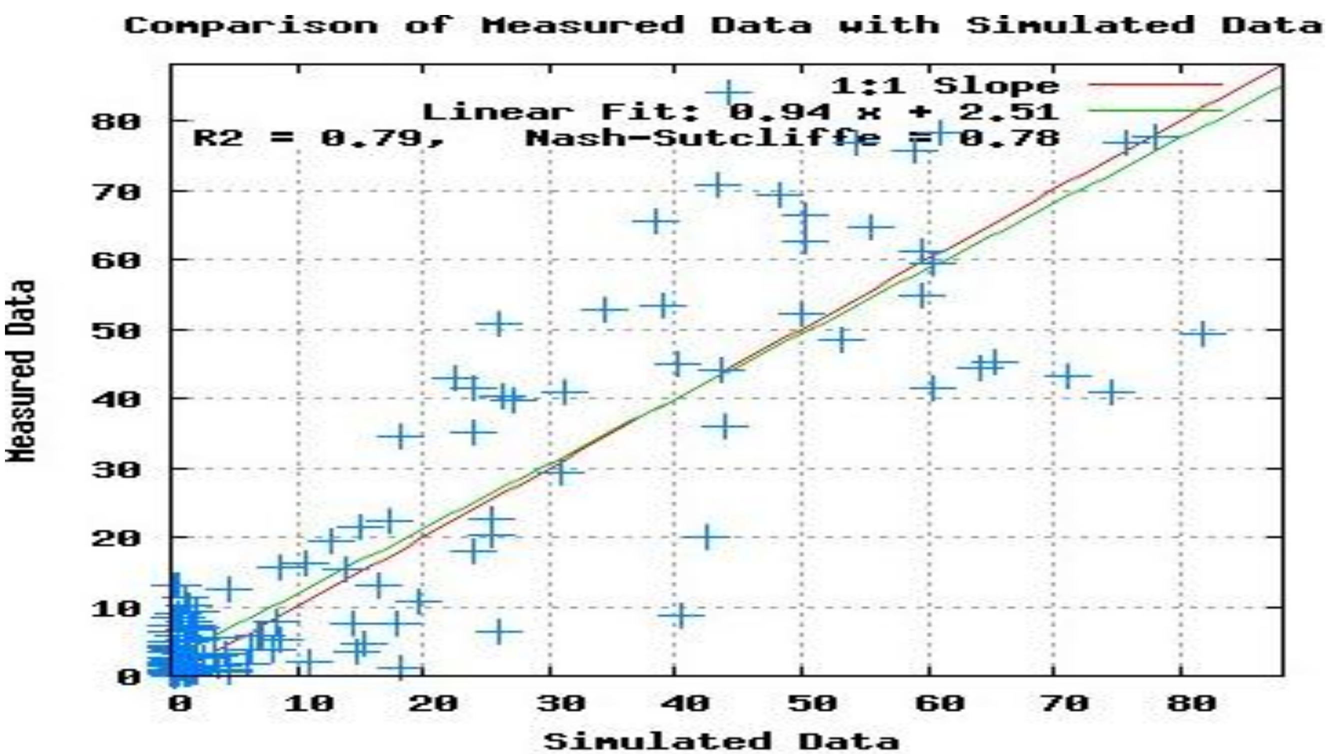

Figure 4. 7 Scatters plot of Observed Vs Simulated Flow for calibration (1996 – 2008)

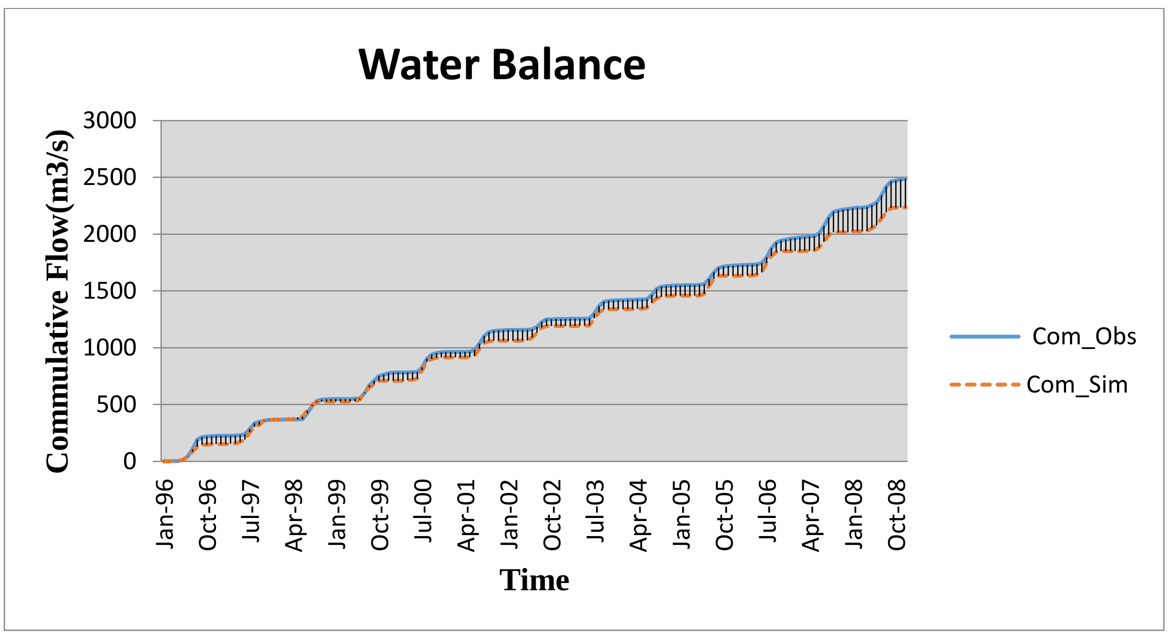

Figure 4. 8 Cumulative simulated and observed discharges for the calibration period

4.5 Stream Flow Validation Analysis

Validation process using an independent set of observed data is necessary to comprehend the degree of the certainty of the model prediction. Model performance in calibration and validation periods may not be similar. Recent studies revealed that there are a number of difficulties of climate model validation. That is because of the complexity of the nature of climate and time dependent uncertainties of modeling dataset. Another reason is the hydrologic condition in the calibration period may not be the same as the hydrologic condition during the validation period.

The validation was carried out using the calibrated parameters. For model validation the remaining observed stream flow data of Ribb River from 2009 to 2014 were used. In the validation process, the model was run with input parameters set during the calibration process without any change.

The validation period has also shown a good agreement between monthly measured and simulated flows figure(4.9).The validation result showed that the coefficient of determinations (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.7 and 0.68 respectively. In general, the model performance assessment indicated a good correlation and agreement between the monthly measured and simulated flows. The scatters plot of the values of the measured and the simulated monthly stream flows data has also shown a fair linear correlation between the two datasets. The trend and the magnitude of the two data set values are shown in figure (4.10). In addition to the R2 and NSE the efficiency of the model is measured by the water balance which is the cumulative discharge comparison of simulated and observed discharge (Figure4.11) shows 13% s over estimated.

