JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

HYDRAULIC AND WATER RESOURCES ENGINEERING

HYDRAULIC ENGINEERING MASTER OF SCIENCE PROGRAM

SOIL AND WATER ASSESSMENT TOOL (SWAT) BASED EVALUATION OF STREAM FLOW AND SEDIMENT YIELD OF GOLINA CATCHMENT, LOWER AWASH RIVER BASIN, ETHIOPIA

A THESIS SUBMITTED TO THE SCHOOL OF GRAGUATE STUDIES OF JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY IN PARTIAL FULIFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING PROGRAM.

By: ALEMU BIRESAW ERKU

OCTOBER, 2016

JIMMA, ETHIOPIA

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OCTOBER, 2016

JIMMA, ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis:

Soil and Water Assessment Tool (SWAT) based evaluation of stream flow and sediment yield of Golina catchment, Lower Awash River basin, 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

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

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ABSTRACT

Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. The main objective of this study ~~was~~ to evaluate stream flow and sediment yield of Golina catchment.

A physically based watershed model was applied based on its necessity to Golina catchment for evaluating of stream flow and sediment yield. The model was calibrated and validated for both flow and sediment concentration at Golina catchment outlet (323.4km^2) to evaluate stream flow and sediment yield. 25 years daily metrological, flow and sediment rating curve equation for sediment data were used for model calibration and validation.

The area of watershed was divided in to 8 sub basins and 29 HRUs by using soil and water assessment tool (SWAT) model. SWAT_CUP was used to calibrate the model parameters of flow and sediment with the time series of 2000 to 2009 for calibration and 2010 to 2014 for validation. Sensitivity analysis result shows that Base flow alpha factor (Alpha_Bf) and Cropping practice factor (USLE_C) were the most sensitive parameters affecting stream flow and sediment yield of the catchment respectively.

The Calibrated and validated values of stream flow and sediment yields were, (R^2=0.82, ENS=0.80, and (R^2=0.86, ENS=0.84,) for flow. Similarly (R^2=0.8, ENS=0.78, PBIAS=20.5RSR=0.46) and (R^2=0.94, ENS=0.84, PBIAS=34.6, RSR=0.42) respectively for sediment yields. This result indicates that the observed values show good agreement with simulated value for both flow and sediment yield.

For this study, the SWAT model yields average annual sediment of 68.82 ton/km^2 (6882 ton/ha) at Golina catchment. By applying watershed management intervention measures both land use redesign for steep slopes and terracing activities the sediment yields of Golina catchment reduced by 20.07% and 30.11% respectively. The result of the study could help different stakeholders to plan and implement appropriate soil and water conservation strategies.

Key Words: *Geographic Information system (GIS), Golina Catchment, Sediment yield, Stream flow, SWAT Model.*

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ACRONYMS

Alpha__Bf	Alpha Base factor
AMC	Antecedent Moisture Content
BMPs	Best Management Practices
ANRS	Amhara National Regional State
CH_K2	Effective Hydraulic Conductivity of the main channel
CH_N2	Manning's Roughness Coefficient
CN	Curve Number
Cn2	Moisture Condition Curve Number
CSA	Central statistical Agency
DEM	Digital Elevation Model
DEW02	Dew Point Temperature Calculator
Dr-Ing	Doctor Engineer
EHRS	Ethiopian Highland Reclamation Study
ENS	Nash-Sutcliffe Efficiency
ESCO	Soil Evapotranspiration Coefficient Factor
GIS	Geographical Information System
GW_DELAY	Ground water delay
GWQ	Ground Water Flow
GWQMN	Threshold depth of water in the shallow aquifer
HEC-HMS	Hydrologic engineering center Hydrologic modeling system
HRU	Hydrological Response Unit
ICOLD	International Committee on Large Dams
ITCZ	Inter-Tropical Convergence Zone
LH-OAT	Latin Hypercube One-factor-At-a-Time
LU	Land use

M.a.s.l	Meter at sea level
Mm	Mille Meter
MoWIE	Ministry of Water Irrigation and Electricity
MRS	Mean Relative Sensitivity
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Services Agency
NRCS	Natural Resource Conservation Service
PBIAS	Mean Relative Bias (Percent Bias)
PD	Probability Distribute
PET	Potential Evapotranspiration
R^2	Coefficient of Determination
RSR	Observations Standard Deviation Ratio
SCS	Soil Conservation Service
SOL_AWC	Soil available water capacity
SOL_Z	Total soil depth
SUFI2	Sequential Uncertainty Fitting Version 2
SURLAG	Surface Lag
SURQ	Surface runoff
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
US	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USLE	Universal Soil Loss Equation
WGEN	Weather Generator

CHAPTER ONE

INTRODUCTION

1.1. Study Background

Soil erosion is a process of detachment of soil particles due to raindrop energy and/or surface runoff, the transport of sediment by surface runoff and the deposition of sediments as the velocity of surface runoff decreases (Jackson et al., 2001). Soil erosion causes worldwide environmental problems leading to degraded soil productivity and water quality, causes sedimentation in the reservoirs and increases the probability of floods as a result of reduction of flood storage capacity (Bewket, 2003).

The poor land use practices, improper management systems and lack of appropriate soil conservation measures have been major causes of soil erosion and land degradation problems in ~~the country~~ (Tesfahunegn et al., 2012). Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high. For more than 34% of the land area of Ethiopia the soil depth is already less than 35 cm (Zemenfes, 1995: SCRP, 1996). Hurni (1989) indicated that Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. These call for immediate measures to save the soil and water resources degradation.

Sedimentation embodies the processes of erosion, entrainment, transportation, deposition, and the compaction of sediment. These are natural processes that have been active throughout geological times and have shaped the present landscape. Sedimentation is of vital concern in the conservation, development, and utilization of our soil and water resources. Poor land use practice is one of the primary factors that affect sedimentation (Lambin *et al.*, 2003).

Sedimentation reduces water storage capacity and negatively affects water supply, flood control capability, river barge navigation, viability of aquatic life, and the recreational value of reservoirs, because public funds for best management practices (BMPs) to reduce sedimentation are increasingly limited, and federal, state, and local governments are placing more emphasis on achieving economically efficient sediment reduction. Erosion of cropland is a major source of sediment accumulation in the catchment (Beven, 2008). Therefore, to address the above situation, watershed management is one of the most important approaches, which helps to reduce land degradation, increase vegetation cover, and increases the productivity of the watershed area (Easton et al., 2010).

Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system (Nejadhashemi et al., 2011). As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes. Hence to analyze the stream flow and sediment yield of Golina catchment with respect to quantity and quality of runoff is essential for the proper and sustainable utilization of Irrigation Project in the catchment. A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource (Easton et al., 2010).

The main intention of this study was evaluate Stream flow and sediment yield of Golina catchment, Lower Awash River Basin, Ethiopia. The study was done by using soil and water assessment tool (SWAT) that is a continuous time, physically based, distributed watershed model (Jamtsho and Gyamtsho, 2003).

The problem of land degradation is a threat and devastating challenge to the proposed catchment and downstream areas due to generating high runoff discharges and imposing hug sediment yield, which may result in reducing water storage capacity of irrigation projects, unless the upper watershed is treated with appropriate watershed management interventions and strategies(Easton et al., 2010).

Therefore, to address the above situation, watershed management is one of the most important approaches, which helps to reduce land degradation, increase vegetation cover, and increases the productivity of the watershed area (Surur, 2010).

1.2. Statement of the problem

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

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

Soil erosion causes different problems in existing hydrological conditions. Like increasing the percentage of impervious areas will increase volume of surface run off, decreases time of concentration which makes several distraction by generating higher amount of runoff and increasing the amount of sediment yield in the catchment as well as decreases the amount of water percolated in to the ground that in turn decreases the amount of water to be recharged in to the ground; and finally imbalances over all hydrological conditions of the catchment. Population growth over the last years caused various effects on resource bases like deforestation, expansion of residential area, and agricultural land. High population pressure relaying on natural resources coupled with poor land resources management practices and poverty resulted in severe soil erosion and sedimentation, this in turn has been a serious threat to national and household food security. Poor upstream watershed management and traditional conservation practices have led to these rates. Uncontrolled deforestation, forest fires, grazing, improper method of tillage, and unwise agricultural and land use practices accelerate soil erosion resulting in a large increase of sediment inflow into streams. Golina catchment which is one of the tributary of Lower Awash Basin is facing these types of effects.

1.3. Objective of the study

1.3.1. General Objective

The main objective of this study ~~was~~ to evaluate stream flow and sediment yield of Golina catchment using Soil and Water Assessment (SWAT model) Tool.

1.3.2. Specific Objectives

- To analyze the applicability of SWAT model to the study area.
- To determine sediment yield of the study catchment with existing land use.
- To identify the most erodible sub catchment.
- To develop future land use scenario for best management practices.

1.4. Research Questions

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

1. Is SWAT model applicable to Golina catchment?
2. How to determine sediment yield of the study catchment?
3. Which sub catchment is vulnerable ~~by~~ soil erosion?
4. How to improve future land use practices?

1.5. Significance of the Study

Understanding stream flow and sediment yield of the catchment is essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable management of natural resources in the country in general and at the study area in particular.

Moreover, the study presents a method to evaluate stream flow and sediment yield and their impact on hydrological regime. 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. It is believed that the research findings is strongly assist Decision / Policy Makers in planning development activities in a way to fit stream flow and sediment yield of the study area. In addition, this study provides scientific information on the future water resource development and fills the gaps of other research works by incorporating the recommendations in other research works.

1.6. Scope of the study

The study was limited to evaluate stream flow and sediment yield of Golina catchment using Soil and Water Assessment (SWAT model) Tool. As the work's main initial approach, it may require further improvement and research on aspects beyond the scope like ground water, climate change, water quality and other limitations that were happened on the courses of study. The study was conducted from February 2016 up to October 2016.

CHAPTER TWO

LITERATURE REVIEW

2.1. Soil Erosion Definitions and Concepts

Water and wind are the main agents responsible for soil erosion. Sedimentation and soil erosion includes the processes of detachment, transportation and deposition of solid particles also known as sediments (Julien, 2002). These soil erosion sequences are demonstrated in Figure2.1. The forms of water responsible for soil erosion are raindrop impact, runoff and flowing water (Wischmeier& Smith, 1978). Erosion from mountainous areas and agricultural lands are the major source of sediment transported by streams and deposited in reservoirs, flood plains and deltas (Meyer and Turner, 1994). Sediment load is also generated by erosion of beds and banks of streams, by the mass movements of sediment such as landslides, rockslides and mud flows, and by construction activity of roads, buildings and dams. Many environmentalists, policy makers and researchers agree that land degradation mainly caused by soil erosion has been one of the chronic problems in Ethiopia (Zeleke and Hurni, 2001). The Ethiopian Highland Reclamation Study (EHRS) estimated that the average annual soil loss from arable land was100 tons/ha and the average productivity loss on cropland was1.8 % (Constable, 1985).

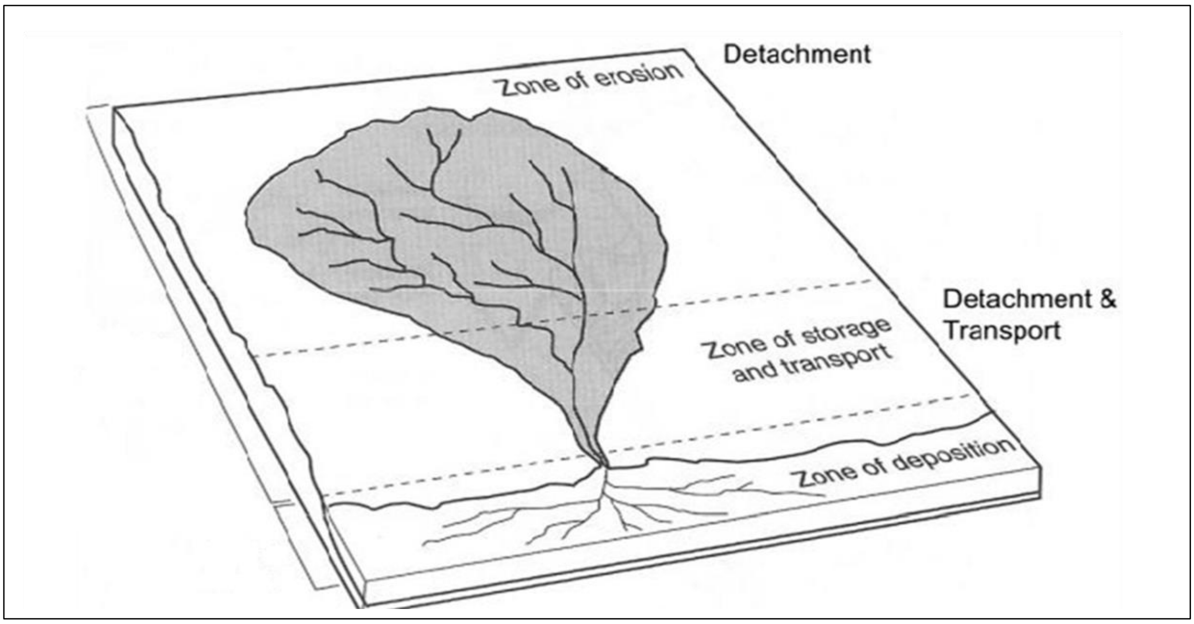

Figure 2.1. Factors that influence Soil erosion (Wischmeier & Smith; 1978).

The erosion potential of a site is influenced by several factors, which includes soil erodibility factor (k-factor), rain fall erosivity factor, topography factor, land use /land cover factor, Support practice factor (p-factor) (Wischmeier & Smith; 1978).

Characteristics of rain fall significantly play a major role in determining sediment yield on land surface (Sage, 1994). Factors that affect the yield in these categories are: climate vegetation, soil, topography and human activities.

2.1.1. Rain fall Erosivity Factors

Rain fall affects erosion potential of an area. Rain fall characteristics such as frequency, intensity and duration directly influence the amount of runoff that is generated (Bewket, 2003). Rain fall erosivity is defined as the capacity of rain fall to cause erosion. As the frequency of rain fall increases water has less chance to drain through the soil between storms. The soil should remain saturated for longer periods of time and storm water runoff volume may be potentially greater (Lambin *et al.,* 2003).

2.1.2. Soil Erodibility Factor

The vulnerability of a soil to erosion is known as erodibility factor (Kidanu, 2004). The soil structure, texture, infiltration capacity and percentage of organic matter influence its erodibility. The most erodible soil generally contain high portion of silt and very fine sand percentage of clay or organic matter tends to decrease soil erodibility (Hougton, 1995).

2.1.3. Topography /Slope Length Factor

Slope length is defined as the horizontal distance from the origin of over land flow to the point where either the slope gradient decrease enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier&smith1978).

Slope length and steepness greatly influence both the volume and velocity of surface runoff. Long slops deliver more runoff to the base of slopes increase runoff velocity both conditions enhance the potential for soil erosion to occur (Abebe, 2005).

2.1.4. Land use Land cover Factor

Although the terms “Land use”(LU) and “Land cover are sometimes used inter changeably , they are actually different, simply put Land cover is what covers the surface of the earth and Land use describes how the land is used (Belay, 2002). Land use/ Land cover factor(C-factor) is used within MUSLE to reflect the cropping and management practices on erosion rates and is the factor used most often to compare the relative impacts of management options on conservation plans (USDA-ARS,2001).

2.1.5. Support Practice Factor

Support practices factor is the ratio of soil loss from any conservation support practice to that with up and down slope tillage practice. On none- cultivated land support practices factor includes hill side terrace, check dams and other practices which conserve moisture and runoff reduction (Kassa, 2003). Support practice factor for cultivated land includes strip cropping contour plaguing, bunds, drainage system and others (Gebrehiwet, 2004).

2.2. Soil erosion process

The processes of soil erosion are Sheet erosion happens when raindrop impact transports particles and becomes runoff traveling over the surface of the ground (Fortuin, 2006). Rill erosion occurs when water from sheet erosion combines to form small concentrated channels (Hadgu, 2008)). Erosion rates increase due to higher velocity flows as rill erosion starts. When water in rills concentrates to form larger channels, it results in gully erosion (Fortuin, 2006). Finally, stream channel erosion takes place when water flows cut into the bottom of the channel and makes it deeper (Fortuin, 2006). Soil erosion may not be obvious on the ground surface as raindrops are transporting some amount of particles but soil erosion will be more noticeable when water flow concentrates to form rills and gullies (Kim, 2006).

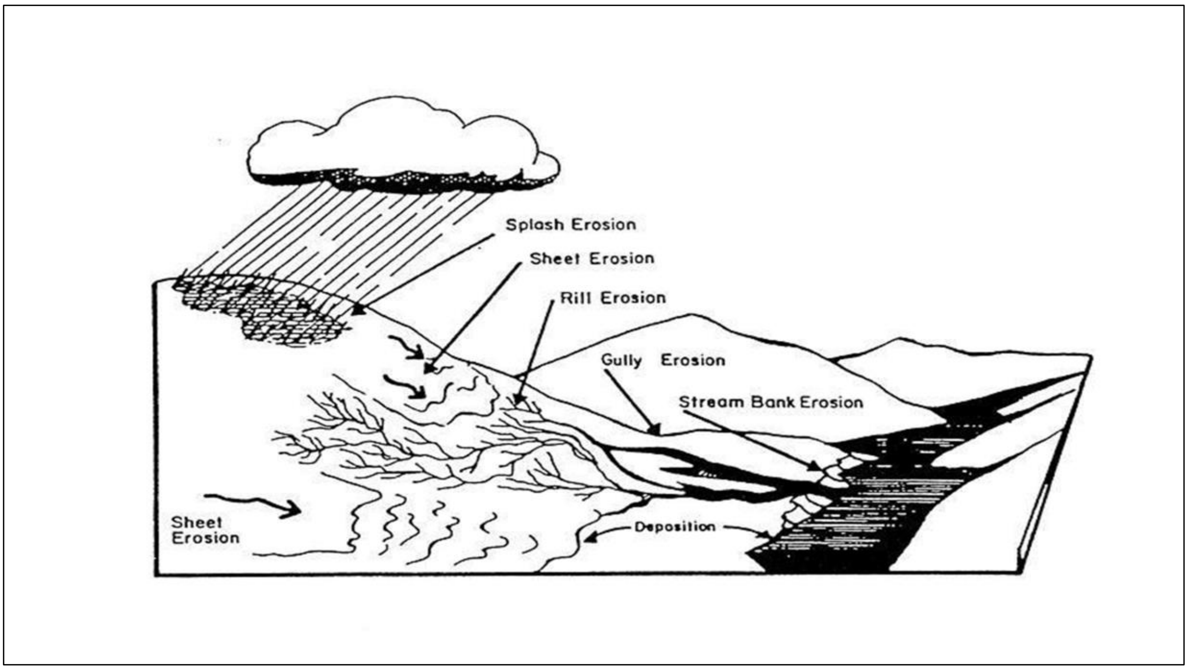

Figure 2.2: The mechanisms of soil erosion (USACE, 1985)

2.3. Soil erosion models

The soil erosion prediction methods were first developed in the U.S.; consequently many soil loss estimation equations were developed by a number of researchers. Smith and Whitt presented one of the first rational soil erosion equation and it is a method of estimating soil losses from fields of clay pan soils (Smith & Whitt, 1947).

$$A = C \cdot L \cdot S \cdot K \cdot P \quad 2.1$$

Where: A – Annual soil loss, in tones /ha/year, C – Average annual soil loss from clay pan soils for a specific rotation, slope length, slope Steepness and row direction, S – Slope steepness, L – Slope length, K – Soil erodibility, P – Support practice.

