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ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

SEDIMENTATION MODELING

(CASE STUDY, GOLOLCHA DAM RESERVIOR, UPPER WABE SHEBELLE RIVER BASIN, ETHIOPIA)

By

Hussen Muhammed Hussen

A Thesis Submitted and Presented to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Masters of Science in Civil Engineering under the Stream of Hydraulic Engineering

Advisor

Daneal Fikresellassie (PhD)

August-2020

Addis Ababa, Ethiopia

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Approval by Board of Examiners

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CERTIFICATION

The undersigned certify that I have read and here by recommend for acceptance by Addis Ababa University Institute of Technology a thesis entitled “Sedimentation Modeling” (a case study of Gololcha Dam Reservior, Upper Wabe Shebelle River Basin, Ethiopia) in partial fulfillment of the requirements for the degree of Master of Science in civil engineering specialization in Hydraulic engineering.

Dr. Daneal Fikresellassie

Date

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DEDICATION

I would like to dedicate this study in memory of my beloved grandparents.

ACKNOWLEDGMENT

I would like to present grateful thanks to my Advisor Dr. Daneal Fikresellassie for his invaluable encouragement, advices, professional guidance and critical comments for the accomplishment of this thesis work during conducting my research.

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ABSTRACT

Sedimentation of reservoirs is a critical problem that jeopardizes service life of hydraulic structures by reducing their active storage capacity. This investigation is intended to estimate sediment yield of Gololcha dam watershed, Wabe shebelle River basin, Ethiopia and to detect the sub basins that are under severe sediment load and developing scenarios as intervention measures in reducing this yield from catchment. The soil and water assessment tool is used in simulating Gololcha watershed having catchment area of 841.463Km^2. The model calibration and validation for flow and sediment is done through isolating sensitive parameter. Slope length for lateral subsurface flow (SLSOIL) was one of the sensitive parameter for flow and SCS runoff curve number (CN2) for sediment.

The model evaluation result showed that determination coefficient of 0.74, Nash-Sutcliffe of 0.73, bias percentage of -9.1 for calibration of flow and determination coefficient of 0.61, Nash-Sutcliffe of 0.6, bias percentage of -2.5 for validation of flow. For sediment calibration and validation, the result obtained with determination coefficient of 0.79, Nash-Sutcliffe of 0.77, bias percentage of 0.7 and determination coefficient of 0.78, Nash-Sutcliffe of 0.52, bias percentage of 10.1, respectively. Thus, the model found to be good in simulating the flow and sediment for the study area. The estimated result indicated that the average annual sediment load at the dam site was 234,768 ton/yr. In this finding Spatial difference of sediment yield for Gololcha watershed disclosed that sub basins 2,3,4,5 and 14 are the critical sub basins generating mean annual sediment load varying from 5.48 ton/ha to 16.22 ton/ha.

Different Scenarios developed through land use refinement and operation management for the critical sub basins identified for sediment reduction from the catchment. High amount of sediment reduction observed when intensively cultivated land changed to forest mixed. In addition to this, the combination of contouring and terracing showed more effective management practices than when they are practiced separately.

Keywords: Gololcha watershed, sediment yield, calibration, validation, SWAT, SWAT-CUP

ABBREVIATIONS

ASCE	American Society of Civil Engineers
AGU	American Geo physical unit
CN	Curve Number
DEM	Digital Elevation Model
GIS	Geographic Information System
Ha	Hectare
HRU	Hydrologic Response Unit
LULC	Land use land cover
mm	Milli meters
MUSLE	Modified Universal Soil Loss Equation
NMAE	National Meteorological Agency of Ethiopia
NSE	Nash Sutcliffe Efficiency
SCS	Soil Conservation Services
SUFI-2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
USDA	United state department of agriculture
USLE	Universal soil loss equation
UTM	Universal transverse Mercator
WGS	World geodetic system
WWDSE	Water Work Design and Supervision Enterprise

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CHAPTER ONE

1. INTRODUCTION

1.1 Back ground

Sedimentation is a problematic situation that can result in dropping water storage capacity of the reservoir. The erosion process includes detachments and the movement of soil particles by water, wind or agents associated with farming activities that gradually results in declining of active storage capacity of hydraulic structures through entering the reservoirs unless the upper watershed is treated with appropriate watershed management interventions and strategies. Changes in land use, land cover and land degradation are growing at alarming rate and these played a great role in increasing soil erosion in Ethiopia (Tsegaye, 2019). Belay (2018) stated that land use land cover changes to cultivated land worsen soil erosion harms unless proper management is undertaken. Natural resource degradation in Ethiopia has been ongoing for centuries (Hurni, et al.2010). Similarly (Gashaw, 2018) states that land degradation is main reason of continuing food insecurity, rural poverty, low and lessening agricultural productivity.

Degradation widespread, gullying frequently and long history of land use with high erosion damage especially on slopes (Hurni et al. 2016). The overall current soil erosion amounts are greatly variable and large by international standards, and sheet, rill, and gully erosion are the principal processes (Haregeweyn et al. 2015). Organic matter loss in the topmost soil and nutrients unavailability has adversely affected the yield in the Highland region of Ethiopia (Philor, 2011).

According to (Berry, 2003) the loss of land resource productivity is an important problem in Ethiopia and with continuing population growth the situation is expected to become worst in the future. Soil types, agro ecological and topography parameters are other factors that increase the degradation process influenced by man (Dubale, 2001).

Gololcha dam is a proposed project on Gololcha River to generate surplus in agricultural production, food grains, vegetables and fruit products for agricultural led industrialization through irrigating the nearby command areas in order to improve the condition of food scarcity in Ethiopia. Therefore, it is important to predict sediment inflow to Gololcha reservoir and sustain it through long-term management practices.

Many reservoirs are suffering from extreme sedimentation because either the upstream sediment supply was never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data. The amount of sediment deposit depends on the types of sediment in the river system, the shape of the reservoir, the detention storage time and the operating procedures. The heaviest particles, such as gravel and thick sand, are the first ones to fall, while finest sediments enter into the reservoir. Hence, the finest particles do not mix readily with the reservoir water; it can be deposited near the base of the dam.

According to (White, 2009) around 40,000 great reservoirs from worldwide affected by siltation and it is predictable that from 0.5% up to 1% of the total storage capacity is dropped annually. Borji (2013) states the Grand Ethiopian renaissance dam storage capacity will be lost at an average amount of 0.3% per year.

In order to overcome this challenge a systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects. Although empirical formulas are adopted, which simply simulate rainfall runoff relationship, which are developed in other similar agro climatic zones; there is a great uncertainty on the estimations because it does not consider complex interaction that occur in the watershed.

As a result, thorough understanding of hydrological processes in the catchment is a pre requisite for successful water management and environmental restoration. Due to temporal and spatial heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. Therefore, mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes.

This investigation intends to predict the sediment yield of Upper Gololcha River catchment to the Gololcha dam reservoir and to identify the sub catchments, which are producing much sediment yield. In addition to this, suggesting appropriate watershed management interventions to eradicate the adverse impact of this yield on Gololcha reservoir.

1.2 Statement of the Problem

Erosion of soil is a critical problem that leads to loosing of top soil, which do have good fertility than sub soil. In addition to this, the eroded soil will transport to downstream and goes to the reservoirs, which endanger the sustainability and service life of reservoirs because of siltation.

As a result, careful assessment in quantifying of sediment yield is required in order to maintain the storing capacity of the reservoir and prolong its economic life by taking appropriate measures that could reduce the rate of sedimentation. Gololcha watershed is suffering from soil erosion that can significantly affect the active storage capacity of Gololcha reservoir found within the catchment.

So this investigation concerns to predict sediment yield of Gololcha catchment with the help of physical based model through combining spatially integrated hydrological parameters, digital elevation model, land use land cover and soil map in ArcSWAT model, which is ArcGIS interface.

1.3 Research Question

The basic questions that will be answered by this research are: -

- How much is the sediment yield in the Gololcha dam watershed?
- How much is the Sediment yield of each sub basins?
- Which catchment management practice is effective?

1.4 Objective of Research

1.4.1 General objective

- To estimate the sediment inflow to the Gololcha dam reservoir using SWAT model, which is ArcGIS interface.

1.4.2 Specific objective

- To quantify the sediment yield from sub watershed at the outlet of catchment.
- To identify the critical sub basins based on sediment yield generated.
- To develop scenarios for intervention measures in reducing sediment yield from watershed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Soil Erosion and Sedimentation Processes

Soil erosion due to water include detachment from the soil mass, transport of some or all of the eroded soil as sediment downslope, and during its transit depositing some of the sediment or picking up more eroded soil. In following a droplet of runoff down the hillslope, three distinct forms of erosion are seen in the upland areas. These are sheet erosion, rill erosion, and gully erosion (Marcelo et al,2008).

A. Sheet erosion

It also known as interrill erosion, occur uniformly between rills or gullies and results primarily from raindrop impact. The washing away of a thin layer of the land surface and erosive potential of this impact depends on raindrop size, fall velocity, and total mass at impact, but can be devastating. In the absence of vegetation, mulch, or other cover to absorb the impact, raindrops can detach tremendous quantities of soil.

B. Rill erosion

Rills may be very shallow or very deep, but generally form parallel channels running downslope on the planar surface. Their location is controlled somewhat randomly by small irregularities in the micro-topography, so if they are destroyed by tillage they will reform in different places.

Rill erosion is much more visible than interrill erosion. These small channels carry runoff and sediment from interrill areas, the rain that falls directly on them, and any sediment produced from erosion within the rill. Rill erosion increases rapidly as the slope steepens or lengthens and as the runoff rate increases.

C. Gully erosion

It is a substantial removal of soil by large concentrations of runoff. This occur in the low portions of the macro-topography where the planar hillslopes converge, so they are best thought of as the uppermost portions of the watershed channel system. These processes occur primarily in the upland areas and upper channels of a watershed. After the flow has reached the watershed channel system, sediment may also be generated from streams or channels because of streambed and bank erosion, in which case the channel is said to be degrading.

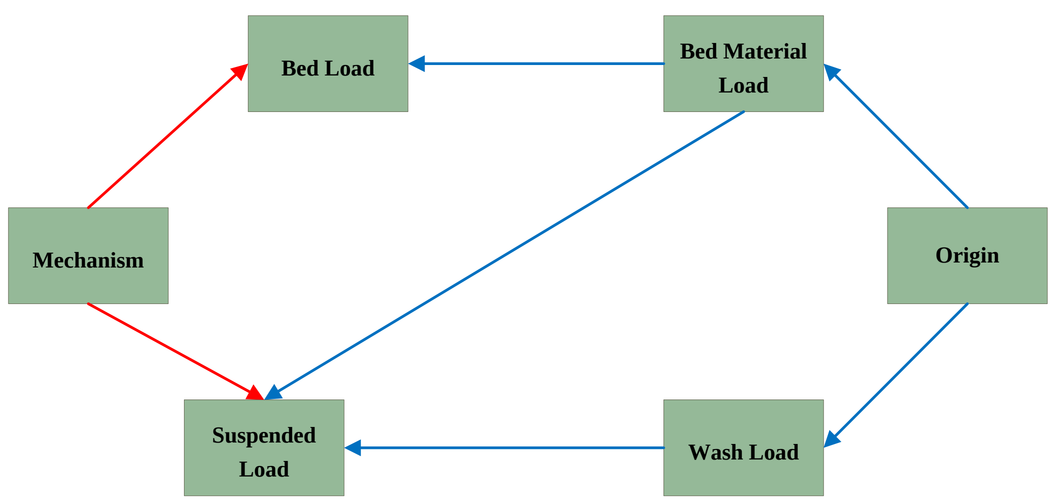
In the other way, if more sediment is added from the upland areas than the channel flow can transport significant deposition and storage of upland sediment may occur within the channel system, in which case the channel is said to be aggrading. In a stable channel, very little net erosion occurs because of equilibrium between the sediment transported out of the channel system and that added by the upland erosion processes.

Rainfall causes increasing water saturation or the formation of a seal on soil surface. Because of both processes, infiltration into the soil is decreased. Water on soil surface occurs as soon as rain intensity begin to exceed infiltration rate(Nill, 1996).

2.2 Modes and mechanisms of Sediment transport

2.2.1 General

Sediment is broken material mainly formed by means of physical and chemical disintegration of rocks from the earth's crust. Physical disintegration defines the material that is broken down by human interference or due to the construction or engineering works whereas chemical disintegration is due to chemicals in fluids, wind, water and ice or by the force of gravity acting on the particle itself (Bhuiyan.F 2011).



(Breusers, H. N. C,1974)

Figure 2.1 Mechanism and origin of sediment transport

2.2.2 Bed Load Transport

Transport of Bed load denotes to the sediment, which is in almost continuous contact with streambed, carried forward through sliding, rolling or hopping. Bed material starts sliding or rolling in endless contact with bed when the value of shear velocity begin to exceed critical value in beginning of motion. Hopping also happen for increased values of bed shear velocity, which moves particles along the bed by more or less regular jumps.

2.2.3 Suspended Load Transport

Transport of Suspended load represents to the part of total sediment transport, which is maintained in suspension by turbulence in flowing water for considerable periods without contacting the streambed. These materials, primarily contains sand and silt that are held in suspension by the upward flux of turbulence generated at the bed of the channel (Vortag et al, 2010). Suspended sediment load sustained, if the particle fall velocity is less or equal to upward currents (Van Hieu Bui et al, 2019).

2.3 Origin of Transported Material

I. Bed material load

Bed material comes from channel bed and sides, which consist of suspended Load and bed load. The flow condition determines the type and quantity of transported material that includes particles, which roll and slide along the bed as well as those near the bed transported in saltation or suspension.

II. Wash Load

Fine sediment comes from outside the channel mostly by land erosion that does not have direct relationship with local conditions. This load encompasses particle sizes finer than that found in appreciable quantities in the bed material. Since it is in near-permanent suspension, they are transported through the stream without deposition. The discharge of the wash load through a reach is governed by the rate with which these particles become available (Bhuiyan.F, 2011).

2.4 Sediment Properties

The sediment carried by natural streams comprises usually particles ranging from gravel or sand down to very small particles classified as silt or clay. The very fine fractions are carried as wash Load or even as colloidal suspension for which electrochemical forces play a leading role.

For the alluvial stream hydraulics, the most important particles are those found in range of sand (0. 06 mm to 2 mm), gravel (2 mm to 20mm). From a hydraulic point of view the most important sediment properties are related to size, shape and specific gravity (Frank et al,1967).

2.4.1 Size determination

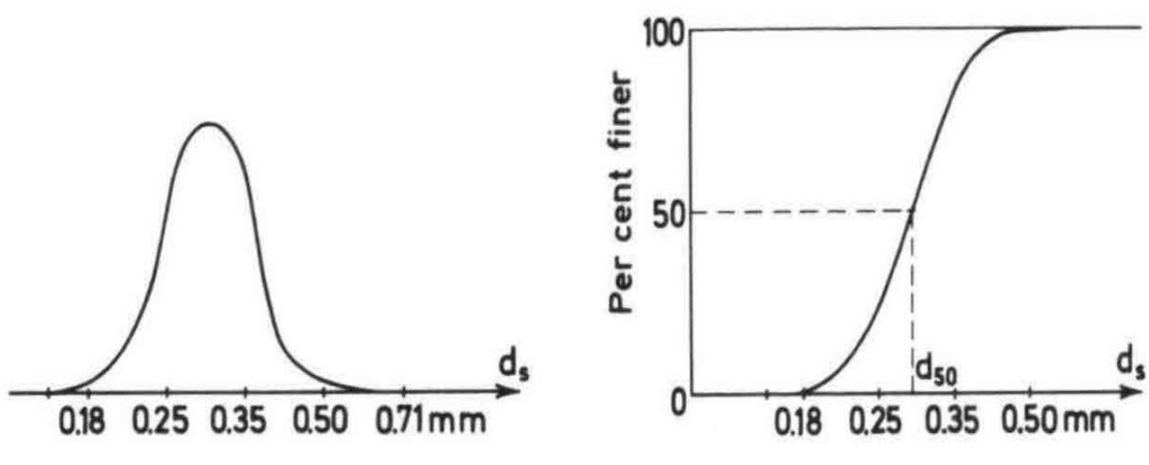
The American Geo Physical Union (AGU) for clay, silt, sand, gravel, cobbles and boulders gives classification of particles according to size.

Table 2.1 Grain size determination

Boulders and cobbles	Direct measurement
Gravel and sand	Sieving
Fine sand, silt and clay	Sedimentation or micro scope analysis

2.4.2 Particle size distribution

The most usual and convenient method for particle size distribution analysis is the sieve analysis, which is applicable for particle sizes not smaller than 0.06 mm. Sufficient number of representative sediment samples are analyzed, and the result is presented as a frequency curve (figure a) or as a cumulative frequency curve (distribution curve, figure b) (Frank. E and Eggert. H, 1967).



(a) (b)

Figure 2.2 Particle size distribution

Where the abscissa represents sieve diameter d_s and the ordinate indicates how many percent (by weight) of the total sample finer than the diameter d_s.

2.4.3 Shape

Besides the grain diameter, also the shape is of great importance. A flat particle has a smaller fall velocity and more difficult to transport as a rounded particle. (Breusers, 1974).

Several definitions can be used to characterize the shape:

a. Roundness

Roundness depicts average curvature of radius of the edges and the radius of circle inscribed in the maximum projected area of the particle. Roundness is a function of abrasion induced by transport and it increases slowly with distance. Thousands of kilometers of transport in a river are required to achieve even moderate rounding. Beaches where sand moves in and out with each wave are ideal places for rounding of sand particles if they stay there for any length of time (L. C.Van Rijn).

b. Sphericity

It is the ratio of surface area of sphere and surface area of particle at the same volume.

c. Shape factor

Generally represented by the Corey shape factor, defined as:

$$SF= {}^{c}\!/\!\sqrt{ab} \qquad \text{Equation …2.1}$$

in which a, b, c are three mutually perpendicular axes from which a is major, b is intermediate and c is minor axis. The shape factor for natural sand is approximately SF≈ 0.7 and for sphere SF=1

2.4.4 Density

Most sediments originate from disintegration or decomposition of rock.

Table 2.2 Origin of sediment

Clay	**Fragments of feldspars and micas**
Silt	Silica’s
Sand	Quartz
Gravel	Fragments of original rock
Boulders	All components of original rock

The density of most sediment particles (<4 mm) varies between narrow limits. Since quartz is predominant in natural sediments, average density can be assumed 2650 Kg/m^3 (specific gravity

2.65). Sometimes heavy minerals are present which can be segregated during ripple formation or other modes of transport. Clay minerals range from 2500-2700 Kg/m^3.

2.4.5 Fall velocity

Fall velocity is an important parameter in studies on suspension and sedimentation of sediments. The fall velocity is obtained from equilibrium between gravity force and flow resistance:

$$\frac{\Pi}{6} * D^3 (\rho_s - \rho_w) g = C_D * \frac{1}{2} \rho_w \omega^2 * \frac{\pi}{4} D^2 \quad \text{Equation….2.2}$$

Gravity Force = Flow Resistance

In which C_D, drag coefficient and ω, fall velocity.From above relation follows:

$$\omega = \sqrt{\frac{4}{3} * \frac{gD}{CD} * \Delta} \quad \text{Equation…2.3}$$

Where $\Delta = \frac{\rho s - \rho w}{\rho w}$

Values of C_D depends on a Reynold s number ω*D/ν and the shape of the particle (expressed by SF= $c/\sqrt{ab}$).

For spherical particles and low Reynolds number (Re<1), C_D can be given by $C_D = \frac{24}{Re}$ so that:

$$\omega = \frac{\rho s - \rho w}{18\nu} gD^2 \quad \text{(stokes law)} \quad \text{Equation….2.4}$$

For large Reynolds numbers C_D becomes a constant so that W varies as $(\Delta gD)^{0.5}$ therefore W varies with $D^{0.5-2}$. Relation between C_D, Re and SF are also given by Albertson (1953).

2.4.6 Bulk density and porosity

In estimating the life of a reservoir and similar cases, the calculated weight of the sediment transported to the reservoir has to be converted in to volume. For this the sediment dry weight per unit volume in place, bulk density ρ_b has to be estimated.

Bulk density express mass of dry sedimentary material within a unit of volume (Kg/m^3). The volume taken by the sediment depends on the conditions of settling and is a function of consolidation time.

According to Lane et al (1953), bulk density of deposits in reservoirs is estimated by the empirical relation.

$$\rho_{bt} = \rho_{b1} + B \log t \qquad \text{Equation…2.5}$$

Where t- time in years

ρ_{b1}- initial bulk density taken to be the value after one year of consolidation

B- Consolidation coefficient

Table 2.3 Initial bulk density for sediment

Reservoir operations	Sand		Silt		Clay	
	ρ_{b1}	B	ρ_{b1}	B	ρ_{b1}	B
Sediment always submerged or nearly submerged	1500	0	1050	90	500	250
Normally a moderate reservoir drawdown	1500	0	1185	45	750	170
Normally considerable reservoir drawdown	1500	0	1275	15	950	100
Reservoir normally Empty	1500	0	1320	0	1250	0

(Breusers, H. N. C, 1974)

For sediments of containing material of more than one size class proportional addition of the fractions can be made. Data given in table are based on normal conditions and applicable for first estimate.

2.5 Hydrologic model

Hydrologic models classified into three different categories (V. P. Singh et al. 2002).

A. Physically based models that depend on solving governing equations such as mass conservation and momentum equations. Parameters and state variables are directly measured either in the field or reasonably assumed based on site characteristics.

B. Conceptual models utilize simple mathematical equations to express the core hydrological processes such as runoff, base flow, surface storage, evapotranspiration, percolation and snowmelt. The merit of this approach is that the model is much simpler from a mathematical point of view. The processes are predicted with simple equations rather than solving governing partial differential equations. To replace partial differential equations with simple statements, varieties of different model parameters are introduced into model that may have little physical meaning.

c. Empirical models, which are based on analyzing observed input and output then after linking them through statistical or other similar techniques. Empirical models are normally mathematically simpler than their conceptual and physical counterparts, and reasonably good outcomes can be quickly gained by using techniques such as regression and neural networks.

2.5.1 SWAT Model Description

Soil and Water Assessment Tool developed by united state department of Agricultural Research Service, which simulates the land phase of the hydrologic cycle in daily basis.

It is physically based, at river basin scale, computationally efficient, continuous-time model that functions on daily period and is aimed to forecast impact of management on water, sediment and agricultural chemical yields in un-gauged catchments (Gassman et.al, 2007).

SWAT model designed to route water and sediments from individual watersheds through the river systems. It can incorporate the tanks and the reservoirs/check dam off-stream in addition to streams. The agricultural areas can be integrated with respect to their management practices (Arnold et al., 1998). SWAT model can satisfactorily estimate sediment yield for even poorly gauged catchments(Ndomba and Griensven, 2011).

The model uses SCS curve number and Green Ampt method having daily rainfall data as input to generate surface run off whereas modified universal soil-loss equation (MUSLE) used to predict sediment loss. Soil Conservation Service curve number use land use ,soil permeability and antecedent moisture conditions (SCS, 1972) whereas Green Ampt computes infiltration as function of wetting front metric potential and effective hydraulic conductivity (Green Ampt, 1911).

2.5.2 Hydrological process in SWAT

SWAT simulates different hydrological processes through integrating spatial variation in topography, soil, land use, slope and other watershed characteristics. The simulated hydrological process encompasses runoff, infiltration, Lateral flow, channel routing, percolation to shallow aquifers, deep aquifers and evapotranspiration (Arnold et al., 1998). From these hydrological process the surface runoff, lateral flow (subsurface flow), base flow (return flow) contribute to the stream flow in the main channel whereas water that enters deep aquifer is assumed to be lost out of watershed under investigation. All the hydrological process raised above are simulated in surface, soil,vadose (intermediate) zone, shallow and deep aquifers as shown in Figure 2.3.

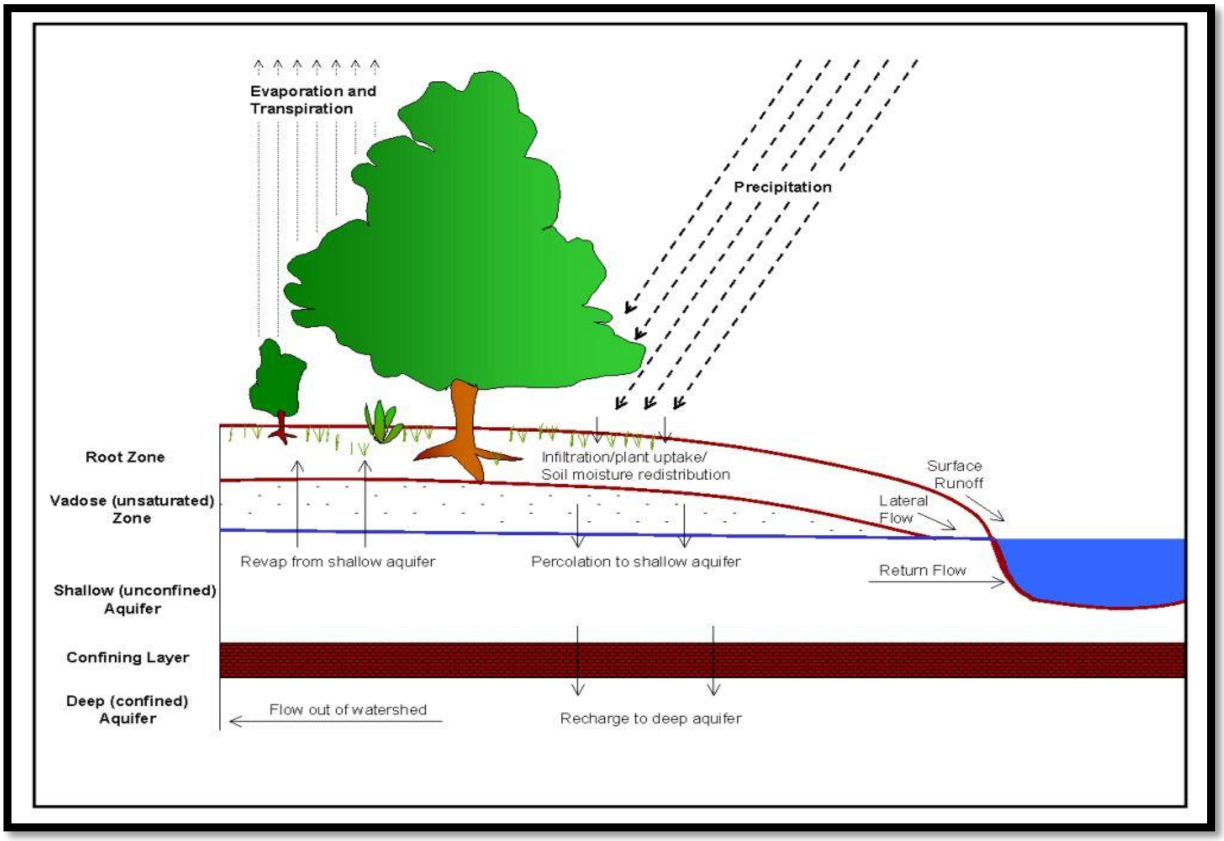


Figure 2.3 Schematic illustration of hydrologic cycle

Water balance is the driving agent behind every process that can happen in catchment during simulating the SWAT model. The simulated hydrologic cycle is done based on water balance equation.