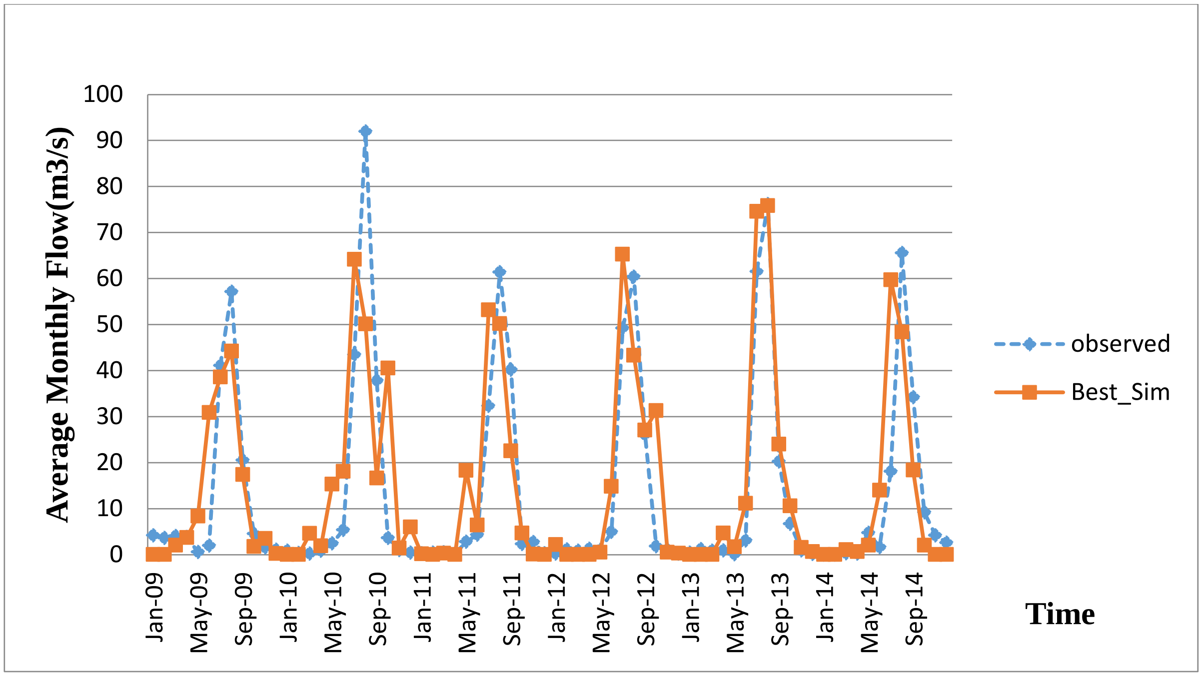

Figure 4. 9 Average Monthly Observed and Simulated Flow Validation (2009 – 2014)

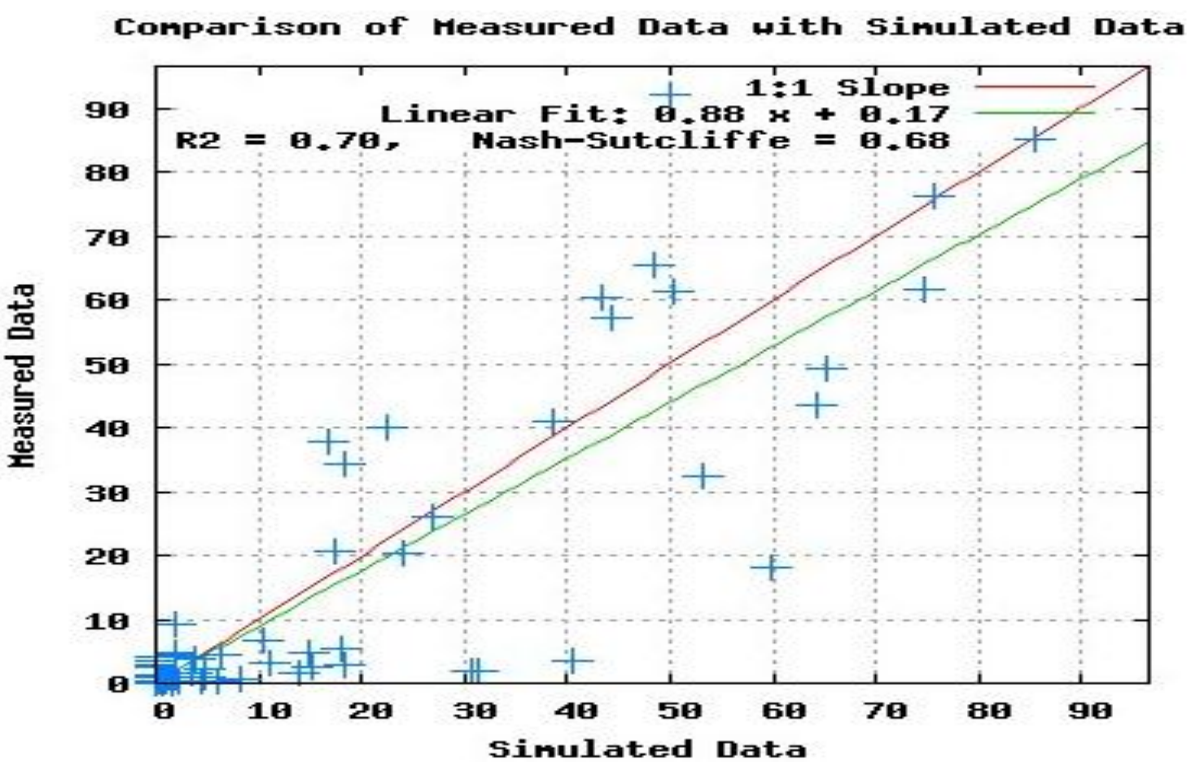

Figure 4. 10 Scatter plots of Observed Vs Simulated Flow for Validation (2009 – 2014)

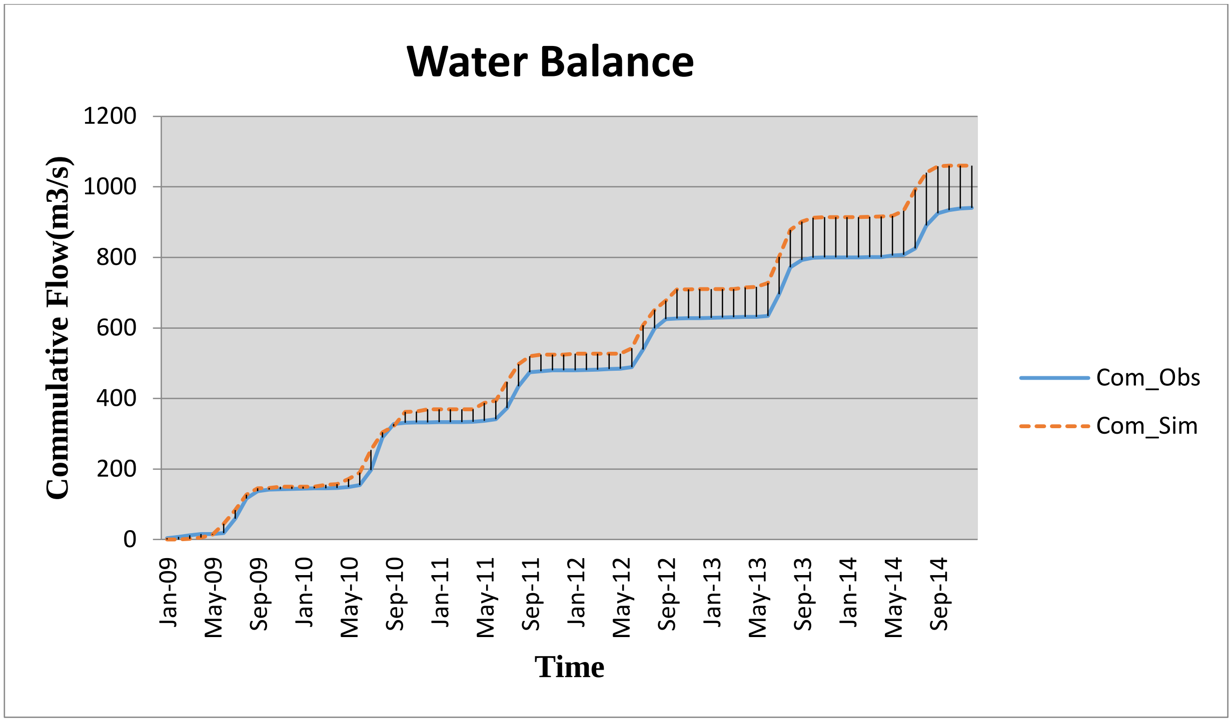

Figure 4. 11 Cumulative of simulated and observed discharges for the Validation period

Table 4. 3 Summery of the Calibration and Validation period, R^2 and NSE

	Period	R2	NSE
Calibration	1996-2008	0.79	0.78
Validation	2009-2014	0.70	0.68

4.6 Sediment Yield Sensitivity Analysis

Once the flow was accurately represented by the model the focus is shifted to the calibration and validation of the model for sediment. This involves changing the parameters that control sediment generation within the model. The sediment parameters used for calibration and validation was selected on the sensitivity analysis performed using SWAT interface for a period of 1994-2014. During sensitivity analysis, 60 iterations have been done for sediment and 6 parameters were tested for sediment sensitivity analysis. 6 of the sediment parameters were sensitive with their effect on the simulated result when their value is changed and selected for calibration. USLE equation support practice (USLE_P) was the most sensitive parameter for sediment.