Then, the Universal Soil Loss Equation model (USLE) was adopted by the Soil Conservation Service in U.S. in 1958 and became the most widely used and accepted model to make long term assessments of soil erosion. The USLE model was developed by Wischmeier and Smith based on data from more than 10,000 test plots throughout the East of the U.S. in 20 years (Wischmeier and Smith, 1965). The USLE has six factors and is applicable to calculate sheet and rill erosion only. However, the USLE is known to have a few shortcomings. If just one of the input data is not accurately specified, the multiplication of the six factors will lead to a large error of results (Sonneveld and Nearing, 2003)

2.4. Modes of sediment transport mechanism

According to the mechanism of transport two major modes of sediment transports may be distinguished:

2.4.1. Bed load

Movement of particles in contact with the bed of the channel by rolling, sliding and jumping

2.4.2. Suspended load

It is movement of particles in the flow. The settling tendency of the particle is continuously compensated by the diffusive action of the turbulent flow field .There is no sharp distinction between bed load and suspended load.

2.5. Origin of transport material

Based on the origin of the transport material distinction is made as follows:

2.5.1. Bed material

The origin of this transport is the bed, which means that the transport is determined by the bed and flow condition (can consists of bed load and suspended load).

2.5.2. Wash load

Transport of particle not or in small quantities in the bed. The material is supplied by external sources (erosion) and no direct relationship with local condition exists (can only be transported as suspended load, generally fine material < 50µm). It can have influences on turbulence and viscosity and therefore have some influence on the flow. Wash load is not important for changes in the bed of rive but only for sedimentation in the reservoirs.

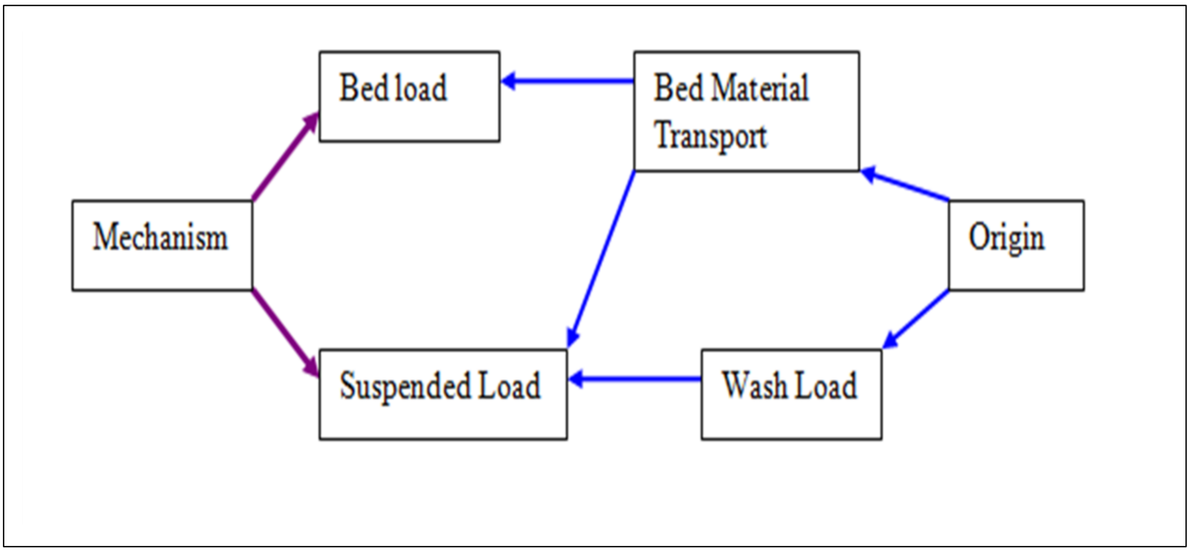

Figure 2.3. Flow charts of sediment transport mechanisms

2.6. Hydrological Models

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

On the basis of process description, the hydrological models can be classified in to three main categories (Cunderlik, 2003).

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 (Arnold, *et al.*, 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), are considered as semi-distributed models.

Hydrologic models can be further divided into event-driven models, continuous- process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff- volume forecasting and for estimates of water yield (Cunderlik, 2003).

Table 2.1. Comparison of three selected semi-distributed hydrological models

Description	SWAT	HEC-HMS	HBV
Model type	Semi-distributed Physically-based Long-term	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
Temporal scale	Day $^{+}$	Day $^{-}$	Day $^{-}$
Spatial scale	Medium $^{+}$	Flexible	Flexible
Process modeled	Continuous	Continuous & event	Continuous & event
Cost	Public domain	Public domain	Public domain

2.7. SWAT Model Application Worldwide

The SWAT model has good reputation for best use in agricultural watersheds and its uses have been successfully calibrated and validated in many areas of the USA and other continents (Ndomba, 2002; Tripathi *et al.,* 2003). The studies indicated that the SWAT Model is capable in simulating hydrological process and erosion/sediment yield from complex and data poor watersheds with reasonable model performance statistical values. Ndomba (2002) was applied the SWAT model in modeling of Pangari River (Tanzania) to evaluate the applicability of the model in complex and data poor watersheds. Tripathi *et al.,* (2003) applied the SWAT model for Nagwan watershed in India with the objective of identifying and prioritizing of critical sub- watersheds to develop an effective management plan and the model was verified for both surface runoff and sediment yield. Accordingly, the study concluded that the SWAT model can be used in ungauaged watersheds to simulate the hydrological and sediment processes.

SWAT has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences, hundreds of SWAT-related papers presented at numerous other scientific meetings, and large number of articles published in peer-reviewed journals (Gassman, 2007).

However, Cibin *et al.* (2010) indicated that SWAT model parameters show varying sensitivity in different years of simulation suggesting the requirement for dynamic updating of parameters during the simulation. The same study also indicated that sensitivity of parameters during various flow regimes (low, medium and high flow) is also found to be uneven, which suggests the significance of a multi-criteria approach for the calibration of the model.

2.8. SWAT Model Application in Ethiopia

The SWAT model application was calibrated and validated in some parts of Ethiopia, frequently in Blue Nile basin. Through modeling of Gumara watershed (in Lake Tana basin), Awulachew *et al*. (2008) indicated that stream flow and sediment yield simulated with SWAT were reasonable accurate. The same study reported that similar long term data can be generated from ungagged watersheds using the SWAT model. A study conducted on modeling of the Lake Tana basin with SWAT model also showed that the SWAT model was successfully calibrated and validated (Setegn *et al.,* 2008). This study reported that the model can produce reliable estimates of stream flow and sediment yield from complex watersheds. Gessese (2008) used the SWAT model performed to predict the Legedadi reservoir sedimentation. According to this study, the SWAT model performed well in predicting sediment yield to the Legedadi reservoir. The study further put that the model proved to be worthwhile in capturing the process of stream flow and sediment transport of the watersheds of the Legedadi reservoir.

In addition to the above, the SWAT model was tested for prediction of sediment yield in Anjeni gauged watershed by Setegn *et al.,* (2008). The study found that the observed values showed a good agreement at Nash-Sutcliff efficiency (ENS) of 80 %. In light of this, the study suggested that the SWAT model can be used for further analysis of different management scenarios that could help different stakeholders to plan and implement appropriate soil and water conservation strategies. The SWAT model showed a good match between measured and simulated flow and sediment yield in Gumara watershed both in calibration and validation periods (Asres and Awulachew, 2010). Tekle (2010) through modeling of Bilate watershed also indicated that SWAT Model was able to simulate stream flow at reasonable accuracy. The literature reviewed and presented above showed that SWAT is capable of simulating hydrological and soil erosion process with reasonable accuracy and can be applied to large and complex watersheds.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Awash Basin is situated between latitudes 7°53’N and 12°N and longitudes of 37°57’E and 43°25’E in Ethiopia. It covers a total land area of 110,000 km² of which 64,000 km² is in Western Catchment of the basin. This catchment drains to the Awash Main River or its tributaries. The remaining 46, 00 km², most of which comprises the so-called Eastern Catchment drains into a desert area and does not contribute to the awash main river course. The River Awash rises at an elevation of about 3,000m in the central Ethiopian highlands, west of Addis Ababa and flows through Koka Reservoir, to north-eastwards along the Rift Valley until eventually discharging into the wilderness of the Danakil Depression at Lake Abe 250meter above sea level (m.a.s.l) at the border to Djibouti. The main river length is about 1,200 km.

Golina catchment is one of the tributary of Millie River which drains from Northern Wollo highlands and then joined Lower part of the Awash River Basin, Ethiopia. In terms of geographic coordinate system, the catchment lies between 11°56’ to 12°00’N latitudes and 39°23’ to 39°47’E East longitudes. The total area of the watershed is 323.4km^2.

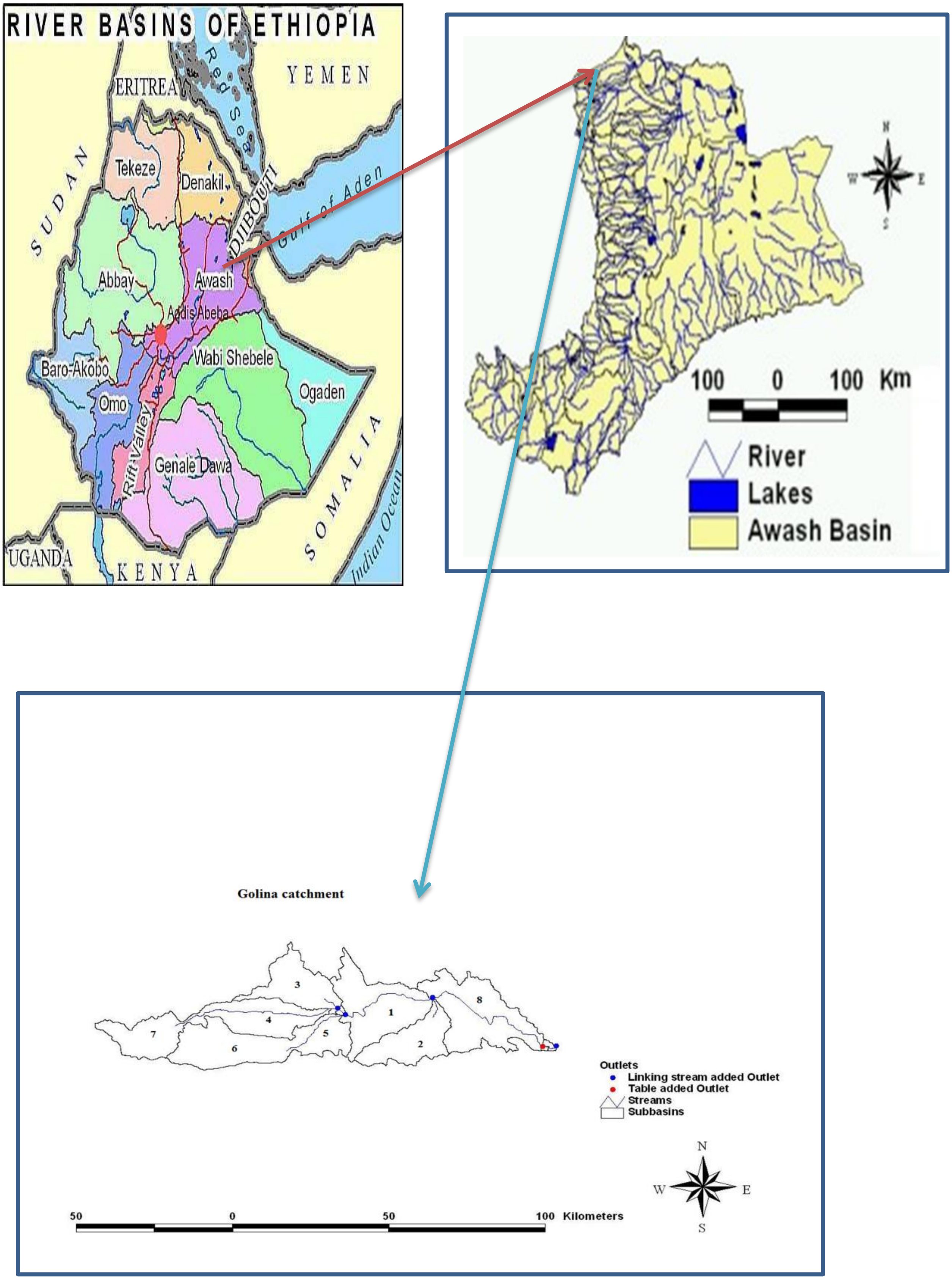

Figure 3.1.Map showing location of the study area

3.1.2. Climatic Condition

3.1.2.1. Rain fall

Rainfall records of five stations were selected to describe the rainfall regime of the studied area. 25 years of rainfall record (1990 -2014) were collected for the analysis purpose of this study in order to have adequate data. There is high spatial and temporal variation of rainfall in the study area. The main rainfall season which accounts around 70-90% of the annual rainfall occurs from July to August, while small rain also occurs during the other months.

The monthly rainfall distributions of the study area indicate that July and August are the wettest months of the year in all the selected stations. The mean monthly rainfall of the Logia, Mille, Sirinka, Mersa and Woldia stations for the period of 1990-2014 is shown in Figure 3.2.

The mean annual rainfall is computed to be 1216mm. Woldia and Sirinka stations have a maximum mean monthly rainfall of 577mm in July and 590mm in August respectively. Golina catchment has a maximum mean monthly rainfall of 500mm in July and 485mm in August respectively as shown in Figure 3.3.

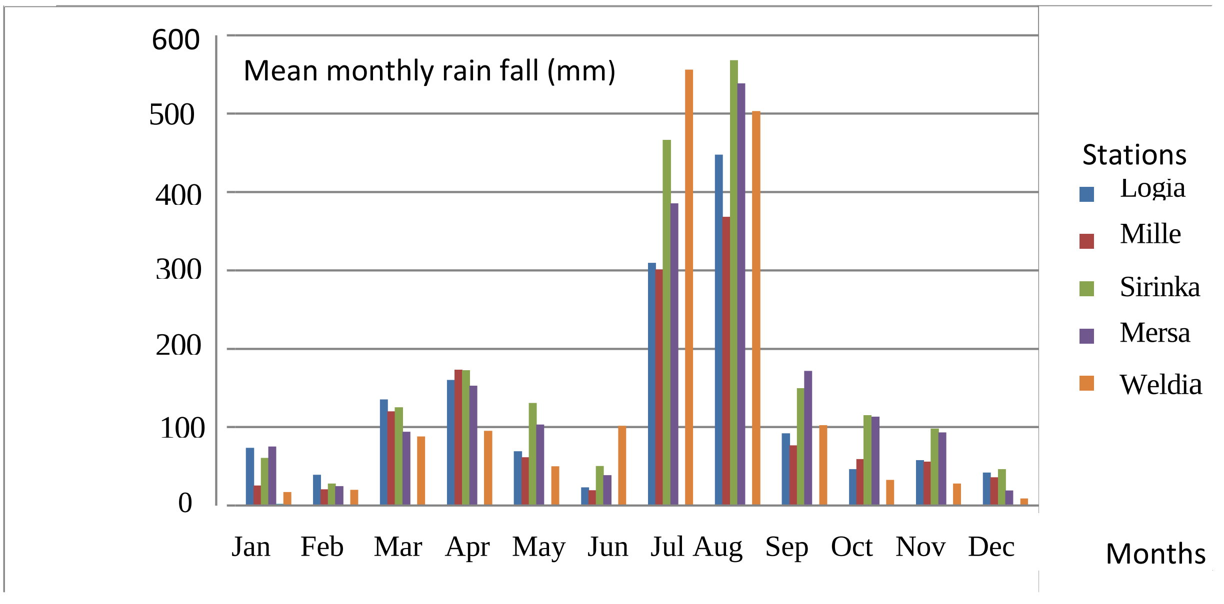

Figure 3.2. Mean monthly rainfall of different station (1990-2014)

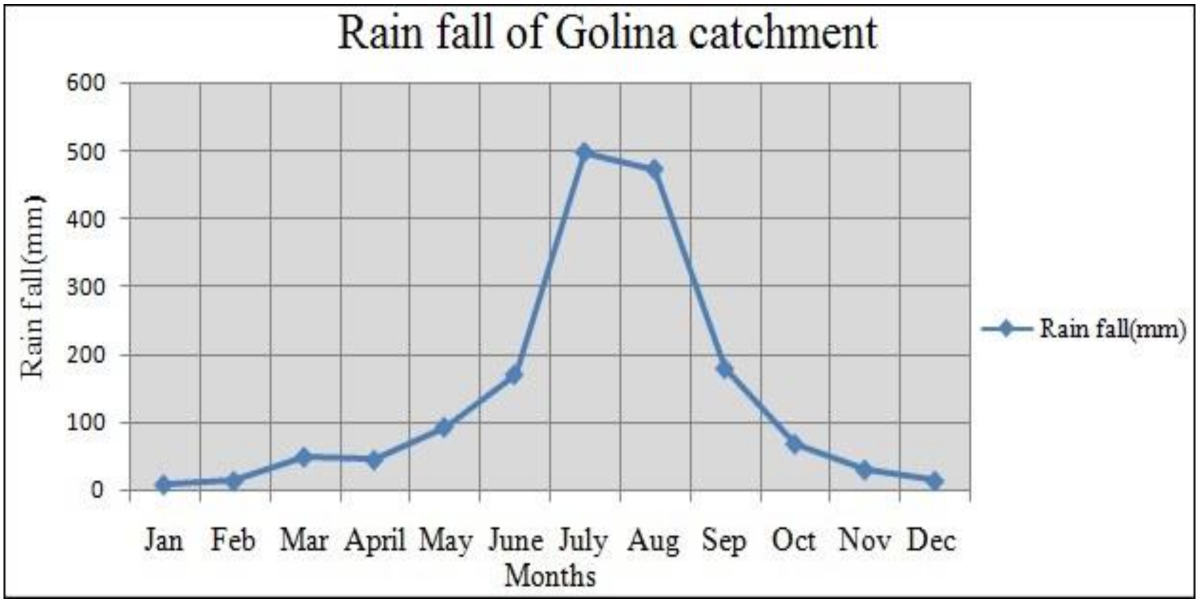

Figure 3.3.Mean monthly rainfall of Golina catchment (1990-2014)

3.1.2.2. Temperature

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

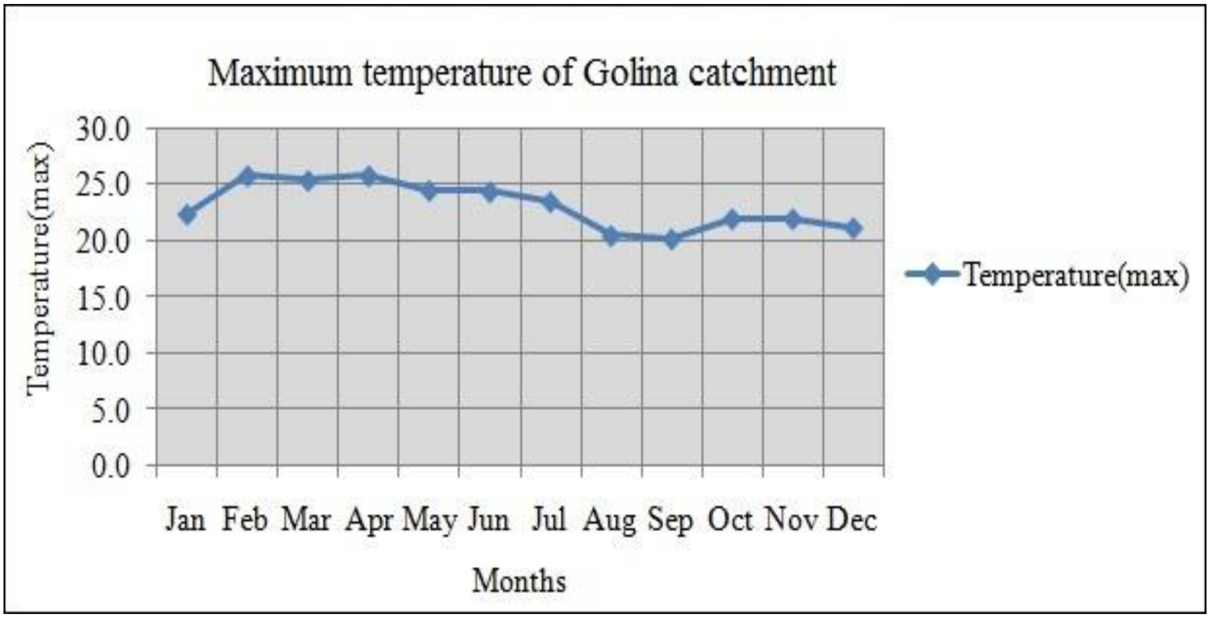

Figure 3.4. Mean monthly maximum temperature of Golina catchment (1990-2014).