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \quad \text{Equation…2.6}$$

Where SWt-final soil water content (mmH_2O)

SWo-initial soil water content on day i(mm H_2O)

t-time (days)

R_{day}- amount of precipitation on day i(mm H_2O)

Q_{surf}-amount of surface of run off on day i(mm H_2O)

E_a- amount of evapotranspiration on day i(mm H_2O)

W_{seep}-amount of water entering vadose zone from soil profile on day i(mm H_2O)

Q_{gw}-amount of return flow on day i(mm H_2O)

2.5.3 Soil conservation service CN method

The SCS curve number system calculates direct run-off having the total precipitation and watershed characteristic coefficient as an input. The curve number relies on particular soil and land use type, which indicate the run-off potential of land cover and soil complex (Soil conservation service, 1972).

The most popular form of SCS-CN method is given by-

$$Q = \frac{(P - Ia)^2}{(P - Ia) + s} \qquad P > Ia$$

$$Q = 0 \qquad P \leq Ia$$

$$S = \frac{25400}{CN} - 254 \qquad \text{Equation…2.7}$$

Where Q- run off (mm H_2O)

P-total precipitation (mm H_2O)

Ia- Initial abstraction encompasses interception, surface storage and infiltration prior to runoff (mm H_2O)

S- Potential maximum retention parameter for moisture content of soil (mm H_2O)

CN-weighted curve number

The initial abstraction is approximated as $Ia = 0.2S$ hence the above equation can be rewritten as (Chow et al, 1998)

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{Equation…. 2.8}$$

The dimensionless curve number uses land use, soil type and antecedent moisture condition: 1-dry condition, 2- average moisture and 3-wet condition.

$$CN1 = CN2 - \frac{20(100 - CN2\ )}{(100 - CN2 + \exp[2.533 - 0.0636 * (100 - CN2)])}$$

$$CN3 = CN2 * \exp[0.00673 * (100 - CN2)] \qquad \text{Equation…2.9}$$

Where, CN1 is for dry condition, CN2 is for normal (average) condition and CN3 is for wet condition (Neitsch et al., 2011). In order to predict sediment loss the peak run off rate plays a great role since it is an indicator of storm erosive power. SWAT uses modified rational system to calculate peak runoff rate.

$$Qpeak = \frac{\alpha tc * Qsurf * A}{3.6tc} \qquad \text{Equation.... 2.10}$$

Where Qpeak- peak runoff rate (m^3/sec)

αtc- fraction of daily rainfall that occurs at the time of concentration

Qsurf -surface runoff (mm)

A- Sub basin area (km^2)

tc- concentration time for the sub basin (hr) and 3.6 is a unit conversion factor.

2.5.4 Modified Universal Soil Loss Equation (MUSLE)

MUSLE is proposed with substituting of the rainfall factor with runoff factor to consider variability of delivery ratio (Williams and Berndt, 1977). Mainly, this model proposed for estimation of the sediment yield on a single storm basis at outlet of the catchment depend on runoff characteristics, as the best indicator for sediment yield forecast. It also improves accuracy of soil erosion prediction over USLE and RUSLE.

The modified universal soil loss equation (Williams, 1995) is as follows:

$$Sed = 11.8\,(Q_{surf}\, q_{peak} Area_{hru})^{0.56}\, K_{USLE} * C_{USLE} * P_{USLE} * CFRG * LS_{USLE} \qquad \text{Equation...2.11}$$

Where, S_{ed} is defined as Sediment yield rate (tones/day),Q_{surf} is surface runoff volume (mm/day), q_{peak} is peak runoff rate (m^3/s), $Area_{hru}$ is area of the HRU (ha), K_{USLE} is USLE erodibility factor of soil (0.013 metric ton m^2 hr/(m3-metric ton cm)), C_{USLE} is USLE crop management factor or cover management factor, P_{USLE} indicate USLE support practice factor, CFRG is coarse fragment factor and LS_{USLE} is USLE topographic factor.

2.5.5 SWAT Model Performance

The performance of SWAT model is evaluated using statistical and graphical methods to compare observed data with model predictions. This include determination coefficient (r^2), Nash and Sutcliffe (NSE), Percentage of Bias (PBIAS) and time series plots.

I. Determination Coefficient (r^2)

Determination Coefficient is an indicator of how well the variance of observed values are replicated by model predictions (Krause et al., 2005). Its values varies from 0 up to 1, whereas 0 represents no correlation and 1 indicates perfect correlation.

When r^2 is used as performance measure, it is recommended that regression line gradient and intercept should be reported. In order to get a good agreement between observed and model prediction, the intercept should be close to zero and the gradient should be close to one.

$$r^2 = \frac{(\sum_{i=1}^{n}(Oi-\bar{O})(Pi-\bar{P}))^2}{\sum_{i=1}^{n}(Oi-\bar{O})^2 \sum_{i=1}^{n}(Pi-\bar{P})^2} \qquad \text{Equation…2.12}$$

Where: - n is number of observations during the simulation time

P_i and O_i are the predicted and observed values on each comparison point i.

$\bar{p}$ and $\bar{O}$ are the arithmetic means of the predicted and observed values.

II. Nash and Sutcliffe (NSE)

The Nash and Sutcliffe efficiency (NSE) depict how well simulated result matches observed data along a 1:1 line and it can vary form -∞ to 1. If observed value is similar to all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it specifies deviances between measured and predicted values. If E_{NS} is negative, predictions are very poor; the average value of observed data is the better estimation than model prediction (Nash and Sutcliffe, 1970).

According to (Moriasi, 2015) the advantage of this statistical measure is that it can be used with continuous long-term simulations to determine how well model simulates trends for the output response of concern. In addition to this, it helps to evaluate performance of model for numerous output response like stream flow, sediment, nutrients and pesticides.

$$NSE = \frac{\sum_{i=1}^{n}(Oi-\bar{O})^2 - \sum_{i=1}^{n}(Oi-Pi)^2}{\sum_{i=1}^{n}(Oi-\bar{O})^2} \qquad \text{Equation…2.13}$$

III. Percentage of bias (PBIAS)

Bias Percentage indicates whether the average tendency of the estimated data to be higher or lower than the observations. Adding to this it also measures over and underestimation of bias and expresses it as a percentage. Zero is Optimum value, whereas low value, show well simulations. Negative values point to model over estimation and Positive values show model underestimation (Gupta et al, 1999). The advantage of BPIAS is that it can help to identify average model simulation bias (whether it is over predicted or under predicted) (Moriasi, 2015).

$$PBIAS = \frac{\sum_{i=1}^{n}(Oi-Pi)}{\sum_{i=1}^{n} Oi} * 100 \qquad \text{Equation…2.14}$$

2.6 Sediment modeling

Semi distributed physics based watershed model, soil and water assessment tool mostly used to compute the sediment yield from the watershed. In addition to this, it is important to identify the areas that are suffering from erosion based on their silt load, considering appropriate measures to eradicate these erosion rates through different management practices for planning land use and sustainable water resource.

Watershed sediment yield describes total amount of sediment that generated within a watershed and delivered at its outlet during any given time. It starts with soil erosion, which is defined as the removal (detachment) of soil particles from the earth's surface. A portion or all of the eroded soil is then transported by flowing water as sediment.

Sediment yield refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which is also the amount, which will enter a reservoir located at the downstream limit of its tributary watershed (Vanoni, 2006). The specific sediment yield is the yield per unit of land area (Morris, 2010). In a watershed, sediment yield includes erosion from land surface slopes, gullies, streams, and mass wasting, minus sediment that is deposited after it is eroded but before it reaches the point of interest.

2.6.1 Estimation of Watershed Sediment Yield

Estimation of Watershed sediment yield is critical in planning soil conservation and sustainable development of natural resources since Sediment generated from erosion can pollute streams, rivers, and estuaries, fill reservoirs and navigation channels, and cover valuable floodplain lands and properties.

2.6.2 Bed Load Equations

In many circumstances, direct or indirect measurements of bed load are not possible thus, it is necessary to estimate bed-load transport rates using general capacity-limiting sediment-transport equations. Bed load of African rivers accounts frequently between 5% and 10 % of the suspended load (Walling and Webb, 1987). WAPCOS (1990) used as 10% to 20% of the suspended load.
Almost all bed load formulae are one of three types in which the sediment transport rate per unit channel width (q_{sb}) is related to either:

A. Excess shear stress $(\tau_0 - \tau_{cr})$ $q_{sb} = x^* \tau_0(\tau_0 - \tau_{cr})$ Du Boys type

B. Excess discharge/unit width $(q-q_{cr})$ $q_{sb}= x'*s^k (q-q_{cr})$ Schoklitsch type

C. Excess stream power /unit width $(\omega-\omega_{cr})$ $q_{sb}= (\omega-\omega_{cr})^{3/2} d^{-2/3} D^{-1/2}$ Bagnold, 1980

Where x and x' are sediment coefficients, d is flow depth and D is grain size. The critical condition (denoted by the subscript cr) is for initiating sediment movement. Once sediment starts to move on bed of channel the sediment-transport rate increases in a rather orderly fashion as discharge (and shear stress and velocity and stream power), increases and most sediment-transport equations do a fair and similar job of predicting the rate of increase in sediment transport (Vortag et al, 2010).

2.6.3 Sediment transport equation

Erosion initiated by rainfall and runoff is computed with Modified Universal Soil Loss Equation (Williams, 1975). MUSLE is a modified version of Universal Soil Loss Equation developed by Wischmeier and Smith (1965, 1978). USLE forecasts average annual gross erosion as a function of rainfall energy.

In MUSLE, the rainfall energy factor is substituted with a runoff factor. This advances the sediment yield prediction, removes the need for delivery ratios, and allows the equation to be applied to individual storm events. Estimation of Sediment yield improved since runoff functions on rainfall energy as well as antecedent moisture condition.

Delivery ratio (sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor denotes energy used in detachment and transportation of sediment (Neitsch et al., 2011).

2.6.4 Sediment routing in stream channel

Sediment routing expressed in terms of peak runoff rate and stream flow. Every delineated sub basin has its own main reach through which sediment from upland routed and then added to downstream reaches. For modeling sediment transport, bank and bed erosion in channel containing various bed materials and sediment deposition SWAT incorporates stream power equation, which are more physically, based approach.

SWAT 2012 uses the simplified equation of Bagnold (1977) in addition to Kodatie, Molinas and Wu, Yang model that are keep tracks of particle size distribution through the channel reaches.

In simplified version of Bagnold equation, sediment amount which is maximum and transported from reach segment, expressed in terms of peak channel velocity (Neitsch, 2011).

Peak channel velocity ($V_{ch,pk}$) is calculated as :-

$$V_{ch,pk}=q_{ch,pk}/A_{ch}$$

Where $q_{ch,pk}$-peak flow rate in (m^3/sec)

A_{ch}-cross sectional area of flow in (m^2)

The peak flow rate is defined as :-

$$q_{ch,pk}=prf*q_{ch}$$

Where prf-peak rate adjustment factor and q_{ch} is average flow rate.

Maximum amount of sediment which is transported from reach segment expressed as:- $conc_{sed,ch,mx}=c_{sp}*v_{ch,pk}^{spexp}$

Where $conc_{sed,ch,mx}$ is maximum sediment concentration that transported by water in(ton/m3 or kg/L), c_{sp} is coefficient expressed by user , $V_{ch,pk}$ is peak channel velocity in (m/sec) and spexp is the exponent parameter defined by user which normally differs between 1 and 2 and was set at 1.5 in the original stream power equation of Bagnold (Arnold et al 1995). However, in the current version of SWAT 2012 this value is, vary from 1 to 1.5. The maximum concentration of sediment calculated is compared with concentration of sediment in reach at the starting of the time step, $conc_{sed,ch,i}$.

If $conc_{sed,ch,i} > conc_{sed,ch,mx}$, deposition is the overriding process in the reach segment and the net amount of sediment deposited is calculated :

$$Sed_{dep}= (conc_{sed,ch,i} - conc_{sed,ch,mx})*v_{ch}$$

Where Sed_{dep} is the amount of sediment deposited in the reach segment (metric tons), $conc_{sed,ch,i}$ is the initial sediment concentration in the reach (kg/L or ton/m^3), $conc_{sed,ch,mx}$ is maximum sediment concentration that can be transported by the water (kg/L or ton/m^3) and v_{ch} is the volume of water in the reach segment (m^3).

In the contrast when $conc_{sed,ch,i} < conc_{sed,ch,mx}$, degradation is the dominant process in the reach segment and the net amount of sediment reentrained is calculated:

$$Sed_{deg}= (conc_{sed,ch,mx} - conc_{sed,ch,i})*v_{ch}*k_{ch}*C_{ch}$$

Where Sed_{deg} is the amount of sediment reentrained in the reach segment (metric tons), k_{ch} is the channel erodibilty factor and C_{ch} is the channel cover factor. The channel erodibility factor, k_{ch}, is conceptually similar to soil erodibility factor used in USLE equation and expressed as a function of properties of bed or bank materials (Arnold et al, 2012). Channel cover factor, C_{ch}, is expressed as a ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from channel with no vegetative cover. The vegetation decreases degradation by lowering the stream velocity and consequently its erosive power near the bed surface (Arnold et al, 2012).

Once deposition and degradation amount has been calculated, the final sediment amount in reach is determined: $Sed_{ch}=Sed_{chi} - Sed_{dep} + Sed_{deg}$

Where Sed_{ch} is amount of suspended sediment in reach (metric tons),Sed_{chi} is amount of suspended sediment in reach at the starting of the time period (metric tons), Sed_{dep} is amount of sediment deposited in reach segment (metric tons), and Sed_{deg} is sediment amount reentrained in the reach segment (metric tons).

As a result, the sediment amount transported out of reach is calculated as:

$$Sed_{out}=Sed_{ch}*V_{out}/V_{ch}$$

Where Sed_{out} is Sediment amount transported out of reach (metric tons),Sed_{ch} is amount of suspended sediment in reach (metric tons),V_{out} is the volume of outflow during time step (m^3),V_{ch} is the water volume in reach segment(m^3).

2.7 Previous Study

The studies have been done regarding to rate of soil loss and assessing rate of soil formation in Ethiopia. Hurni (1983) estimates the soil formation rate for numerous land units as to differ between exceeding 22 and below 2 t ha^{-1} yr^{-1} depending on the zonal and Altitudinal variability. In addition to this, he also estimates soil loss on slope by considering different land use type with different agro climatic zones as presented in table 2.4, Hurni (1987).

Table 2.4 Soil loss rate

Land cover Type	Estimated soil loss (t ha^{-1} yr^{-1})
Crop land	42
Grazing and browsing land	5
Forest	1
Perennial crops	8
Wood and bushland	5

Bekele (2019) stated that the average total soil loss of country is estimated as 12 t ha^{-1} yr^{-1} which varied based on land cover types as high as 70 t ha^{-1} yr^{-1} in unproductive lands still with an indication of increasing trend. About 43% of the total highland areas of Ethiopia are vastly influenced by soil erosion with an estimated average annual loss of 20 t ha^{-1} yr^{-1}.

Sonneveld et al. (2011) in Ethiopian erosion assessment estimates an average rates starting from 0-100 t ha^{-1} yr^{-1}. Haregeweyn, Tsunekawa,et al. (2106) estimates, an average of soil loss rate 27.5 t ha^{-1} yr^{-1} generated from upper Blue Nile basin. Nyssen et al. (2015) shows in a well-vegetated catchment in southwestern Ethiopia, sediment accumulation rates are 30 t ha^{-1} $yr^{-1}$and sediment export rates through the river as 1.1 t ha^{-1} yr^{-1}. For the northwest wollega region Adugna et al. (2015) estimates soil loss that range from 4.5 t ha^{-1} yr^{-1} in forest and 65.9 t ha^{-1} yr^{-1}in cropland. Dilnesaw(2006) estimates an annual average of 21.53 t ha^{-1} yr^{-1} in modeling of Hydrology and soil erosion of upper Awash river basin. According to Zelalem (2016), the runoff sediment yield modeling by Soil and Water Assessment Tool for management planning of Mojo watershed Ethiopia, shows the estimated soil loss rate from different sub-watershed ranges from 2 t/ha/year to 204 t/ha/year. The average annual sediment load estimates by (USBR, 1964) and (BCEOM, 1999) for the Ribb dam site were 260,000 tons (363 ton/km2/year) and 490,000 tons (675 ton/km2/year) respectively. Getnet (2011) Sedimentation modeling for Ribb dam (catchment area 844km2), estimation of the average annual sediment yield was 72.79 ton/km2/year. Haile (2010) estimates 898 ton/Km^2/year and 855 ton/Km^2/year for kessie and karadobi respectively, in Impact of land use change on reservoir sedimentation. The annual average sediment in run off sediment yield modeling and development of management intervention scenarios for Guder catchment estimated as 7.5 ton/ha/year (Nadew et al, 2018).

Feyissa (2016) Sediment management in Gibe I reservoir (catchment area 3602km2), estimation of average annual sediment yield was estimated 106.178 ton/km^2/year whereas Nina (2016) estimates sediment yield estimation for Megech Dam reservoir was 1348.6ton/Km^2/year. Beyene (2017) Sediment yield estimation for Gelana Reservoir (catchment area, 644.28 km2) was 89.14 ton/km2 /year. Lemma (2018) also estimates in sedimentation problem and mitigation measure of Koga reservoir an average annual sediment load of 158 ton/Km^2/year.

According to Yared (2019) in estimation of watershed sediment yield (catchment area 2634 km2) for Gidabo Dam was estimated to 95.37 ton/km2/year. Sidelil (2019) in estimating the sediment yield to chacha Dam reservoir having catchment area (577.5 km2) was 144.28 ton/km2/year. Alemu et al (2018) estimates the annual sediment deposition in Lake Ziway was 2.039M ton/year in Estimating the sediment flux and budget for data limited Rift Valley lake Ethiopia. Sediment yield estimated at Grand Ethiopian Renaissance Dam in Sedimentation and sustainability of Hydropower reservoirs was 1378 ton/Km^2/year (Borji, 2013).The maximum soil loss rate for Gudar and Fincha estimated as 78 ton/ha/yr and 256 ton/ha/yr (Habtamu,2011).

Other studies within Wabe shebele river Basin is that of Herweg and Ludi (1999) sheet and rill erosion from cropland at a rate of 7 t ha^{-1} yr^{-1} whereas from mixed land at rates of 22 t ha^{-1} yr^{-1} (Haregeweyn and Yohannes 2003) and 31 t ha^{-1} yr^{-1} (Muleta et al 2006). Dereje (2015) also estimates an average of 16.372 t ha^{-1} yr^{-1} sediment load flowing to melka wakena reservoir. The annual average simulated sediment yield from Hunde Lafto watershed was 45.4 ton/ha/yr (Ayala et al, 2017). According to(Weldu and Edo,2019) the soil erosion in Erer sub basin, northeast wabe shebelle basin estimated mean erosion rate in 2000 and 2018 was 75.85 t ha^{-1} yr^{-1} and 107.07 t ha^{-1} yr^{-1} respectively.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Description of study area

The Gololcha River, which is the right tributary of wabe shebele, located in the semi-arid area of the western wabe shebele basin. The river flows generally in an easterly direction whereas; its annual rainfall is near 1100 mm. It is locally known as Dhare river which originates from East of Gasera town from plateaus of 2400 masl altitude and Gololcha there after until it reaches the area around the beginning of the very extensive plain lands of the Sawena wereda which is at an altitude of about 1500 masl.

The watershed area falls in parts of the three woredas namely Gololcha, Ginir, and Sawena in Bale zone Oromia regional state. It can be accessed at about 603 Km away from Addis Ababa. (WWDSE, 2008), Fig.3.1.

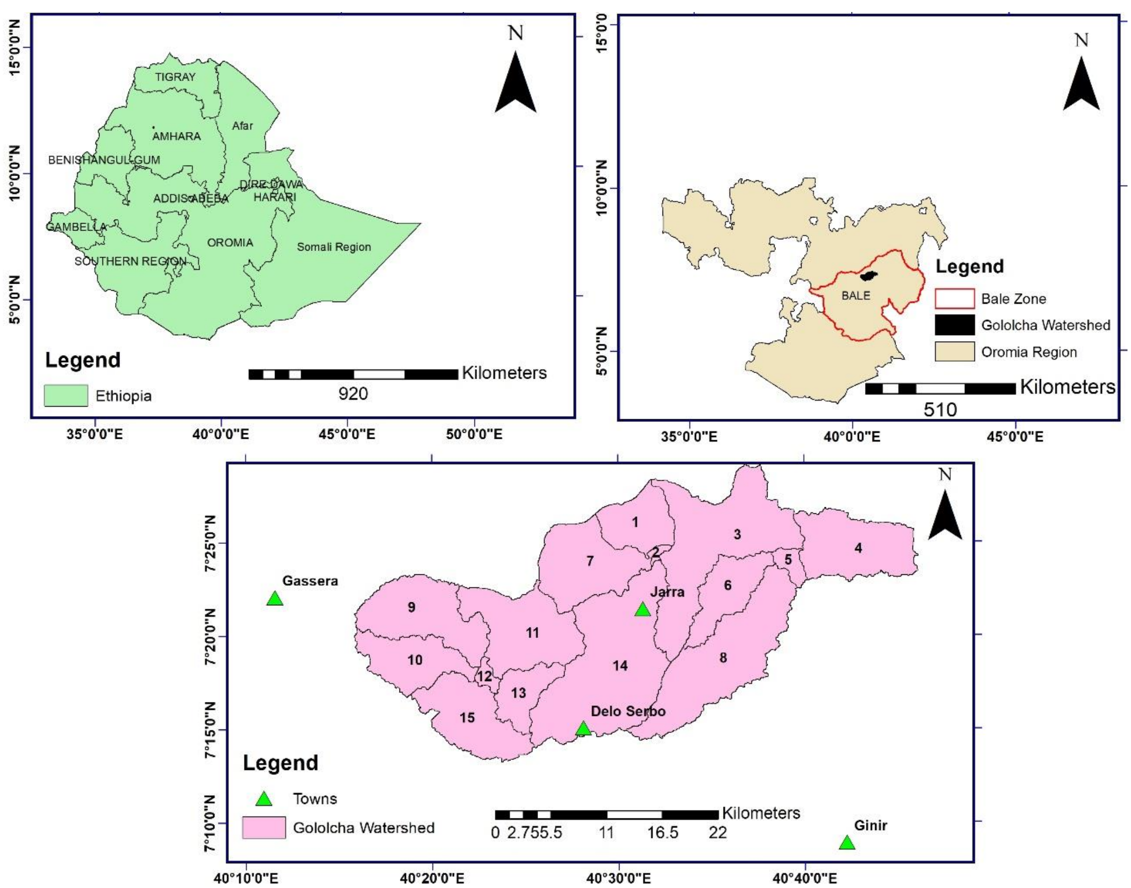


Figure 3.1 Map of study area

3.2. Spatial Data

3.2.1 Digital elevation model (DEM)

Digital elevation model defines Topography, which defines the elevation of any point in a given area at a specific spatial resolution as a digital file. DEM is needed for raster-based hydrological analysis in a geographical information system (GIS).

For this study, DEM data is collected from Ministry of Water, Irrigation and Electricity thus a study area delineated from DEM in ArcGIS 10.4.1 – Arc SWAT 2012 interface where land use land cover and soil are clipped to it. The DEM has a resolution of 30m by 30m and projected to WGS 1984 UTM 37N which is a projection parameter for Ethiopia, Fig.3.2.