Table 4. 4 SWAT parameters selected for sediment yield calibration based on Sensitivity

Parameter name	Description	Minimum value	Maximum value	Fitted value	Sensitivity Rank
USLE_P	USLE equation support practice	0	1	0.990	1
CH_COV1	Channel cover factor	0	1	0.381	2
CH_ERODMO	channel erodiability factor	0	1	0.168	3
SPCON	Linear parameter for maximum sediment yield	0.0001	0.01	0.001	4
SPEXP	Exponential parameter for maximum sediment yield in channel sediment routing	1	2	1.618	5
USLE_C	Cropping practice factor	0	1	0.820	6

4.7 Sediment Calibration

Once the sediment parameter values are established through use of the manual calibration within Arc SWAT, all the 6 parameters which resulted from sensitivity analysis USLE equation support practice (USLE_P),Linear parameter for maximum sediment yield (SPCON), Exponential parameter for maximum sediment yield in channel sediment routing (SPEXP),Cropping practice factor(USLE_C),channel cover factor(CH_COV1),channel erodiability factor (CH_ERODMO) were found the most influential parameters and were used for further calibration table(4.4).

The manual calibration was made by varying the values of the sensitive parameters within their permissible values. It was carried out repeatedly by changing one of the more sensitive parameter in the model and then observing the corresponding changes in the simulated sediment. The calibrated parameters are within the range of the suggested values of SWAT.

After the calibration result, the simulated sediment was compared with the observed sediment yield on figure (4.12) below showed the hydrographs of the observed and simulated sediment from1996 to 2008 and two year for warm up period for the calibration phase like flow. The calibration period has shown a good agreement between monthly measured and simulated sediment yield figure (4.12). The Calibration result showed that the coefficient of determination (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.77 and 0.71 respectively. The Web scatters plot of the values of the measured and the simulated monthly sediment yield has also shown a fair linear correlation between the two data sets figure (4.13).

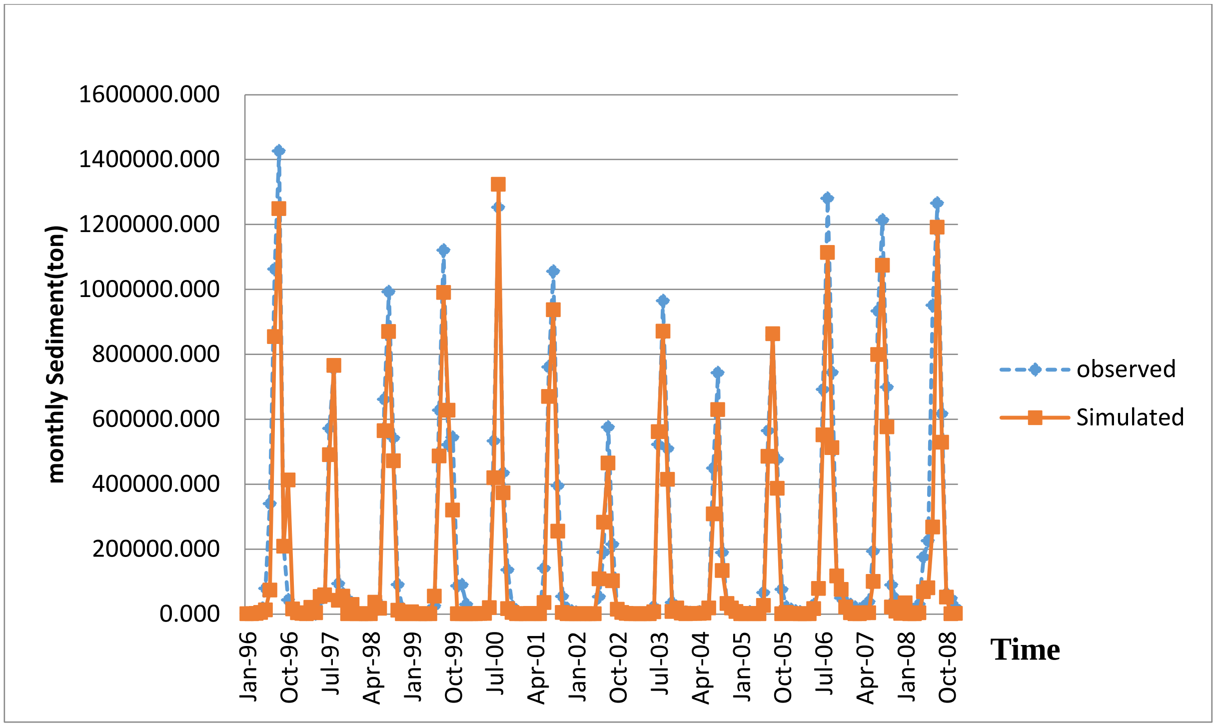

Figure 4. 12 Monthly Measured and Simulated Sediment Yield for Calibration (1996–2008)

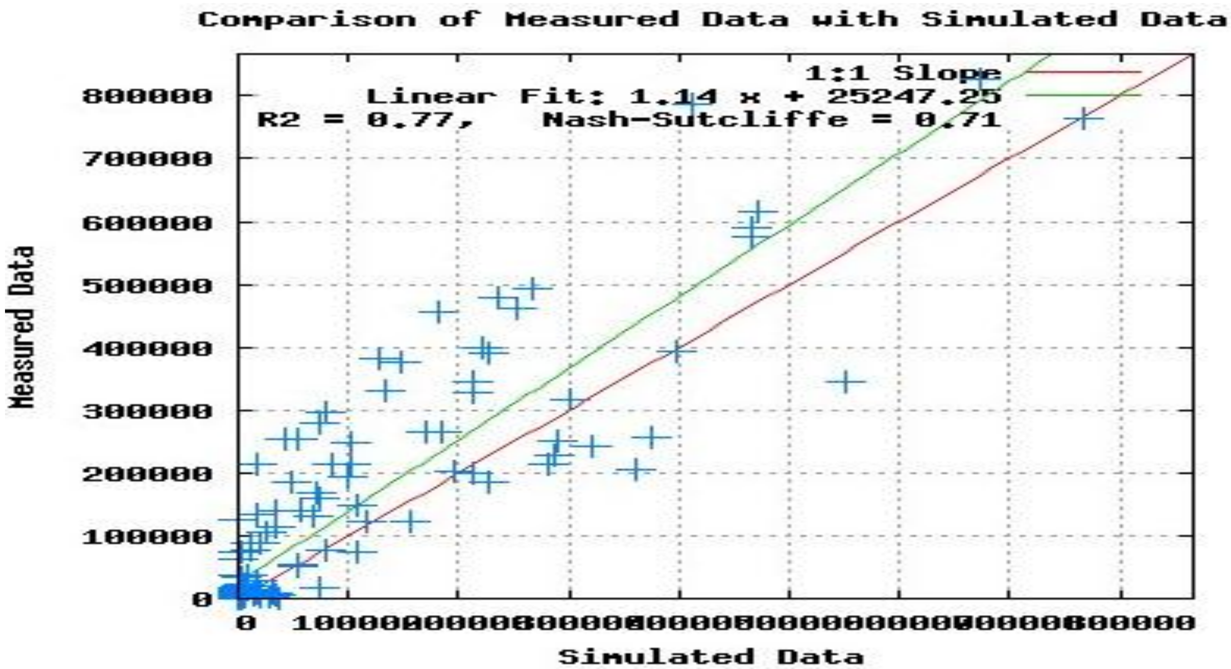

Figure 4. 13 Scatter plot of observed Vs simulated sediment yield for calibration (1996-2008)

4.8 Sediment Yield Validation

Validation of sediment yield was done also using an independent set of observed data to comprehend the degree of the certainty of the model prediction. The validation was carried out using the calibrated parameters. For model validation, the remaining observed sediment data of Ribb River from 2009 to 2014 were used. The validation period has also shown a good agreement between monthly measured and simulated flows figure (4.14).The validation result showed that the coefficient of determinations (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.72 and 0.72 respectively. In general, the model performance assessment indicated a good correlation and agreement between the monthly measured and simulated flows. The scatter plot of the values of the measured and the simulated monthly sediment yield has also shown a fair linear correlation between the two datasets figure (4.15).