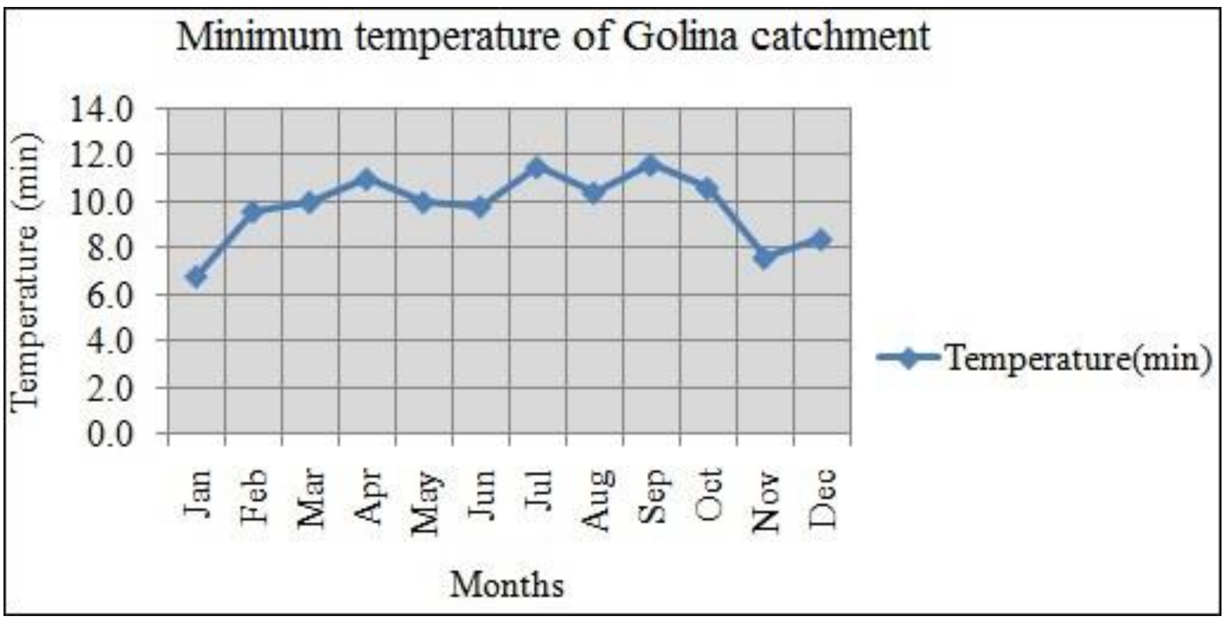

Figure 3.5. Mean monthly minimum temperature of Golina catchment (1990-2014).

3.1.2.3. Wind speed

Wind direction refers to the direction from which the wind is blowing. It is expressed by its direction and velocity. Wind speed is the relevant variable in order to compute evapotranspiration. The mean monthly value show lowest record of 0.6m/s in August and highest record of 1.1 m/s in June.

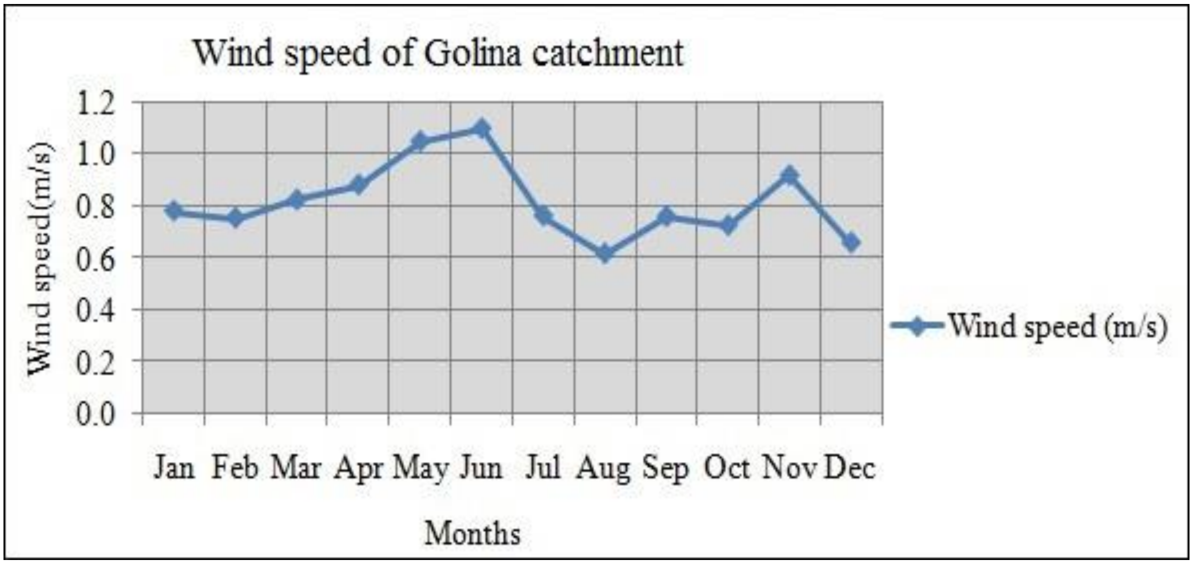

Figure 3.6. Mean monthly wind speed of Golina catchment (1990-2014).

3.1.2.4. Solar Radiation

Solar radiation changes large quantities of liquid water into water vapor through the process of evaporation. Consequently, the evapotranspiration process is determined by the amount of energy available to vaporize water. Maximum sunshine hour for Golina catchment is about 10.2 hours in April and minimum sunshine hour was recorded in August about 1.8 hours.

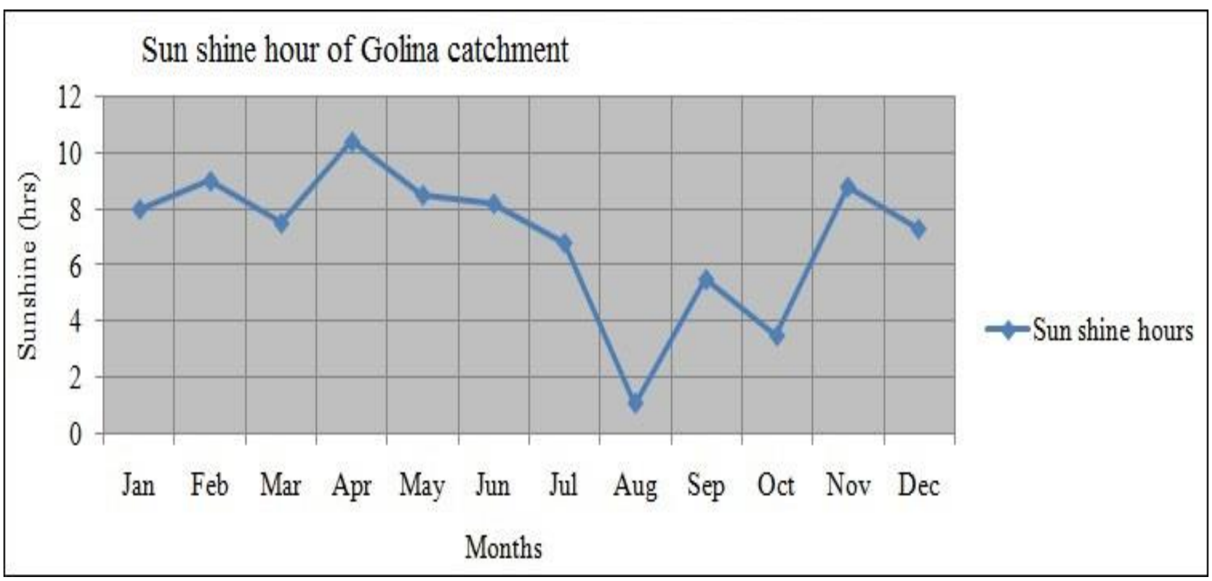

Figure 3.7. Mean monthly solar radiation of Golina catchment (1990-2014).

3.1.2.5. Relative humidity

The Relative humidity record shows that the mean minimum monthly value of 37.9 in January and reaches maximum 86.3 in August as presented in the following (figure 3.8).

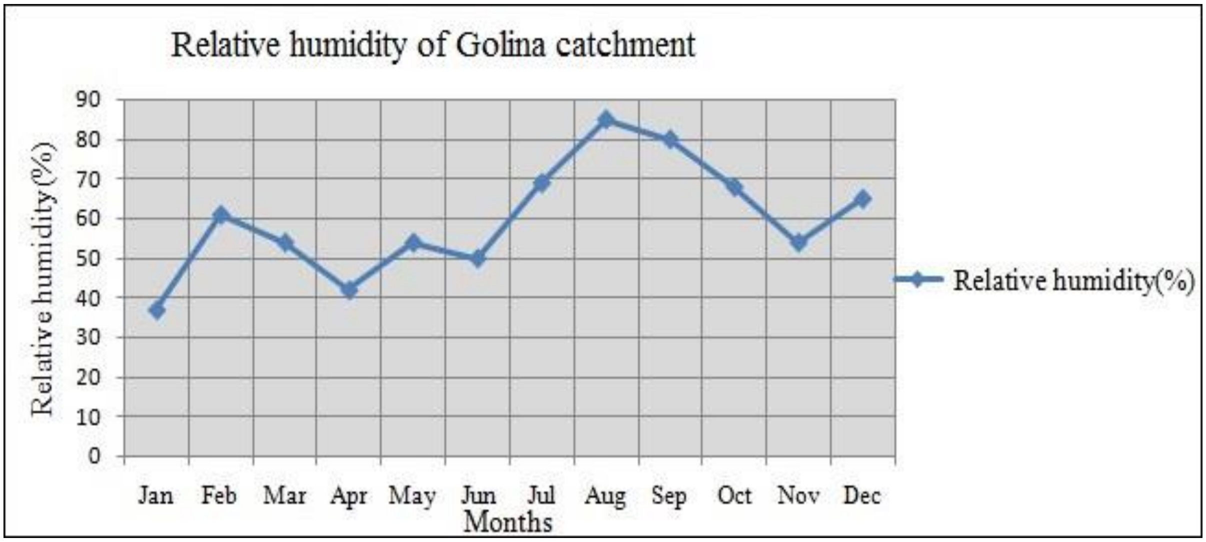

Figure 3.8.Mean monthly relative humidity of Golina catchment (1990-2014).

3.1.3. Soil types, Geology and Land Cover

The geology of north and central Ethiopia, which also includes the current study area, is dominated by Tertiary volcanic strata underlain by Mesozoic sedimentary rocks. The dominant outcrops on the mountains are fissured basalts with silica varieties. The valley and plain areas are comprised of several low lying depositional areas distributed in the middle of the area extended from north to south. The plain area is formed by the accumulation of sediments from the surrounding scraps in an old lake bed. River drainage in the study area originated from the western scraps where the youthful streams have cut deep gorges through the strata they cross and flow to the east across the plain to the Afar Depression through the narrow outlets in the eastern scraps. Due to low gradient, the streams form wide flood plain, alluvial flats and swamps as they reach the plain and deposit huge quantity of sediments. The soil type of the catchment is dominantly alluvial sediment deposit from the escarpment of mountains. The land covers of the catchment are mainly agricultural area, bare land, woodland, and forest.

3.1.4. Hydrogeology

The regional hydrogeological set up of the study area and its surrounding can be summarized as localized graben filling unconsolidated sediment composed of clay, silt, sand, gravel, boulders and pebbles above the Ashangi group volcanic which are intern underlain by Mesozoic sedimentary rocks. Therefore, the unconsolidated sediment is recharged mainly as subsurface inflow from the locally weathered and fractured zone of the volcanic rock of the mountains surrounding the plain area. Major groundwater out flow of Golina River is the Millie- Awash, sub Basin, in Afar Region. The outlets have perennial flows from groundwater discharge.

3.1.5. Population

According to the 2007 Census, each successive Population and Housing Census showed that the total population size of the country, Ethiopia, increased. For instance, the results of the 2007 census shows that the population of the country increased by more than 20.8 million people from 1994 to 2007. Similarly, from 1984 to 1994, the population of the country increased by 13.2 million people (Table 3.1).

Table 3.1. Population Size of Ethiopia (in millions) 1984-2007 (CSA, 2008).

census year	Population of the country	Population of the study area
1984	39.9	0.12
1994	53.1	0.53
2007	73.9	0.94

3.1.6. Agriculture

The agriculture production system in the area is a subsistence type of crop and livestock production system. In this production system, the crop production is entirely dependent on livestock where the contribution of livestock include, drat power, transportation, manure, and income generating purposes. Due to high population pressure, the land is moderately to intensively cultivate.

Generally, the watershed is well known by rain fed cereal crops production. Major types of crops grown in the area includes barely, wheat, maize, teff, sorghum, finger millet and small extent pulses and oil crops. In this watershed, some farmers also practices traditional irrigation development activities from perennial rivers and springs.

Livestock production is an important and integral component of the agricultural sector in Golina catchment. Communities keep livestock for multi-purpose i.e. for draft power, transportation, for production of milk and meat, and earning income.

3.1.7. Topography/Slope

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

Table 3.2. The slope classes of the Golina catchment

Slope classes	Land forms	Slope range	Area (ha)	Coverage (%)
Class 1	Flat	0-2	19404	60
Class 2	Genteel slope	2-10	3234	10
Class 3	Moderately steep	10-15	4851	15
Class 4	Steep slope	15-30	1617	5
Class 5	Very steep slope	>30	3234	10

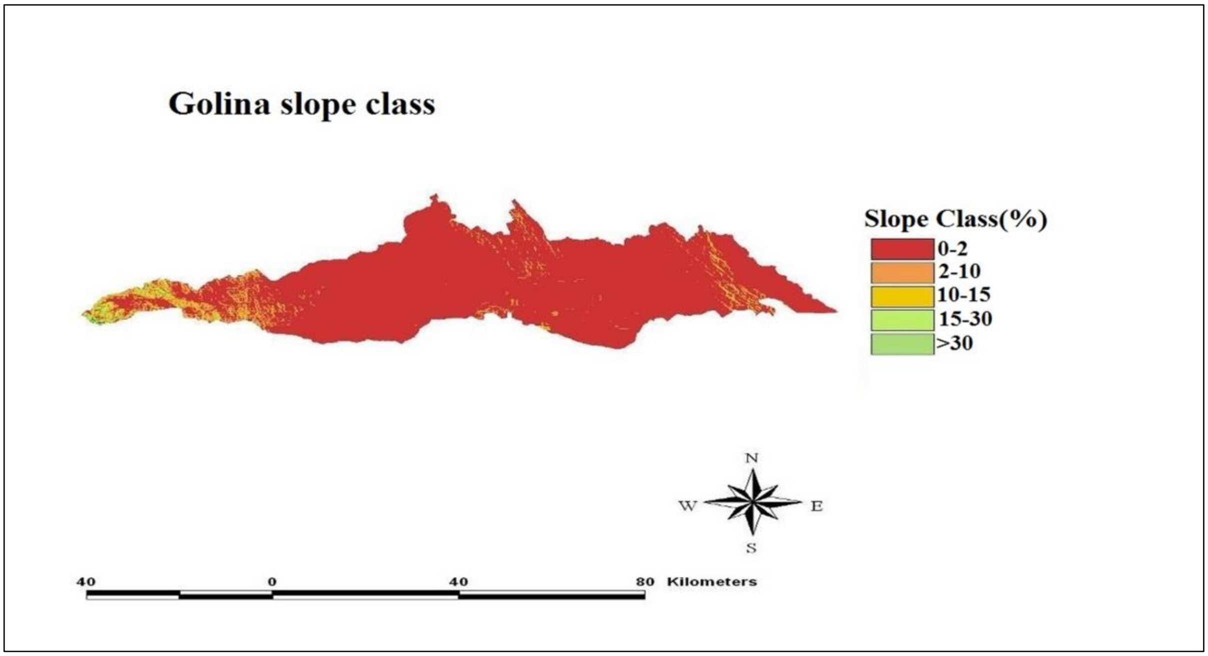

Figure 3.9. Slope class map of study area

3.2. Materials Used

For proper implementation of this study the following equipment's and materials was required for data collection, processing and evaluation. Some of the software and materials required for this study include:

- Arc GIS 9.3
- Arc SWAT model (software)
- SWAT-CUP(SUFI2)
- Global mapper 10
- DEW02
- PCPSTAT
- GPS Garmin 60
- color printer
- Excel Spread sheet and other software if necessary.

3.3. Hydrological Model Selection Criteria

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-depended (and therefore subjective). Among the various project-dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 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?).

3.4. Reasons for selecting SWAT model

The reasons behind for selecting SWAT model for this study are;

- The model was applied for land use and land cover change impact assessment in different parts of the world.
- The model simulates the major hydrological process in the watersheds
- It is readily and freely available.

3.5. SWAT hydrological 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.

SWAT splits hydrological simulations of a watershed in to two major phases: the land phase and the 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.

3.5.1. Water balance equation

The land phase of the hydrologic cycle is modeled in SWAT based on the water balance equation (Neitsch, *et al*, 2005):

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad 3.1$$

Where SW_t is the final soil water content [mm], SW_o is the initial soil water content on day 1 [mm], t is the time [days], R_{day} is the daily precipitation [mm], Q_{surf} is the amount of surface runoff [mm], E_a is the evapo-transpiration [mm], ω_{seep} is the amount of water entering the unsaturated zone [mm] and consists of the infiltration rate minus the capillary rise, and Q_{gw} is the amount of return flow [mm].

The water balance for each HRU is represented by four storage volumes: snow, soil profile (0- 2 m), shallow aquifer (2-20 m) and deep aquifer (>20 m) (David et al., 2007). Each HRU in a sub- catchment is liable for water and sediment movement, nutrients and pesticides loadings that are routed through channels, ponds and reservoirs towards the watershed outlet (Neitsch et al, 2011).

The second component of the simulation of the hydrology of a watershed is the routing phase of the hydrologic cycle. It consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network.