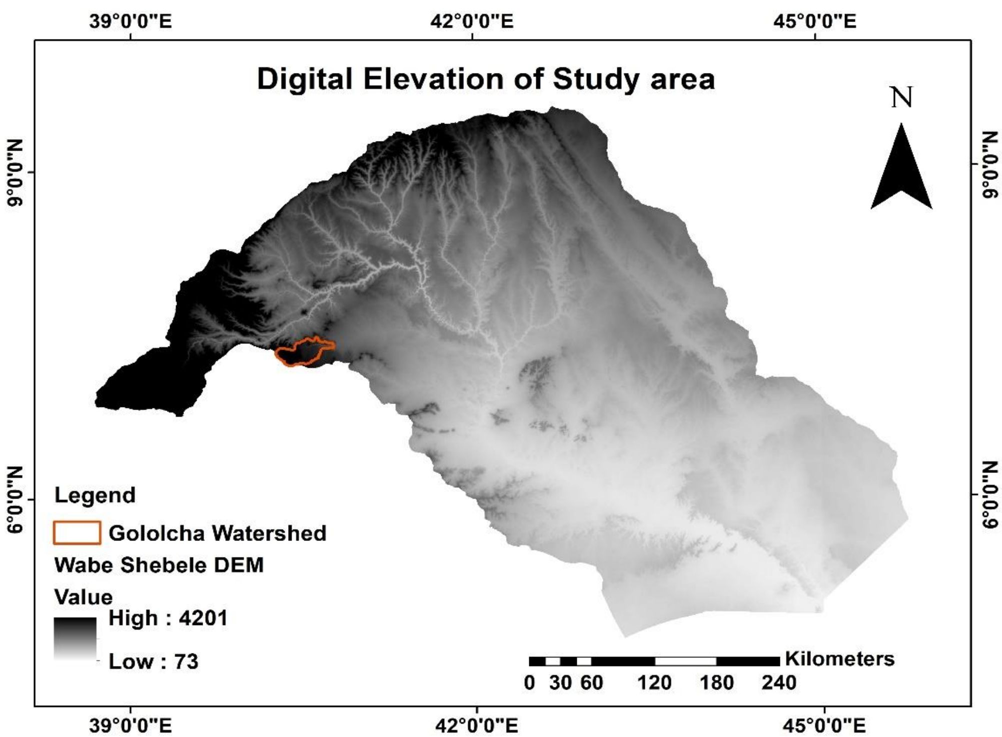


Figure 3.2 Digital elevation of Gololcha watershed

3.2.2 Land Use land cover (LULC) data

The map of LULC for the study area was obtained from ministry of water, irrigation and electricity and projected in Arc Map before it is imported to Arc SWAT. The land use data successfully loaded and clipped with 100% overlaps to the watershed boundary.

For Gololcha watershed, six LULC were identified , which includes open forest, dense woodland, exposed sand and soil surface, intensively cultivated, moderately cultivated and grass land. The LULC image classification illustrate intensively cultivated was the most dominant LULC class in the study landscape, Fig.3.3.

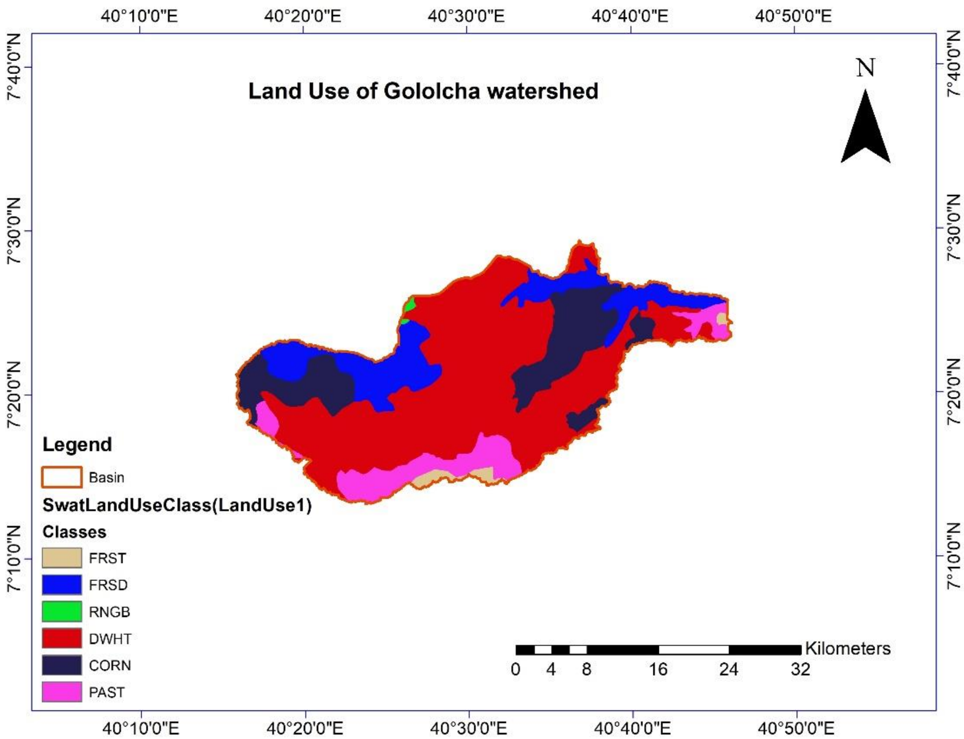


Figure 3.3 Land use land cover of Gololcha watershed

The detail of these Land use land cover are presented with their respective percentage of coverage area in table 3.1.

Table 3.1 LULC of Gololcha watershed

Land cover type	SWAT land use class	SWAT code	(%)Watershed Area
Open forest	Forest Mixed	FRST	1.39
dense wood land	Forest Deciduous	FRSD	16.05
Exposed sand and soil surface	Range Brush	RNGB	0.25
Intensively cultivated	Durum Wheat	DWHT	55.76
Moderately cultivated	Corn	CORN	17.23
Grass land	Pasture	PAST	9.32

3.2.3 Soil data

SWAT model needs different soil textural and physio-chemical properties such as available water content, hydraulic conductivity, soil texture, bulk density and organic carbon content for different layers of each soil type. Since the soil database defines the surface and upper subsurface of a watershed and used to determine a water budget for the soil profile, daily runoff and erosion.

Soil data of Gololcha watershed obtained from Ministry of Water, Irrigation and Electricity (MoWIE) projected in Arc Map before importing to Arc SWAT. The soil data successfully loaded and clipped with 100% overlaps to the watershed boundary. Five soil types are identified for Gololcha catchment, the classified image depicts vertisols is the most dominant soil in the watershed, Fig.3.4.

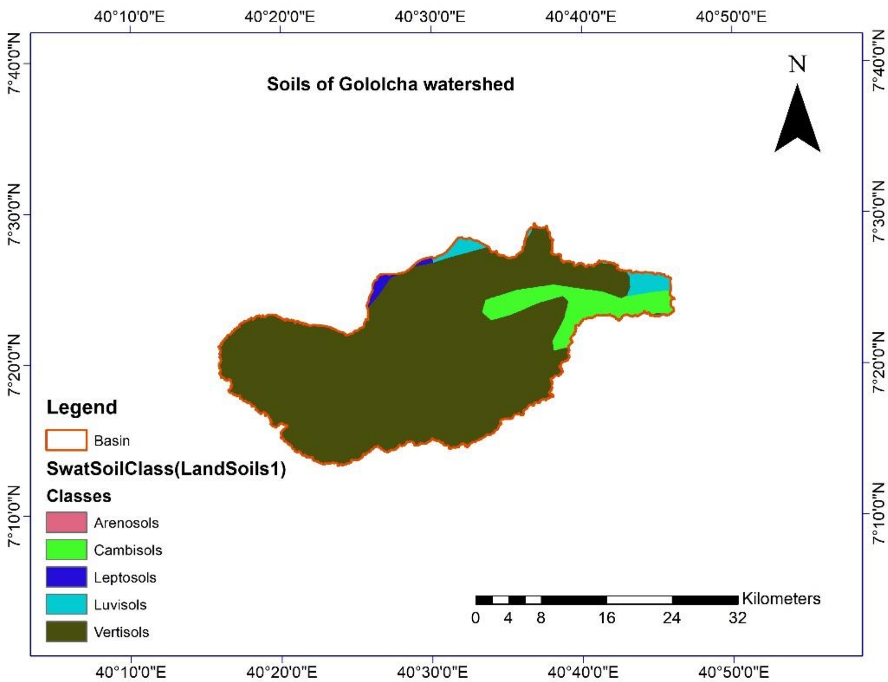


Figure 3.4 Soil map of Gololcha watershed

The major soils for the study area with their respective percentage of coverage area enumerated in table 3.2.

Table 3.2 Major soils of Gololcha watershed

Name of soil	SWAT soil class	Hydrologic soil group	(%)Watershed Area
Arenosols	Cambic arenosols	A	0.01
Cambisols	Calcic cambisols	B	8.04
Leptosols	Lithic leptosols	A	0.78
Luvisols	Chromic luvisols	B	2.48
Vertisols	Pellic vertisols	D	88.69

3.2.4 Land slope

The land slope for the Gololcha catchment is categorized in to five classes starting from flat to very steep, Fig.3.5.

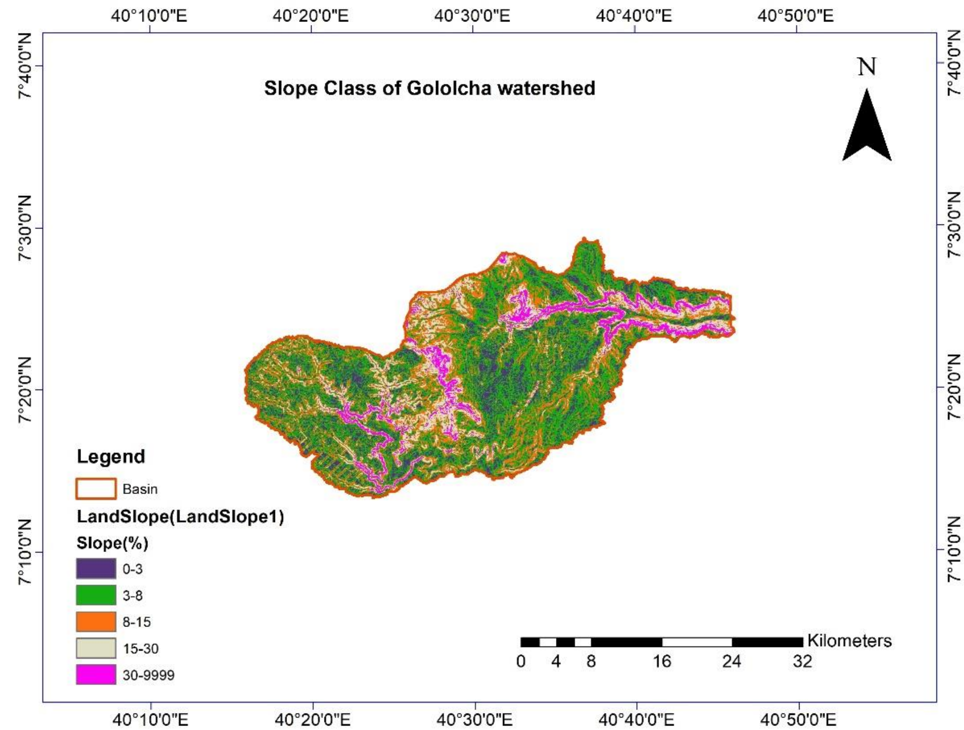


Figure 3.5 Land slope classes of Gololcha watershed

The slope classes for the study area are presented with their percentage of coverage area in the Table 3.3

Table 3.3 Land slope classes for Gololcha watershed

Slope class (%)	Slope categories	(%)Watershed Area
0-3	Flat or Almost flat	16.19
3-8	Gently sloping	41.43
8-15	Sloping	23.31
15-30	Steep	12.83
30-9999	Very steep	6.24

3.3. Data analysis

Analysis of data is the most important step in describing quantitatively each process in the hydrologic cycle, encompassing an extremely wide range of phenomena. Thus, Hydro -

meteorological data for water resource development and management studies should be stationary, consistent, and homogeneous when they are used in frequency analyses or system simulations.

3.3.1 Meterological data

The meterological data obtained from national meterological agency have missing points in their time series for all station. However the missing data for first class order station is somewhat lower when compared to others. Hence filling the gaps will be the first task before any analysis. For Gololcha watershed, seven weather stations wich are found with in and aruond the catchment were selected, Table 3.4.

Table 3.4 Location of Meteorological stations

No.	Station Name	Longitude UTM	Latitude UTM	Elevation (m)
1	Agarfa	590152.8366	803309.7709	2550
2	Deloserbo	661924.6941	801647.2565	2200
3	Gassera	631631.6873	814599.4075	2350
4	Ginnir	687739.8179	788834.0327	1750
5	Goba	608240.2329	777178.585	2614
6	Jarra	667988.664	813521.315	2040
7	Robe	615946.6804	788620.0373	2480

3.3.1.1 Filling missed data

In this investigation , method of mean of station own time series and regression used to fill in missing datas in order to check some basic screening procedure regarding trend analysis, autocorrelation,consistency and outlier detection. However in the case of model simulation the missed time series are left for the model with missing code identifier since the model itself can genarate by SWAT WXGEN.

A. Arthimetic mean

$P_x = \frac{1}{n}\sum_{i=1}^{n} pi$ ……… Equation 3.1

Where P_x-missing precipitation

n- number of time series

Pi-precipitation at i^{th} time series

B. Multiple regression

Multiple regression is statistical tool for estimation of relationship between dependent and independent variables.

$Y=a_o+a_1X_1+a_2X_2$…………. $+a_nX_n$ ………..Equation 3.2

where Y-dependent variable

X-independent variable

a_o-Intercept

a_1, a_2, a_n- multiple regression coefficient.

The output summary of regression statistics computed in XLSTAT 2019 between dependent and independent (explanatory) stations presented (See appendix: 5).

3.3.1.2 Graphical analysis

Graphical analyses are quite useful as the starting point for detecting change and the nature of any change uncovered.The simplest and often used in identifying anomalies between stations through plots. Generally this should be done first, before doing other tests between stations where measurements have been taken at the same time interval.

In this analysis for the stations namely, Agarfa, Ginnir and Jarra relatively some peak values are observed when compared to the other nearby stations.

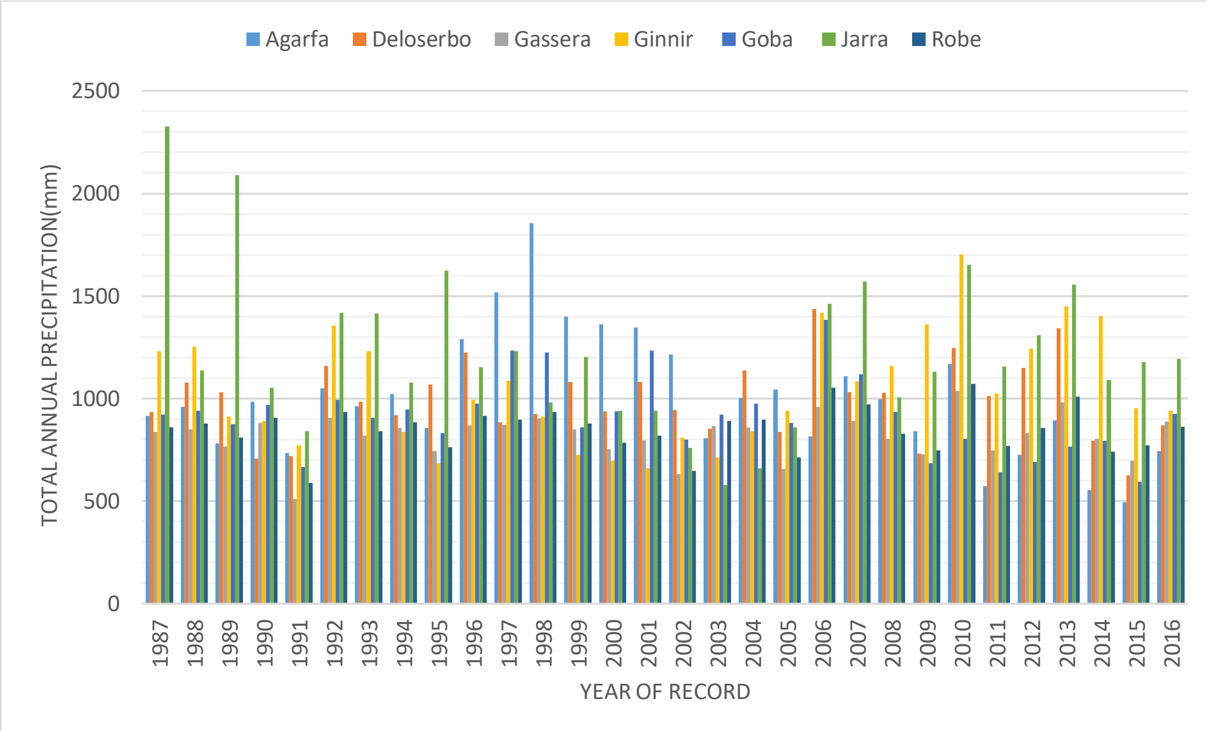


Figure 3.6 Comparison plot of total Annual precipitation

3.3.1.3 Test for Absence of Persistence

Before applying any test regarding identification of precipitation trends over the time series from selected stations, it is required to test the null hypothesis whether the fluctuations in sereis have a random nature or not. Therefore, the precipitation time series data of all station was first tested for the presence of autocorrelation using the serial lag-1 correlation coefficient (r_1) at a 5% significance level with a two-tailed test:

$$r_1 = \frac{\sum_{i=1}^{n-1}(xi-\bar{x})(xi+1-\bar{x})}{\sum_{i=1}^{n}(xi-\bar{x})^2} \quad \text{……….Equation 3.3}$$

Null hypothesis at 95% confidence interval was tested using two tailed test:

$$r_1(95\%) = \frac{-1\pm 1.96\sqrt{n-2}}{n-1} \text{………….Equation 3.4}$$

The outcomes of lag-1 autocorrelation coefficeint between adjacent observations in time series of all stations were computed in micrsoft excel 2016 presented (see Apendix:6).As a result, no significant correlation exists between successive values of observations.Thus time series are independent and no persistence in time series.

3.3.1.4 Test for Absence of trend

It is common practice to test whole time series for absence of trend or one can choose to test only specific periods of time series if these show signs of a possible trend.

For this study, Spearman's Rank-Correlation Method, which is non-parametric alternative, used in checking absence of trend for all-time series. Using the ranks for the paired values rxi and ryi, the value of the Spearman coefficient R_S computed using:

$$Rs = 1 - \frac{6 * \sum_{i=1}^{n}(rxi - ryi)^2}{n^3 - n} \text{.... Equation 3.5}$$

Where n- total number of sample data

rxi- is the rank of the variable x, which is the chronological order number of the observations.

ryi- is transformed to its rank equivalent for series observation of y.

For sample sizes greater than ten, the following statistic was used to test the above hypotheses:

$$t = Rs\left[\sqrt{\frac{n-2}{1-Rs^2}}\right] \text{ .... Equation 3.6}$$

Where t follows a Student's t distribution with $n - 2$ degrees of freedom (v) and bounded at two-tailed 5% level of significance in between:

$$(-\infty,(v,2.5\%))\ U\ (t(v,97.5\%)),+\infty)$$

With the bounded region of the null hypothesis, the time series has to be said "No Trend" if it satisfies and fall for t_t in between: $(t_\alpha\ (v,2.5\%))<t_t<(t_\alpha\ (v,97.5\%))$.

The Spearman coefficient and the test statistic are based on the Pearson coefficient that assumes the values are from a circular, normal, stationary time series (Haan, 1977). The transformation from measurements on a continuous scale to ordinal scale, which ranked, eliminates the sensitivity to the normality assumption. The circularity assumption will not be a factor because each measurement transformed to a rank. The results of Rs and t_t for all stations having rainfall measurements calculated using Microsoft excel are presented (See Appendix: 7).

3.3.1.5 Consistency checking

To determine relative consistency, one can compares the observations from a certain station with the mean of observations from several nearby stations, which is called the 'base station' or 'pattern'.

In this investigation, for consistency of rainfall time series, hydrognomon software version 4.1.0(.26) was used. The software uses methodology of double mass curve between rainfall measurements of neighboring stations. The method is semi empirical and combines the graphical display of rainfall time series with some statistical hypotheses and the least squares method. It is implemented on annual rainfall data, without preclusion of the implementation on monthly time series and coefficients that arise from the adjustment can be used consequently for the reduction of all-time series with smaller time step.