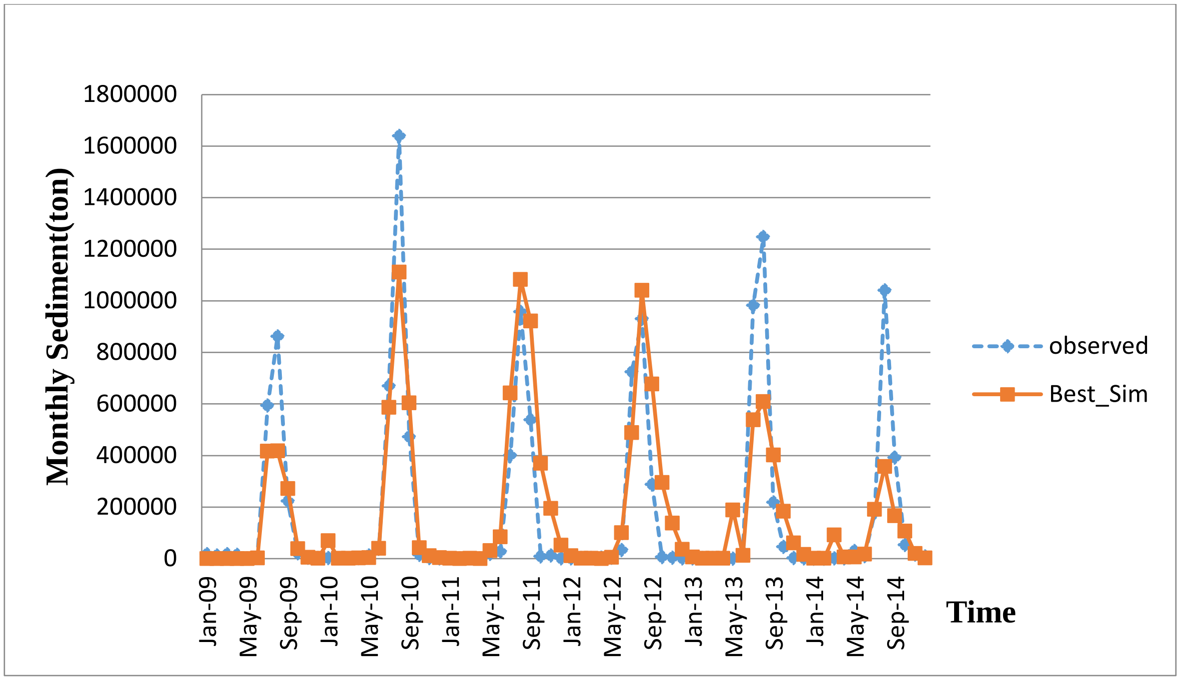

Figure 4. 14 Monthly Measured and Simulated Sediment Yield for validation (2009 – 2014)

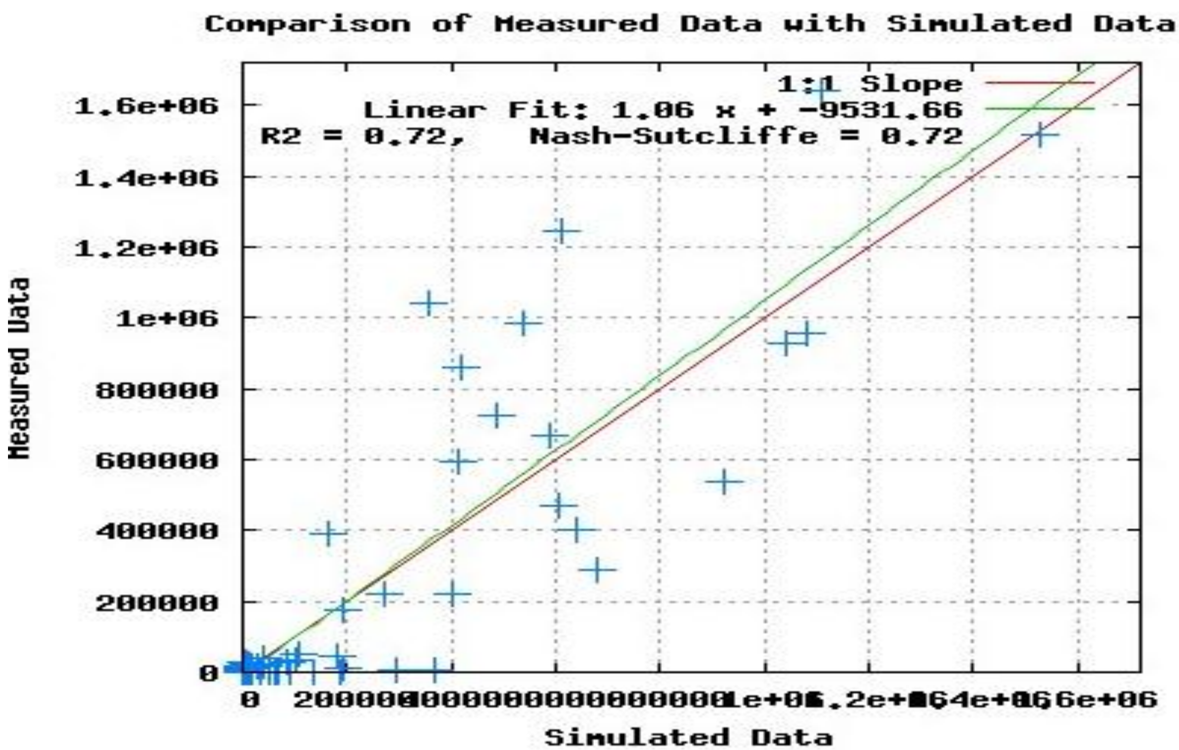

Figure 4. 15 Scatter plot of observed Vs simulated sediment yield for validation (2009-2014)

Table 4. 5 Summary of the Calibration and Validation period, R^2 and NSE of Sediment Yield

	Period	R2	NSE
calibration	1996-2008	0.77	0.71
validation	2009-2014	0.72	0.72

4.9 Land use/land cover change scenario analysis on hydrological processes

Three land use/cover change scenarios are developed to analyze the impact of land cover changes to the hydrological regime. Base scenario: current land use practices, scenario1: shrub and bush lands completely changed to forest land and scenario2: Grass land completely changed to cultivated land.

4.9.1 Base scenario: current land use practices

It offers a reference point or baseline data when interpreting the hydrological implications of other management scenarios. This scenario uses the existing land use land cover types to analyze the impacts on hydrological responses. The analyzed result of this scenario shown that, the average minimum monthly stream flow of 1.23m3/s February and average maximum stream flow of 128.14m^3/s occurs during rainy period august Figure (4.16) and the maximum monthly sediment yield at the watershed outlet is 13114300 tones during august and the minimum one is 19739.846tones per month figure (4.17).

4.9.3 Scenario 1: Shrub and Bush Lands Completely Changed to Forest Land

In this land use change scenario more focus is given to the protection of existing forest from deforestation and the expansion of new forest land by replaced shrub and bush land. The results of this scenario (Figure 4.16) indicate that the scenario had a pattern similar stream flow to base scenario (table 4.6) but change of sediment yield, when compared to the base period (table 4.7). The reduction in sediment yield during the wet season can be resulted due to the reduced slopes, soil and water conservation measures and afforestation from the upstream (table 4.7).

4.9.2 Scenario 2: Grass Lands Completely Changed to Cultivated Land

The report released from the Ministry of Finance and Economy and the government policy and strategies on green economy (Ethiopian Climate Resilient Green Economy strategic plan (CRGE, 2011), shows a 15% expansion of agricultural land and 3% re-forestation work accounts for growth in the agricultural sector over the last five years. Grass land and bare land conversion to agricultural practices was considered. The result of this scenario shows that stream flow does not significantly differ from the base scenario which is increased by 1.01m3/s annually and a significant sediment yield can be observed 15380813tones increased annually (table4.7) due to the agricultural land expansion. However, the trends of the two graphs are similar despite the value difference at each month. The reduction in stream flow during the dry season can be explained by considering the increase of irrigation agriculture and water supply for domestic use from the upstream.