Two options are available to route the flow in the channel network: the variable storage and Muskingum methods. The variable storage method uses a simple continuity equation in routing the storage volume; the variable storage method was developed by (Williams, 1969). The equation is given by:

$$\mathbf{\Delta V_{stored} = V_{in} - V_{out}} \qquad 3.2$$

Where, ΔV_{stored} is the change in volume of storage during the time step (m^3 water) V_{in} is the volume of inflow during the time step (m^3 water), and V_{out} is the volume of outflow during the time step (m^3 water).This equation can also be detailed as follows:

$$\mathbf{V_{storage,2}} - \mathbf{V_{storage,1}} = \Delta\mathbf{t} * \left(\frac{\mathbf{q_{in,1}} + \mathbf{q_{in,2}}}{\mathbf{2}}\right) - \Delta\mathbf{t} * \left(\frac{\mathbf{q_{out,1}} + \mathbf{q_{out,2}}}{\mathbf{2}}\right) \quad 3.3$$

Where: Δt is the length of the time step (s),$q_{in,1}$ is the inflow rate at the beginning of the time step (m^3/s),$q_{in,2}$ is the inflow rate at the end of the time step (m^3/s),$q_{out,1}$ is the outflow rate at the beginning of the time step (m^3/s),$q_{out,2}$ is the outflow rate at the end of the time step (m^3/s),$V_{storage,1}$ is the storage volume at the beginning of the time step (m^3 water), and$V_{storage,2}$ is the storage volume at the end of the time step (m^3 water).

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

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

$$S = K[x\, I^m + (1-x)\, Q^m] \quad 3.4$$

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

$$S_2 - S_1 = K\,[x\,(I_2-I_1) + (1-x)\,(Q_2-Q_1)] \quad 3.5$$

Where suffixes 1and 2 refer to the conditions before and after the time interval Δt. The continuity equation for the reach is; from equation 3.5, Q_2 is valuated as;

$$Q_2=C_0I_2+C_1I_1+C_2I_2 \qquad 3.6$$

Where; $Co = \frac{-Kx+0.5\Delta t}{K-Kx+0.5\Delta t}$, $C1 = \frac{Kx+0.5\Delta t}{K-Kx+0.5\Delta t}$, $C2 = \frac{K-Kx-0.5\Delta t}{K-Kx+0.5\Delta t}$

Note that $C_0 + C_1 + C_2 = 1$ equation 3.6 can be written for the n^{th} time step on

$$Qn = C_0I_n + C_1I_{n-1} + C_2Q_{n-1} \qquad 3.7$$

It has been found that for best results the routing interval Δt should be so chosen that K> Δt >2Kx. If Δt <2Kx, the coefficient C_0 will be negative. Generally negative values of coefficients are avoided by choosing appropriate values of Δt.

3.5.2. Surface Runoff

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration (Solomon, 2005). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating the surface runoff: the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911). The Green and Ampt method needs sub-daily time step rainfall which made it difficult to be used for this study due to unavailability of sub-daily rainfall data. Therefore, the SCS curve number method was adopted for this study. The general equation for the SCS curve number method is expressed by equation 3.4:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad 3.8$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm water), I_A is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water); *S* is retention parameter (mm water).

The retention parameter varies spatially due to changes with land surface features such as soils, land use, slope and management practices. This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as:

$$S = 25.4 * \left(\frac{1000}{CN} - 10\right) \qquad 3.9$$

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

The initial abstraction, I_a, is commonly approximated as $0.2S$ and equation 3.5 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad 3.10$$

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

3.5.3. 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).

There are many methods that are developed to estimate potential evapotranspiration (PET). SWAT provides three options for PET calculation: Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and Hargreaves (Hargreaves *et al.,* 1985) methods. The methods have various data needs of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind sped; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only.

For this study, the Penman-Monteith method was selected as the method is widely used and all climatic variables required by the model are available for the five stations around the study watershed area.

$$ET_O - \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(es - ea)}{\Delta + \gamma(1 + 0.34U_2)} \quad 3.11$$

Where: ET_o reference evapotranspiration (mm day-1), R_n 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).

3.5.4. Sediment transport

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

$$Sed_{deg} = \left(Conc_{sed,ch,mx} - Conc_{sed,ch,i}\right) * V_{ch} * K_{ch} * C_{ch} \quad 3.12$$

$$Sed_{dep} = \left(Conc_{sed,ch,i} - Conc_{mx}\right) * V_{ch} \quad 3.13$$

Where: Sed $_{deg}$ is the amount of sediment re-entered in the reach segment (metric tons),$Conc_{sed,\ ch,\ i}$ is the amount of initial sediment concentration in the reach (kg/L),$Conc_{sed,\ ch,\ mx}$ is the maximum concentration of sediment that can be transported by the water ton/m^3,K_{ch} is the channel erodibility factor (cm/hr.),C_{ch} is the channel cover factor, V_{ch} is the volume of water in the reach segment (m^3) and Sed_{dep} is the amount of sediment deposited in the reach (metric tons). After calculating degradation and deposition the final amount of sediment in the reach and amount of sediment out of the reach is calculated with the following equations.

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \quad 3.14$$

$$Sed_{out} = Sed_{ch} * \left(\frac{V_{out}}{V}\right) \quad 3.15$$

Where; Sed $_{ch}$ =amount of suspended sediment (metric tons), Sed_{chi} = amount of suspended sediment in the reach (metric tons), Sed_{deg} = amount of sediment re-entered in the reach segment (metric tons), Sed_{out} = amount of sediment transported out of the reach (metric tons), V_{out} = the volume of out flow (m3), Vch = volume of water in the reach (m^3)

3.5.5. Sediment Transport Equations by Using MUSLE

The improved equations developed based on the USLE model are such as the Modified Universal Soil Loss Equation (MUSLE) by J.R. Williams (Williams, 1975); The RUSLE assumes that detachment and deposition are controlled by the sediment content of the flow (Pitt, 2007). The Modified Universal soil lose equation (Williams, 1975) is;

$$\mathrm{Sed} = 11.8 * (\mathrm{Q_{surf}} * \mathrm{q_{peak}} * \mathrm{A_{hru}})^{0.56} * \mathrm{K_{USLE}} * \mathrm{C_{USLE}} * \mathrm{P_{USLE}} * \mathrm{SL_{USLE}} * \mathrm{CFRG} \qquad 3.16$$

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

3.6. Sediment rating curve

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

$$S = aQ^b \qquad 3.17$$

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

$$\mathrm{S} = 86.40 * \mathrm{Q} * \mathrm{C} \qquad 3.18$$

Where S= sediment load in ton/day, Q= flow of a stream m^3/s, C= sediment concentration (mg/L) and 86.4 is conversion factor.

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

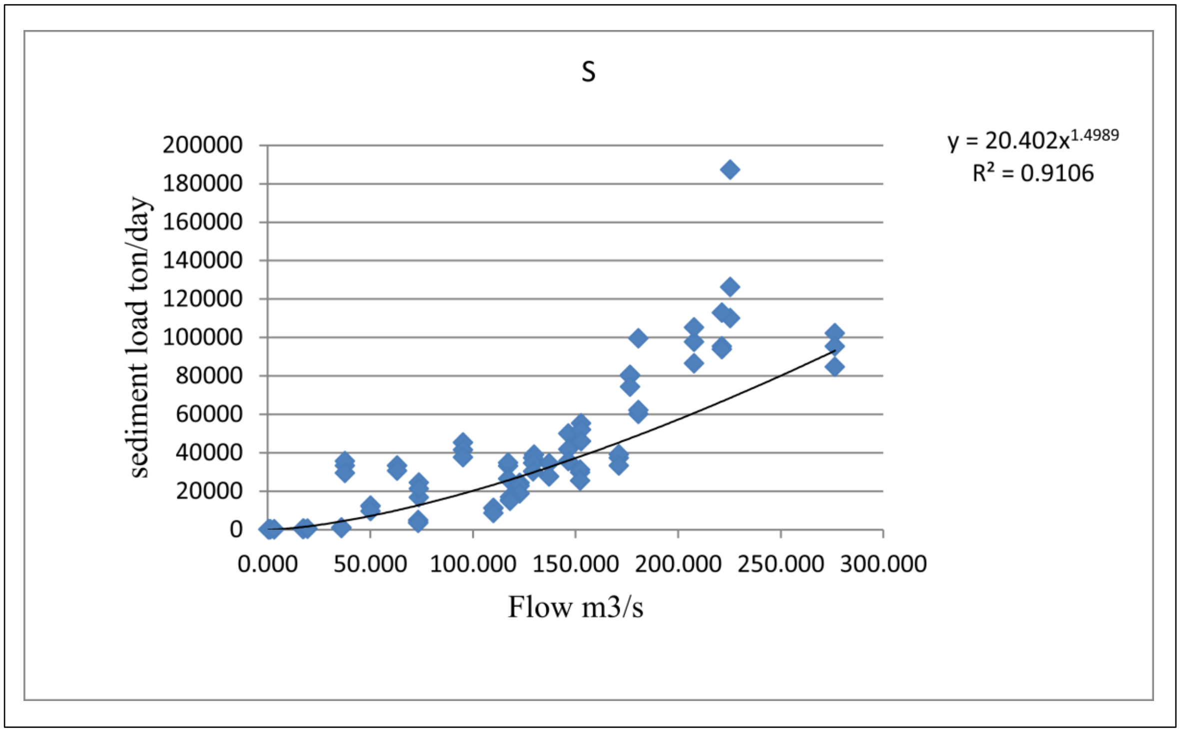

Figure 3.10.Sediment Rating Curve of the Study Area

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. Methodology

The following framework illustrates the general workflow of the study

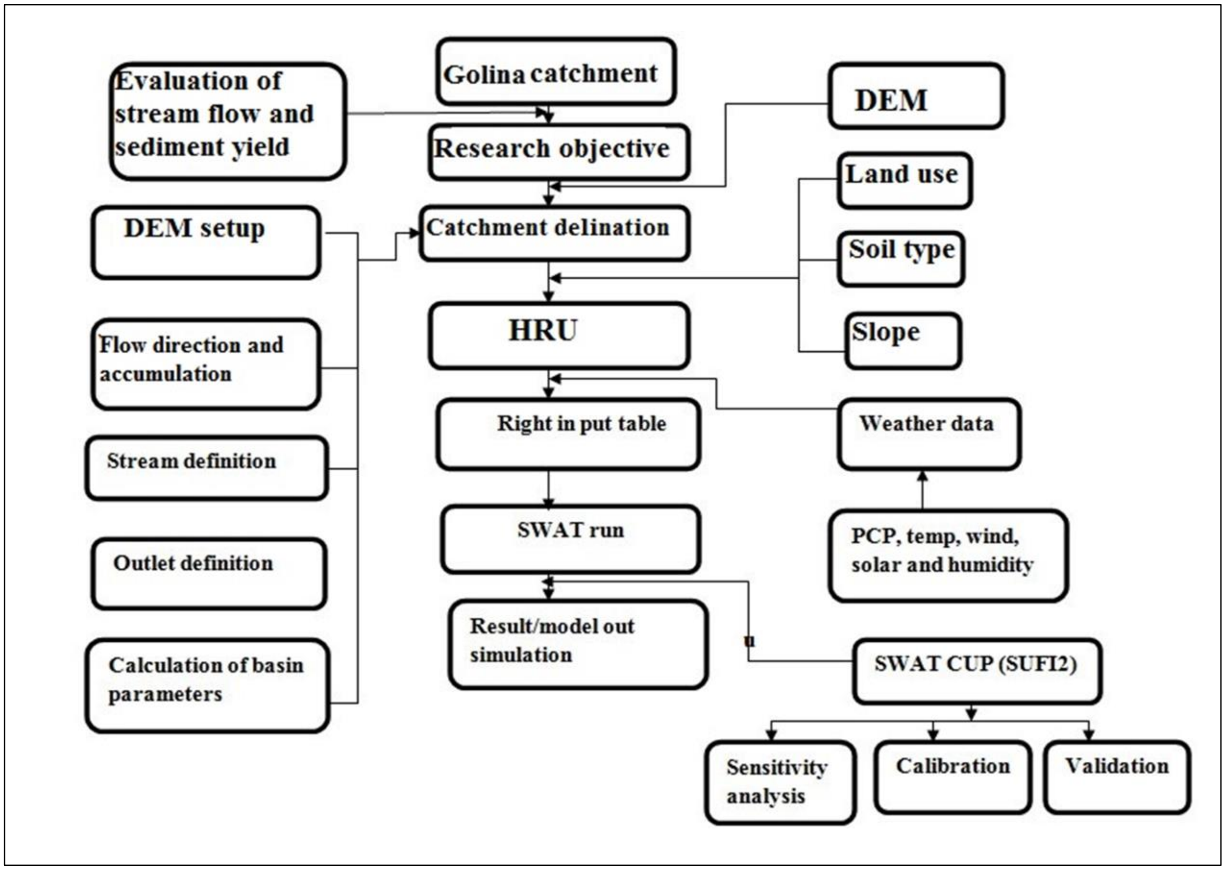

Figure 3.11. Conceptual frame works of research design

3.9. Model Input Data Collection and Analysis

SWAT is highly data intensive model that requires specific information about the watershed such as topography, land use and land cover, soil properties, weather data, and other land management practices. These data were collected from different sources and databases. The data are analyzed as presented in the next sub-sections.

3.9.1. Digital Elevation Model

Digital Elevation Model (DEM) data is required to calculate the flow accumulation, stream networks, and watershed delineation using SWAT watershed delineator tools. A 30m by 30m resolution Digital Elevation Model was obtained from MoWIE (Ministry of Water, Irrigation and Electricity) as shown in Figure 3.14.

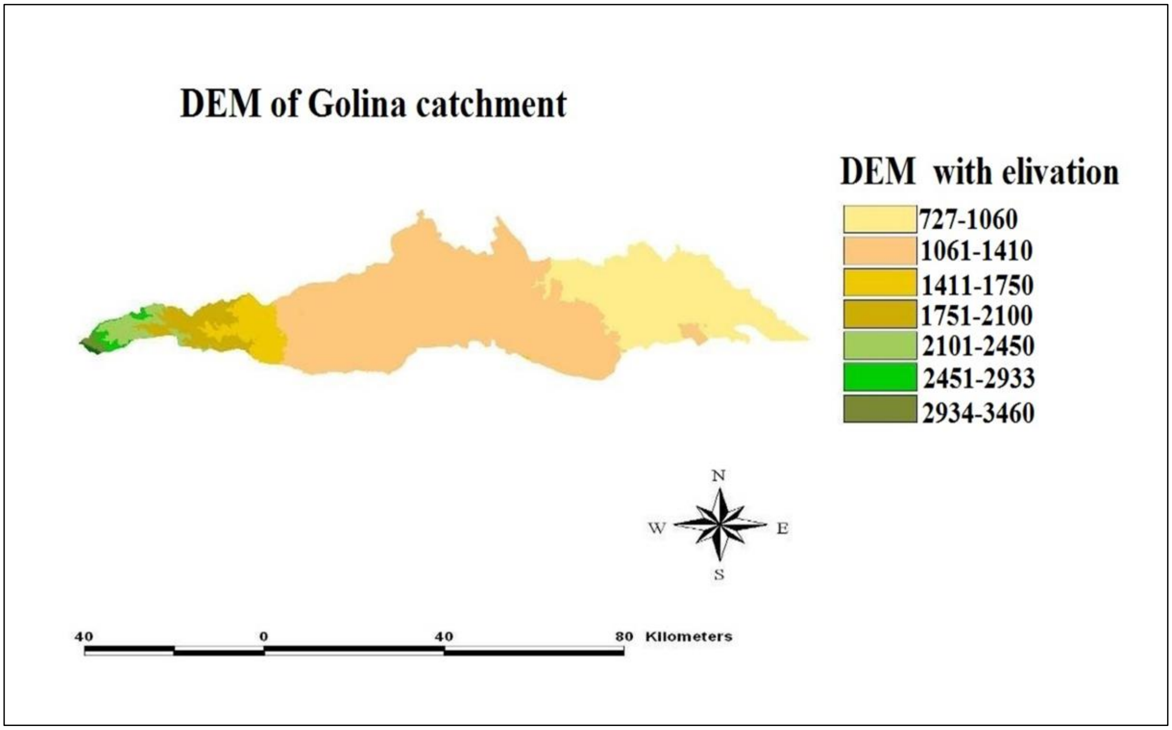

Figure 3.12. Digital Elevation Model of Golina catchment

3.9.2. 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 woldia which have all components of climatic variables mentioned above were used as weather generator station. Five meteorological stations (Sirinka, Woldia, Mersa, Logia and Mille) 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 (1990- 2014), though there were quite a number of missing data. Apendex1 shows the stations used for this study including their class and location.

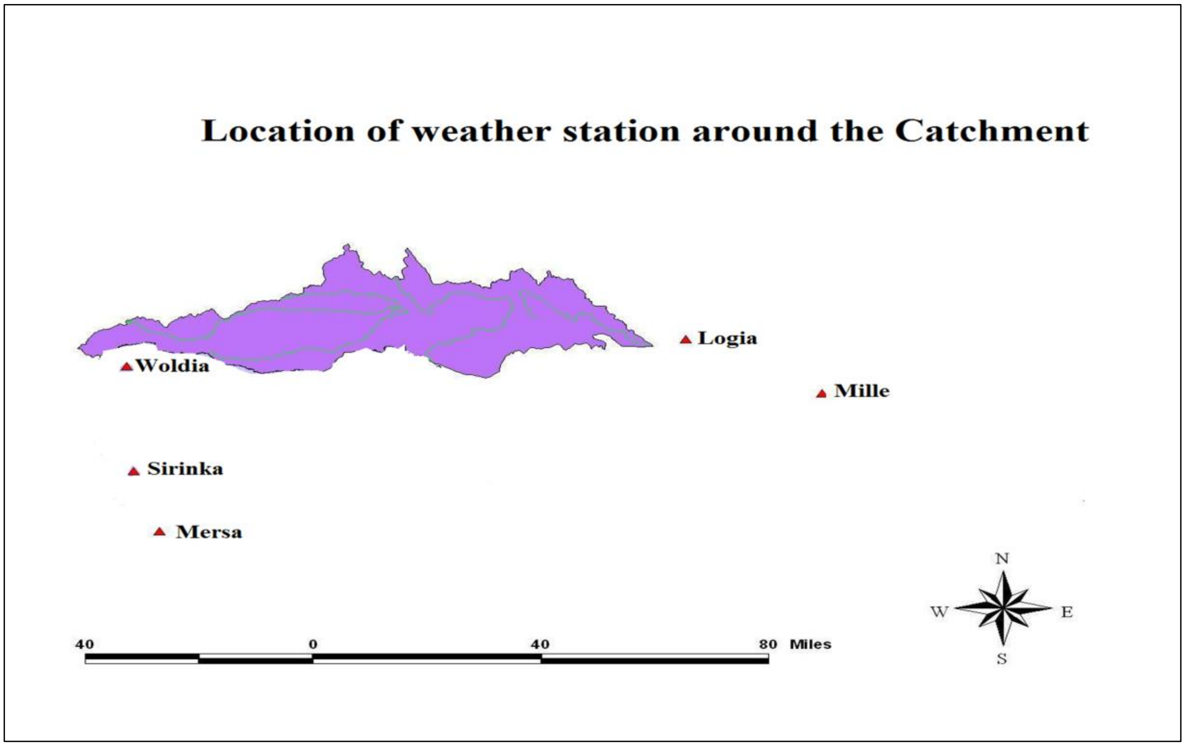

Figure 3.13. Location of meteorological stations around the catchment

3.9.2.1. 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).

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

$$Px = 1 + \frac{1}{M}(P1 + P2 + \cdots + Pm \quad 3.19$$

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

$$Px = +\frac{Nx}{M}(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pm}{Nm}) \quad 3.20$$

Where, P_x =Missing value of precipitation to be computed, N_x = Average Annual value of rainfall for the station, N1, N2…N_n= Average Annual value of rainfall for the neighboring station1, P2...P_n= Rainfall of neighboring station during missing period= 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 Apendex2.

3.9.3. Soil Data

SWAT model requires soil physical and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained from MoWIE (Ministry of Water, Irrigation and Electricity).