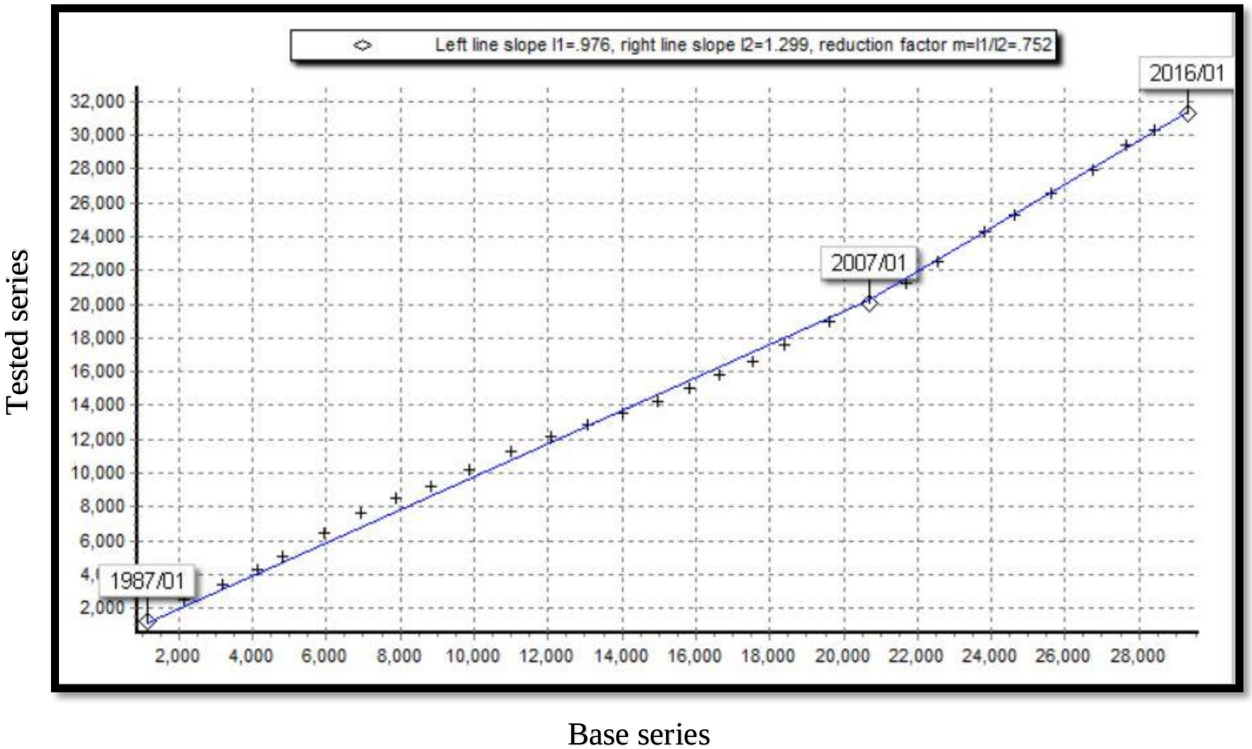


Figure 3.7 Double mass curve of Ginnir station before adjustment

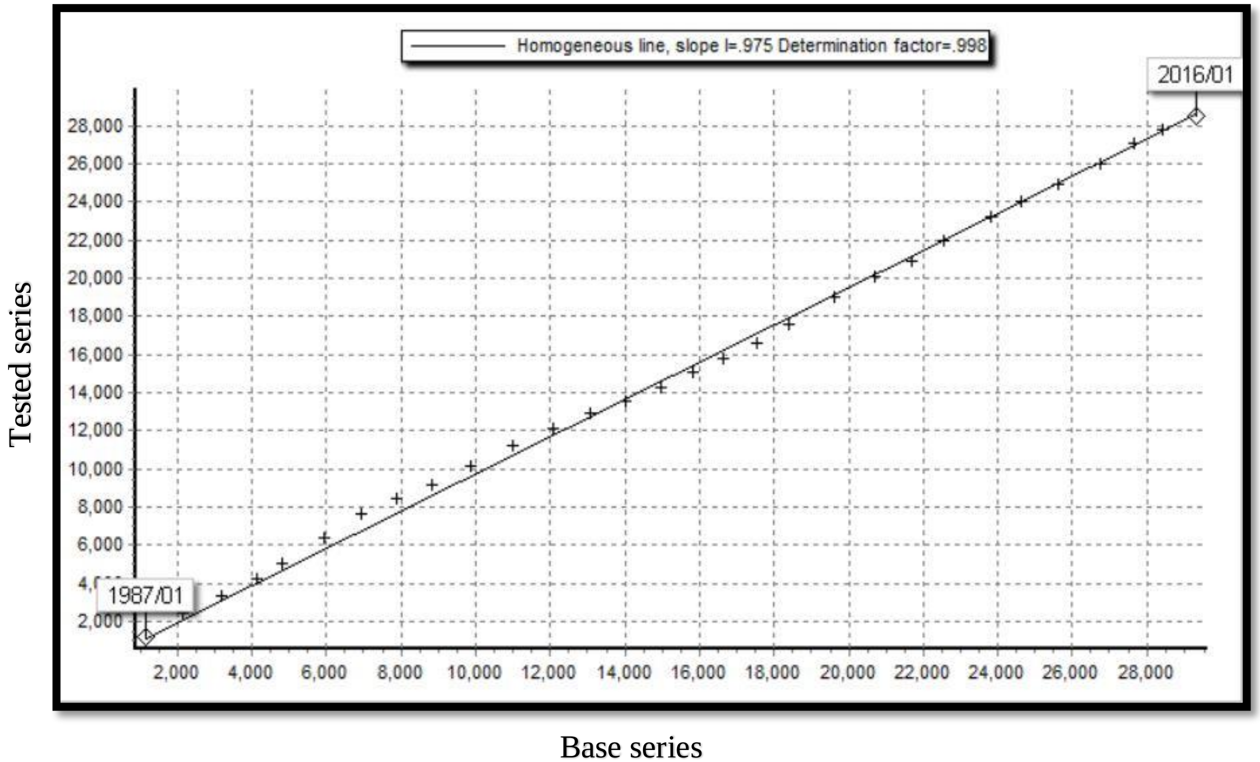


Figure 3.8 Double mass curve of Ginnir station after adjustment

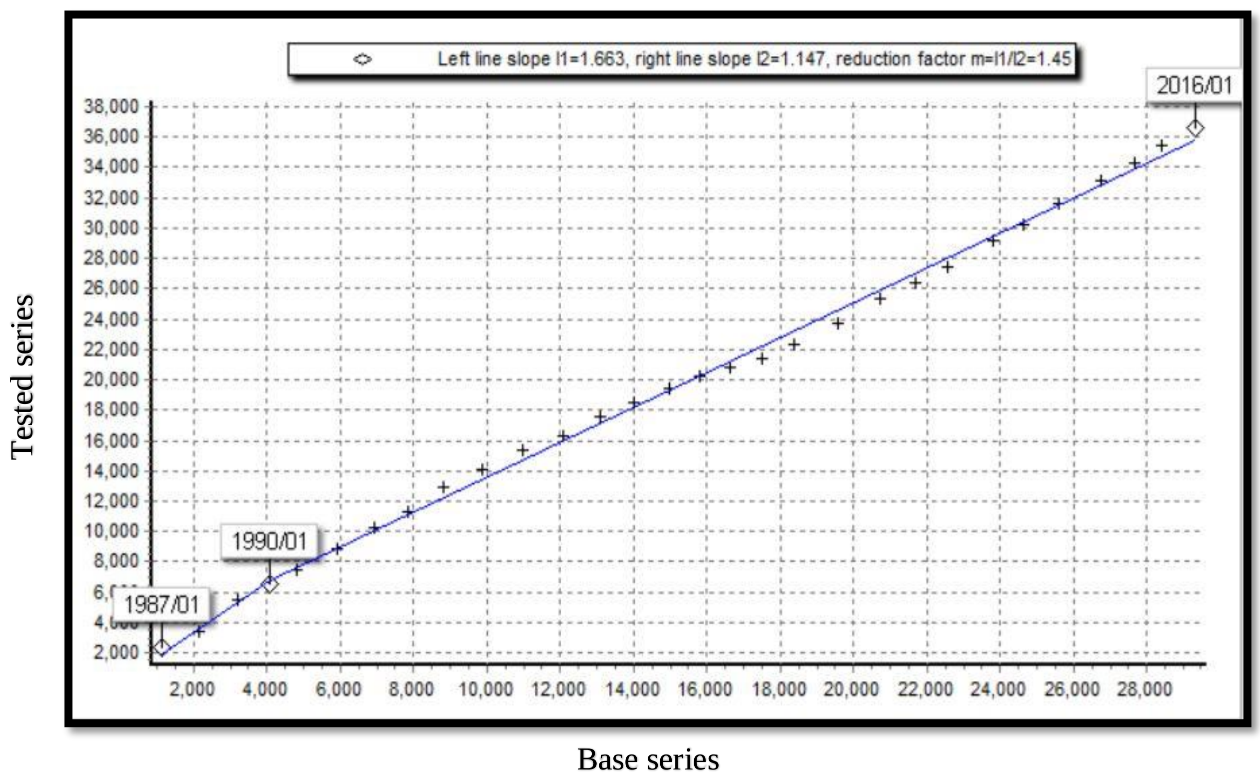


Figure 3.9 Double mass curve of Jarra station before adjustment

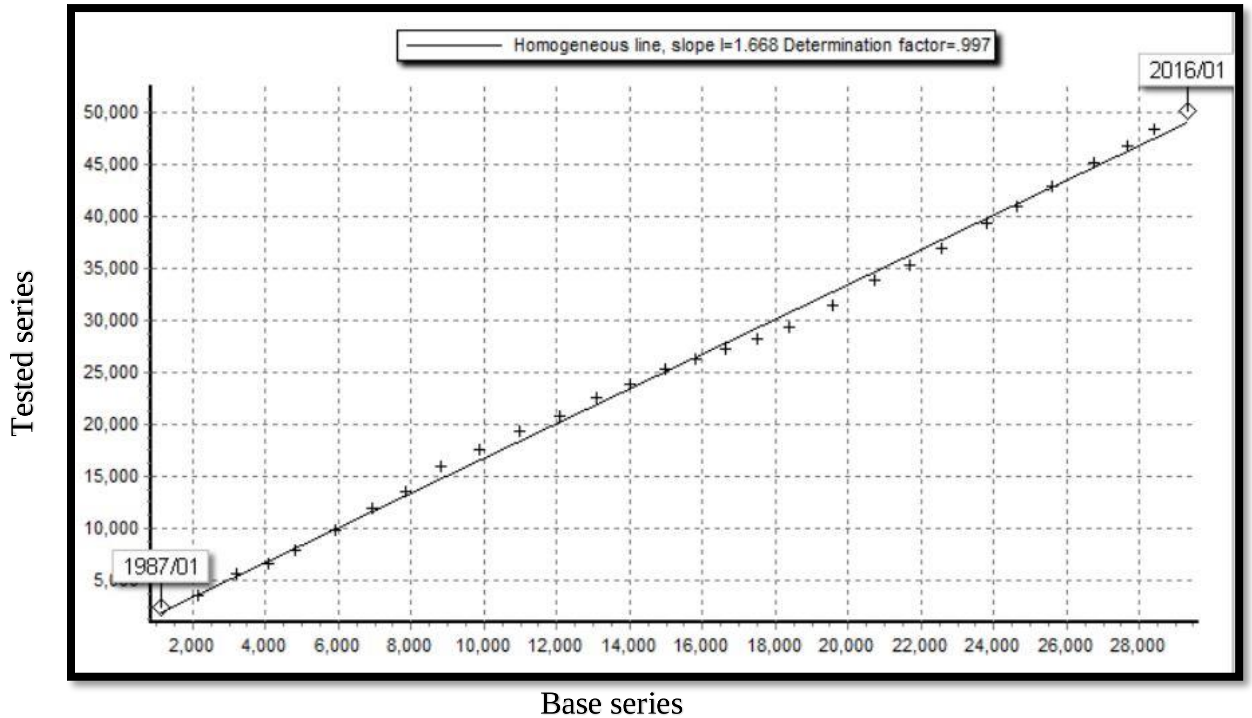


Figure 3.10 Double mass curve of Jarra station after adjustment

3.3.1.6 Testing for outliers

Outliers are a recorded value that seems to be unusual, doubtfully lower or greater than other observed values. This can arise because of error on reading or measuring devices or events that disturb the observed phenomena. Extreme events can create problems in data analysis and modeling through causing the sample mean and standard deviation to be much larger than the population values (Mc ceun, 2010). For this study, outlier detection is performed in XLSTAT 2019, using Grubbs test that detects outlier based on the difference of mean of the sample and the most extreme data considering standard deviation. The output summary statistics from XLSTAT presented (see appendix: 8).

3.3.1.7 Temperature data

The temperatures time series data from 1987-2016 are available only for two stations, which are found near to Gololcha watershed, namely Robe and Ginnir station.

The daily maximum and minimum air temperature are aggregated in order to observe the trend of temperature over time. Thus, the maximum yearly average temperature at robe and ginnir stations are 24.25C^{o} and 25.6C^{o} respectively. Whereas the minimum yearly average temperatures are 7.15C^{o} and 12.71C^{o} for the whole time series.

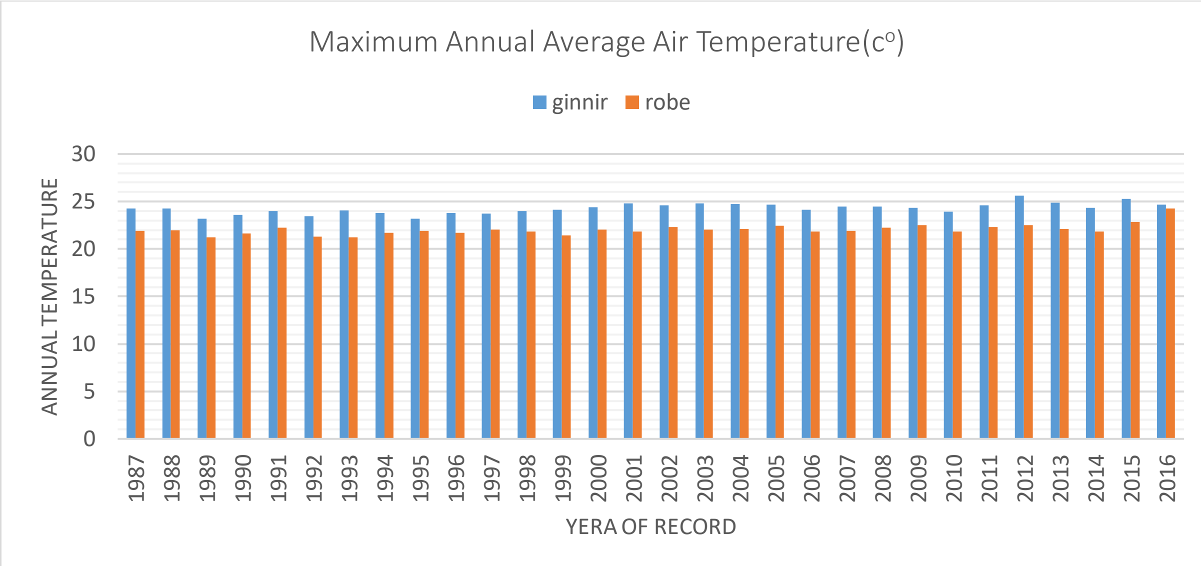


Figure 3.11 Maximum annual average air temperature

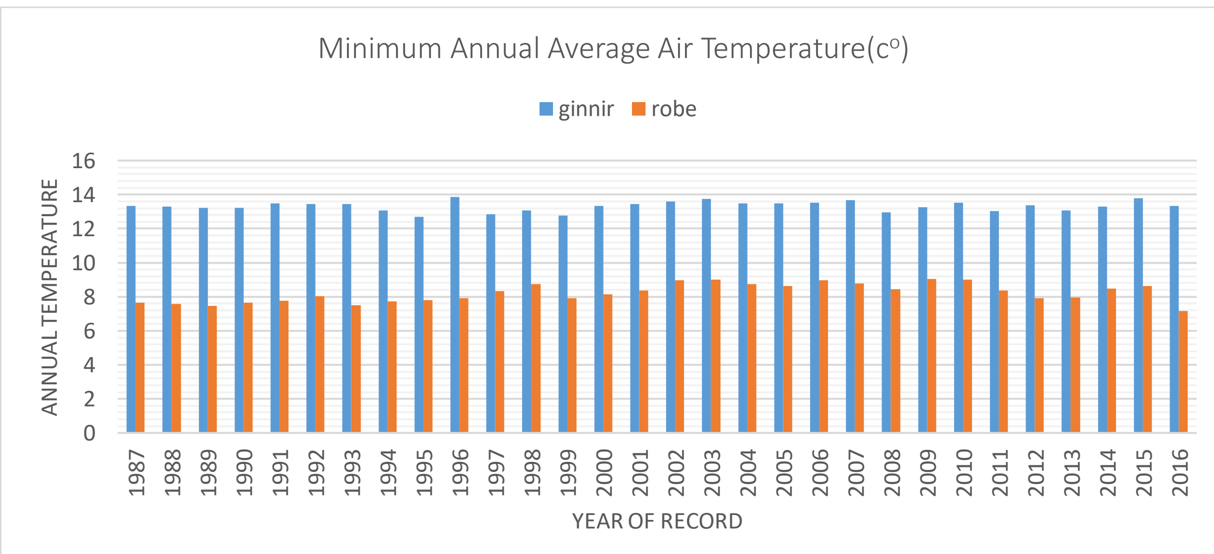


Figure 3.12 Minimum annual average air temperature

3.3.2 Hydrological Data

Hydrological data are necessary for performing calibration and validation of the model output. The observed hydrological time series compared with the simulated result in order to know how well the model captures the observed data based on performance evaluation statistical measures through sensitivity analysis.

3.3.2.1 Flow data

Daily observed stream flow data is obtained from Ministry of Water, Irrigation and Electricity (MoWIE) hydrology department for the record period of 1990-2009 years. However, these daily time series data are transferred to point of interest and aggregated to monthly time step in order to perform calibration and validation. The stream flow gage station is located at (7^0 2'00''N, 40^0 48'00''E) Weib near Dembel having catchment area of 1215 Km^2.

According to Admassu (1989) in areas where catchments with flow records are near ungauged catchments, which are of interest, information can be transferred from gauged catchment to the ungauged catchments. The relation developed for flood flow used for flow transfer by considering the sediment yield is high during flood period and have no exaggerated value.

$$Qu = Qg\left(\frac{Au}{Ag}\right)^{0.7}$$

Where Qu – flow at ungauged site (m^3/sec)

Qg- flow at nearby gaged site (m^3/sec)

Au- ungauged site catchment area (km^2)

Ag- gauged site catchment area (km^2)

3.3.2.2 Sediment Data

In this investigation, regional approach followed according to experience obtained at various locations that developed for no measured sediment data catchments (WWDSE, 2011). Due to absence of observed sediment data, in Gololcha watershed the result of sediment yield from ArcSWAT2012 model is compared to result of regional equation developed from main hydropower sites in Ethiopia to perform calibration and validation of sediment yield.

Suspended sediment Inflow (t/ Km^2/yr.) $Ss = \frac{44085 * Ro^{0.4674}}{A^{0.57083}}$

Where A- catchment area (Km^2)

Ro- Annual Runoff (mm/yr.)

Whereas the bed load considered as 20% of suspended sediment load. Thus total load will be the summation of suspended and bed load. The above regional equation has a coefficient of determination (r^2) 0.91 and developed from main hydropower sites as shown in Table 3.5.

Table 3.5 Used Data to derive regional equation for large dams in Ethiopia

Hydropower reservoirs	Catchment area(Km^2)	Annual Runoff (mm/yr.)	Load (t/Km^2/yr.)
Gibe III	34400	450	1900
Tekeze Dam	30390	123	1283
Karadobi Dam	82230	350	1150
Wabe-shebele at Hamaro	63455	49	296

3.4. Missed data filling for model simulation

SWAT needs daily precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation. However all these weather parameters are not complete for some gaging stations except for those categorized as first order class. As a result, weather generator station with statistical data has to be set in order to generate representative climate data for the sub basins.

Station near to Gololcha watershed with missing time series are filled with negative 99(-99.0) which is missing code identifier in order to fill in missing information or simulate weather data by the SWAT WXGEN.

3.5. Weather Generator

For this study Ginnir station that is close to Gololcha catchment is used as weather generator and the statistical parameters are prepared using WGNmaker4.1.xlsm Excel macro, which is designed to calculate the weather station statistics desired to form user weather station files to SWAT(see appendix:2).

3.5.1 Statistical parameters of precipitation data

The daily precipitation time series from 1987-2017 was used to prepare the statistics parameters on monthly basis in WGNmaker4.1xlsm.

Table 3.6 Statistical parameters of precipitation data

month	PCPMM	PCPSTD	PCPSKW	PR_W(1)	PR_W(2)	PCPD
Jan	21.00	4.78	8.10	0.04	0.51	1.77
Feb	30.23	5.74	7.74	0.03	0.72	2.61
Mar	64.42	7.45	4.00	0.13	0.57	5.32
Apr	165.93	14.71	4.40	0.33	0.65	12.16
May	124.34	12.51	6.94	0.32	0.48	9.77
Jun	28.46	4.46	4.84	0.13	0.30	3.68
Jul	18.83	3.03	5.75	0.10	0.28	3.06
Aug	31.78	7.26	13.37	0.13	0.26	3.35
Sep	77.58	8.61	5.34	0.28	0.57	8.68
Oct	141.61	10.06	2.43	0.35	0.71	13.35
Nov	72.71	8.29	4.23	0.15	0.58	6.74
Dec	30.48	5.75	7.43	0.06	0.54	3.00

PCPMM Average total monthly precipitation

PCPSTD Standard deviation for daily precipitation on a month

PCPSKW Skew coefficient for daily precipitation on a month

PR_W (1) Possibility of a wet day following a dry day

PR_W (2) Possibility of a wet day following a wet day

PCPD Average day number of precipitation on a month

3.5.2 Dew Point Temperature

The dew point temperature for the weather generator station is computed using dew02.exe program that is designed to calculate Average daily dew point temperature per month having Daily maximum and minimum temperature (C^o) and Relative humidity in percentage as an input.

Table 3.7 Average daily dewpt temperature on a month (C^o)

month	Tmp_max	Tmp_min	hmd	dewpt
Jan	24.95	12.47	65.05	12.88

Feb	25.9	13.44	65.53	13.89
Mar	25.66	14.18	66.76	14.28
Apr	24.11	14.18	69.19	13.94
May	23.86	14.15	70.12	13.97
Jun	23.83	13.43	70.85	13.84
Jul	23.69	13.06	70.17	13.49
Aug	24.31	13.23	69.35	13.76
Sep	24.76	13.47	67.9	13.79
Oct	23.11	13.41	69.24	13.05
Nov	23.12	12.61	67.34	12.34
Dec	23.99	12.23	64.86	12.11

Tmp_max- average daily maximum temperatue in a month(C^o)

Tmp_min-average daily minimum temperatue in a month (C^o)

Hmd-average daily humidity in a month (%)

Dewpt-average daily dewpoint temperature in a month.

3.6. Arc swat model setup

3.6.1. Watershed Delineation

Delineating of watershed is the first task after setup of swat project, which includes DEM setup, Stream Definition, Outlet and Inlet Definition, Watershed Outlet Selection and Definition and calculation of sub basin parameters. To define stream network and watershed, threshold area based option used to define the minimum size of sub-basins and finally watershed was partitioned into a number of sub basins, for modeling purposes. As a result, these sub-basins influence the level of spatial complexity that is represented in the SWAT model. The contributing area resulted in 15 sub-basins for being delineated having total catchment area of 84146 hectare.

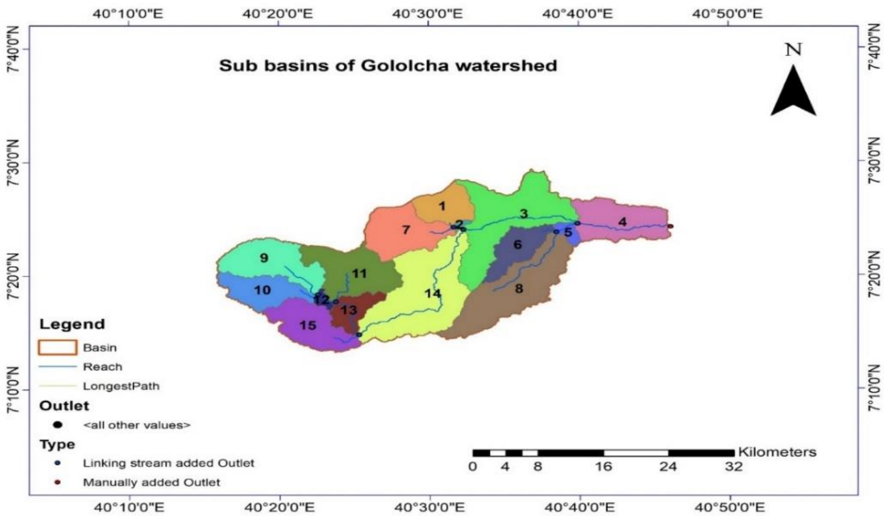


Figure 3.13 Delineated sub basins in Gololcha catchment

3.6.2. Hydrologic response unit (HRU)

HRUs are portions of sub basin that have unique land use, management and soil attributes. They are smallest unit of calculation in SWAT made up of overlying elevation, soil, land-use, and slope.

Hydrologic response units are used in SWAT runs since they make simpler a run by lumping all similar soil and land use areas in to single response unit, which leads to increase the accuracy of loadings prediction from the sub basin. Dividing the watershed into areas having unique land use, soil and slope combinations assists model to reflect variations in sediment yield and other hydrologic conditions for different land covers and soils.

Hydrologic response units are lumped land areas within the sub-basin that encompasses of unique land cover, soil and management combinations. The runoff is estimated independently for each HRU and routed to obtain the total runoff for the watershed. The HRU analysis tool in Arc SWAT used to load land use, soil layers and slope map to the project.

The delineated watershed by Arc SWAT and the prepared land use and soil layers were clipped 100% to watershed boundary. HRU analysis in SWAT consist of divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option that considers different slope classes for HRU definition) selected and Finally LULC, soil and slope map reclassified in order to correspond with the parameters in the SWAT database.

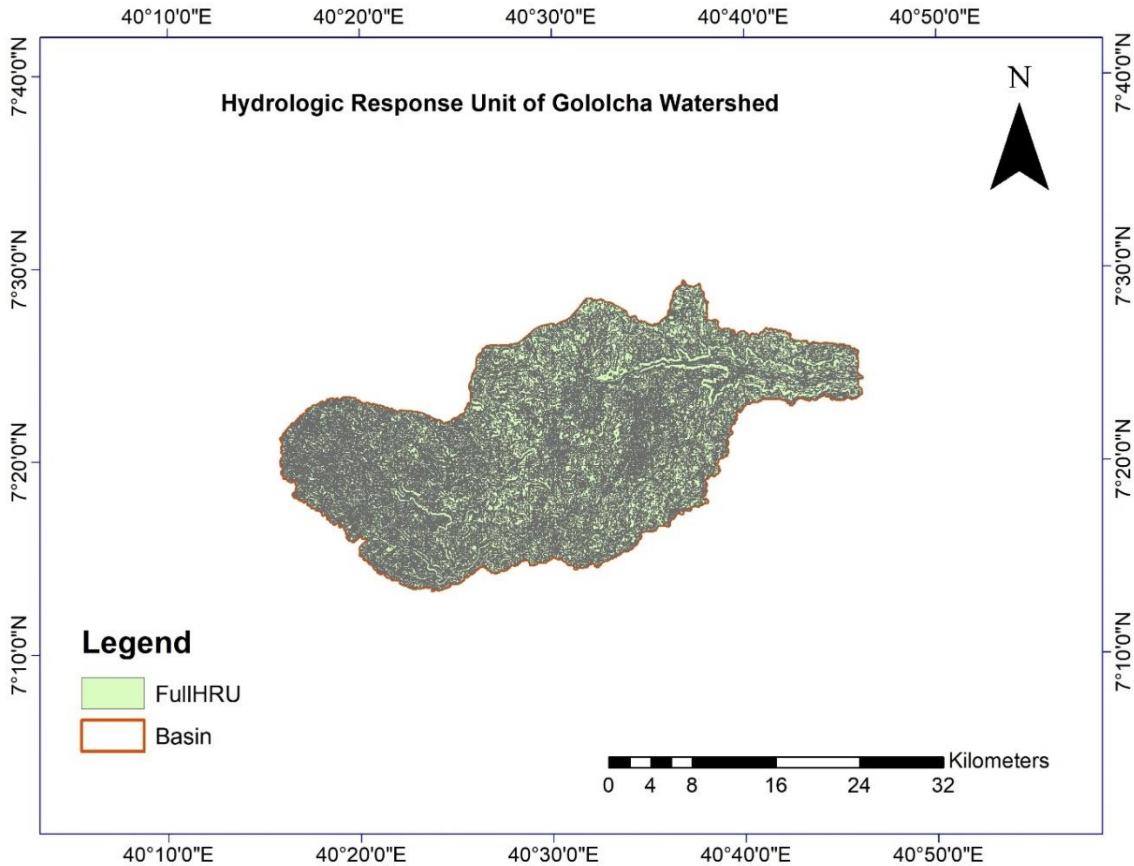


Figure 3.14 Full Hrus of Gololcha Watershed

In this investigation for the HRU definition, threshold value of 10% to soil, 10% to land use and 10% to slope were used. The HRU distribution for Gololcha watershed determined through assigning multiple HRU to each sub basin as a result 15 sub basins and 140 HRUs were created by integrating land use, soil and slope maps.