Table 4. 6 Average Monthly flow of Different Land Use Scenarios

Month	Base Scenario (m3/s)	Scenario1 (m3/s)	Scenario2 (m3/s)	Scenario1-Base Scenario(m3/s)	Scenario–Base Scenario(m3/s)
1	5.118	5.216	5.649	0.098	0.531
2	1.227	1.260	1.387	0.032	0.160
3	2.219	2.271	2.510	0.052	0.290
4	2.463	2.536	2.632	0.073	0.169
5	8.667	8.872	8.953	0.205	0.286
6	22.076	22.507	23.373	0.432	1.297
7	89.051	89.835	92.559	0.784	3.508
8	128.140	129.006	130.892	0.865	2.751
9	107.069	107.829	108.125	0.760	1.056
10	65.711	66.259	66.384	0.548	0.673
11	34.042	34.387	34.769	0.344	0.727
12	15.553	15.759	16.269	0.206	0.715
Annually	40.111	40.478	41.125	0.367	1.014

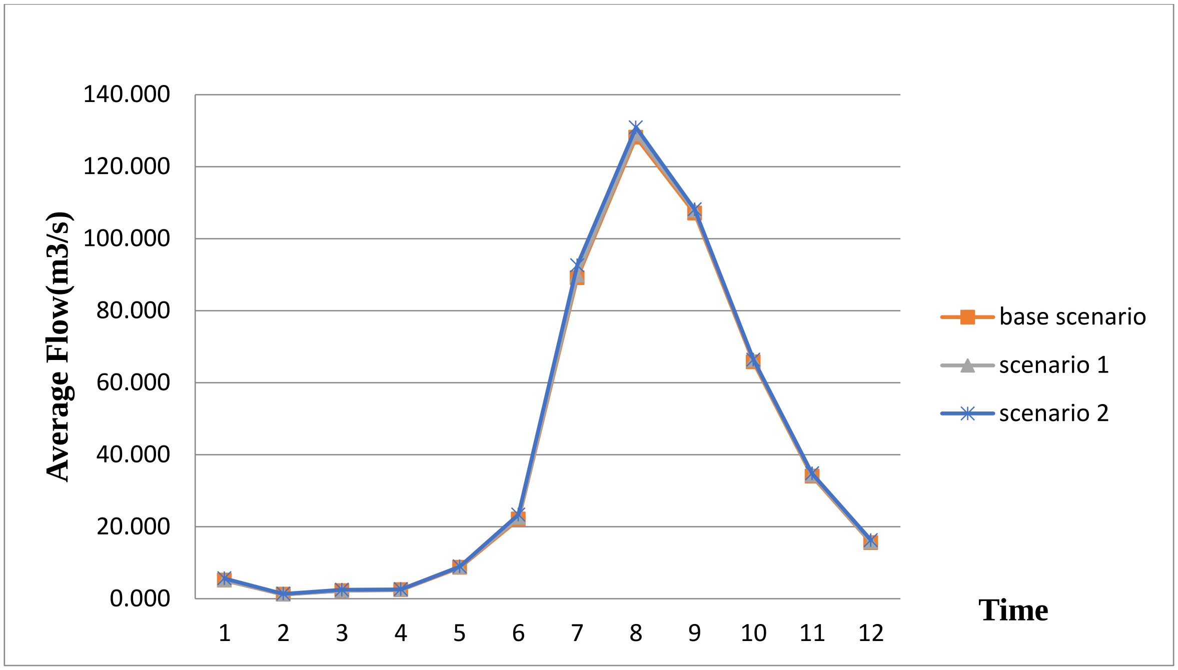

Figure 4. 16 Average Monthly Flow Hydrograph of different land use scenario

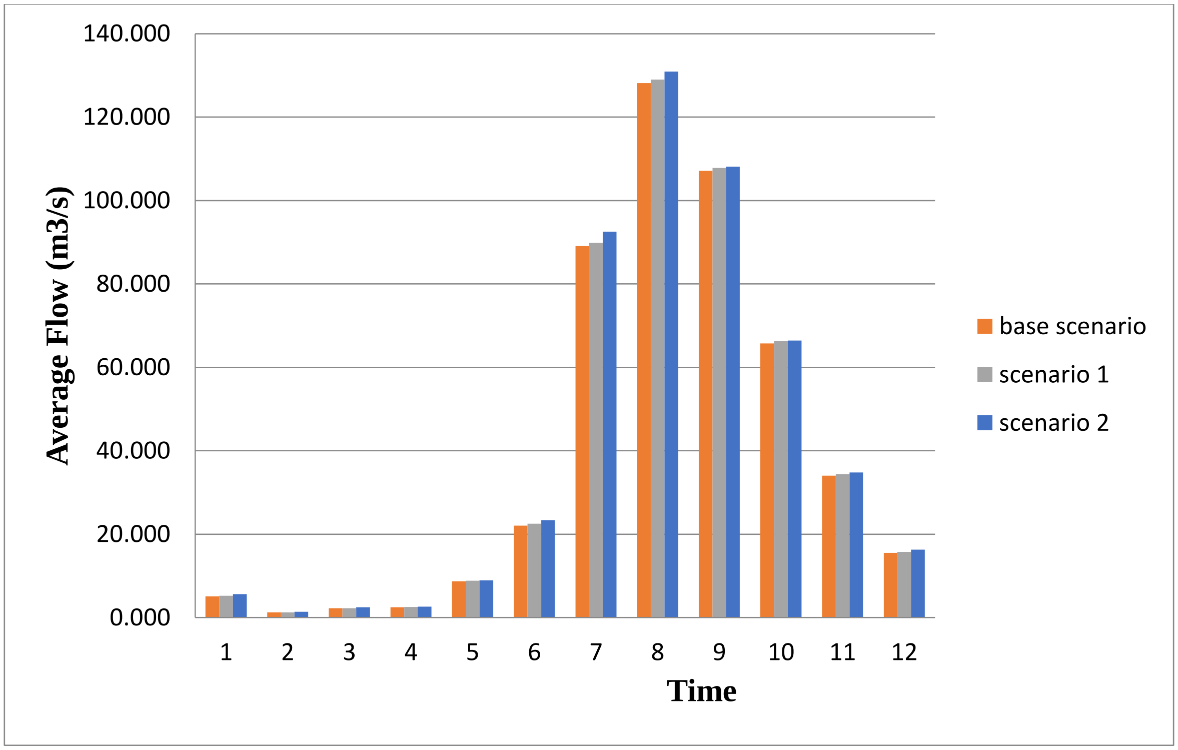

Figure 4. 17 Average Monthly Flow Hydrograph of different land use scenarios (bar graph)

Table 4. 7 Monthly Sediment Yields of Different Land Use Scenarios

Month	base scenario (ton)	scenario1 (ton)	Scenario2 (ton)	scenario1 -base scenario (ton)	Scenario2 – base scenario (ton)
1	616535	616932.3	888716	397.3	272181
2	19739.85	19961.06	29150.14	221.209	9410.289
3	161581.5	162095.8	231490.2	514.3004	69908.67
4	8206.619	8415.776	10960.51	209.157	2753.893
5	206452.2	206390.5	276384.2	-61.67	69932.05
6	1734226	1732717	2482302	-1509	748076
7	10750300	10740300	15589000	-10000	4838700
8	13114300	13103200	18989100	-11100	5874800
9	6333890	6332400	9164260	-1490	2830370
10	1254246	1254014	1759359	-232	505113
11	374744	375448	517503	704	142759
12	60669	61101.4	77478.3	432.4	16809.3
Annually	34634890	34612976	50015703	-21914.3	15380813