Nine soil types were identified in the Golina catchment and the details are shown in table 3.3 and figure 3.16. The Chromic Fluvisol and Eutric Regesol are the major soil types covering 26.3%and 19.7% of the overall sub watershed area, respectively. The smallest portion of the area is covered by Humic Nitisols.

Table 3.3. Soil type and its area coverage

No.	Soil Type	SWAT code	Area(ha)	Coverage (%)
1	Mollic Andisol	ANm	2296.14	7.1
2	Eutric Cambisols	CMe	1358.28	4.2
3	Chromic Fluvisol	FLc	8505.42	26.3
4	Leptosol	LP	5142.06	15.9
5	Humic Nitisols	NTu	32.34	0.1
6	Chromic Luvisols	LVx	355.74	1.1
7	Eutric Regesol	RGe	6370.98	19.7
8	Ortic Solonachalk	SCo	6112.26	18.9
9	Haplic Luvisol	LVh	2166.78	6.7

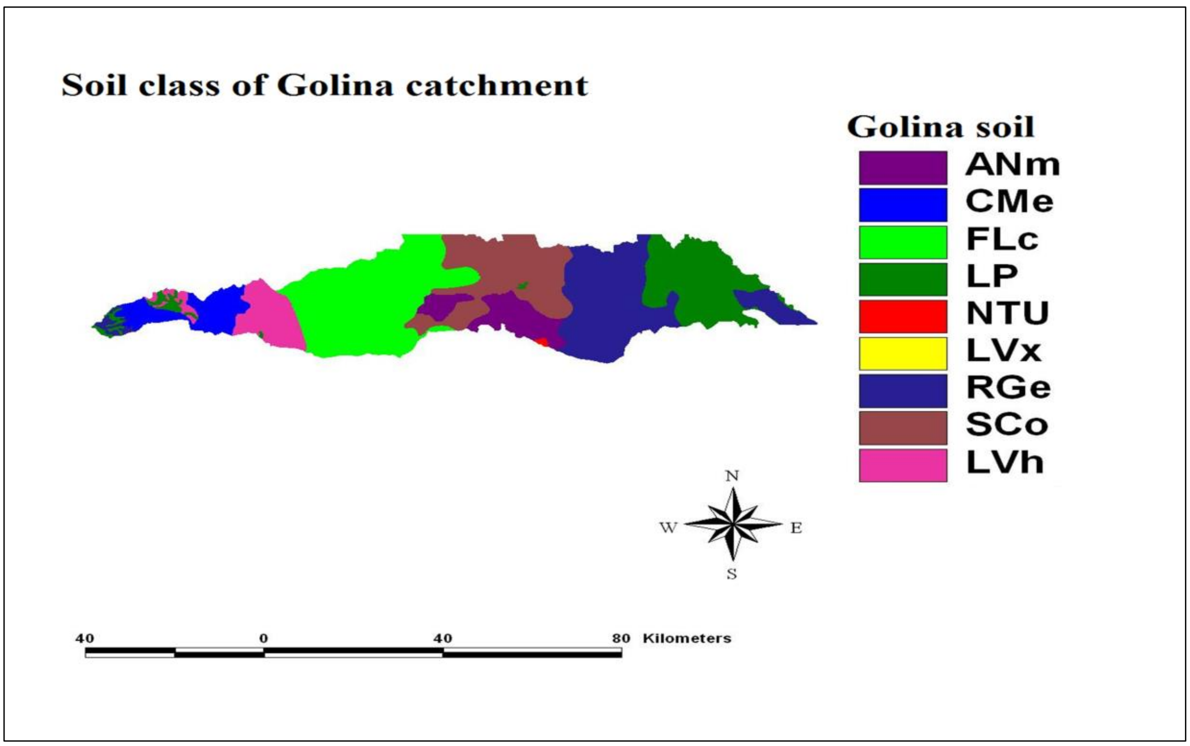

Figure 3.14. Soil class of Golina catchment

3.9.4. Land Use/Land Cover

Land use is one of the highly influencing the hydrological properties of the watersheds. It is one of the main input data of the SWAT model to describe the Hydrological Response Units (HRUs) of the watersheds.

Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model. These data were also obtained from MoWIE (Ministry of Water, Irrigation and Electricity).

The sub watershed is composed of eight land use types: (PAST), (URHD) and FRST covering 28.5%, 23.7% and28.6% the largest portion of it respectively as shown in figure 3.17 and table 3.4. The land uses of the area were defined according to SWAT's system of nomenclature.

Table 3.4. Land use type and its area coverage

No.	Land use /land cover	SWAT code	Area(ha)	Coverage (%)
1	pasture	PAST	9050	28.5
2	Urban	URHD	7530	23.7
3	Forest-Mixed	FRST	9540	28.6
4	Range-Brush	RNGB	2800	0.9
5	Range -Grasses	RNGE	3450	1.1
6	Forest-Evergreen	FRSE	1500	0.5
7	Wetland non forested	WETN	600	0.2
8	Agricultural land	AGRR	5250	16.5

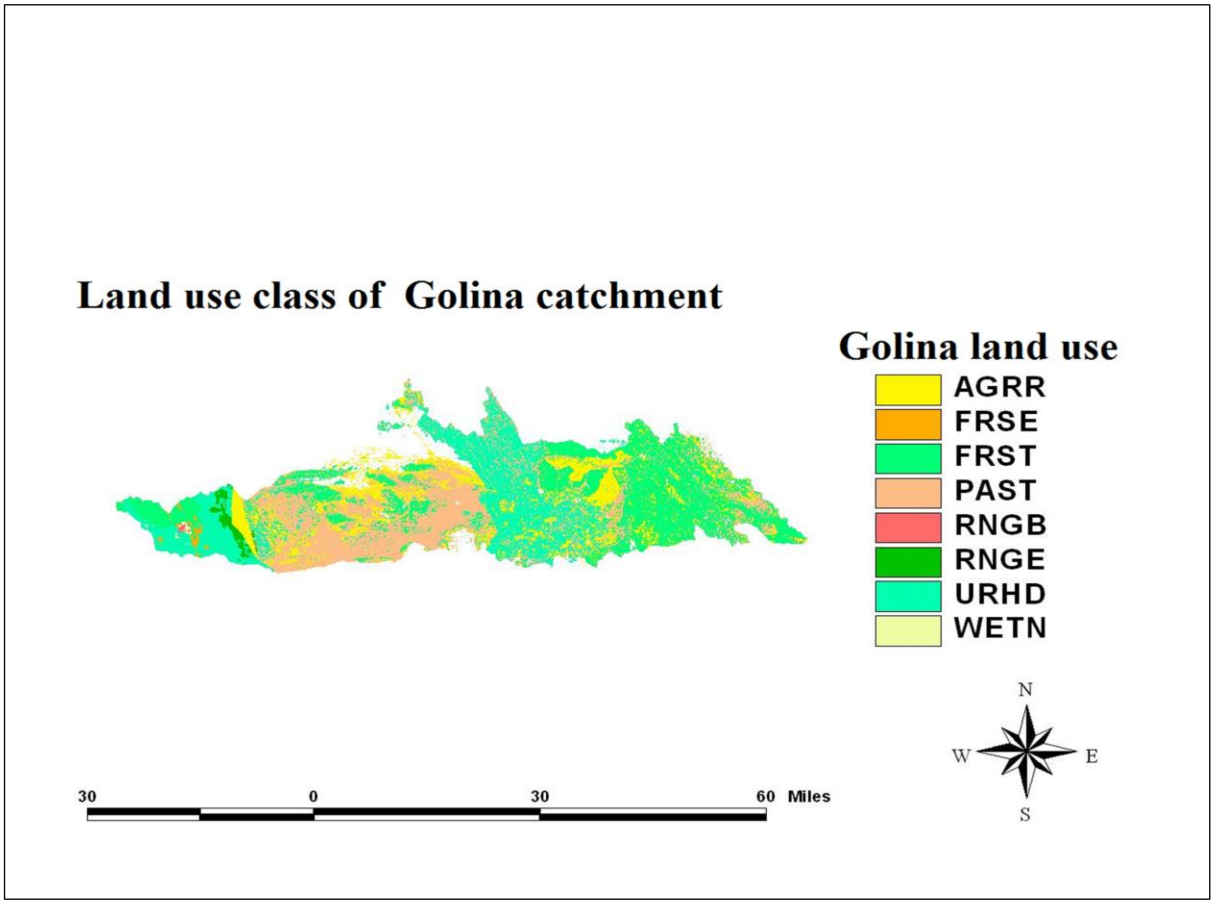

Figure 3.15. Land use class of Golina catchment

3.9.5. Hydrological Data

The stream flow and sediment data of the Golina catchment is needed for the calibration and validation of the model. The daily stream flow (1990-2014) and sediment data (2000-2004) of Golina catchment were collected from MoWIE (Ministry of Water, Irrigation and Electricity).

3.10. Model Setup

3.10.1. Watershed Delineation

The watershed and sub watershed delineation were performed using 30 m resolution DEM data using Arc SWAT model watershed delineation function. First, the SWAT project set up was created. The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. Once, the DEM setup was completed and the location of outlet was specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tools.

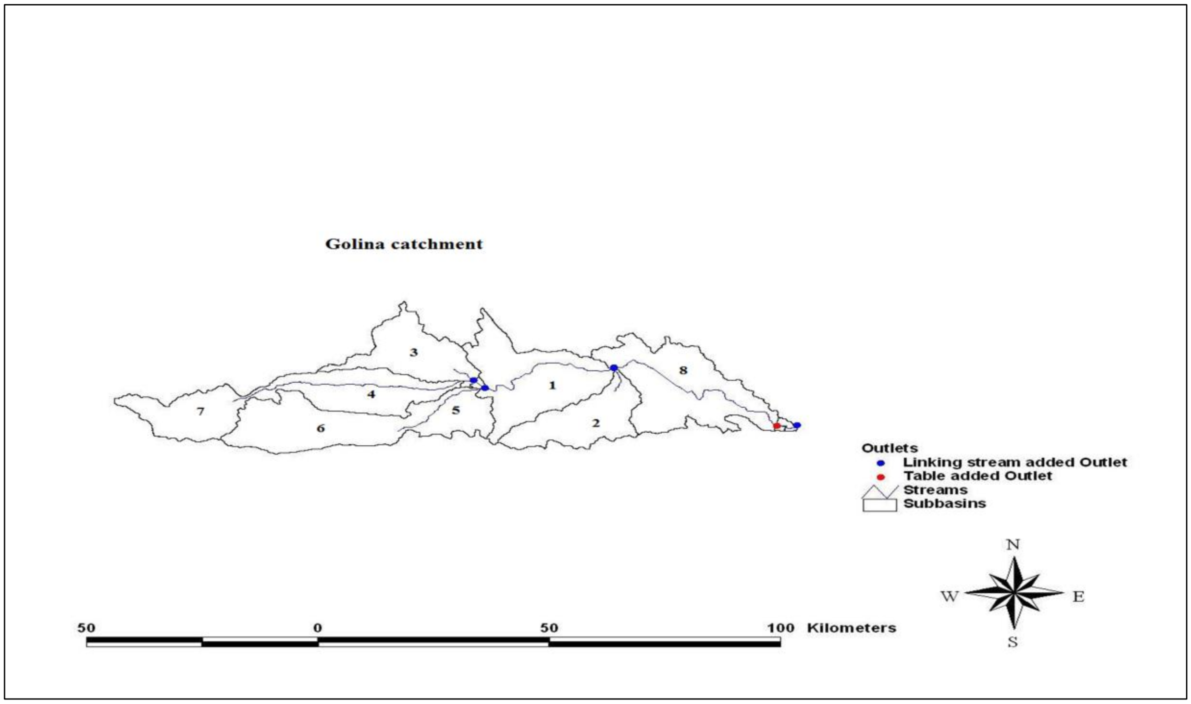

Figure 3.16. Watershed and sub watershed map of Golina catchment

During the watershed delineation process, the topographic parameters (elevation, slope) of the watershed and its sub watershed were also generated from the DEM data.

3.10.2. Hydrologic Response Units Analysis

The sub watersheds were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. In general the threshold level used to eliminate minor land use and land covers in sub basin, minor soil with in a land use and land cover area and minor slope classes with in a soil on specific land use and land cover area. Following minor elimination, the area of remaining land use and land covers, soils and slope classes are reapportioned so that 100 % of their respective areas are modeled by SWAT. Land use, soil and slope characterization for the Golina catchment was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. These tools allowed loading land use and soil maps which are in raster format in to the current project, evaluates slope characteristics and determining the land use/soil/slope class combinations in the delineated sub watersheds.

In the model, there are two options in defining HRU distribution: assign a single HRU to each sub watershed or assign multiple HRUs to each sub watershed based on a certain threshold values. The SWAT user's manual suggests that a 20 % land use threshold, 10 % soil threshold and 20 % slope threshold are adequate for most modeling application. However, Setegn *et al*, 2008, suggested that HRU definition with multiple options that account for 10% land use, 20% soil and 10% slope threshold combination gives a better estimation of runoff and sediment components. Therefore, for this study, HRU definition with multiple options that accounts for 10% land use, 20% soil and 10% slope threshold combination was used. These threshold values indicate that land uses which form at least 10% of the sub watershed area and soils which form at least 20% of the area within each of the selected land uses will be considered in HRU.

Hence, Golina catchment was divided in to 8 sub basin and 29 HRUs, each having a unique land use and soil combinations. The number of the HRUs varies with in the sub watersheds.

3.10.3. Weather Generator

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed one (Danuso, 2002). The Model requires the daily values of all climatic variables from measured data or generates from values using monthly average data over a number of years. This study used measured data for all climatic variables. However, the weather data obtained for the stations in and around Golina watershed had missed records in some of the variables. Therefore, these missed values were filled with the weather generator utility in the Arc SWAT Model from the values of weather generator parameters. Weather data of Sirinka station with continuous records were used as an input to determine the values of the weather generator parameters. Hence, for weather generator data definition, the weather generator data file wgn stations .dbf was selected first. Subsequently, rain fall data, temperature data, relative humidity data, solar radiation data and wind speed data were selected and added to the model.

The SWAT Model contains weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently.

To generate the data, weather parameters were developed by using the weather parameter calculator WXPARM, PCPSTAT and dew point temperature calculator DEW02, which were downloaded from the SWAT website. The WXPARM program calculates the monthly daily average and standard deviation as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month by reading of the daily values of the variables from Sirinka stations. Average Daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity. Moreover, daily solar radiation was calculated from the daily available sunshine hour's data.

3.10.4. Sensitivity Analysis

Calibration is necessary to optimize the values of the model parameters which help to reduce the uncertainty in the model outputs. However, in such type of model with a multiple parameters, the difficult task is to determine which parameters are to be calibrated. In this case, sensitivity analysis is important to identify and rank parameters that have significant impact on the specific model outputs of interest (Van Griensven *et al*., 2006). Therefore, for this study, sensitivity analysis was done prior to the calibration process in order to identify important parameters for model calibration. The average monthly stream flow and sediment data of the last years of the watershed gauging station were used to compute the sensitivity of the stream flow and sediment parameters.

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

The sensitivity analysis is made using a built-in SWAT CUP sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven, 2005).Sensitivity analysis was performed for a period of 1990-2014.Up on the completion of sensitivity analysis, the mean relative sensitivity (MRS) values of the parameters were used to rank the parameters, and their category of classification. The category of sensitivity was defined based on the (Lenhart *et al*., 2002) classification presented below (Table 3.5).

Table 3.5. Category of sensitivity (Lenhart *et al*., 2002)

Class	MRS	Category of sensitivity
I.	$0.00 \leq$ MRS <0.05	Small to negligible
II.	$0.05 \leq$ MRS <0.20	Medium
III.	$0.2 \leq$ MRS <1	High
IV.	MRS >1	Very high

Based on the above classification, parameter producing MRS values of medium, high and very high were selected for calibration process.

3.10.5. Model Calibration and Validation

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

The graphical and statistical approaches were used to evaluate the SWAT model performance a number of times until the acceptable values were obtained for surface runoff and base flow independently. The flow calibration procedure made by SWAT developers in Santhi et al. (2001) and Neitsch et al. (2005) was carefully followed. SWAT developers assumed an acceptable calibration for hydrology at R^2 >0.6 and ENS >0.5 (Santhi et al., 2001; Moriasi et al., 2007). Calibration of sediment yield was performed after calibration of flow within the given time step. Like flow calibration, sediment yield calibration was done based on sensitive parameters. Validation is also a process of proving the performance of model and it is carried out for time periods different from calibration period, but without any further adjustment of calibrated parameters.

The time of modeling for calibration and validations are:

- Flow calibration period (2000-2009)
- Flow validation period (2010-2014)
- Sediment calibration period (2000-2009)
- Sediment validation period (2010-2014)

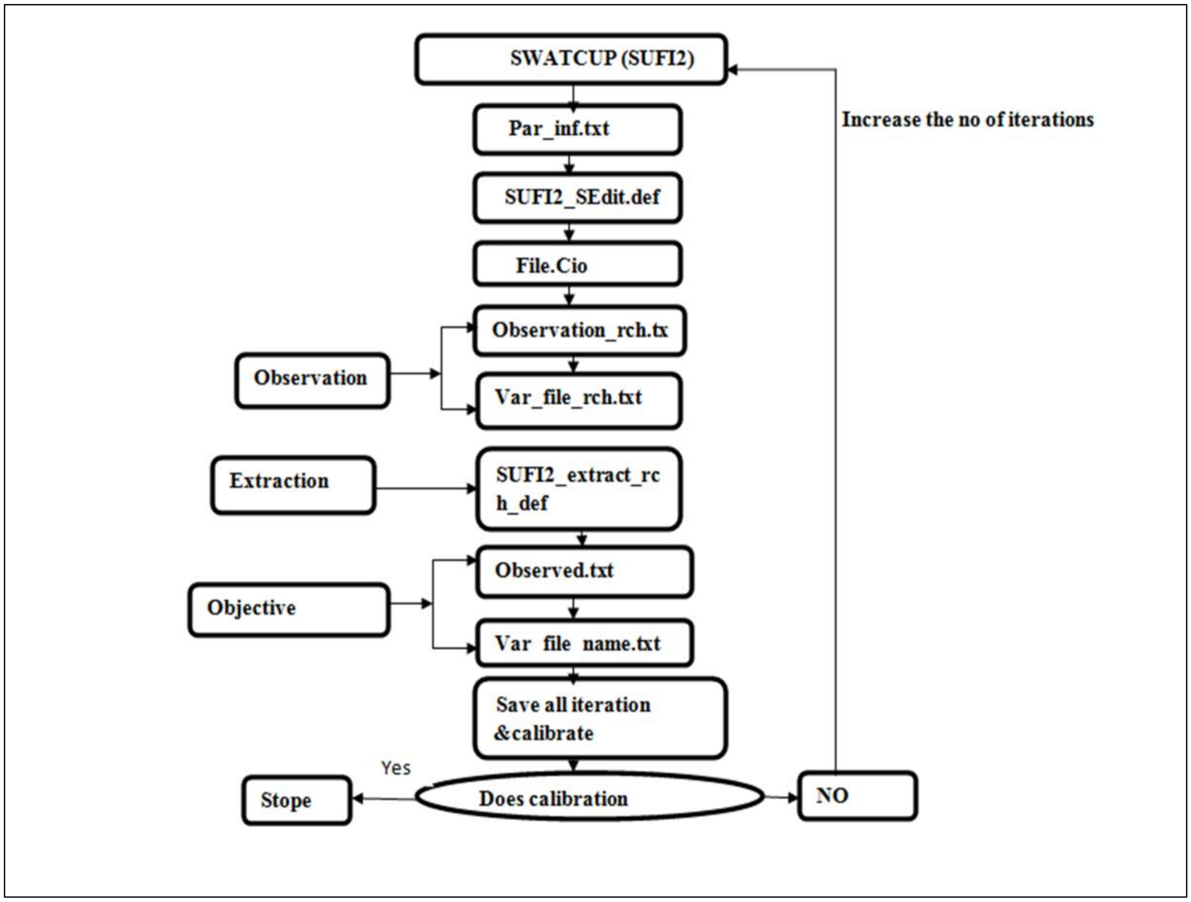

Figure 3.17 Calibration procedures for flow and sediment

3.10.6. Model Performance Evaluation

To evaluate the model simulation outputs in relation 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, two methods have been used: coefficient of determination (R^2) and Nash and Sutcliffe simulation efficiency (ENS).