3.6.3. SWAT methodology for simulation of run off and sediment yield

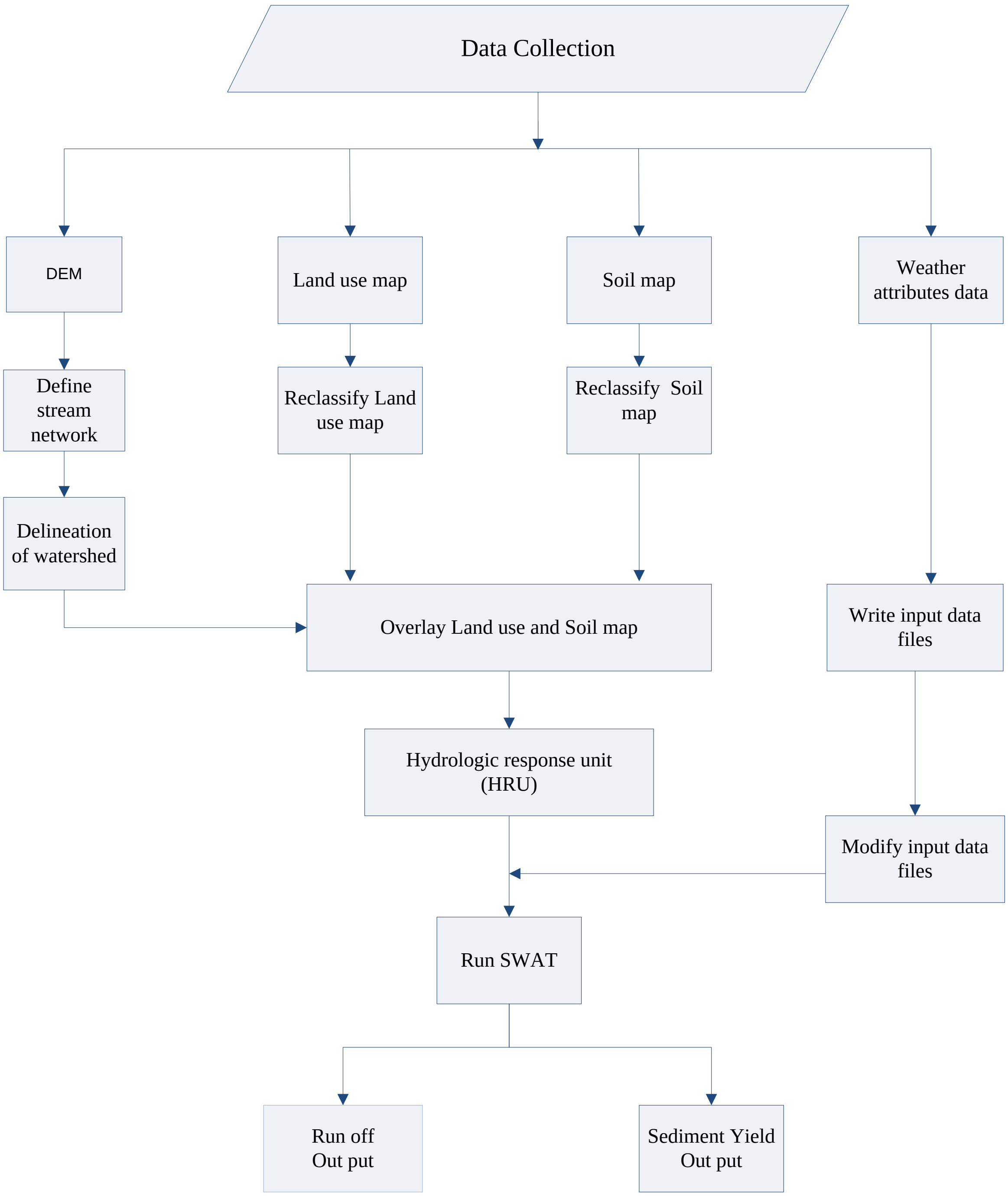


Figure 3.15 Flow chart of SWAT model for simulation of Runoff and Sediment yield

3.7. SWAT CUP

SWAT-CUP is stand-alone program that is developed for SWAT. Using this generic interface, any calibration, uncertainty or sensitivity program can easily be linked to SWAT.

In this study, the auto-calibration procedure using SWAT-CUP 2012 was supported by manual calibration for the values of parameters that were set by default in Arc SWAT. Automated model calibration needs that the uncertain model parameters are systematically altered, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. This interface provide a link between the input-output of a calibration program and the model. Text file formats are used to handle file exchange.

A flow chart of the linkage between SWAT and five optimization programs is depicted in the Figure below.

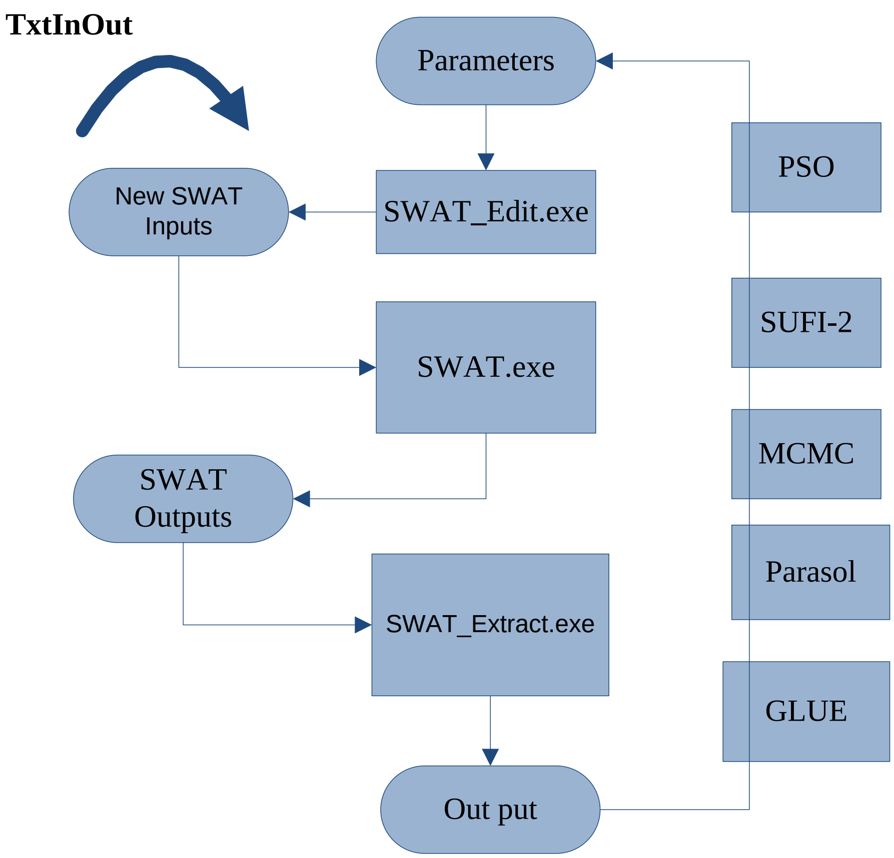


Figure 3.16 Schematic linkage between SWAT and five optimization programs

3.7.1. Sensitivity Analysis

Analysis of Sensitivity is the method of identification of most influential parameter on the model output variable. In addition to this, it helps in providing information on the most significant processes in a study region and reduce parameters number in the calibration procedure by removing the parameters identified as not sensitive. The model sensitivity is defined as the rate of the change in Variable (model output) to parameter change (a model input representing the process in watershed) since Sensitivity analysis and calibration are usually not easy with a large number of parameters (Abbas pour, 2013). Sensitivity analysis is a modeling tool that is essential to the proper use of a model because it enables the modeler to understand the importance of variables and the effects of errors in input on computed outputs(McCuen, 2010).

As a result, ways of reducing the parameters number via analysis of sensitivity are essential for efficient use of these models (Van Griensven et al. 2006). Sensitivity analysis of parameter provides understandings on which parameters contribute most to the output variance due to input variability (Holvoet et al., 2005). It aids emphasis the uncertainty analysis and calibration thus used for providing statistics to goodness of fit (Srinivasan et al., 2012).

For this study, analysis of sensitivity is performed in SWAT-CUP using sequential uncertainty fitting-2 algorithm and the parameters, are ranked depending on t-stat and p-value. The higher in absolute value of t-stat, the lesser the p-value, the more sensitive the parameter. SUFI-2 executes a joint optimization and uncertainty analysis using global search procedure and can deal with a large parameters number using Latin hypercube sampling (Abbaspour and Johnson, 2004).

Therefore, performing Sensitivity before model calibration is essential to identify best sensitive parameters and to use these in the subsequent calibration. Analysis of Sensitivity can be done in two ways namely Local and Global analysis of Sensitivity.

3.7.1.1. Local (one-at-a-time) sensitivity Analysis

In Local sensitivity analysis, all parameters are kept unchanged while altering one to identify its effect on some model output or objective function (Eawag, 2017). It shows the sensitivity of a variable to changes in a parameter if all other parameters are kept unchanged at some reasonable value. The advantage of one at a time analysis of sensitivity is that it is simple and quick whereas its drawback is that sensitivity of one parameter is often dependent on the values of other parameters, which are all fixed to values whose accuracy is not known (Abbaspour, 2017).

3.7.1.2. Global (All at a time) sensitivity analysis

In Global, analysis of sensitivity a t-test is used to detect relative importance of each parameter. The sensitivities are estimated using the average alterations in objective function resulting from changes in each parameter, while all other parameters are changing. Sensitivities of Parameter determined by calculating the multiple regression system, which regresses the Latin hypercube generated parameters against the objective function values. This provides relative sensitivities grounded on linear approximations and, hence, only delivers partial information about sensitivity of objective function to model parameters (Eawag 2017).

In this analysis, the most sensitive parameters are screened based on their t-stat and p-value. The higher in absolute value the value of t-stat, and the lesser the p-value, the more sensitive the parameter. In Global analysis of sensitivity, to see an impact of each parameter on the objective function since all parameters are changing, a larger number of runs depending on number of parameters and procedure are needed.

The of Global sensitivity has an advantage since it produces more results that are reliable whereas its limitation is that parameter ranges and number of runs affect the relative sensitivity of parameters (Abbaspour, 2017).

3.7.2. Calibration and Validation of the model

3.7.2.1. Model Calibration

Calibration of model is a procedure to minimize a difference between model simulation and observation through parameterization. It is performed through careful choosing of values to model input parameters within their respective uncertainty ranges by comparing with model predictions for a given set of considered conditions with measured data for the same conditions (Arnold et al. 2012).

In this finding, model calibration conducted using the Sequential Uncertainty Fitting Version 2 programmer, which is set up in the SWAT-CUP software package. Uncertainty analysis also includes estimating an effect of model structure and input data uncertainty on model output variables.

According to Abbas pour et al. (2017) in SUFI-2 uncertainty within parameters defined through ranges having uniform distribution which account those causes of uncertainty resulting from driving variables , parameters ,conceptual model and observed data since uncertainties in the parameters can lead to uncertainty in model output. This referred to as 95% prediction uncertainity or 95PPU and calculated at the 2.5% and 97.5% levels of cumulative distribution of an output variable using Latin hypercube sampling.

Procedural creation of SWAT –SUFI2 Input files is depicted in figure below (Abbaspour, 2012).

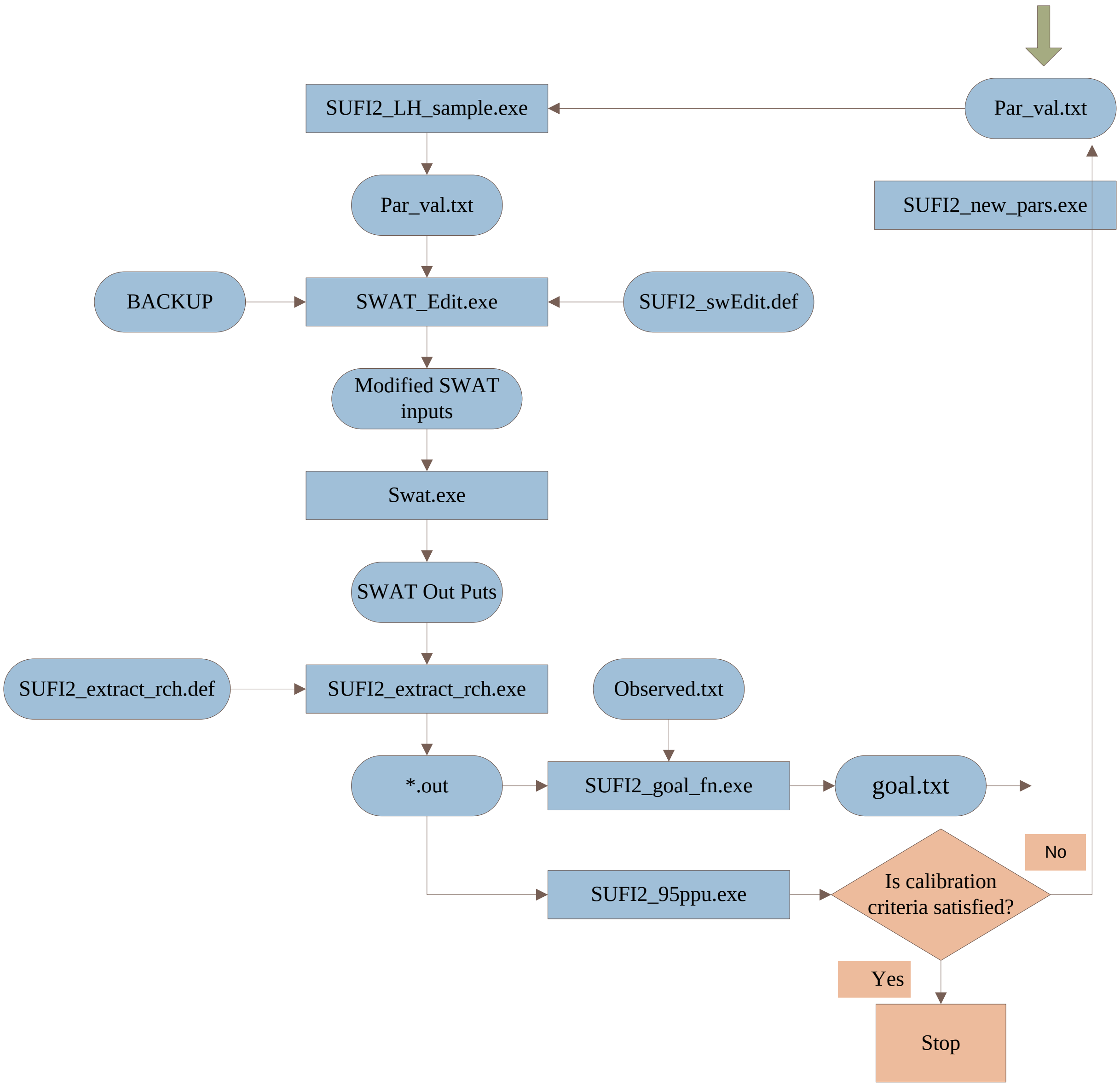


Figure 3.17 Calibration process using SUFI2 Algorithm

3.7.2.2. Model Validation

Once the model is calibrated, testing of a model on an independent data set is performed without any extra adjustment of parameters that were used during calibration. This testing of a model on an independent data set expressed as model validation, which ensures that whether the calibrated parameters set performs reasonably well or not, under independent data set on another period (time scale).

According to (Dilnesaw, 2006) under different management scenarios, the model can be used with some confidence for future prediction since the model predictive capability is demonstrated through reasonable calibration and validation process.

For this study in order to perform validation, the calibrated parameter ranges as they were used in calibration kept unchanged, the observed data's that were not used for calibration period selected and the same number of simulation as calibration runs ordered in SWAT-CUP 2012.

3.7.2.3. Model Performance evaluation

The performance of model can be evaluated using statistical and graphical methods in order to compare observed data to model predictions. The graphical methods can help us in depiction of the simulated result against the observed data through visualizing whether the model underestimate or overestimate the measured data and lag effect in rising and falling limb of hydrograph can be seen easily whereas the statistical method shows how well the predicted result matches the measured data. According (Krause et al, 2005) reasons for evaluating model performance:

- To present historic and future watershed behavior in quantitative estimation of models ability.
- To compare the current modelling effort with previous study outcomes.
- To provide a way for evaluating improvements for modelling approach through adjustments of model parameter values, model structural modification, encompassing of additional observational information and representation of important spatial and temporal characteristics of the watersheds.

It is recommended to use visual inspection at first stage since we can understand some insights through time series plot. In addition to this computing statistical measures and finally comparing with the recommended performance evaluation criteria is the finest way in achieving good results between observed data and what have been modeled.

According to Moriasi et al (2016) model evaluation can be judged satisfactory for flow simulation if daily, monthly or Annual $r^2>0.6$, NSE>0.5, PBIAS≤±15 for watershed scale model.
In this research both the graphical and statistical measures such as coefficient of determination (r^2), Nash-Sutcliffe (NSE) and Percentage of Bias (PIAS) selected and used for model performance evaluation.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Sensitive parameters

Prior to calibrating the model, sensitivity analysis carried out in order to identify the most influential parameters, which do have an impact on output variable. For this study, both flow and sediment sensitive parameters identified for Gololcha catchment separately. According to (Abbaspour et al. 2007), some parameters are sensitive to both flow and sediment whereas some are sensitive to flow only and others sensitive to sediment only as a result sensitivity analysis performed independently for both flow and sediment.

4.1.1 Parameters sensitive to flow

Seventeen parameters that are highly sensitive for flow in Gololcha watershed selected and ranked based on their p-value and t-stat in SWAT- CUP. The lesser the p-value and the higher in absolute value of t-stat, the more sensitive the parameter.

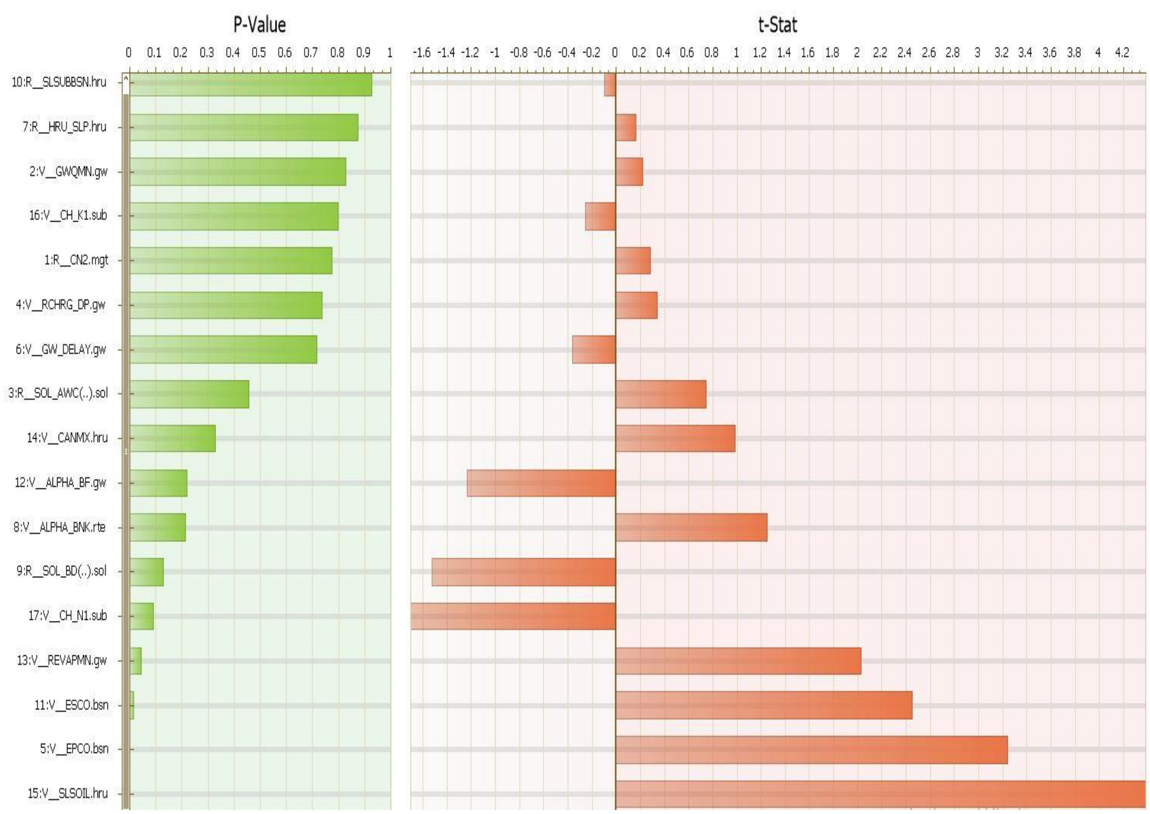


Figure 4.1 Global sensitive parameters to flow

Slope length for lateral subsurface flow (SLSOIL) is the highest sensitive parameter whereas the next most sensitive parameters are Plant uptake compensation factor(EPCO), Soil evaporation compensation factor(ESCO), Threshold depth of water in the shallow aquifer for revap to occur(REVAPMN), Manning value for the tributary channels(CH_N1) as they are listed in table 4.1.

Table 4.1 Sensitive parameters to flow

No	parameters	Description of parameters	Range		p-value	t-stat	rank
			Min	max			
1	SLSOIL	Slope length for lateral subsurface flow	0	150	0.000	4.383	1
2	EPCO	Plant uptake compensation factor	0	1	0.001	3.238	2
3	ESCO	Soil evaporation compensation factor	0	1	0.015	2.450	3
4	REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur	0	500	0.043	2.025	4
5	CH_N1	Manning value for the tributary channels	0.01	30	0.090	-1.701	5
6	SOL_BD	Moist bulk density	0.9	2.5	0.128	-1.525	6
7	ALPHA_BNK	Base flow alpha factor for bank storage	0	1	0.212	1.249	7
8	ALPHA_BF	Baseflow alpha factor	0	1	0.218	-1.233	8
9	CANMX	Maximum canopy storage	0	100	0.327	0.982	9
10	SOL_AWC	Available water capacity of the soil layer	0	1	0.457	0.745	10
11	GW_DELAY	Groundwater delay	0	500	0.716	-0.364	11
12	RCHRG_DP	Deep aquifer percolation fraction	0	1	0.735	0.338	12
13	CN2	SCS runoff curve number	35	98	0.776	0.285	13
14	CH_K1	Effective hydraulic conductivity in tributary channel	0	300	0.798	-0.256	14
15	GWQMN	Treshold depth of water in the shallow aquifer required for return flow to occur	0	5000	0.828	0.218	15
16	HRU_SLP	Average slope steepness	0	1	0.873	0.160	16
17	SLSUBBSN	Average slope length	10	150	0.925	-0.094	17

4.1.2 Parameters Sensitive to Sediment

Eleven sensitive parameters for sediment identified in study area among these soil conservation service curve number is the first sensitive parameter. In addition to this (SOL_AWC), (SPEXP), (HRU_SLP), (USLE_P) are also most sensitive parameters as they are presented in table 4.2.

Table 4.2 Sensitive parameters to sediment

No	parameters	Description of parameters	Range		P - value	t-stat	rank
			Min	max			
1	CN2	SCS runoff curve number	35	98	0.000	11.05	1
2	SOL_AWC	Available water capacity of the soil layer	0	1	0.000	10.83	2
3	SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing	1	1.5	0.000	6.41	3
4	HRU_SLP	Average slope steepness	0	1	0.000	4.42	4
5	USLE_P	USLE equation support practice	0	1	0.000	3.85	5
6	USLE_K	USLE equation soil erodibility (K) factor	0	0.65	0.000	3.83	6
7	ADJ_PKR	Peak rate adjustment factor for sediment routing in the main channel	0.5	2	0.014	2.48	7
8	SLSOIL	Slope length for lateral subsurface flow	0	150	0.019	-2.35	8
9	CH_K1	Effective hydraulic conductivity in tributary channel	0	300	0.127	-1.53	9
10	SOL_ALB	Moist soil albedo	0	0.25	0.184	-1.33	10
11	SLSUBBSN	Average slope length	10	150	0.258	-1.13	11

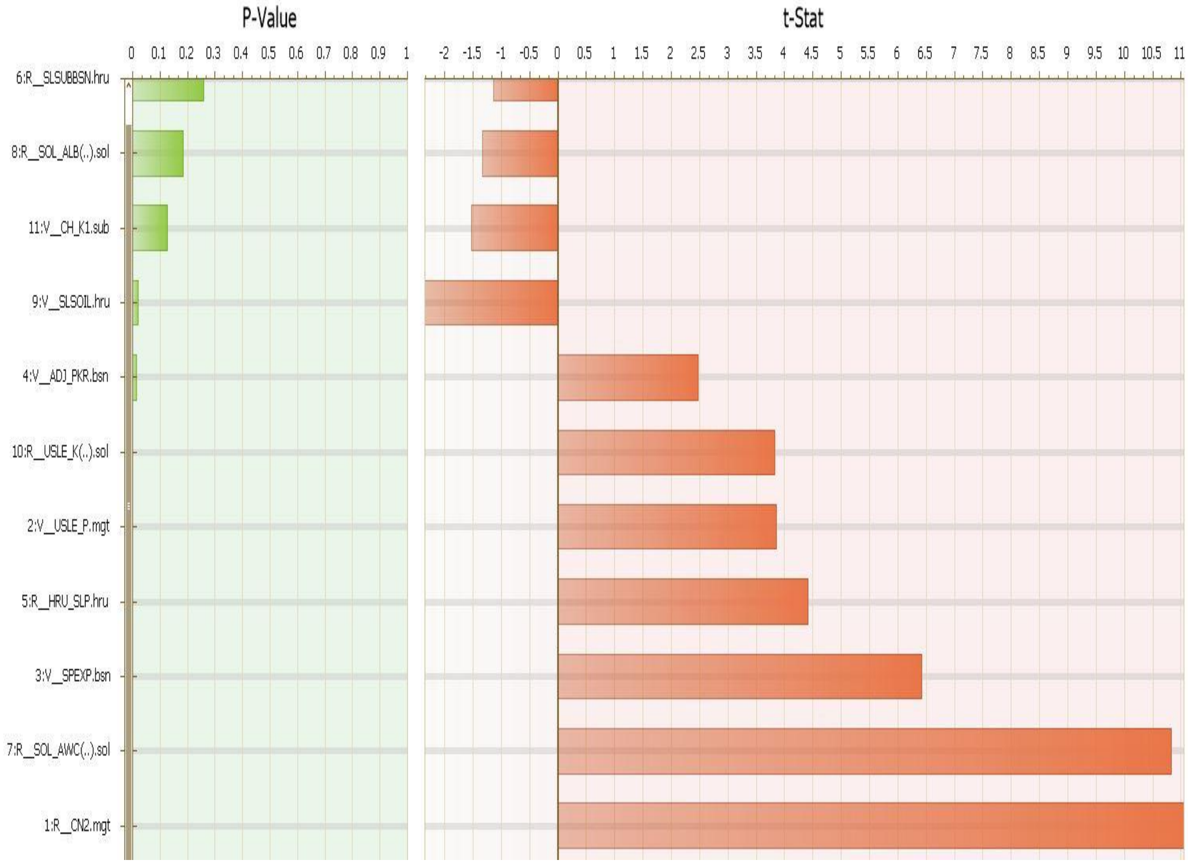


Figure 4.2 Global sensitive parameters to sediment

4.2 Flow Calibration and Validation

4.2.1 Flow calibration

Calibration of ArcSWAT model carried out through parameterization using SUFI-2 Algorithm in SWAT CUP with 500 number of simulations in each iteration based on the sensitive parameters for flow that were identified in sensitivity analysis.