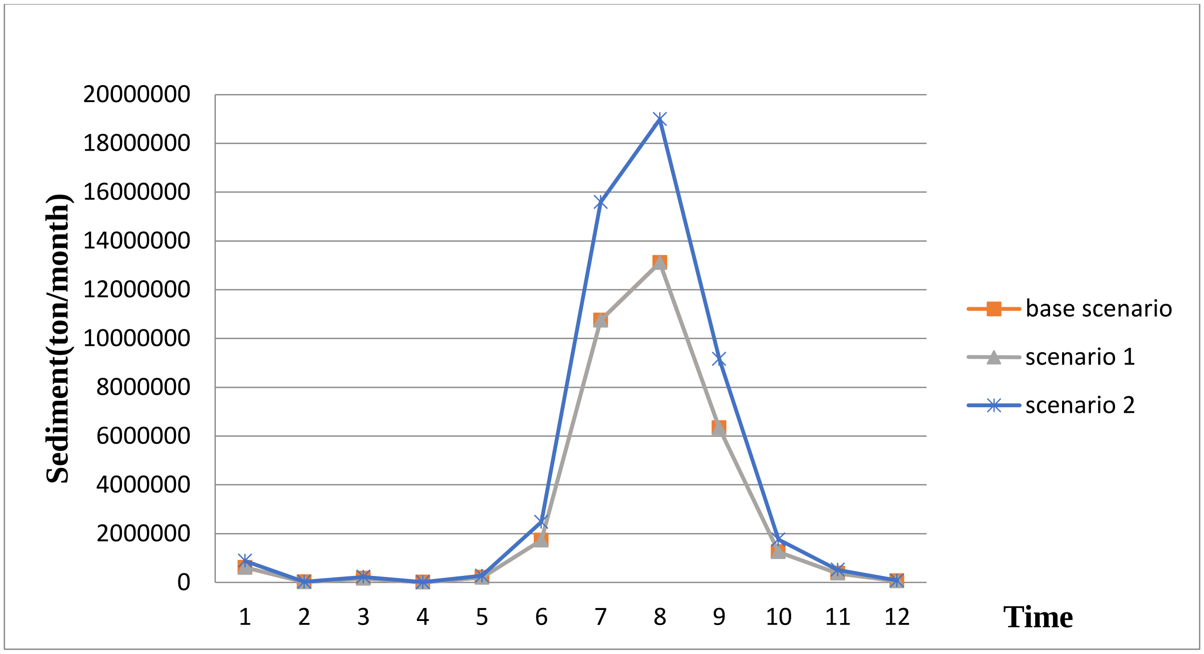

Figure 4. 18 Monthly Sediment Yields of Different Land Use Scenarios

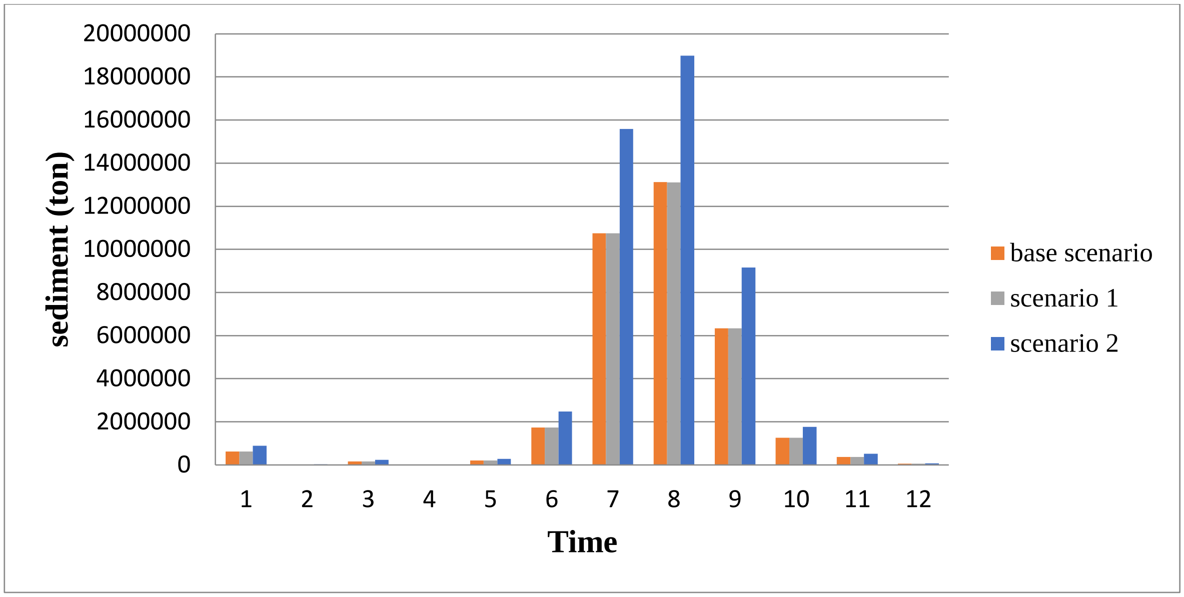

Figure 4. 19 Monthly Sediment Yields of Different Land Use Scenarios (bar graph)

Land use/cover change is an important characteristic in the runoff process that affects infiltration, interception, erosion, and evapotranspiration. This Changes cause different problem in existing hydrological conditions. Change in land use type of certain area like scenario 2 grass lands changed to cultivated land will increase volume of surface runoff, decrease time of concentration which makes several distractions by generating higher amount of runoff as well as decrease the amount of water percolated in to the ground. This in turn decreases the amount of water to be recharged in to the ground, and finally imbalances over all hydrological condition of catchment. Table (4.8) below shows the response of different hydrological components to different land use.

Table 4. 8 Average annual values of different hydrological components of a watershed

Scenario	SURQ (mm)	LATQ (mm)	GWQ (mm)	ET (mm)	PERC (mm)	TLOSS(mm)	WYLD (mm)	SEDYID (ton/hr)
Base Scenario	259.51	136.13	617	402	656.2	5.93	1006.2	14.489
Scenario1	259.53	137.23	625	392	664.76	5.93	1015.4	14.471
Scenario2	278.09	135.79	624	376	663.98	6.34	1031.6	21.146

ET=Actual Evapotranspiration from HRU, SW=Soil water content, PERC=water that percolates past the root zone during the time step, SURQ=Surface runoff contribution to stream flow during time step, TLOSS = Transmission losses, water lost from tributary channels in the HRU, transmission through the bed, GW_Q= Ground water contribution to stream flow, LATQ=Lateral flow contribution to stream flow, WYLD (water yield=SURQ+LATQ+GWQ-TLOSS).

In general, Changes in land use type of the area like increasing the percentage of cultivated land increase volume of surface runoff, facilitating soil erosion, decrease the amount of water percolated in to the ground. Whereas, increasing the percentage of forest lands in turn increases the amount of water to be recharged in to the ground, decrease erosion potential, due to decreased velocity of water which permits a greater degree of scouring. Therefore, with agricultural expansion and human interaction, hydrological responses are expected to be modified or changed.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Land and water resources degradation are the major problems on the Ethiopian highlands. Poor land use practices and improper management systems have a significant role in causing high soil erosion, sediment transport and loss of agricultural nutrients. Hydrologic simulation models are very essential way used to assess hydrological characteristics of watershed. They are efficient tools for evaluating effects and impacts that occur in hydrologic regime. They can be used to find out, predict and understand what happened and will happen throughout a basin in time and space.

SWAT2009 is an effective tool in analyzing the impacts of land use/cover changes on stream flow and sediment yield. The ability of SWAT to adequately predict stream flows and sediment yield was evaluated through sensitivity analysis, model calibration, and model validation. The model was successfully calibrated and validated for both stream flow and sediment yield of Ribb watershed using SUFI2 algorithms. A SUFI-2 algorithm is an effective method but it requires additional iterations as well as the need for the adjustment of the parameter ranges. The model evaluation statistics for stream flows and sediment yield prediction gave good results that was verified by Nash Sutcliff efficiency NSE > 0.5 and coefficient of determination $R^2 > 0.60$. The most sensitive parameter for stream flow in Ribb catchment was the initial SCS curve number II (Cn2) and for sediment yield generation was USLE equation support practice (USLE-P).The hydrological model, SWAT simulates the flow and sediment in a better way with satisfactory (R2, NSE) (0.79, 0.78), (0.7, 0.68) for flow calibration and validation and (R2, NSE) (0.77, 0.71), (0.72, 0.72) for sediment calibration and validation respectively.