The determination coefficient (R^2) describes the proportion of 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, and typical values greater than 0.6 are considered acceptable (Santhi et al., 2001). The R^2 is calculated using the following equation:

$$\mathbf{R^2} = \frac{\sum[\boldsymbol{X_i - X_{av}}]\,[\boldsymbol{Y_i - Y_{av}}]}{\sqrt{\sum\,[\boldsymbol{X_i - X_{av}}]^2}\;\sqrt{\sum\,[\boldsymbol{Y_i - Y_{av}}]^2}} \qquad 3.21$$

Where, X_i – measured value (m^3/s), X_{av} – average measured value (m3/s), Y_i – simulated value (m^3/s) and Y_{av} – average simulated value (m^3/s)

The Nash – Sutcliffe simulation efficiency (ENS) indicates that how well the plots of observed versus simulated data fits the 1:1 line. ENS is computed using the following equation:

$$\text{ENS} = 1 - \frac{\sum(X_i - Y_i)^2}{\sum(X_i - X_{av})^2} \qquad 3.22$$

Where, X_i – measured value, Y_i – simulated value and X_{av} – average observed value

Value of ENS ranges from negative infinity to 1 (best) i.e., $(-\infty, 1]$. ENS value < 0 indicates the mean observed value is better predictor than the simulated value, which indicates unacceptable performance. While ENS values greater than 0.5, the simulated value is better predictor than mean measured value and generally viewed as acceptable performance (Santhi *et al*., 2001).

3.11. SWAT based watershed management intervention scenarios

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

Table 3.6. soil erosion classifications based on soil loss rate (Arabi et al., 2008).

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

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

3.11.1. Scenario 0: Base line

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

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

Land use redesign of steep slopes in the catchment of Golina was done by using GIS, to prepare slope map of the study area. The inputs used for land use redesign were land use and slope shape files. This activity was performed by overlaying of land use and slope shape file. After overlaying of the two intersections is used to redesign slope and land use. Parts of the catchment was changed to plantation when slopes of the land use is steep (>60%).

3.11.3. Scenario 2: Terracing activity which is a conservation measure

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

Table 3.7. Terracing activity scenario summary (Arabi et al., 2008).

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

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Simulation analysis

After identifications of the sensitive parameter a SWAT model was calibrated and validated on monthly time base to estimate flow and sediment yield of Golina catchment using a time series of 25 years (1990-2014). The first three years (1990-1992) of the modeling period is used for ″warm up″. The data period from 2000-2009 was used for calibration and that from 2010-2014 was used for validation. The area of watershed was subdivided in to 8 sub basins. The overlay of land use, soil and slope maps resulted 29 HRUs.

4.2. Sensitivity Analysis of flow

Sensitivity analysis was performed on flow parameters of SWAT on monthly time steps with observed data of the Golina River gauge station. For this analysis, 26 parameters were considered and only 10 parameters were identified to have significant influence in controlling the stream flow in the watershed. Table 4.1 presents parameters that resulting greater relative mean sensitivity values for monthly stream flow.

Table 4.1. List of Parameters and their ranking with MRS values for monthly flow

Parameters		Lower and upper bound	Rank	MRS index	Category
Name	Description				
ALPHA_BF	Base flow alpha factor (days)	0-1	1	0.233	High high
CN2	SCS runoff curve number (%)	±25	2	0.231	High
ESCO	Soil evaporation	0-1	3	0.159	Medium
CH_N2	Manning's roughness coefficient	0-1	4	0.0713	Medium
CH_K2	Effective hydraulic Conductivity of the main channel(km/mm)	0-150	5	0.049	Small
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0-1000	6	0.0422	Small
GW_DELAY	Ground water delay (days)	0-10	7	0.0402	Small
SOL_AWC	Soil available water capacity(water/mm soil)	±25	8	0.0388	Small
SOL_Z	Total soil depth (mm)	±25	9	0.0296	Small
SURLAG	Surface lag	0-12	10	0.0259	Small

The result of the sensitivity analysis indicated that these 10 flow parameters are sensitive to the SWAT model i.e. the hydrological process of the study watershed mainly depends on the action of these parameters. Alpha factor (ALPHA_BF), Curve number (CN2), soil evapotranspiration factor (ESCO), Manning's roughness coefficient (CH_N2) and Effective hydraulic conductivity of the main channel (CH_K2) are identified to be highly sensitive parameters and retained rank 1 to 5, respectively. The other parameters such as threshold depth of water in the shallow aquifer required for return flow (GWQMN), ground water delay (GW_DELAY), soil available water capacity (SOL_AWC), total soil depth (SOL_Z), and surface lag (SURLAG) are identified as slightly important parameters that were retained rank 6 to 10, respectively. The remaining parameters (16 parameters) were not considered during calibration process as the model simulation result was not sensitive to these parameters in the watershed.

These parameters are related to ground water, runoff and soil process and thus influence the stream flow in the watershed. The result of the analysis revealed that ALPHA_BF is the most important factor influencing stream flow in Golina catchment. The ALPHA_BF is a direct index of ground water flow response to changes in recharges. Golina catchment is characterized with tertiary basalt and volcanic regional geology that have good potential for ground water recharges. In addition, (Setegn *et al.*, 2008) through modeling of Golina catchment found ALPHA_BF to retain rank 3. The other most influencing stream flow parameter in this analysis is the curve number (CN2). According to (Setegn et al., 2008) and (Surur, 2010), CN2 retain rank 1. These may be an additional support to the result of the sensitivity analysis.

4.3. Flow calibration

The simulation of the model with the default value of parameters in the Golina catchment showed relatively weak matching between the simulated and observed stream flow hydrographs. Hence, calibration was done for sensitive flow parameters of SWAT with observed average monthly stream flow data. First, some sensitivity flow parameters were adjusted by manual calibration procedure based on the available information in literatures. In this procedure, the values of the parameters were varied iteratively within the allowable ranges until the simulated flow as close as possible to observed stream flow. Then, auto calibration was run using sensitive parameters that were identified during sensitivity analysis. Table 4.2 presents the result of calibrated flow parameters.

Table 4.2. List of parameters with calibrated values for average monthly stream flow

Parameters		Lower and Upper bound	Calibrated value
Name	Description		
ALPHA_BF	Base flow alpha factor (days)	0-1	0.1
CN2	SCS runoff curve number (%)	±25	-10
ESCO	Soil evaporation	0-1	0.8
CH_N2	Manning's roughness coefficient	0-1	0.02
CH_K2	Effective hydraulic Conductivity of the main channel(km/mm)	0-150	11.14
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0-1000	10
GW_DELAY	Ground water delay (days)	0-10	0.93
SOL_AWC	Soil available water capacity(water/mm soil)	±25	+10
SOL_Z	Total soil depth (mm)	±25	+15
SURLAG	Surface lag	0-12	23

During this step, the model was run for period of 10 years from 2000 to 2009. The result of calibration for monthly flow showed that there is a good agreement between the measured and simulated average monthly flows with Nash-Sutcliffe simulation efficiency (ENS) of 0.8 and coefficient of determination (R^2) of 0.82 as shown in Figure 4.2

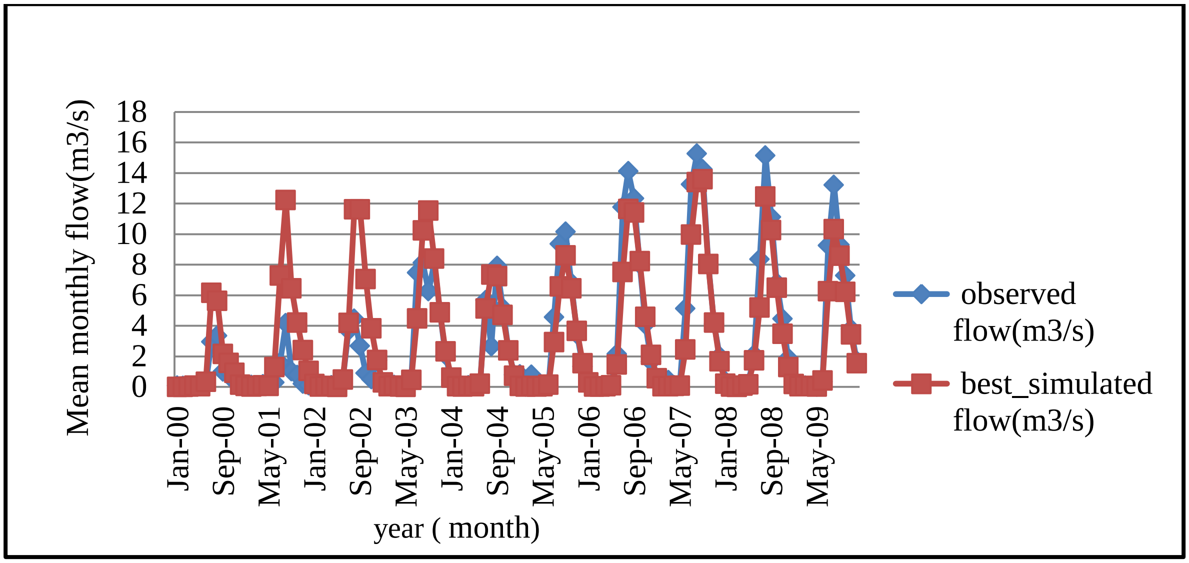

Figure 4.1 Average Monthly Observed and Simulated flow Calibration (2000-2009)

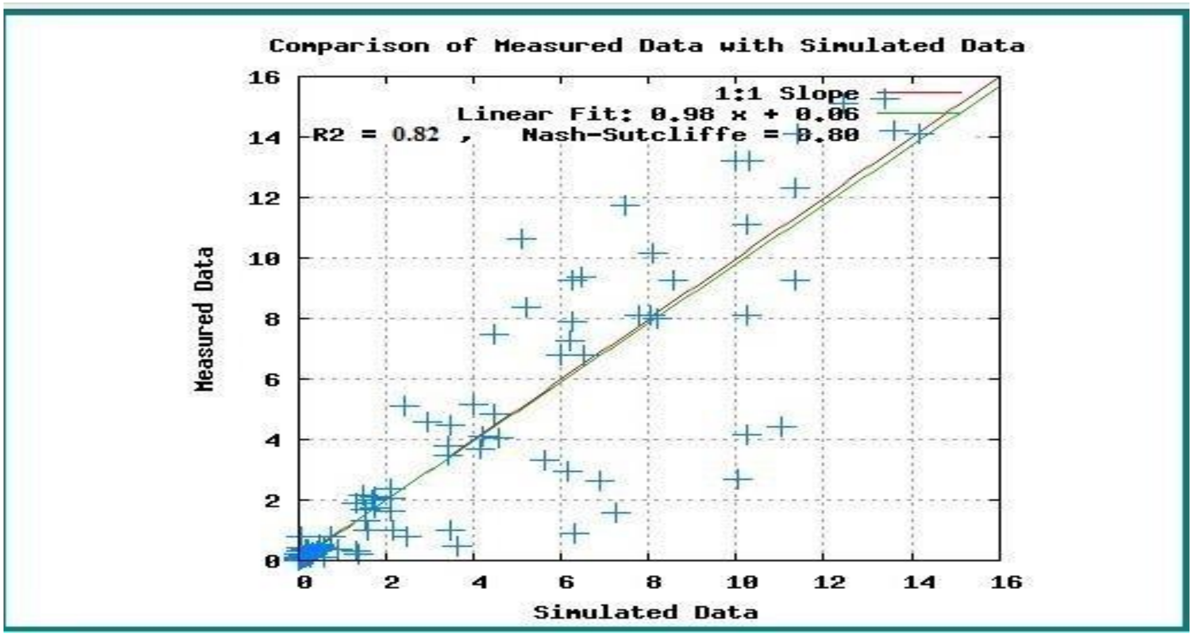

Figure 4.2 Scatters plot of Observed Vs Simulated Flow for calibration (2000-2009).

4.4. Flow validation

The model validation was also performed for 5 years from 2010 to 2014 without further adjustment of the calibrated parameters. The validation result for monthly flow is shown in the figure 4.3, the validation simulation also showed good agreement between the simulated and measured monthly flow with the ENS value of 0.84 and R^2 of 0.86 as shown in Figure 4.4.

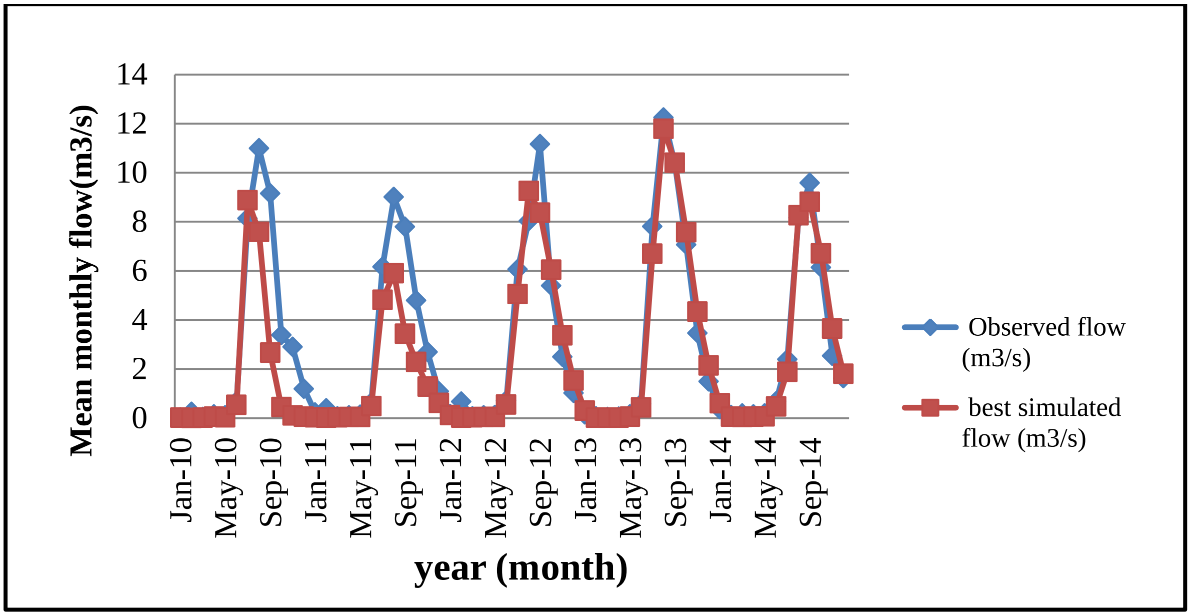

Figure 4. 3. Average Monthly Observed and Simulated flow validation (2010-2014).

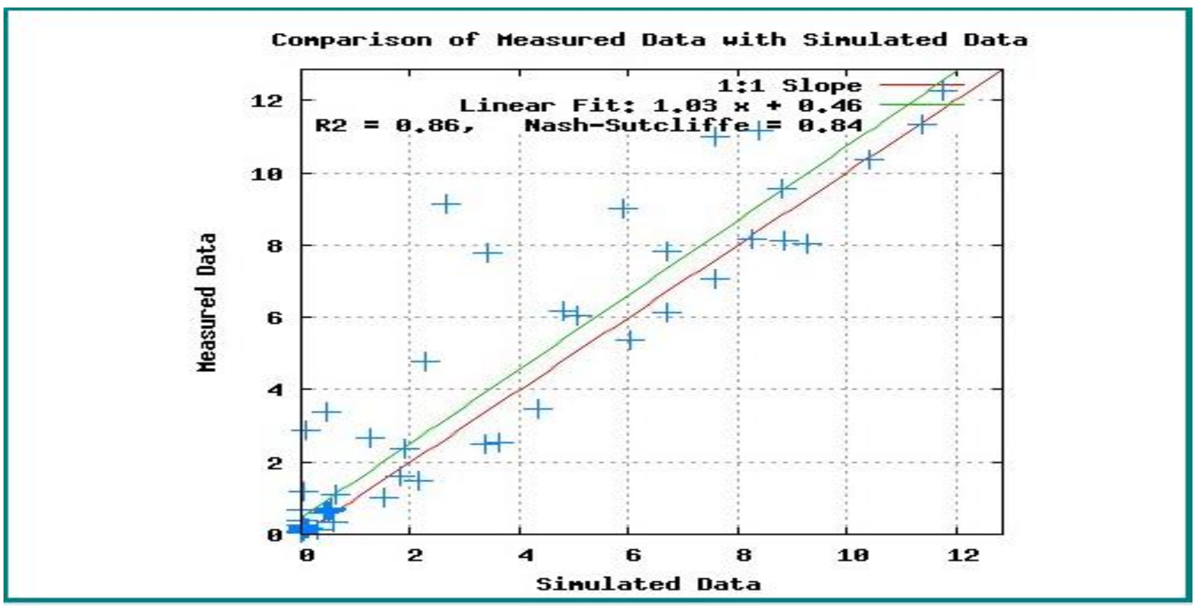

Figure 4.4. Scatters plot of Observed Vs Simulated Flow for validation (2010-2014).

The measured and simulated average monthly flow for Golina was obtained. During the calibration period, they were 9 and 6.31 m^3/s, respectively. The measured and simulated average monthly flow for the validation period was 11.41 and 13.05 m^3/s, respectively. These indicate that there is a reasonable agreement between the measured and the simulated values in both calibration and validation periods as shown in Table 4.3

Table 4.3. Comparison of monthly flow for calibration and validation simulation periods.

Period	Average monthly Flow(m^3/s)		ENS	R^2
	Measured	Simulated		
Calibration(2000-2009) period	9.0	6.31	0.8	0.82
Validation(2010-2014) period	11.41	13.05	0.84	0.86

As can be seen from Table 4.3, the model performance values for calibration and validation of the flow simulations were adequately satisfactory. This indicates that the physically processes involved in the generation of stream flows in the watershed were adequately captured by the model. Hence, the model simulations can be used for various water resource management and development aspects.

Studies that have been conducted in different parts of the country showed similar results. For example, Asres and Awulachew (2010) reported that the SWAT model showed a good match between measured and simulated flow of Gumera watershed both in calibration and validation periods with (ENS = 0.76 and R^2 = 0.87) and (ENS = 0.68 and R^2 = 0.83), respectively. Through modeling of the Lake Tana basin, Setegn *et al*, (2008) indicated that the average monthly flow simulated with SWAT model were reasonable accurate with ENS = 0.81 and R^2 = 0.85 for calibration and ENS = 0.79 and R^2 = 0.80 for validation periods.

4.5. Sediment Yield Sensitivity Analysis

After demonstrating the flow the model was shifted to sediment yield sensitivity analysis, calibration and validation. Sediment yield sensitivity analysis was carried out by identifying the parameters that affect the sediment yield. Six sediment parameters like USLE equation support practice, channel cover factor, channel erodiability factor, linear parameter for maximum sediment yield, Exponential parameter for maximum sediment yield in channel sediment routing, Cropping practice factor were found to be sensitive in different degree of sensitivity. The period of sensitivity analysis, calibration and validations were similar with those of stream flow.