The flow was simulated for seven years including warm up period from 1995-2001 and calibrated from January 1st , 1996 to December 31st , 2001 based on monthly time step at the outlet of Gololcha watershed whereas the beginning year of simulation was used as warm up period.

The result of calibration shows a statistical measures between simulated and observed flow based on monthly time scale with coefficient determination (R^2) of 0.74, Nash Sutcliff Efficiency (NS) of 0.73,Percentage Bias(PBIAS) of -9.1. The graphical plot of observed and simulated flow is depicted in Figure 4.3 and 4.4.

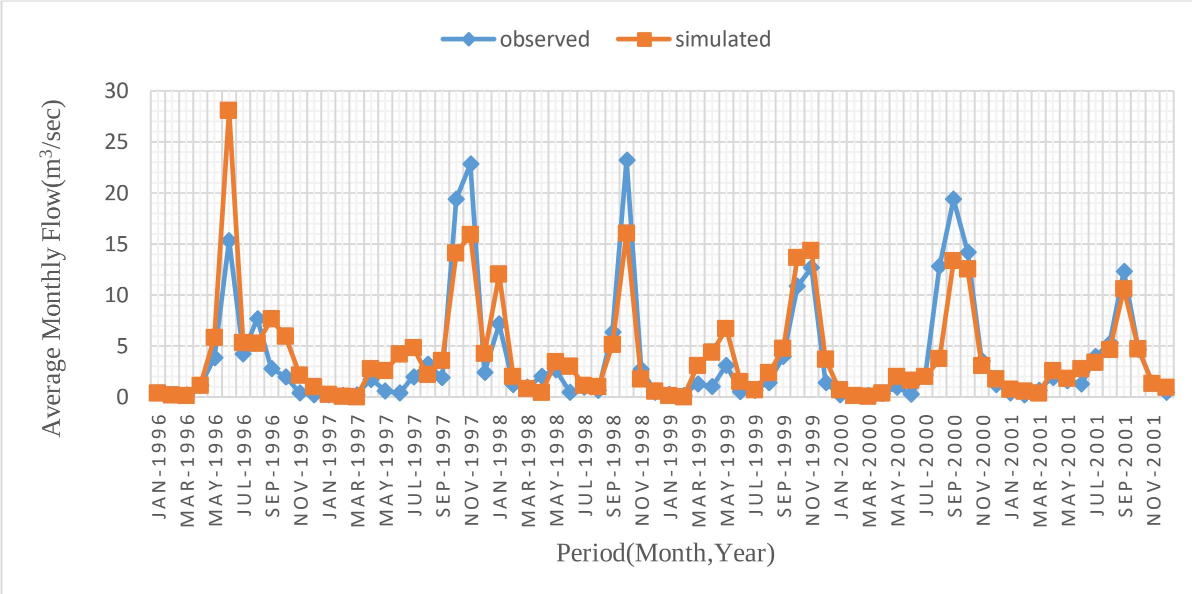


Figure 4.3 observed and simulated monthly flow for calibration

As shown in Fig 4.3 the model over estimates the peak events of the month during period of 1996 and 1999 whereas under estimates during period of 1997, 1998 and 2000. This variation can arise because of weather data quality used as an input in the model or gaged flow used for calibration. In addition to this some gaging station, do have missing climate data, which were left to be filled by the models weather generator. However, the overall flow trend for Gololcha watershed is well simulated by the ArcSWAT model.

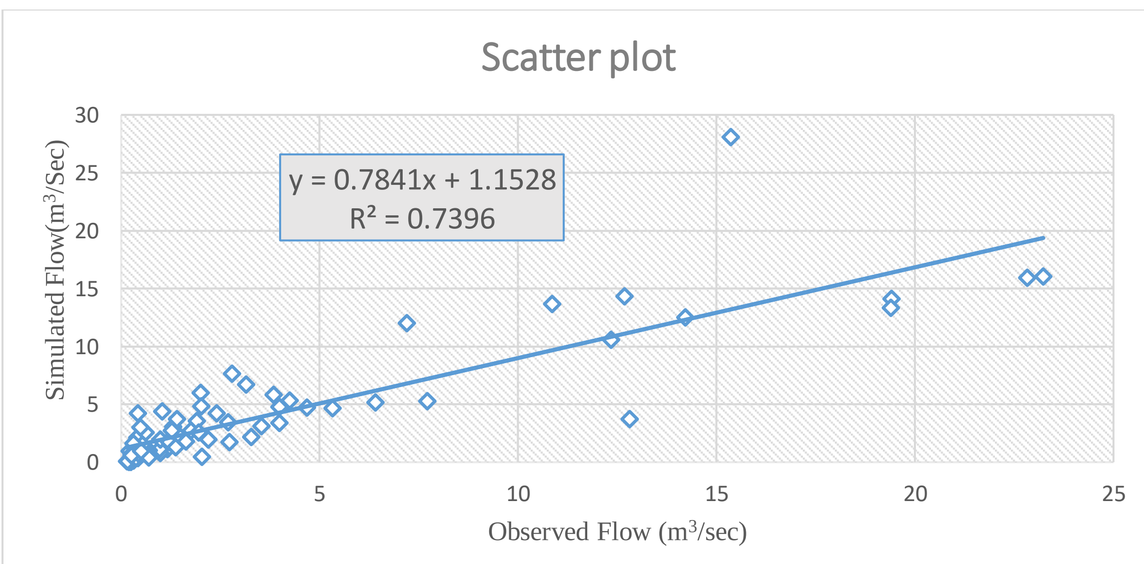


Figure 4.4 Scatter plot of simulated and observed flow for calibration

Table 4.3 simulated and observed Average monthly flow calibration

Period(Year)	Mean of flow(m^3/sec)		Performance evaluation statistical measures (monthly)		
	simulated	observed	R^2	NSE	PBIAS
1996-2001	4.10	3.76	0.74	0.73	-9.1

4.2.2 Flow validation

Validation is a process of testing of a model on an independent data set without any further adjustment of parameters that were used during calibration at another period.

Flow validation were performed starting from January 1st , 2006 to December 31st 2009 based on monthly time step with the same number of simulation as used during calibration period in SWAT-CUP. The outcomes of validation shows a performance evaluation of statistical measures between simulated and observed flow based on monthly time scale with coefficient determination (R^2) of 0.61, Nash Sutcliff Efficiency (NS) of 0.6,Percentage Bias(PBIAS) of -2.5.

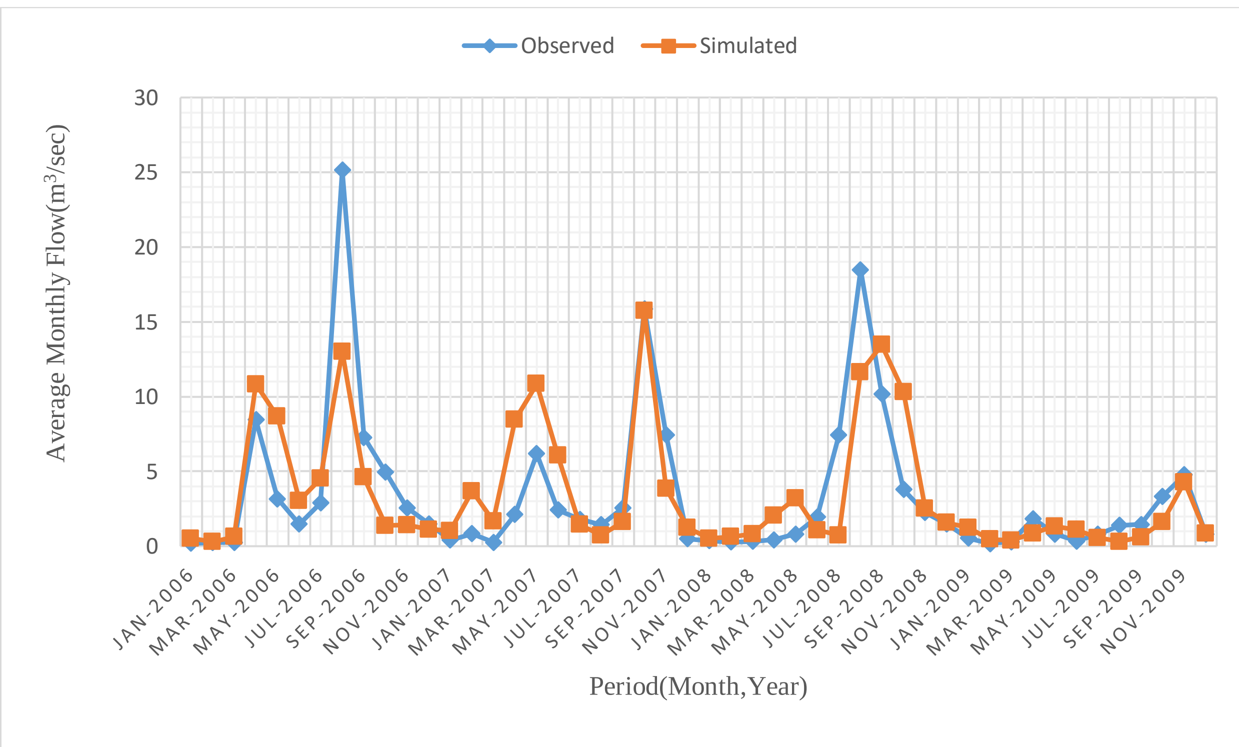


Figure 4.5 observed and simulated monthly flow for validation

Table 4.4 simulated and observed Average monthly flow validation

Period(Year)	Mean of flow(m^3/sec)		Performance evaluation statistical measures (monthly)		
	simulated	observed	R^2	NSE	PBIAS
2006-2009	3.51	3.42	0.61	0.6	-2.5

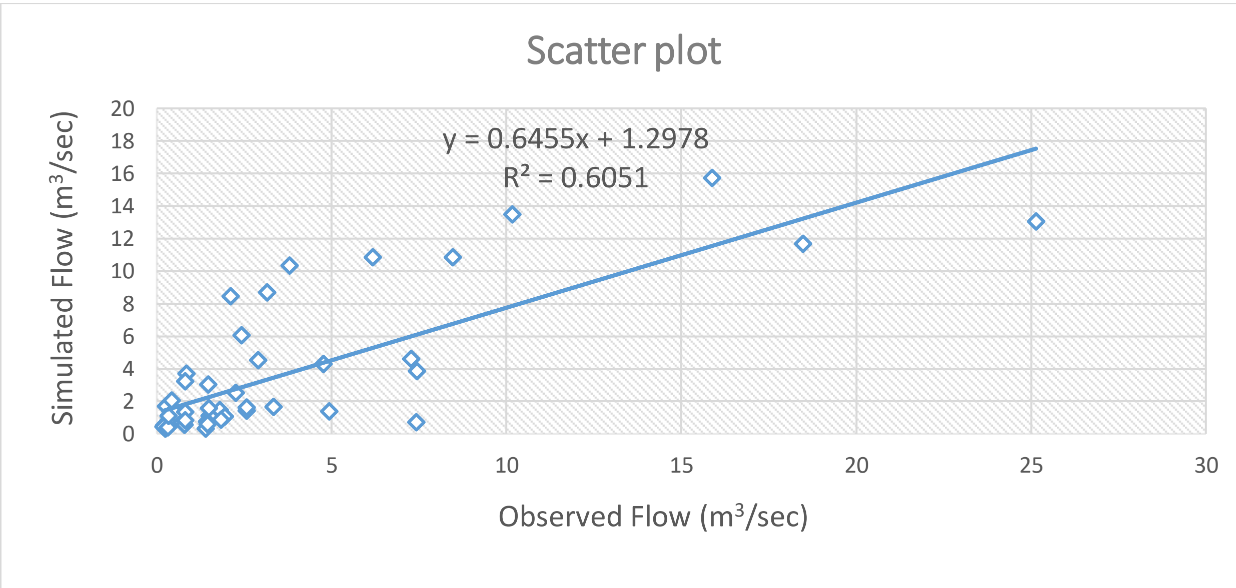


Figure 4.6 Scatter plot of simulated and observed flow for validation

4.3 Calibration and Validation of Sediment

4.3.1 Sediment Calibration

Sediment yield calibration performed after identifying the highly sensitive parameters to sediment according to order of sensitivity analysis.

The model was simulated for eight years including warm up period from 1993-2000 and calibrated from 1994 to 2000 based on Annual time step at the outlet of watershed whereas the beginning year of simulation was used as warm up period. Since there is, no measured sediment data in Gololcha catchment method of Regional equation described in methodology portion used to calibrate and validate the result of sediment yield simulated in ArcSWAT2012.

The result of calibration for sediment shows statistical measures between simulated and Regional equation based on yearly time step with determination coefficient (R^2) of 0.79, Nash Sutcliff

Efficiency (NS) of 0.77, Percentage Bias (PBIAS) of 0.7. The graphical plot comparison and scatter plot presented in Figure 4.7 and 4.8.

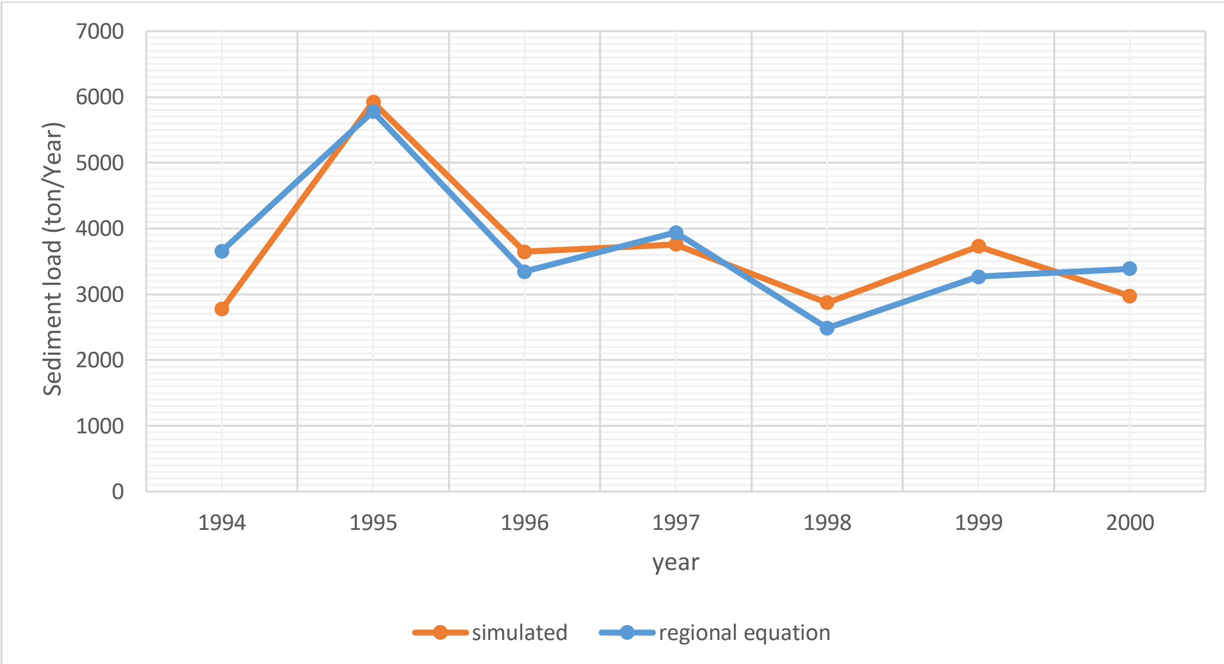


Figure 4.7 Comparative of Simulated and regional equation Annual sediment for calibration

As depicted in Fig 4.7, ArcSWAT model simulated well the sediment yield based on annual time step for Gololcha watershed when compared to result of regional equation depending on performance evaluation statistical measures.

Table 4.5 Simulated and regional equation Average Annual sediment calibration

Period(Year)	Mean of Annual Sediment(ton/year)		Performance evaluation statistical measures (Annual)		
	simulated	Regional equation	R^2	NSE	PBIAS
1994-2000	3667.14	3694.54	0.79	0.77	0.7

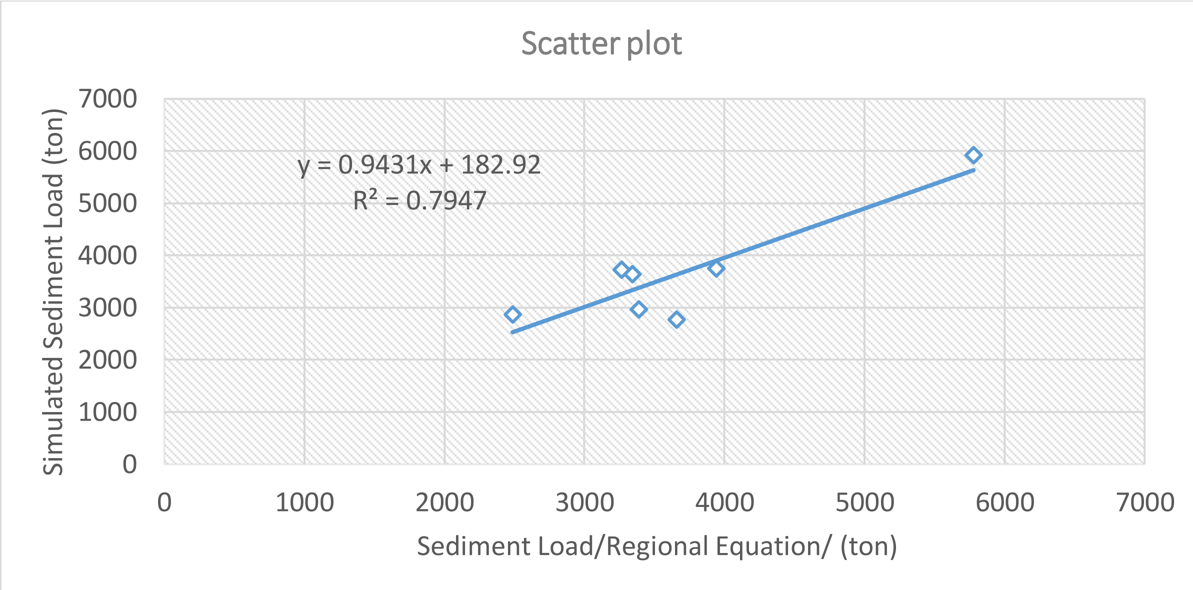


Figure 4.8 Scatter plot of simulated and regional equation sediment for calibration

4.3.2 Sediment Validation

Validation of sediment yield from ArcSWAT done after calibration process based on Annual time step for five years starting from 2005-2009.

As a result statistical measures between simulated and observed (Regional equation) shows good agreement with coefficient determination (R^2) of 0.78, Nash Sutcliff Efficiency (NS) of 0.52, Percentage Bias (PBIAS) of 10.1.

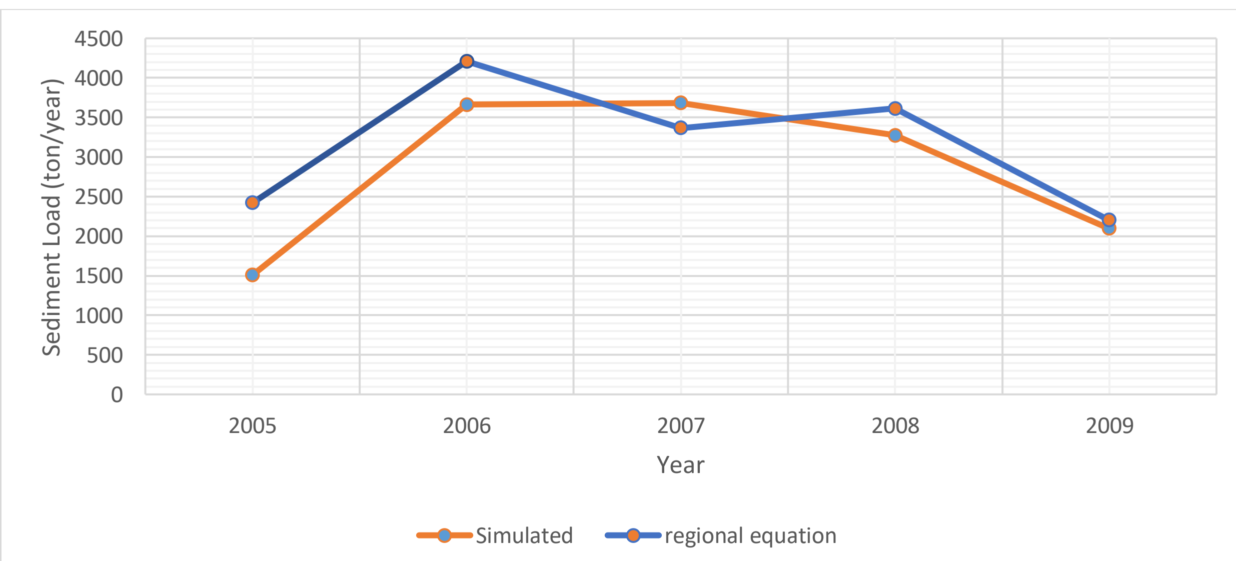


Figure 4.9 Comparison of Simulated and regional equation Annual sediment for validation

Table 4.6 Simulated and regional equation Average Annual sediment validation

Period(Year)	Mean of Annual Sediment(ton/year)		Performance evaluation statistical measures (Annual)		
	simulated	Regional equation	R^2	NSE	PBIAS
2005-2009	2843.80	3161.78	0.78	0.52	10.1

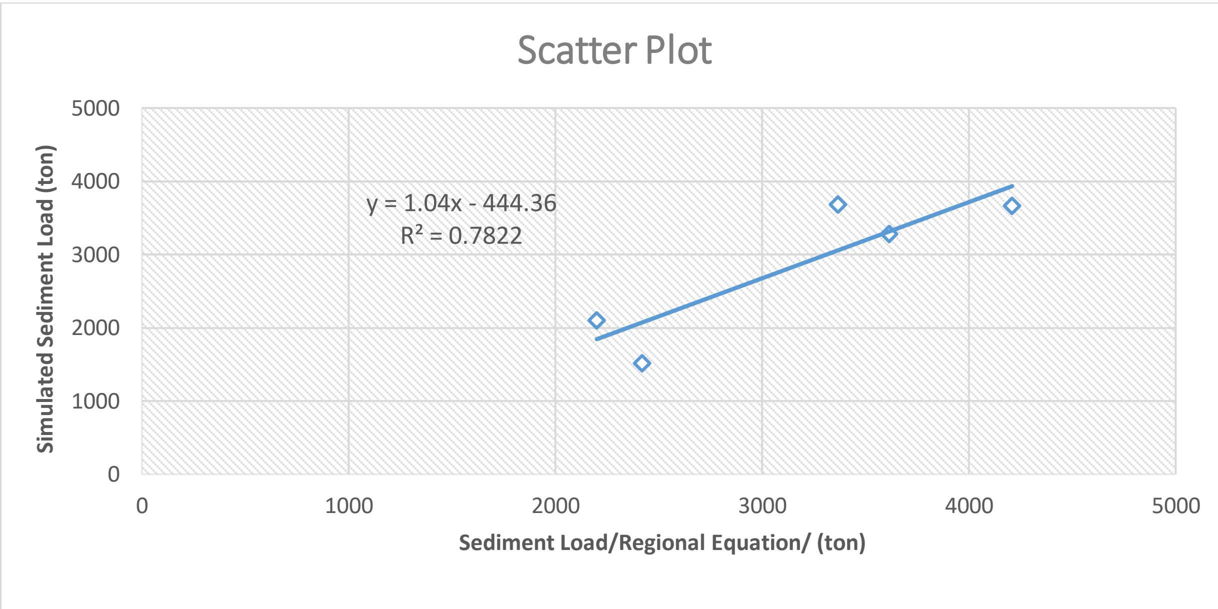


Figure 4.10 Scatter plot of simulated and regional equation sediment for validation

In this investigation, it was found that the average annual basin values of total sediment loading was about 234,768 tons for Golocha catchment at the dam site. However, the study conducted by WWDSE in association with MCE and WAPCOS in Wabi Shebelle River basin Integrated Development Master Plan Study Project (March -2005) shows the estimated mean annual sediment load at dam site was about 210,000 tons.

The result obtained by the model is somewhat near to the estimated value by the WWDSE even though it is greater. As a result, the ArcSWAT can be used in order to simulate sediment yield to the study area. The Annual Specific sediment yield from the catchment calculated as the overall sediment yield (234,768 tons) divided by area of catchment (84146.3 hectares) which equals to 2.79 ton/ha/year.

4.4 Temporal and Spatial sediment yield variation

4.4.1 Temporal sediment yield variation

The difference of sediment yield from season to season observed for the Gololcha catchment in using SWAT model for the 24 year of simulation starting from 1990 to 2013, that can be influenced by land use land cover type, topography, type of soil, contributing area for yield and climate condition.