Three land use/cover change scenarios are developed to analyze the impact of land use/cover changes to the hydrological regime. Base scenario: current land use practices, scenario1: shrub and bush lands completely changed to forest land and scenario2: Grass land changed to cultivated land. The base scenario or current land use practice has cultivated land, grass land, shrub and bush land, and forest land, built up area and water body. The model result for different land use scenarios in the study are showed that the wet season flow increases for the study period, while the dry season flow decreases significantly. This is mainly attributed to land use scenario2 conversion of grass land, shrub land in to cultivated land areas which in turn increased surface runoff during wet seasons and reduced base flow during the dry seasons. It is also concluded that as the peak flow increases it is suspected of carrying more sediment which makes the increasing of Lake Tana level and water more turbid. The annual average simulated stream flow for base scenario, scenario1 and scenario2 was 40.11,40.48 and 41.13 m3/s respectively and also the annual average simulated sediment yield for base scenario, scenario1 and scenario2 was 14.49, 14.47 and 21.15 ton/ha respectively.

Therefore, it can be deduced that LULC impact for the study area might be the most sensitive than the propagated uncertainty on catchment flow. The rapid expansion of agriculture, deforestation and high population growth in the area resulted in high rate of soil erosion in the catchment area. Degradation of the catchment has affected the flow characteristics in the catchment as observed from increase in surface runoff and decreasing base flow. The continuation of the land use/land cover change is becoming a serious threat to the Ribb catchment. The land use/land cover change should be controlled in the catchment and some appropriate measures should be taken for the stabilization of the land cover change. 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. The output of this study can help planners, decision makers and other different stakeholders to plan and implement appropriate soil and water conservation strategies.

5.2 Recommendation

Based on the study findings, the following recommendations are made:

- The model simulation in this study considered only land use change effect by assuming all other thing constant. But change in climate and soil management practices and other land use variables also contribute great impact on hydrological process of the catchment. Therefore, it is recommended to consider these variables for future studies.
- The performance of the model can be improved by increasing the number of rainfall and discharge gauging stations within the catchment. It helps to develop a clear rainfall runoff and soil loss relationship.
- From the result of land use scenarios, it is recommended that developing Land use planning, protect the water sources like springs, rivers and forests and Soil and Water Conservation (SWC) structure should be considered an integral planning strategy that will help to reduce the amount of soil loss.
- Further study need for detail analysis of land cover in the catchment by taking more ground control point and checking the overall accuracy like measuring the amount of conserved soil on each terracing.

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APPENDIXES

Appendix A: land use, soil and slope

SWAT model simulation Date: 10/15/2015 12:00:00 AM Time: 00:00:00

MULTIPLE HRUs Land Use/Soil/Slope OPTION THRESHOLDS: 5 / 20 / 20 [%]

Number of HRUs: 183

Number of Sub basins: 25

	Area [ha]	Area [acres]
Watershed	127240.4893	314417.6112

LANDUSE:	**Area [ha]**	**Area [acres]**	**% Wat**
Cultivated Land --> AGRC	79456.9063	196341.9883	62.45
Grass Land --> PAST	36271.2415	89628.0512	28.51
Shrub and Bush Land --> RNGB	6703.4247	16564.4977	5.27
Forest Land --> FRST	4419.5980	10921.0477	.47
Built Up Area --> URMD	389.3188	962.0262	0.31

SOILS:	**Area [ha]**	**Area [acres]**	**% Wat**
Eutric Leptosols	46889.8882	115867.2583	36.85
Eutri Fluvisols	32188.4244	79539.2062	25.30
Chromic Luvisols	48083.0221	118815.5518	37.79
Urban	79.1546	195.5949	0.06

SLOPE:	**Area [ha]**	**Area [acres]**	**% Wat**
20-9999	34550.8640	85376.9126	27.15
5-20	68118.1790	168323.4262	53.53
0-5	24571.4463	60717.2724	19.31

Appendexi B: Values and Description of Weather generator (WGEN) parameters used by SWAT model

Month	Tmpmx	Tmp Mn	Tmpstmx	Tmpstdmn	Pcpmn	Pcp Std	Pcp Skw	Pr_W(1)	Pr_W(2)	PcPd	Hhrmx	Slr Av	Dw Pt	wid av
Jan	22.78	24.39	24.98	24.57	23.83	21.76	18.82	18.85	20.06	21.15	21.70	19.46	5.46	1.11
Feb	8.13	9.31	10.27	10.93	10.89	10.46	10.04	9.98	9.41	8.59	7.96	21.17	5.42	1.25
Mar	1.41	1.46	2.21	1.96	2.30	2.20	2.00	1.54	1.51	1.53	1.51	20.95	6.68	1.26
Apr	1.24	1.43	1.59	1.84	1.96	1.23	1.21	1.21	1.09	1.39	1.51	20.50	7.68	1.32
May	9.33	3.66	32.93	40.00	100.92	175.48	411.76	409.06	199.13	62.34	26.26	19.54	9.96	1.30
Jun	2.67	1.01	4.35	3.77	8.38	8.10	11.30	12.18	8.75	6.75	3.43	18.38	11.86	1.22
Jul	15.04	12.26	8.40	4.43	6.11	2.77	1.48	1.73	2.14	8.18	5.11	15.73	12.24	1.08
Aug	0.04	0.04	0.12	0.14	0.25	0.48	0.91	0.76	0.47	0.15	0.08	16.38	12.24	1.19
Sep	0.26	0.31	0.43	0.66	0.66	0.84	0.97	0.95	0.80	0.69	0.46	19.31	11.42	1.11
Oct	1.62	1.24	5.43	8.90	13.00	21.38	29.90	29.19	21.71	10.52	3.86	20.05	9.74	0.91
Nov	21.70	7.96	1.51	26.26	3.43	5.11	5.11	0.08	0.46	3.86	0	18.65	8.14	0.94
Des	22.78	24.39	24.98	24.57	23.83	21.76	18.82	18.85	20.06	21.15	21.70	18.94	6.61	1.01

Description

TMPMX = Average or mean daily maximum air temperature for month (^oC).

TMPMN = Average or mean daily minimum air temperature for month (^oC).

TMPSTDMX = Standard deviation for daily maximum air temperature for month (^oC).

TMPSTDMN = Standard deviation for daily minimum air temperature for month (^oC).

PCPMM = Average or mean total monthly precipitation (mm H2O).

PCPSTD = Standard deviation for daily precipitation for month (mm H_2O/day).

PCPSKW = Skew coefficient for daily precipitation in month.

PR_W1 = Probability of a wet day following a dry day in the month.

PR_W2 = Probability of a wet day following a wet day in the month.

PCPD = Average number of days of precipitation in month.

SOLARAV = Average daily solar radiation for month (MJ/m^2/day).

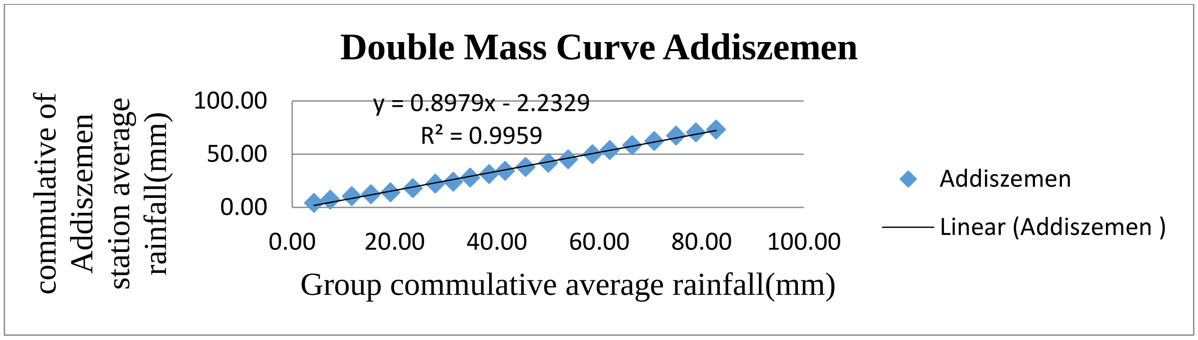
DEWPT = Average daily dew point temperature in month (^oC).