Table 4.4. Sediment sensitivity parameters

No.	SWAT parameter code	Mean sensitivity index	Rank	sensitivity class
1	USLE_C	0.552	1	High
2	SPCON	0.499	2	High
3	SPEXP	0.202	3	High
4	USEL_P	0.091	4	High
5	CH_EROD	0.062	5	High
6	CH_COV 1	0.051	6	Medium

4.6. Sediment yield Calibration

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

Table 4.5. Calibrated sediment parameters

No.	Parameter Name	Description	Min	Max	Fitted value
1	CH_COV1	Channel cover factor	0	1	0.35
2	CH_EROD	channel erodiability factor	0	1	0.05
3	SPCON	Linear parameters for maximum sediment yield	0.0001	0.01	0.000595
4	SPEXP	Exponential parameter for maximum Sediment yield in channel sediment routing	1	2	1.05
5	USLE_C	Cropping practice factor	-25	25	7.5
6	USLE_P	Support practice factor	0	1	0.55

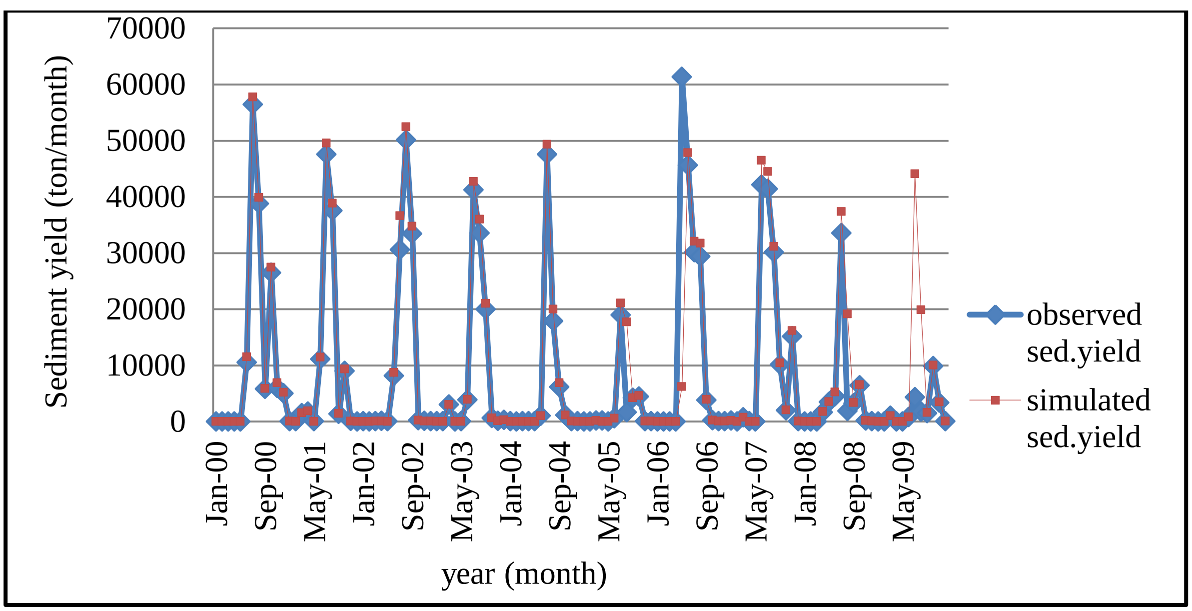

Figure 4.5 Monthly Measured vs Simulated Sediment Yield for Calibration (2000-2009)

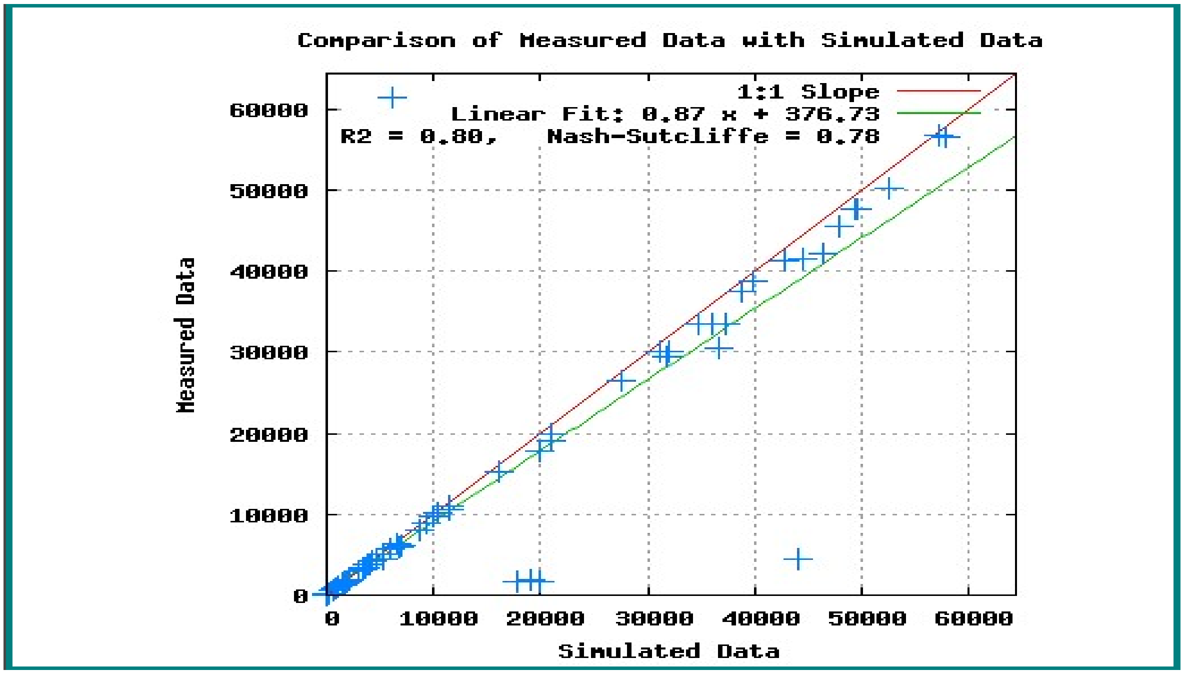

Figure 4.6 Scatter plot of observed Vs simulated sediment yield for calibration 2000-2009)

4.7. Sediment yield validation

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

Table 4.6. Calibration and validation of sediment yield values

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

Figure 4.7 Monthly Observed and Simulated Sediment Yield Validation Graph (2010-2014)

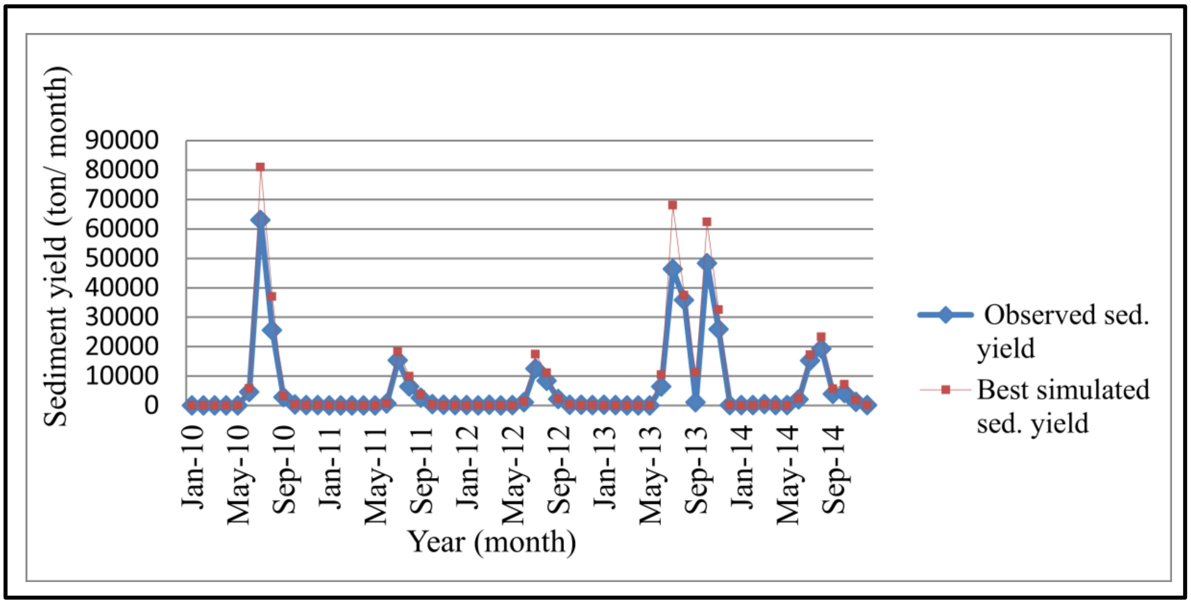

Figure 4.7 Monthly Measured and Simulated Sediment Yield for validation (2010-2014)

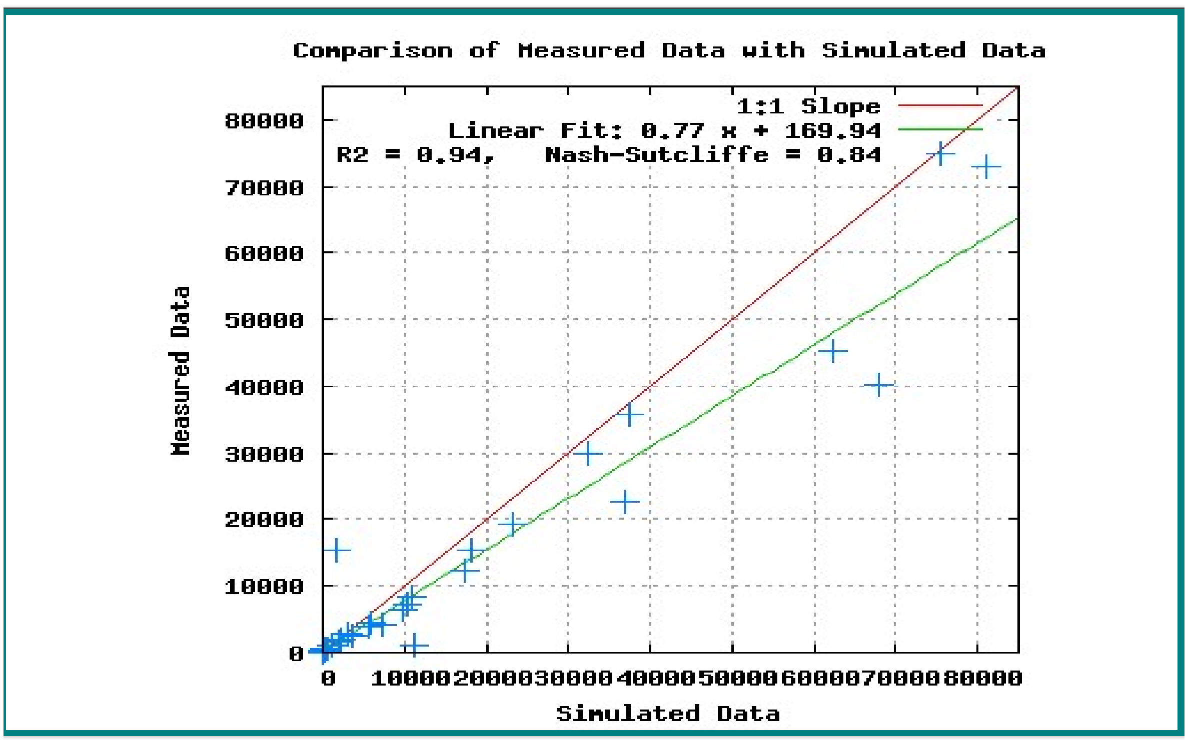

Figure 4.8.Scatter plot of observed Vs simulated sediment yield for validation (2010-2014)

4.8. Sediment yield in the Sub basin

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

Table 4.7. Sediment yield and its severity in the sub basin

Sub basin	Sediment yield (ton/ha/yr.)	Classes
1	83.96	High
2	75.31	High
3	64.21	Moderate
4	67.74	Moderate
5	58.82	Moderate
6	79.63	High
7	49.31	Moderate
8	71.65	High

The output of SWAT model shows that sub basin 1 was high potential of soil erosion. Sediment yield in the watershed varies from hydrological response to hydrological response based on land use, soil and slope in each hydrological response units. The SWAT model yields average annual sediment of 68.82 ton/km2 (6882 ton/ha) at Golina catchment outlet.

4.9. Watershed management intervention scenario results

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

4.9.1. Scenario1: land use redesign for steep slopes

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

Table 4.8. Sediment yield of the Base scenario and Redesign land use

Sub basin	Base scenario Sediment yield (ton/ha/yr.)	Redesign land use Sediment yield (ton/ha/yr.)
1	83.96	67.16
2	75.31	60.24
3	64.21	49.31
4	67.74	53.04
5	58.82	44.82
6	79.63	63.63
7	49.31	36.31
8	71.65	56.65

After doing all the above procedures the model was run by using SWAT model with the redesign land use and calibrated parameters. The modified land use reduces the sediment yield by 20.07% of the existing one. Soil erosion and sediment loads were decreased because of the steep slope (>30) were not used for agricultural practice.

4.9.2. Scenario2: Terracing activities

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

Table 4.9. Sediment yield of the Base scenario and terracing activities

Sub basin	Base scenario Sediment yield (ton/ha/yr.)	Terracing activities Sediment yield (ton/ha/yr.)
1	83.96	58.81
2	75.31	52.72
3	64.21	44.94
4	67.74	47.41
5	58.82	41.17
6	79.63	55.74
7	49.31	34.51
8	71.65	50.15

By performing the activities of terracing practice the sediment load in the watershed reduce by 30.11% of the base line conditions. The following figure shows sediment yield of the base line or existing and the two scenarios, land use redesign for steep slopes and Terracing activity.

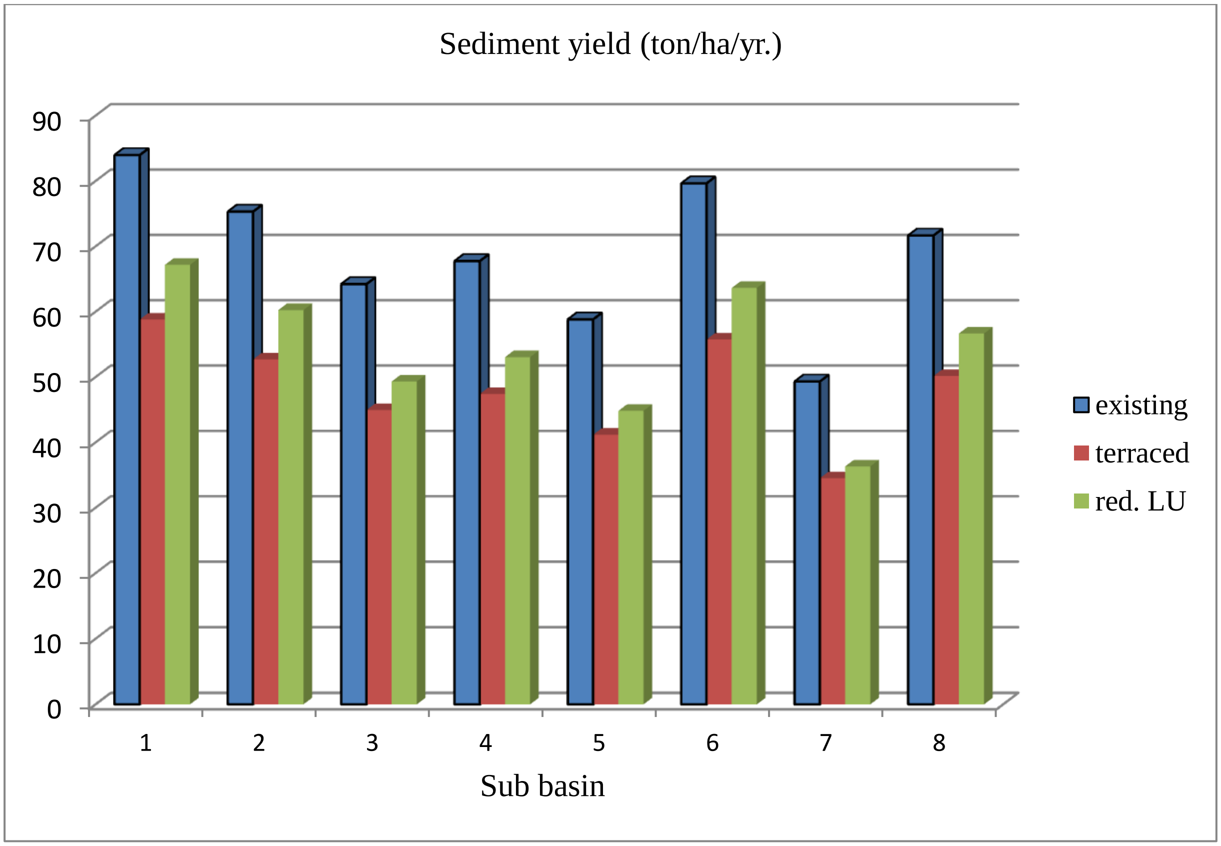

Figure 4.9. Sediment yields of the existing and the two scenarios

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

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

- Graphical and statistical analysis was used to evaluate the performance of SWAT model in the study area.
- The SWAT model was calibrated from 2000-2009 and the validation period is 2010-2014 on monthly time basis to demonstrate its applicability for simulating stream flow and sediment yield in the catchment.
- The average monthly observed stream flow and average monthly simulated stream flow were compared using graphical and statistical method. Similarly average monthly observed sediment yield values are compared with average monthly simulated sediment yield values using graphical and statistical methods.
- The results show that good estimation of average monthly stream flow and sediment yields based on the values of coefficient of determination (R^2) and Nash Sutcliffe model efficiency (E_{NS}) during the calibration and validation periods.
- The value of coefficient of determination and Nash Sutcliffe efficiencies were 0.82and 0.80 in calibration, 0.86 and 0.84 in validation for flow analysis. Similarly, the values of R^2 and E_{NS} were 0.80 and 0.78 for calibration, 0.94 and 0.84 for validation in sediment yield analysis.
- This study provides good understanding of SWAT model set up, sensitive parameters that the model output and hydrological response of the catchment.
- Alpha factor (ALPHA_BF) was found to be the most sensitive parameter which depends up on the management practice and soil parameter.
- SWAT model calibration and validation for Golina catchment can be used to evaluate flow and sediment yield in the catchment area.

5.2. Recommendations

Generally from this specific study the following recommendations were drawn and are believed to play their own role in future research endeavors:

- Hydrological models could be applied to evaluate stream flow, sediment yield and a vital ecosystem services in the catchment and the country in general. This helps for stakeholders and decision makers to make better choices for land and water resource planning and management.
- Soil erosion/sedimentation in the study area and the country in general are mainly caused by increasing population. Nowadays, household family size and its annual crop production are not proportional. Moreover, the farmers are unable to improvement the amount of the production by the existing farming practices. For this reason, improve of household knowledge with the impact of population growth on their living status has paramount importance. Therefore, family planning lessons should be given widely and continuously through formal and informal education in school and some other social gathering area.
- The calibrated model can be used for further analysis of different management scenarios, land use redesign for steep slopes and Terracing activity.
- To reduce soil erosion and sediment load in the catchment best management practice is required. Based on this result it is highly recommended that ridges, mountains, steep and very steep slopes are covered with Afforestation.
- SWAT model was calibrated using observed flow data at gauging station. In order to improve the model performance, the weather stations should be improved both in quality and quantity. Hence, it is highly recommended to establish a good network of both hydrological and meteorological stations.