Table 4.7 Temporal sediment yield variation

Year	Sediment yield(ton/ha)	Year	Sediment yield(ton/ha)
1990	4.84	2002	1.03
1991	0.92	2003	1.01
1992	3.4	2004	2.22
1993	9.58	2005	4.56
1994	4.11	2006	0.37
1995	7.3	2007	3.8
1996	5.65	2008	3.09
1997	3.2	2009	2.53
1998	4.35	2010	2.68
1999	5.01	2011	3.13
2000	1.9	2012	1.63
2001	1.94	2013	5.69

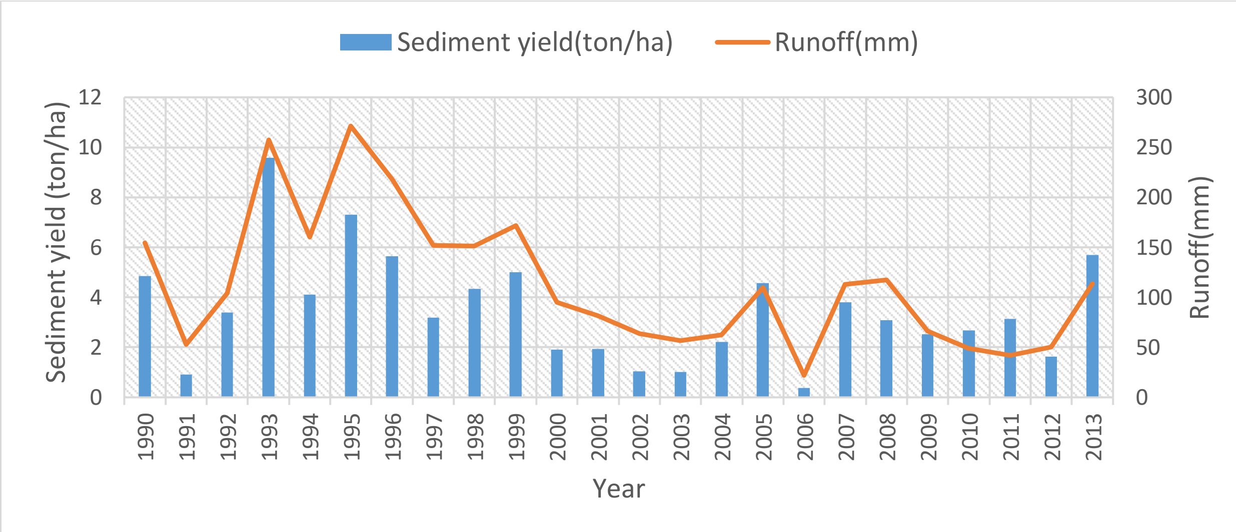


Figure 4.11 temporal pattern of sediment yield

As shown in fig 4.11 the sediment yield variation from year to year was observed that be influenced by the rainfall run off variability which is most driving agent in water balance of watershed. For the heavy rainfall run-off, there is increment of sediment yield since land use land cover type can affect the run off generation potential and infiltration capacity, which leads to soil loss especially on sloping areas.

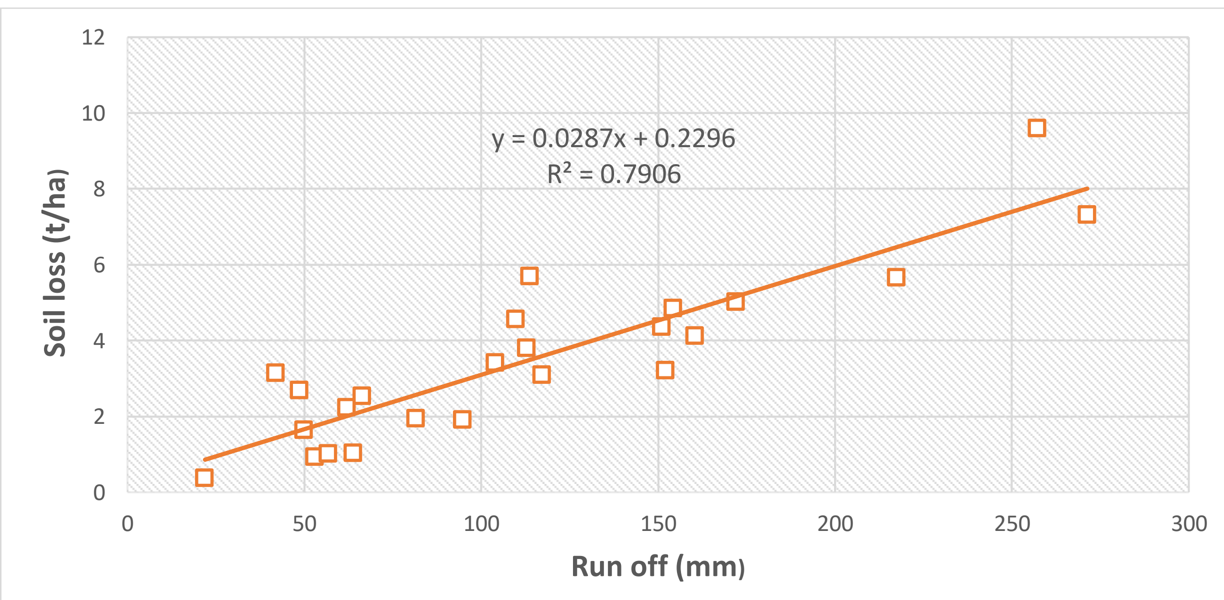


Figure 4.12 Relationship between simulated Run off and simulated soil erosion rate

Most of the area of watershed about 84.14% has a soil erosion rate ranging from 0.04 ton/ha to 5 ton/ha whereas nearly 15.86% of the area is under erosion rate exceeding 5 ton/ha. The larger rate of soil loss is observed from intensively cultivated land and the lesser is observed from dense woodland and grassland as shown in table 4.8.

Table 4.8 Estimated Soil erosion rate under different LULC

LULC	Estimated Soil Erosion rate(t/ha)
Intensively cultivated land	8.34
Grass land	1.2
Dense woodland	0.04
Moderately cultivated land	2.27

4.4.2 Spatial sediment yield variation

In this finding from the total delineated 15 sub basins in ArcSWAT, the sub basin which are facing severe erosion, identified against that do have a less erosion. The annual average sediment yield from the sub basins varies from 0.05 ton/ha to 16.22 ton/ha. In Gololcha catchment the maximum annual average sediment yield is generated from sub basin 5 and 14 which are 16.22 ton/ha and 9.3 ton/ha respectively whereas The minimum sediment load is from sub basin 8 and 11 which are 0.05 ton/ha and 0.25 ton/ha respectively as shown in table 4.8.

Table 4.9 Spatial Sediment yield variation

Sub basin	Sediment load(ton/ha)	Sub basin	Sediment load(ton/ha)
1	2.13	9	0.92
2	7.23	10	1.13
3	5.48	11	0.25
4	6.16	12	2.26
5	16.22	13	0.75
6	1.75	14	9.30
7	1.12	15	1.16
8	0.05		

Based on their sediment load the critical sub basins identified in Gololcha catchment are sub basin 2, 3, 4, 5 and 14 thus needs immediate attention in conservation using intervention measures. The land use of sub basin 5 is intensively cultivated about 36.05%, moderately cultivated 35.94% and dense woodland 28.02% whereas sub basin 14 is intensively cultivated about 72.51%, Grass land 20.67%, open forest 5.14% and dense wood land 1.68% from their total area of sub basin. In addition to this, the slope class greater than 15% is about 38.24% and 20.68% in sub basin 5 and 14 respectively.

This indicate under the combined impact of topography, land use and soil which accelerate the erosion condition there is an increment of sediment yield from the sub basins. According to (Vanoni.2006) Sediment yield from drier areas tends to be limited because of low runoff and yield in wetter areas is limited by the protective soil cover and reduced erodibility of humid zone soils. Cultivation on steep slope, overgrazing, clearance of vegetation and rapid population growth are main factors that aggravate soil erosion (Hurni, 2002). Gebreyesus et al (2009) stated that the main cause behind land degradation is Heavy dependence of some 85% of Ethiopia's increasing population on subsistence agriculture. According to (Vanmaercke et al 2014) states that spatial sediment yield variation is primarily explained by changes in seismic activity, vegetation cover, annual runoff depth and topography. Agro ecological parameters, Topography and soil type are contributing factors in degradation process influenced by human (Gashaw et al, 2018).

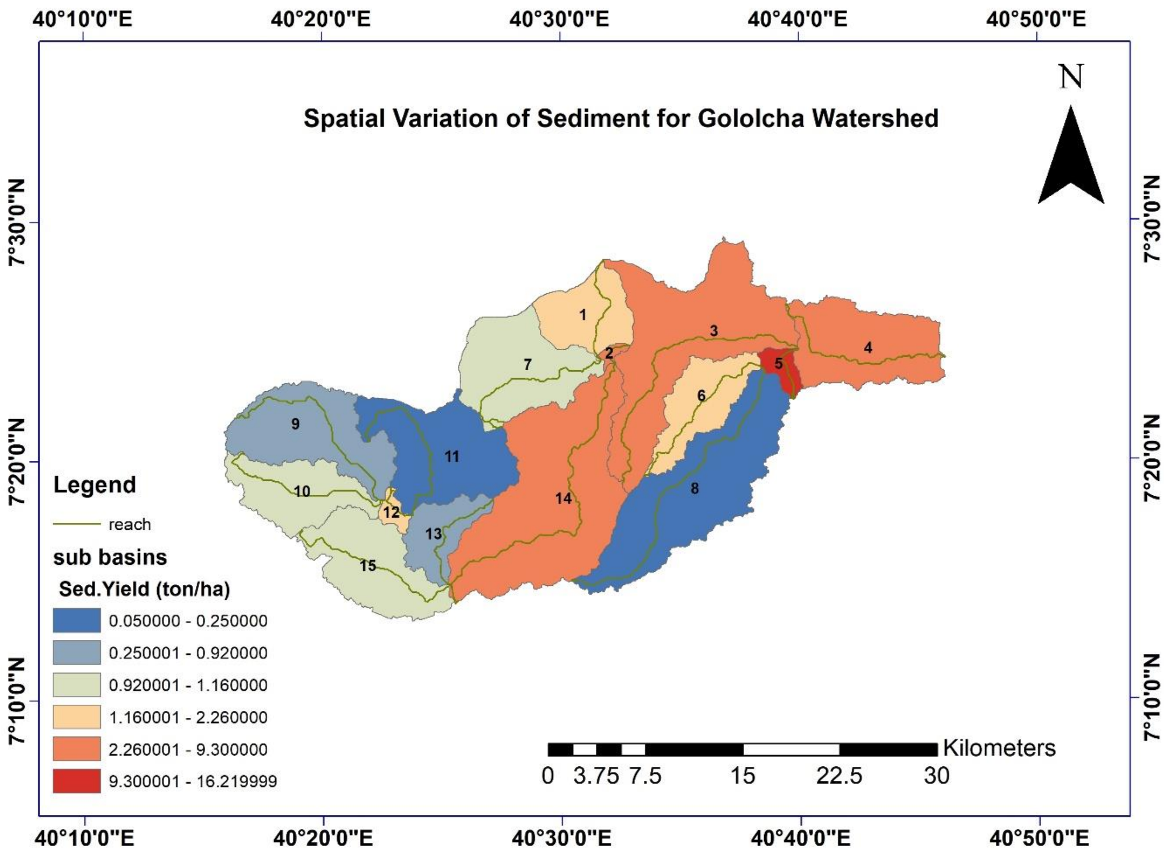


Figure 4.13 Spatial Sediment Yield Variation of Gololcha Catchment

4.5 Scenario development for management practices

In this research after identifying the areas, which are under severe sediment yield production, an effect of LULC change on hydrology and sediment was observed by developing scenarios. The process of assessing likely upcoming events through concerning the alternative possible outcomes is scenario analysis. This can be achieved based on future land use master plan if there is or through changing one land use form to another by specifying the percentage of conversion in ArcSWAT under land use refinement options.

For this study, scenarios developed through reforestation by changing the intensively cultivated land area to forest mixed by 15%, 25%, 35%, 45%, and management operations including contouring and Terracing.

The contour planting and terracing were implemented for the critical sub basins identified and the base line scenario also compared with developed scenarios outcomes in order to evaluate the sediment yield reduction from catchment, thus to use the model for analyzing the effect of different management measures for the study area. In addition to this conducting these scenarios, can help us for sustainable management of land use and water resources and decision-making.

The effectiveness of developed scenarios computed by finding the percentage change in model output as: $E = \frac{So - Si}{So} * 100$

Where E is effectiveness of scenarios implemented, So and S_i are result of model simulation at the base line and after implementation of scenarios respectively.

For Gololcha catchment from the delineated area in ArcSWAT Intensively cultivated area is about 55.76%, moderately cultivated 17.23%, open forest 1.39%, dense woodland 16.05%, Grassland 9.32%, exposed sand and soil surface 0.25%. This indicate that huge land mass is under pressure of Agricultural activities which is easily affected by erosion and this can reduce the lifespan of Gololcha reservoir dam that located at the outlet of catchment unless sediment reduction method given a major concern with in the watershed. Loss of forest and other vegetation cover over time due to population increment and expansion of farmland has contributed greatly to enhance erosion rates (Tefera et al, 2002).Degradation widespread, gullying frequently and long history of land use with high erosion damage especially on slopes (Hurni et al, 2016). According to (Senti et al., 2014) In examining erosion of soil and sediment yield in Lake Haramaya watershed found that anthropogenic drivers were major causes attributed to severe soil erosion happening in the catchment. Land degradation involves the whole process that weakens the capability of land resources to perform essential services and functions in ecosystem (Hurni et al, 2010) composed of two interlocking complex system, which are the natural ecosystem, and the human social system.

Conservation efforts on watershed management has shown some success in reducing run off, soil erosion and associated downstream siltation, increased crop production and productivity (Gashaw, 2015). The effect of human actions on landscape has traditionally been injurious; however, this trend seems to have recently reversed in some parts of the country succeeding the engagement of the communities in land management (Haregeweyn et al, 2015). According to (Nigussie et al., 2017) states that farmers must be considered as important partners not only to counter soil erosion, but also to obtain local expertise on severity of soil erosion and restoration of degraded land.

The influence of land use change, management and conservation practices to reduce the sediment yield from Gololcha critical sub basins observed in this investigation through developed scenarios as presented in table 4.10 and Figure 4.14.

Table 4.10 Average Annual sediment reduced from developed scenarios.

	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Average Annual sediment (ton/ha/yr.)	17.14	16.36	15.22	14.40	13.65	11.37	9.80	8.70
Sediment Reduction from base line scenario (%)	0	4.55	11.2	15.98	20.36	33.66	42.82	49.24

Base line scenario (S_0)-Scenario without conservation measures

Scenario1 (S_1) - 15% intensively cultivated land changed to forest mixed

Scenario2 (S_2) - 25% intensively cultivated land changed to forest mixed

Scenario3 (S_3) - 35% intensively cultivated land changed to forest mixed

Scenario4 (S_4) - 45% intensively cultivated land changed to forest mixed

Scenario5 (S_5) - contouring

Scenario6 (S_6) - terracing

Scenario7 (S_7) - combination of contouring and terracing

The output from applying different management practices showed that the effectiveness of sediment reduction from catchment increases with changing of intensively cultivated land to forest mixed. In addition to this practicing of contour farming and terracing reduces the sediment yield by 33.66% and 42.82% respectively. More over applying these tillage practices together for the critical sub basins significantly increase sediment yield reduction from the watershed by 49.24%. This indicate that there is an increment of 15.58% and 6.42% for contouring and terracing respectively in sediment reduction when compared to implementing the two practices individually as depicted in Figure 4.14. These results show that implementing joined management practices could be effective in decreasing sediment transport for sustainable water resource management in the catchment.

According to (Dilnesaw, 2006) in modeling of hydrology and soil erosion of upper Awash Using parallel terraces with the reduction of slope length by 75% gave the highest reduction in sediment yield which is from 21.53t/ha/yr. to 6.09t/ha/yr.

Terraces carried out mainly to regulate water runoff and erosion, acted as a buffer during the 2015 Ethiopia drought(Kosmowski, 2018). According to (Nadew et al, 2018) applying terraces and filter strips reduced the sediment yield from Guder catchment by 53% and 48% respectively.

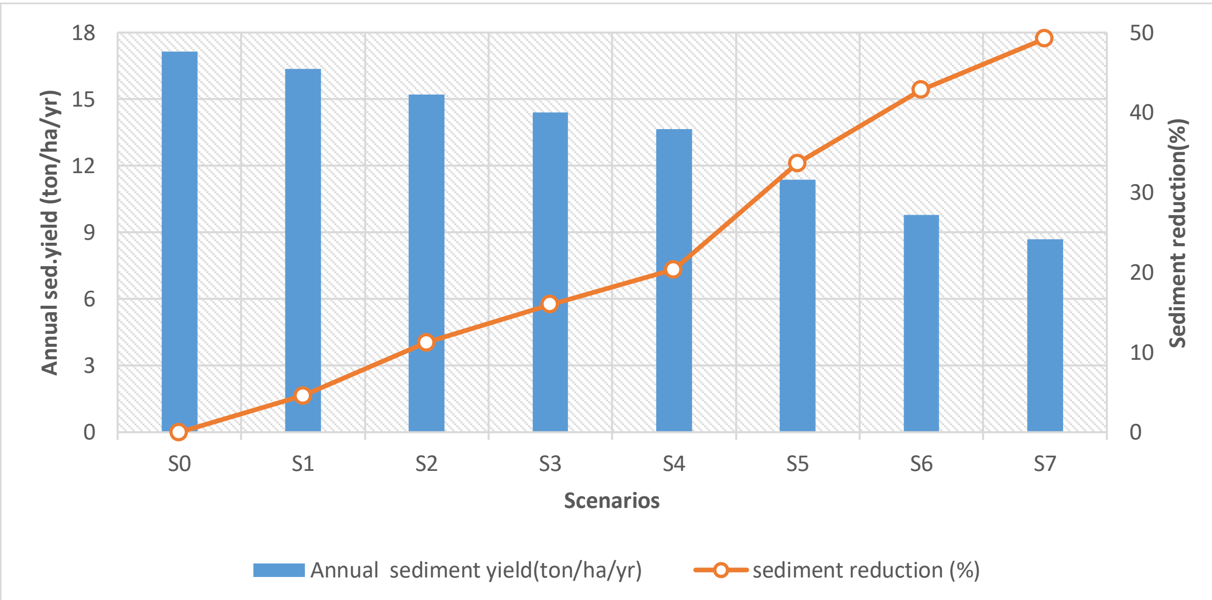


Figure 4.14 Average Annual Sediment reduced for developed scenarios

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this finding, sediment yield estimation for Gololcha catchment simulated with the aid of ArcSWAT model. Spatial data used in delineating watershed with 15 sub basins, 140 Hrus and covering total area of 841.463Km^2 based on threshold for slope, soil and land use with multiple Hru definition. The simulated result from model calibrated and validated for stream flow and sediment by means of sequential uncertainty fitting version two in SWAT CUP through identifying the sensitive parameter.

Slope length in lateral subsurface flow (SLSOIL), (EPCO) factor, (ESCO) factor, Threshold depth of water in shallow aquifer for revap to occur (REVAPMN), Manning value for the tributary channels (CH_N1) are among most sensitive parameters for stream flow. Soil conservations service curve number (CN2), Available water capacity of soil layer (SOL_AWC), Exponent parameter for calculating sediment reentrained in channel sediment routing(SPEXP), Average slope steepness(HRU_SLP), USLE equation support practice(USLE_P) are top sensitive parameter for sediment.

The model performance evaluation result showed that for calibration and validation of stream flow at outlet on monthly time scale with R^2 of 0.74, NS of 0.73, PBIAS of -9.1 and R^2 of 0.61, NS of 0.6, PBIAS of -2.5 respectively. Whereas for sediment calibration and validation on Annual time step the statistical measures with R^2 of 0.79, NS of 0.77, PBIAS of 0.7 and R^2 of 0.78, NS of 0.52, PBIAS of 10.1 respectively. Hence, the model found to be good in simulating the run off and sediment for the study area thus can be used as a research tool in sediment yield modeling for watershed that do behave similar hydro metrological with Gololcha catchment. The result obtained by the model indicate that the average annual basin values of total sediment loading in to reservoir is 234,768 ton/yr.

The critical sub basins 2,3,4,5 and 14 identified based on load that generated from these sub watersheds having mean annual sediment load varying from 5.48 ton/ha to 16.22 ton/ha thus necessitates to be prioritized with intervention measures in order to protect Gololcha reservoir that found at the outlet of catchment. The developed Scenario through Vegetation and operation management showed good improvement in sediment reduction from sub basins that needs to be conserved. High amount of sediment reduction observed when intensively cultivated land changed to forest mixed in addition to this the combination of contouring and terracing depicted effective management practices than when they are practiced separately.

5.2 Recommendation

- The identified critical sub basins showed of serious vulnerability to erosion that can endanger the service life of Gololcha dam reservoir thus needs urgent sustainable management practices. In addition to this, integration of terracing and contouring have shown effective way of sediment reduction from the catchment hence necessitates applying in combination.
- The model found to be good in simulating the run off and sediment for the study area thus can be used as a research tool for further analysis in the future in sediment yield estimation for watershed that do behave similar hydro metrological characteristics with Gololcha catchment.
- This investigation was done based on weather data gathered from meteorological agency used as an input in model simulation, however these datas have series of gaps which are missed thus can influence the result of model output so the representatives organization has to bridge the way of holding these data's.

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APPENDIX

Appendix 1: Land use, Soil, Slope detail in Gololcha watershed

Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 3/22/2019 12:00:00 AM Time: 16:02:49.8791803

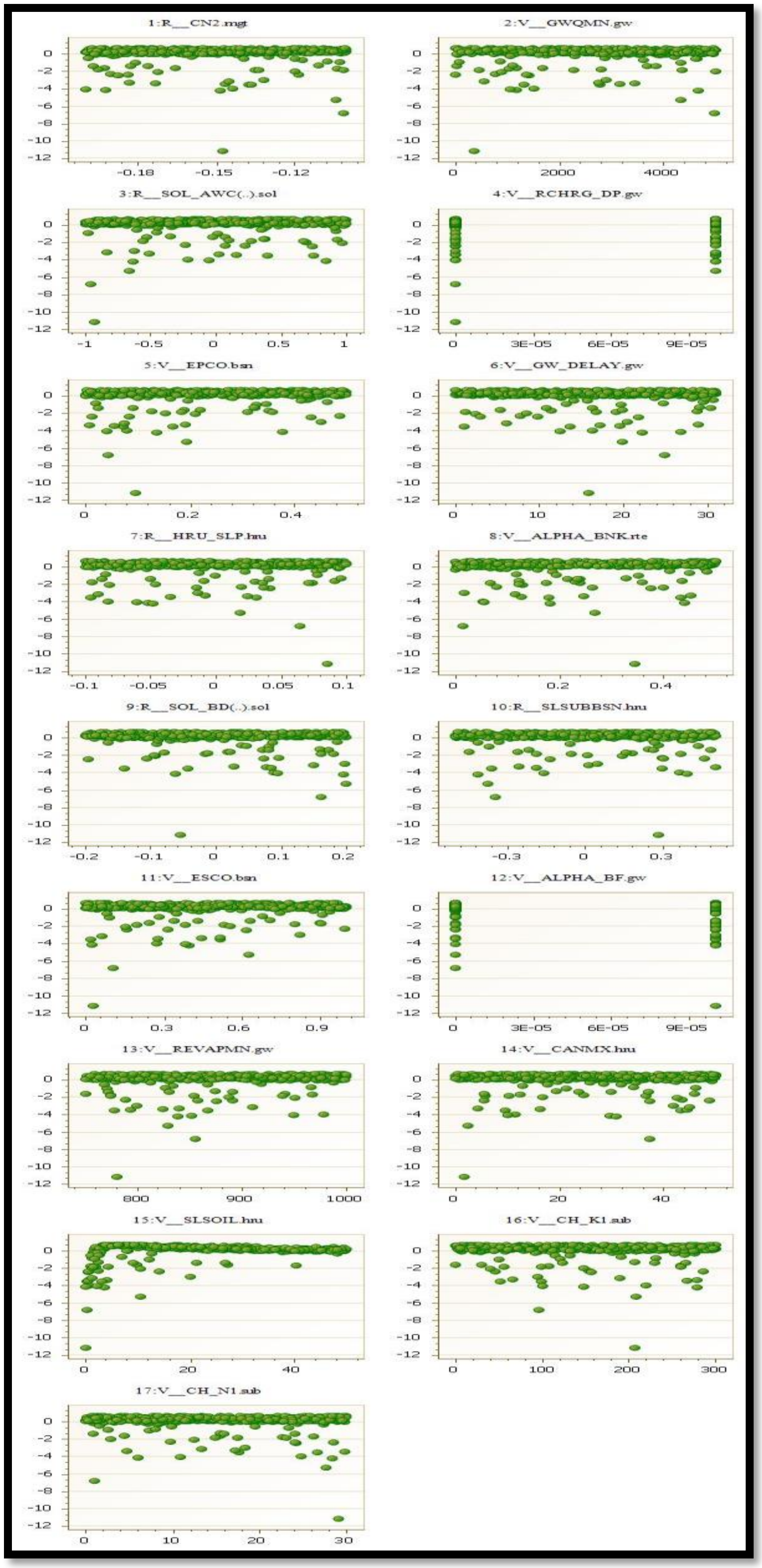
		Area [ha]	Area[acres]	%Wat.Area
Watershed		84146.3205	207929.7653	
Number of Subbasins: 15				
		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Forest-Mixed --> FRST	1171.2894	2894.3146	1.39
	Forest-Deciduous --> FRSD	13502.4939	33365.3374	16.05
	Range-Brush --> RNGB	209.3836	517.3973	0.25
	Durum Wheat --> DWHT	46921.8709	115946.2891	55.76
	Corn --> CORN	14495.3373	35818.7033	17.23
	Pasture --> PAST	7845.9455	19387.7236	9.32
SOILS:				
	Arenosols	9.7511	24.0956	0.01
	Cambisols	6763.2142	16712.2405	8.04
	Leptosols	657.0496	1623.6025	0.78
	Luvisols	2083.4643	5148.3444	2.48
	Vertisols	74632.8412	184421.4823	88.69
SLOPE:				
	0-3	13624.1172	33665.8748	16.19
	15-30	10792.1198	26667.8677	12.83
	30-9999	5252.7625	12979.8387	6.24
	3-8	34865.1167	86153.4466	41.43
	8-15	19612.2043	48462.7375	23.31