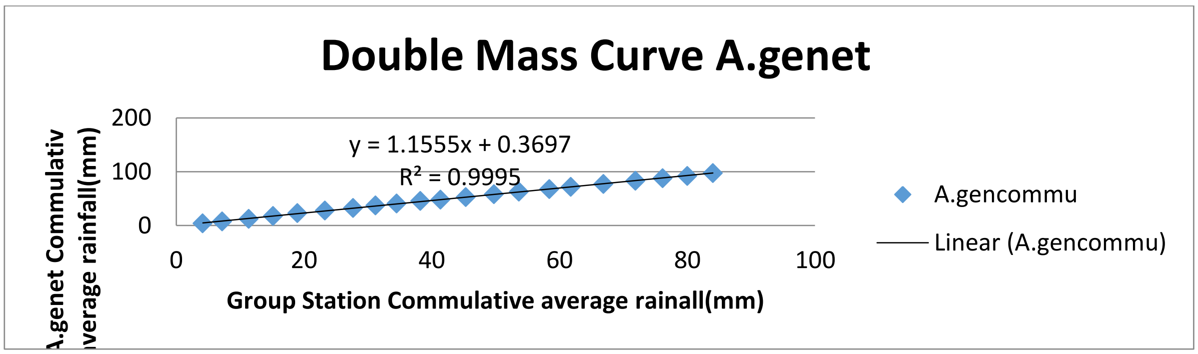
WNDAV = Average daily wind speed in month (m/s).

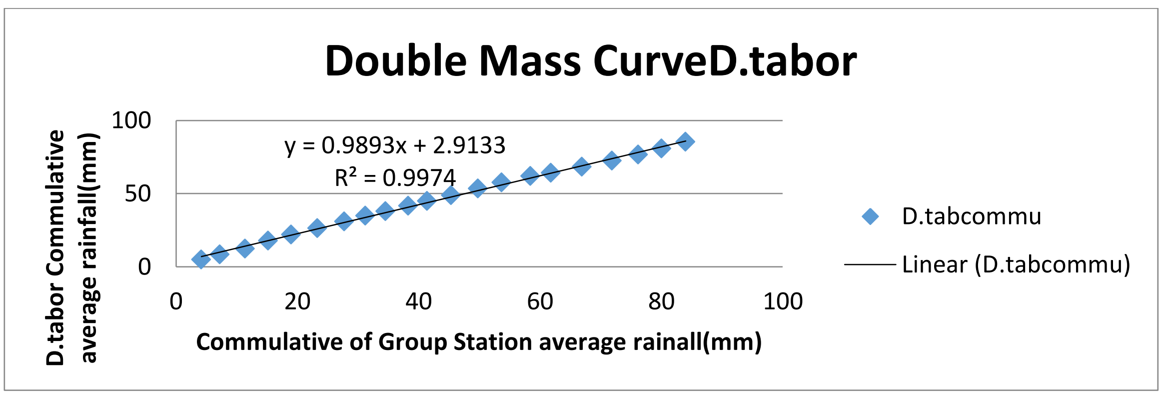
Appendix C. Average monthly flow (m^3/s) of the Ribb River

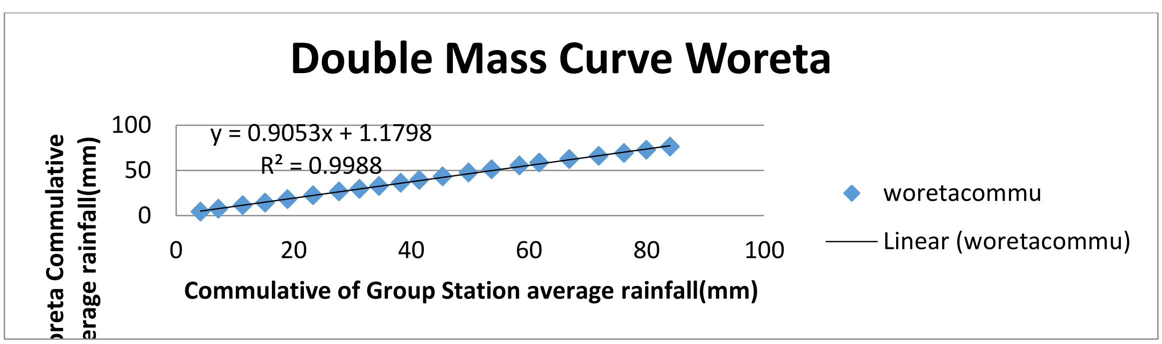
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.35	0.09	0.05	0.07	0.76	7.22	66.89	95.26	50.06	1.99	0.71	0.44
1995	0.31	0.24	0.23	0.66	0.57	1.42	36.45	71.47	29.14	1.84	1.03	0.83
1996	0.55	0.42	0.60	1.47	7.90	29.17	65.58	83.99	22.32	7.22	2.95	1.37
1997	0.74	0.40	0.66	0.46	4.64	7.62	44.29	52.27	13.02	8.56	7.81	1.63
1998	0.71	0.32	0.26	0.18	1.29	3.86	48.36	66.48	43.01	12.40	3.98	0.94
1999	0.80	0.49	0.36	0.30	0.39	3.42	45.27	70.81	39.86	41.03	12.95	13.08
2000	5.05	0.47	0.30	0.99	0.68	2.01	40.95	76.96	35.08	16.20	5.19	1.50
2001	0.80	0.48	0.49	0.43	0.53	15.31	54.81	69.29	34.46	9.16	4.20	2.58
2002	1.67	0.39	0.27	0.39	0.16	6.46	19.92	44.02	21.35	2.34	0.95	0.94
2003	0.57	0.43	0.47	0.13	0.08	3.28	41.42	64.64	41.49	6.59	3.05	2.31
2004	1.68	1.37	1.05	1.83	1.22	3.81	36.10	53.46	19.53	5.94	2.69	1.73
2005	1.35	0.94	1.61	0.66	0.98	7.47	43.30	59.60	40.38	11.28	5.07	3.55
2006	2.63	2.05	0.58	0.79	5.21	10.64	49.45	78.37	52.88	15.77	8.92	7.23
2007	5.94	5.06	3.76	5.20	6.91	20.23	62.79	75.75	50.76	12.93	8.38	6.37
2008	5.85	4.25	0.44	5.39	17.88	22.77	61.26	76.88	45.08	10.13	8.41	4.82
2009	4.16	3.65	4.07	3.80	0.56	1.96	41.09	57.16	20.49	4.55	1.53	1.05
2010	0.85	0.34	0.22	0.81	2.47	5.36	43.42	91.95	37.80	3.64	0.98	0.46
2011	0.32	0.42	0.48	0.16	2.79	4.33	32.28	61.37	40.16	2.29	2.71	0.29
2012	0.23	1.14	0.86	1.24	0.97	4.92	49.19	60.43	26.06	1.80	1.07	0.18
2013	0.40	1.15	0.86	0.92	0.08	3.05	61.53	76.20	20.21	6.66	0.91	0.15
2014	0.03	0.01	0.32	0.20	4.74	1.61	18.05	65.51	34.23	9.16	4.20	2.58

Appendix D: Double Mass Curve of Different Station Rainfall









Appendix E: Annual Rainfall of Different Stations

Year	Addiszemen	Debretabor	Ageregenet	Woreta
1994	1238.90	1794.50	1496.13	1557.70
1995	874.67	1272.60	1237.96	1062.30
1996	1163.80	1480.10	1911.51	1525.87
1997	728.30	1998.40	1851.96	953.53
1998	683.90	1505.83	1879.32	1491.47
1999	1334.94	1617.50	1826.42	1569.99
2000	1594.50	1645.60	1746.94	1443.60
2001	696.90	1470.90	1807.43	1130.90
2002	1349.53	1119.89	1200.07	1142.00
2003	1232.54	1289.27	1684.01	1263.50
2004	1164.60	1198.10	991.79	1227.60
2005	1263.12	1486.90	1612.54	1403.87
2006	1442.20	1634.74	1893.00	1519.57
2007	1181.30	1553.99	1731.64	1238.56
2008	1817.00	1599.68	1941.01	1585.70
2009	1440.50	814.70	1502.48	1167.10
2010	2566.11	1461.00	1951.75	1473.59
2011	2446.80	1533.20	2085.12	1195.30
2012	1902.20	1489.40	1645.07	1240.53
2013	1073.47	1565.53	1684.01	1297.60
2014	1027.14	1633.64	1911.22	1254.23
mean	1479.9	1484.1	1694.826	1321.2
st.dev	503.7568	247.3389	277.356	184.8864
CV	0.340408	0.166663	0.163649	0.139942