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APPENDIXS

Appendix 1: Location and classes of metrological stations

Name	Class	X-Coordinate	Y-Coordinate	Elevation	Meteorological variables
Woldia	3	564974	1304534	2565	PCP,Tmax,Tmin, RH,SLR,Wnd
Sirinka	3	570842	1291502	2133	Rainfall,Tmax,Tmin
Mersa	3	574572	1250968	2700	Rainfall,Tmax,T min
Logia	1	569980	1259081	843	PCP,Tmax,Tmin
Mille	3	569099	1258327	561	PCP,Tmax,Tmin

Appendix 2: Percentage of daily data missed

Name	Class	period	RF	Temp max	Tmin	RH	Sunshine	WND
Woldia	3	1990-2014	6.86	9. 45	9.01	1.77	2.14	1.63
Sirinka	3	1990-2014	2.72	2.91	3.57	No data	No data	No data
Mersa	3	1990-2014	15.6	6.52	6.15	No data	No data	No data
Logia	1	1990-2014	5.4	11.54	6.76	No data	No data	No data
Mille	3	1990-2014	7.21	3.43	10.17	No data	No data	No data

Appendix 3: Sensitive analysis result of stream flow in the catchment

SWAT parameters	Rank	Mean values	Sensitivity class
rchrg_dp	11	0.0213	Small
Biomix	19	0.00154	Small
GW_DELAY	7	0.0402	Small
SURLAG	10	0.0259	Small
epco	14	0.00923	Small
canmx	18	0.00161	Small
ALPHA_BF	1	0.233	High
SOL_Z	9	0.0296	Small
CN2	2	0.231	High
Gw_Delay	13	0.00933	Small
SOL_AWC	8	0.0388	Small
ESCO	3	0.159	High
CH_K2	5	0.049	Medium
Sftmp	27	0	Negligible
Slope	15	0.00766	Small
Slsubbsn	20	0.000256	Small
Smfmn	27	0	Negligible
Smfmx	27	0	Negligible
Smtmp	27	0	Negligible
Sol_Alb	16	0.00457	Small

CH_N2	4	0.0713	Medium
Sol_K	12	0.0105	Small
GWQMN	6	0.0422	Small

Appendix :4 P factor Values and slope length limits for contour farming terraced cultivated lands

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

Appendix: 5 General performance rating for recommended statistics for a monthly time step (Moriasi et al., 2007)

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

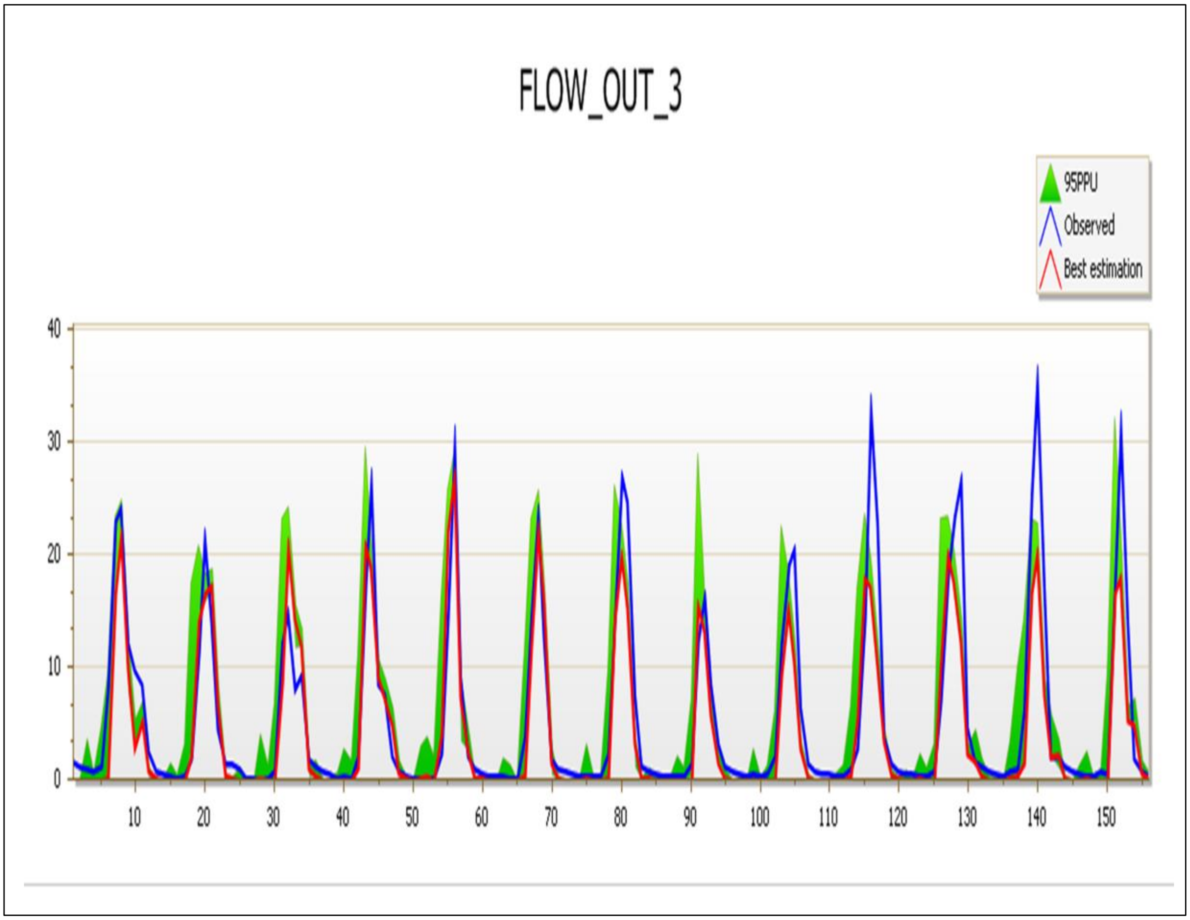
Appendix: 6 SCS Runoff curve number for soil moisture condition II of agricultural lands

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

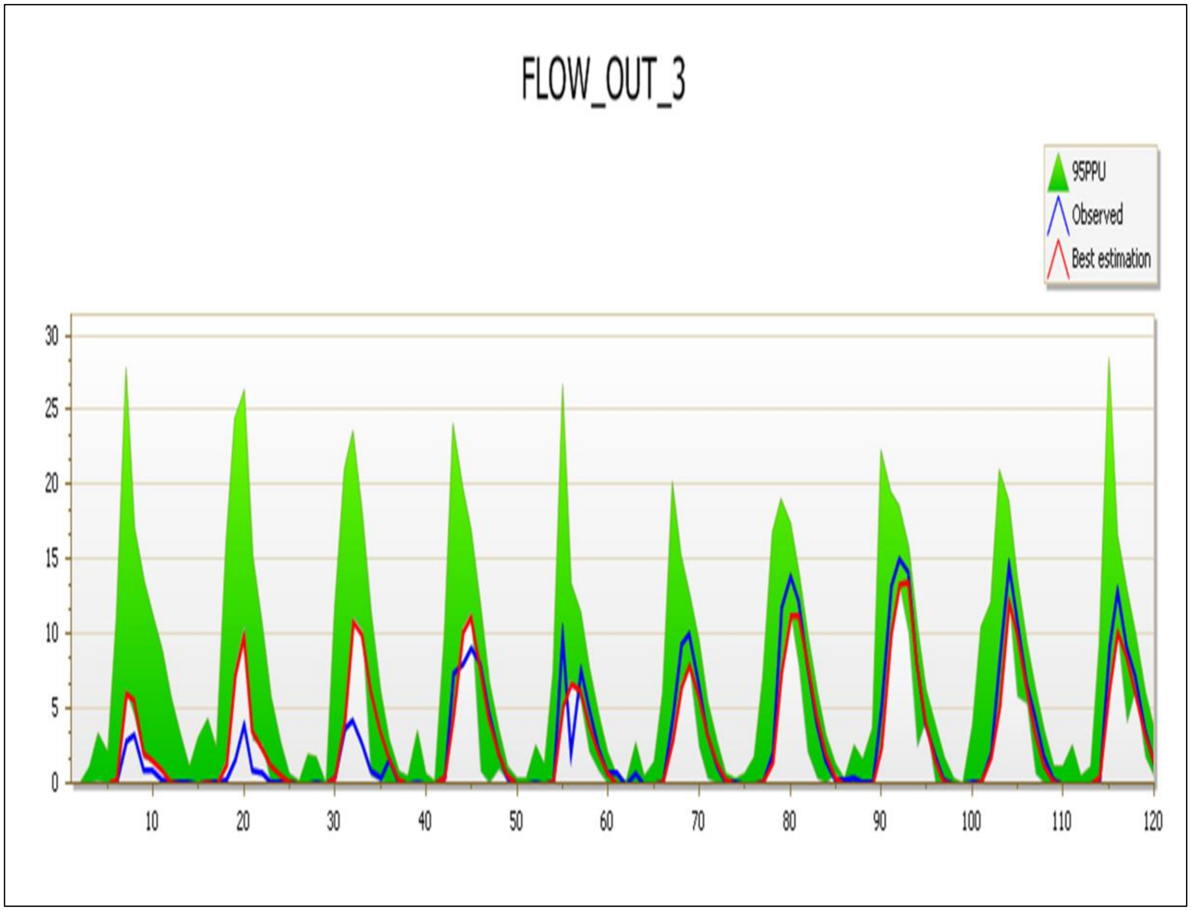
Chromic Vertisols D, Chromic Luvisols=B, Eutric Cambisols=B, Chromic Vertisols=B, Eutric Nitosols= C Lithosols B, Appendix: 6 Monthly flow of Golina catchment (1990-2014)

years	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Annual
1990	1.59	0.93	0.97	1.24	1.68	0.47	27	87.05	38	6.97	2.74	1.4	170.7
1991	0.97	2.85	1.72	3.16	0.35	1.4	72	160.4	50	6.92	4.68	3.7	307.58
1992	1.92	1.36	1.15	0.84	1.42	2.437	65	175.9	58	20.3	4.39	2.7	335.31
1993	2.02	0.63	0.85	1.51	3.11	1.321	51	102.9	25	6.93	3.68	2.7	201.77
1994	2.24	1.41	0.67	1.06	1.02	4.537	83	151.7	52	19.9	8.63	4.9	330.44
1995	2.89	1.8	1.25	3.11	0.32	1.02	14	5.452	11	15.2	5.06	3.8	65.21
1996	1.86	1.69	2.44	1.79	0.05	3.763	81	93.77	33	6.55	3.67	2.1	231.9
1997	1.48	1.17	2.49	2.09	3.44	4.675	105	130.7	42	20.9	8.8	5.3	328.06
1998	3	2.17	1.96	2.24	2.01	8.46	88	102.8	22	11.5	5.36	3	252.57
1999	1.37	1.26	3.09	2.18	1.44	0.994	45	113.3	22	4.2	2.07	1.1	197.61
2000	1.03	0.64	0.64	0.26	0.28	6.898	26	93.49	40	12.6	2.53	1.6	185.67
2001	1.38	1.27	0.78	0.46	1.8	7.907	26	68.94	31	7.6	3.66	2.1	153.04
2002	1.67	1.03	0.53	0.96	0.64	4.096	34	58.92	18	4.94	4.18	3.4	132.83
2003	1.62	0.85	0.81	0.67	1.56	4.785	44	131.5	54	20.9	2.83	1.6	265.13
2004	0.97	0.65	0.43	0.42	1.36	10.98	81	111	35	4.59	1.41	0.8	248.28
2005	0.95	0.87	0.61	0.94	0.12	43.56	37	120.4	80	11	3.22	2.8	301.07
2006	1.83	2.14	0.77	0.68	1.79	7.112	53	96.71	34	6.62	8.03	2.9	216.43
2007	2.11	1.15	1.93	2.18	3.8	21.39	84	107	28	17.1	23.2	4.7	296.56
2008	4.67	3.74	4.07	4.95	3.85	6.429	62	106.4	29	9.61	4.85	3.3	242.14
2009	1.89	0.68	0.42	0.18	2.36	1.857	23	72.72	30	6.39	2.6	1.7	143.43
2010	1.05	0.79	0.61	2.84	0.41	2.826	52	80.21	22	7.61	1.88	1.3	173.87
2011	5.64	4.26	1.9	1.88	1.89	11.4	80	92	39	16.4	11.8	2.3	268.15
2012	1.93	1.27	1.82	1.45	1.03	12.05	32	58.62	24	1.81	1	0.9	137.13
2013	0.46	0.3	0.5	0.1	0.1	2.253	31	44.92	32	7.82	3.39	2.1	125.36
2014	1.41	1.2	0.98	2.02	1.16	10.82	29	36.8	20	9.97	3.88	2.7	120.55
Mean	1.9	1.3	1.3	2.1	2.2	8	56	96	37	10.9	5.6	2.7	225.1
Max	7	5.5	7.3	9.9	11.8	43.6	170	175.9	88	27.1	30.3	7.7	485
Min	0.2	0.1	0.1	0.1	0.1	0.5	2.2	5.5	5.8	1.6	0.7	0.4	65.2

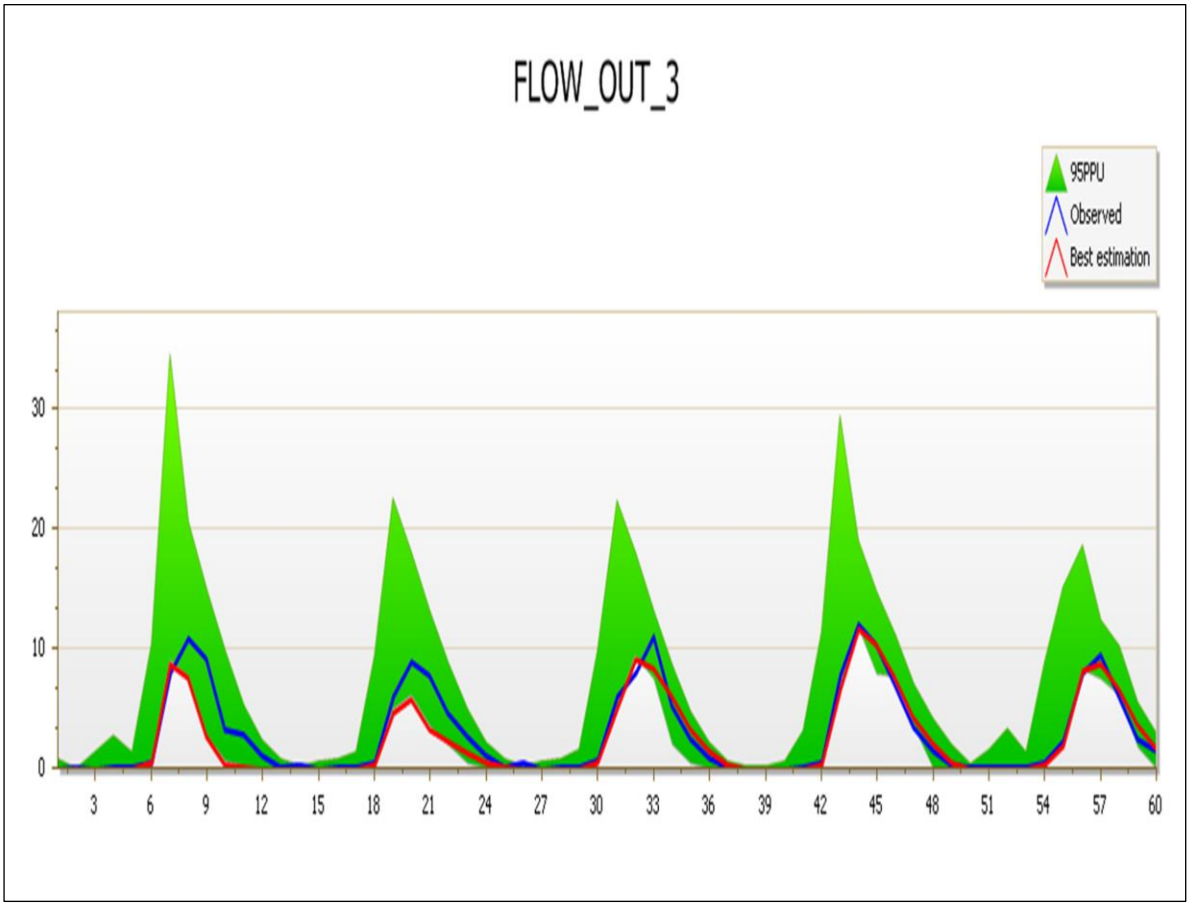
Appendix 7. Flow sensitivity analysis by using SUFI2



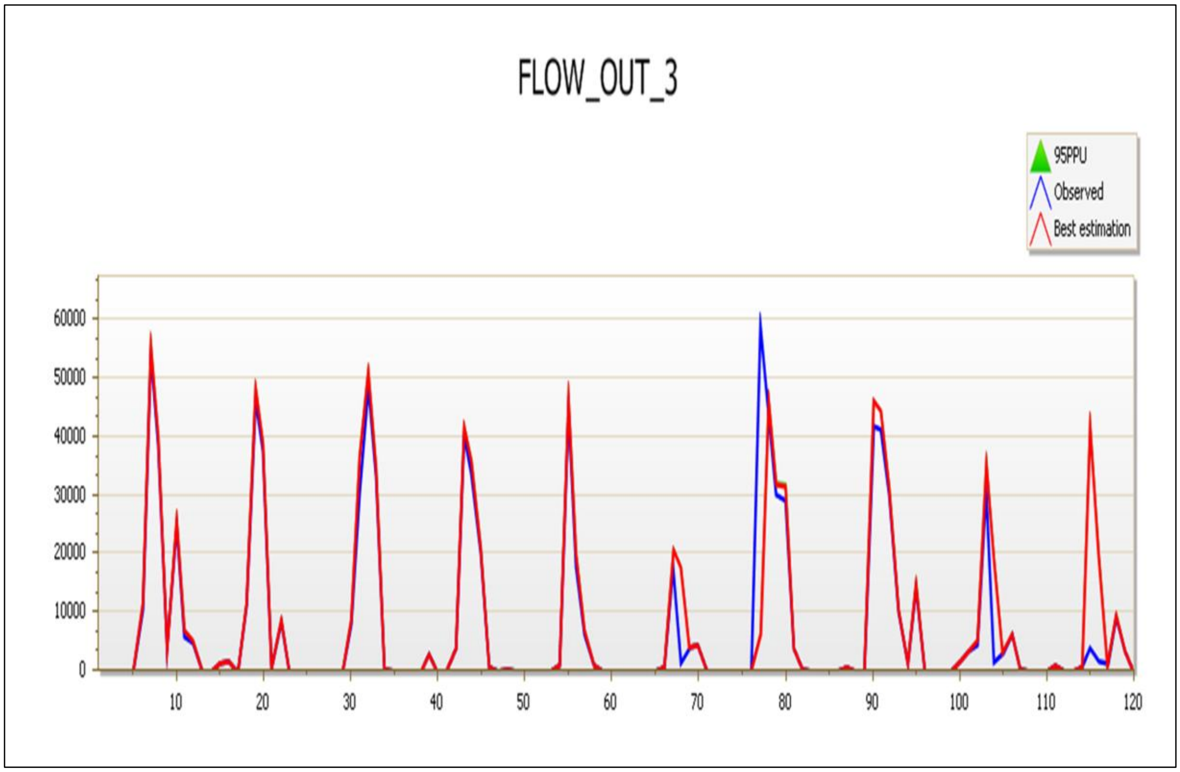
Appendix 8. Flow calibration by using SUFI2



Appendix 9. Flow validation by using SUFI2



Appendix 10.Sediment calibrations in the monthly time step by using SWAT_CUP



Appendix 11. Sediment validations by using SUFI2