Appendix 2: Weather generator statistical parameters

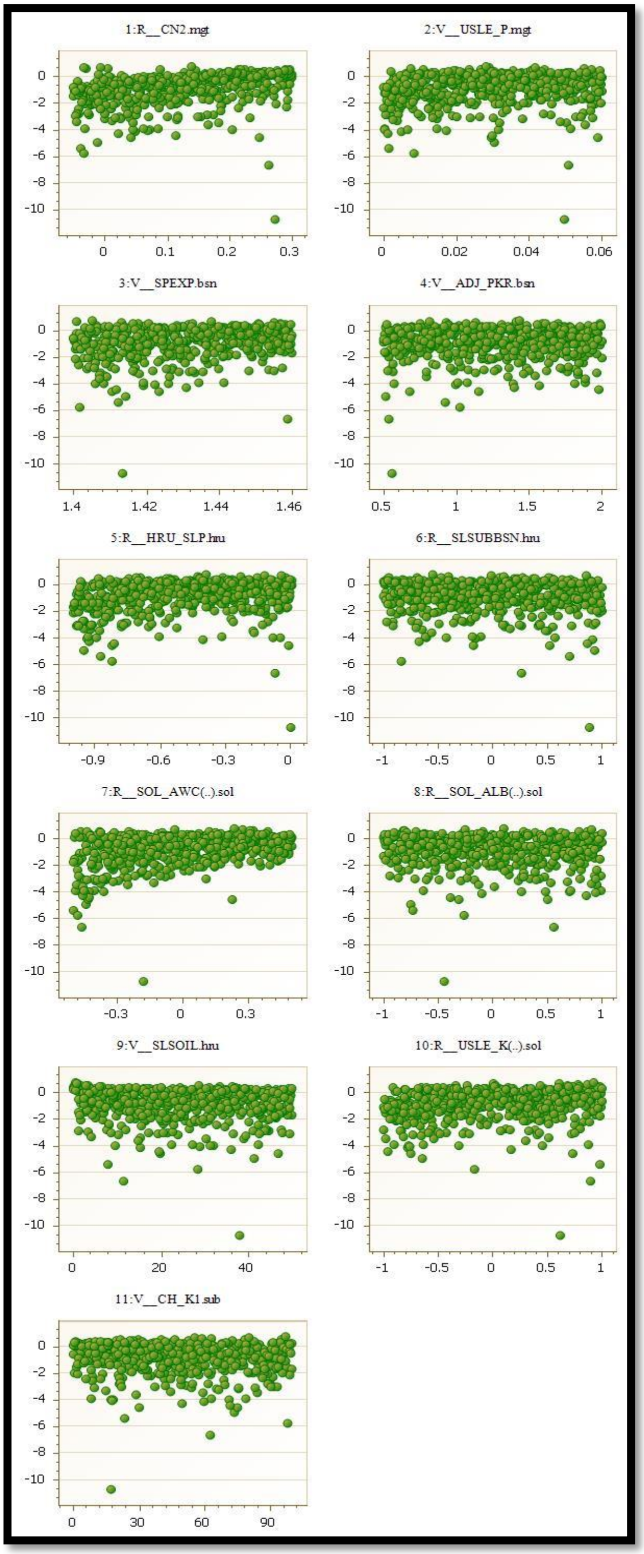
ginnirout

		latitude		788834.03			longitude		687739.82			
		elevation		1750.00								
		rain years		31.00								
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
TMPMX	25.09	26.30	25.88	24.07	23.78	23.72	23.58	24.33	24.88	22.83	22.95	23.93
TMPMN	12.30	13.47	14.31	14.34	14.30	13.46	13.00	13.21	13.52	13.43	12.43	11.96
TMPSTDMX	1.64	1.80	2.23	2.22	1.45	1.53	1.94	1.83	1.63	1.78	1.56	1.49
TMPSTDMN	1.60	1.35	1.44	1.24	1.16	1.25	1.13	0.98	1.10	1.18	1.40	1.54
PCPMM	21.00	30.23	64.42	165.93	124.34	28.46	18.83	31.78	77.58	141.61	72.71	30.48
PCPSTD	4.78	5.74	7.45	14.71	12.51	4.46	3.03	7.26	8.61	10.06	8.29	5.75
PCPSKW	8.10	7.74	4.00	4.40	6.94	4.84	5.75	13.37	5.34	2.43	4.23	7.43
PR_W(1)	0.04	0.03	0.13	0.33	0.32	0.13	0.10	0.13	0.28	0.35	0.15	0.06
PR_W(2)	0.51	0.72	0.57	0.65	0.48	0.30	0.28	0.26	0.57	0.71	0.58	0.54
PCPD	1.77	2.61	5.32	12.16	9.77	3.68	3.06	3.35	8.68	13.35	6.74	3.00
RAINHHMX	19.27	29.10	18.87	54.00	66.67	13.40	12.00	48.67	37.33	21.17	22.73	26.03
SOLARAV	25.74	26.36	27.13	26.50	26.17	25.80	25.52	26.37	26.29	25.11	24.53	24.70
DEWPT	12.88	13.89	14.28	13.94	13.97	13.84	13.49	13.76	13.79	13.05	12.34	12.11
WNDAV	1.65	1.79	1.78	1.83	1.69	2.12	2.32	2.31	1.95	1.57	1.49	1.50

Appendix 3: Dotty Plot for flow sensitive parameters



Appendix 4: Dotty plot for sediment sensitive parameters



Appendix 5: regression statistics

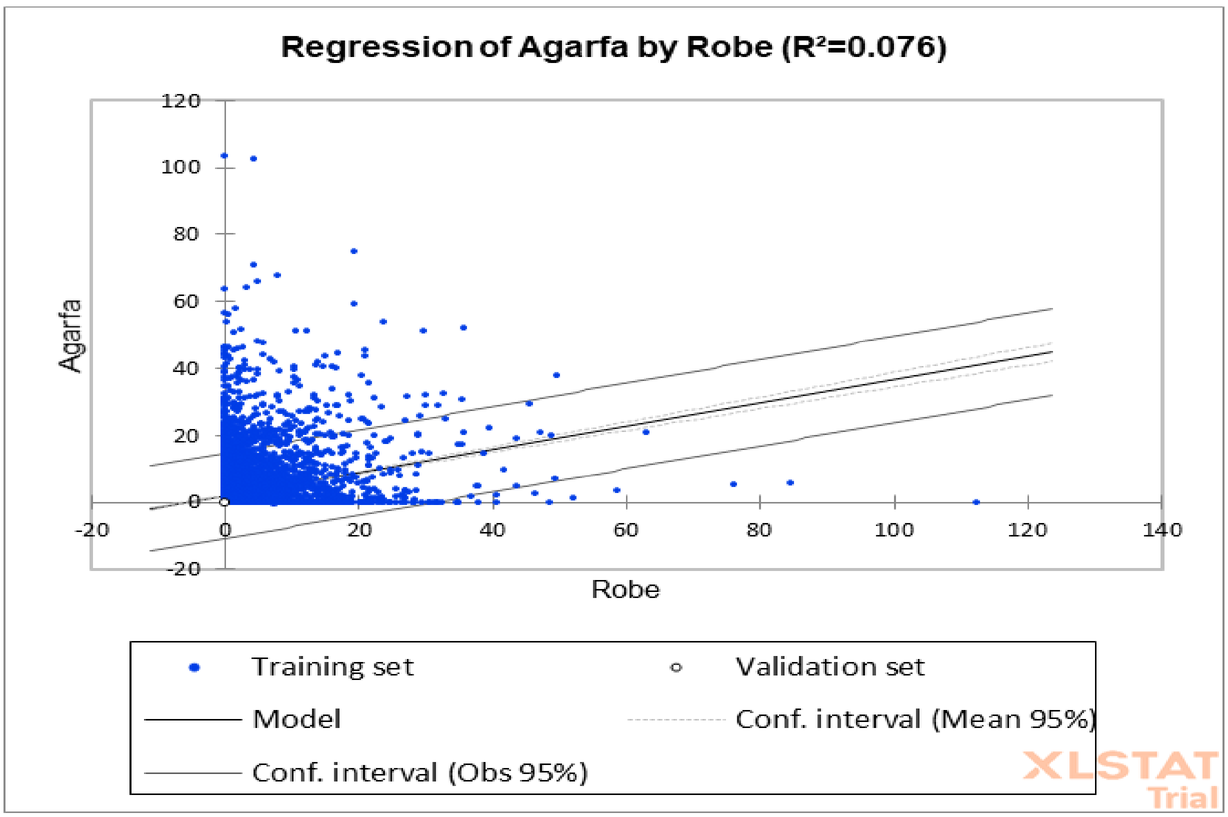
XLSTAT 2019.4.2.63912 - Linear regression

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Agarfa	11321	1286	10035	0.000	103.200	2.758	6.749
Robe	11321	0	11321	0.000	112.300	2.356	5.370

Equation of the model (Agarfa):

Agarfa = 1.93940981504088+0.347314117972994*Robe



Appendix 6: Auto correlation coefficient

n=30 α=5% Significance level	Stations	Computed r_1	Lower class limit(r_1(95%))	Upper class limit (r_1(95%))	Remark
	Agarfa	-0.0690	-0.392	0.323	Not significant
	Deloserbo	-0.0704	-0.392	0.323	Not significant
	Gassera	-0.3753	-0.392	0.323	Not significant
	Ginnir	0.0379	-0.392	0.323	Not significant
	Goba	-0.0955	-0.392	0.323	Not significant
	Jarra	0.0273	-0.392	0.323	Not significant
	Robe	-0.2947	-0.392	0.323	Not significant

Appendix 7: Spearman coefficient and test statistic

n=30 v=28 α=5% Significance level	stations	Rs	t_t	Critical values t_α (v,2.5%)	Critical values t_α (v,97.5%)	Remark
	Agarfa	-0.3219	-1.799	-2.048	2.048	No Significant trend
	Deloserbo	0.0109	0.0577	-2.048	2.048	No Significant trend
	Gassera	0.0367	0.1944	-2.048	2.048	No Significant trend
	Ginnir	0.3010	1.6702	-2.048	2.048	No Significant trend
	Goba	-0.3664	-2.008	-2.048	2.048	No Significant trend
	Jarra	-0.0434	-0.2298	-2.048	2.048	No Significant trend
	Robe	-0.0416	-0.2203	-2.048	2.048	No Significant trend

Appendix 8: Outlier detection

XLSTAT 2019.4.2.63912 - Grubbs test for outliers

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Flow	24	0	24	3.217	88.521	40.092	22.448

Grubbs test for outliers / Two-tailed test:

G (Observed value)	2.157
G (Critical value)	2.802
p-value (Two-tailed)	0.573
alpha	0.05

Test interpretation:

H0: There is no outlier in the data

Ha: The minimum or maximum value is an outlier

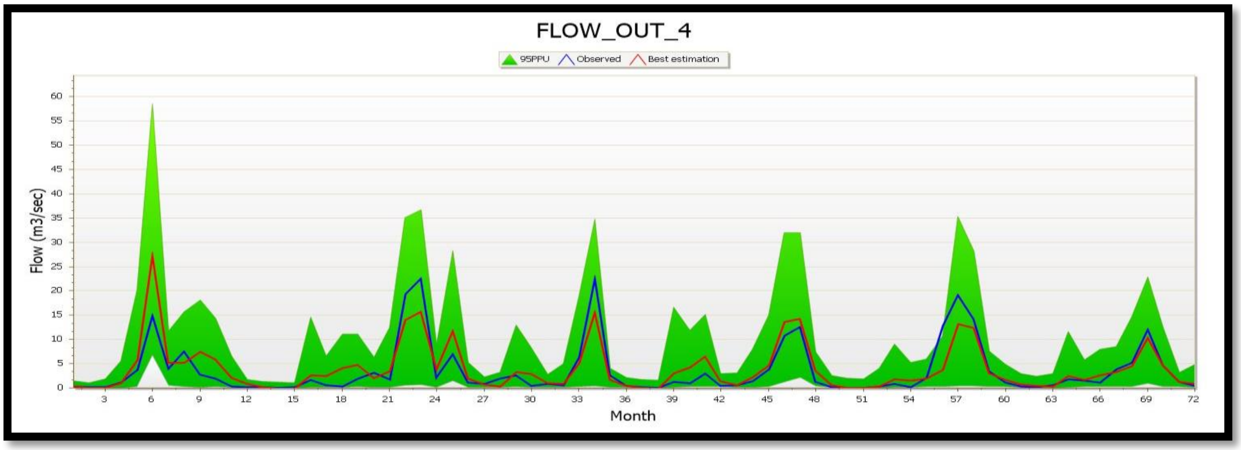
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

Appendix 9: computation of sediment load using Regional Equation

Col 1	Col 2	Col 3	Col 4=col2*col3	Col 5	Col 6=col 4/col5
Year/month	Flow(m^3/sec)	Time(sec)	Volume (m^3)	Area(m^2)	Runoff(m)
1986/01	2.51	86400	216864	8.41E+08	0.000258
1986/02	3.36	86400	290304	8.41E+08	0.000345
1986/03	9.35	86400	807840	8.41E+08	0.00096
1986/04	88.21	86400	7621344	8.41E+08	0.009057
1986/05	202.54	86400	17499456	8.41E+08	0.020796
1986/06	5.03	86400	434592	8.41E+08	0.000516
1986/07	66.44	86400	5740416	8.41E+08	0.006822
1986/08	270.98	86400	23412672	8.41E+08	0.027824
1986/09	76.65	86400	6622560	8.41E+08	0.00787
1986/10	57.59	86400	4975776	8.41E+08	0.005913
1986/11	15.61	86400	1348704	8.41E+08	0.001603
1986/12	4.91	86400	424224	8.41E+08	0.000504
1987/01	3.29	86400	284256	8.41E+08	0.000338
1987/02	3.53	86400	304992	8.41E+08	0.000362
1987/03	6.46	86400	558144	8.41E+08	0.000663
1987/04	100	86400	8640000	8.41E+08	0.010268
1987/05	169.25	86400	14623200	8.41E+08	0.017378
1987/06	207.13	86400	17896032	8.41E+08	0.021268
1987/07	138.68	86400	11981952	8.41E+08	0.014239
1987/08	323.7	86400	27967680	8.41E+08	0.033237
1987/09	171.51	86400	14818464	8.41E+08	0.01761
1987/10	92.5	86400	7992000	8.41E+08	0.009498
1987/11	11.65	86400	1006560	8.41E+08	0.001196
1987/12	7.98	86400	689472	8.41E+08	0.000819

Col 7	Col 8	Col 9	Col 10=Regional Equation	Col 11	Col 12
year	Annual Average runoff(mm/yr)	Area(Km^2)	Suspended sediment(ton/ Km^2/yr)	Bed load=20%*col 10	Total load=col10+col 11
1986	6.872428843	841.46321	2321.979459	464.3958918	2786.375351
1987	10.57312542	841.46321	2839.917366	567.9834731	3407.900839

Appendix10: SWAT-CUP output 95ppu Plot for flow calibration period (1996-2001)

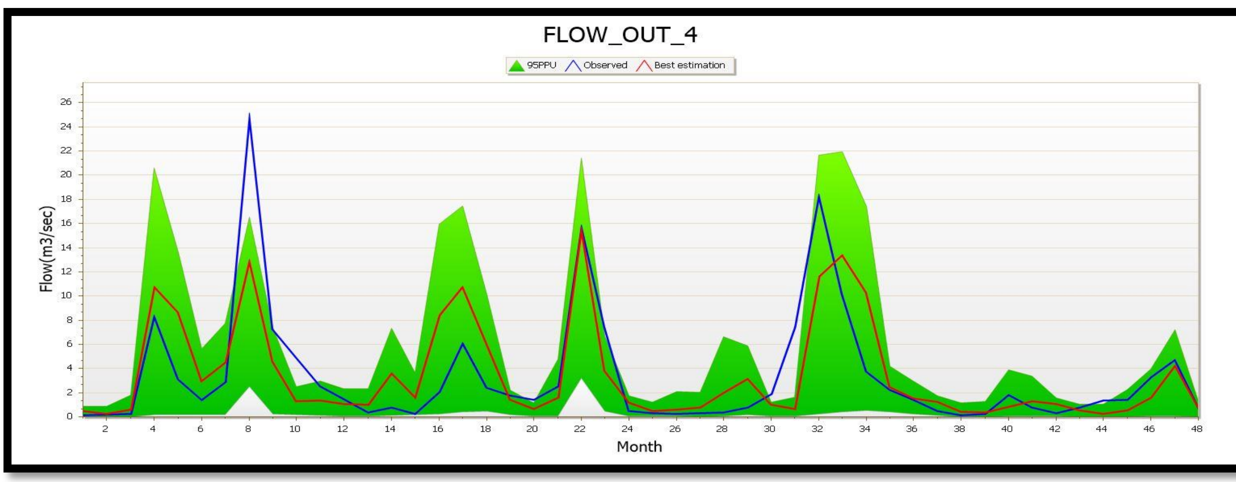


Summary statistics

Goal_type= Nash_Sutcliff No_sims= 500 Best_sim_no= 183 Best_goal = 7.331701e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)
FLOW_OUT_4	0.99	1.94	0.74	0.73	0.5799	8.2e+000	2.1e+000	-9.1	0.81	0.52	0.56	0.92		4.10(3.76)

Appendix11: SWAT-CUP output 95ppu Plot for flow validation period (2006-2009)

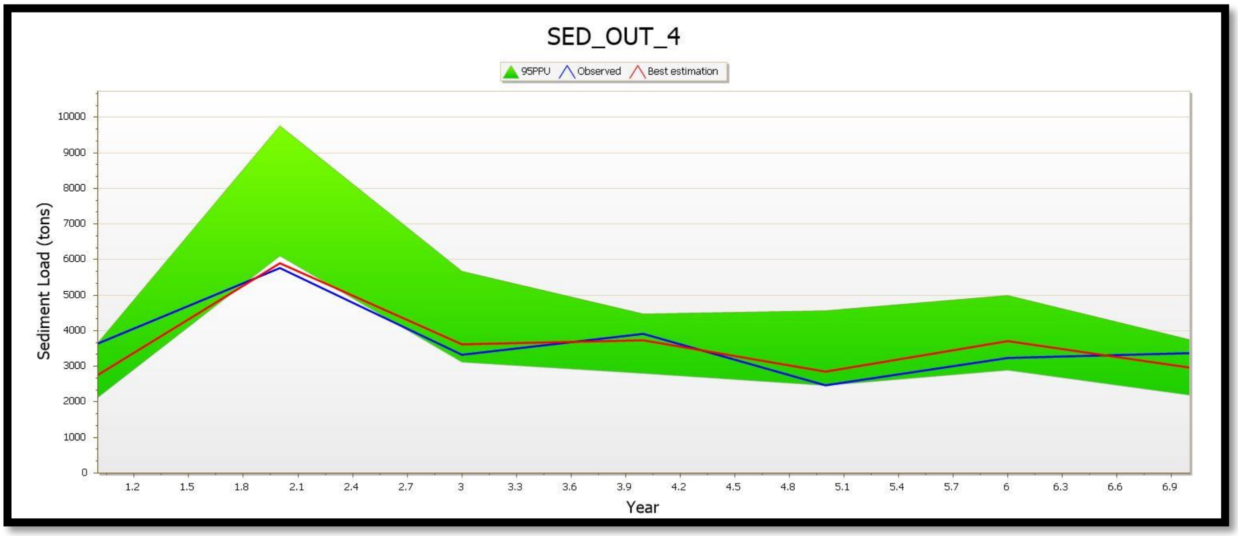


Summary statistics

Goal_type= Nash_Sutcliff No_sims= 500 Best_sim_no= 34 Best_goal = 6.021255e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)
FLOW_OUT_4	0.85	1.19	0.61	0.60	0.3906	9.8e+000	3.4e+000	-2.5	0.72	0.63	0.40	0.98		3.51(3.42)

Appendix12: SWAT-CUP output 95ppu Plot for sediment calibration period (1994-2000)

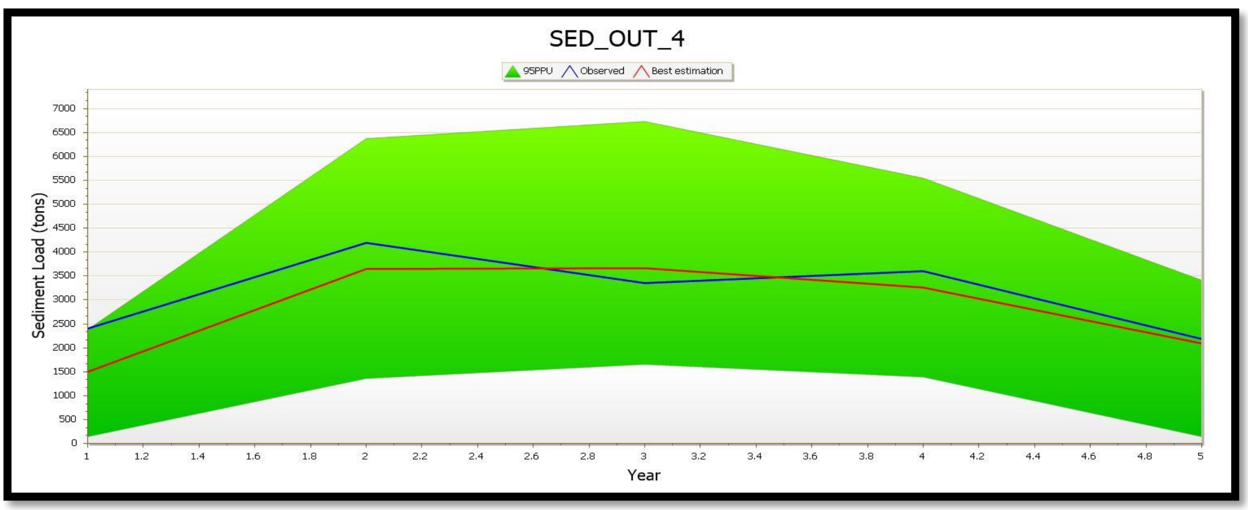


Summary statistics

Goal_type= Nash_Sutcliff No_sims= 500 Best_sim_no= 438 Best_goal = 7.661557e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)
SED_OUT_4	1.00	2.29	0.79	0.77	0.7495	2.1e+005	7.1e+004	0.7	0.88	0.48	0.40	1.01		3667.14(3694.54)

Appendix13: SWAT-CUP output 95ppu Plot for sediment validation period (2005-2009)



Summary statistics

Goal_type= Nash_Sutcliff No_sims= 500 Best_sim_no= 51 Best_goal = 5.180131e-001

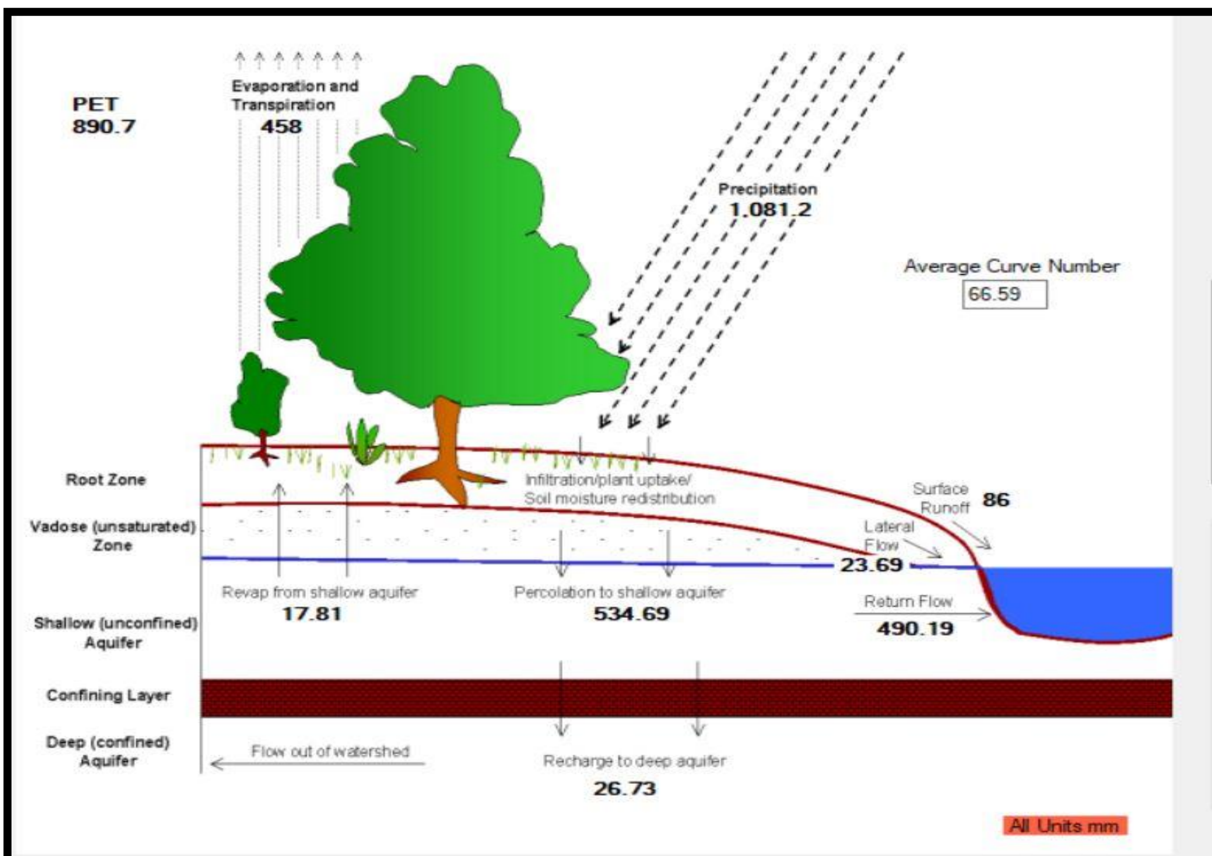
Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)
SED_OUT_4	1.00	5.26	0.78	0.52	0.7521	2.7e+005	1.7e+005	10.1	0.77	0.69	0.35	1.11		2843.80(3161.78)

Appendix14: Annual precipitation for selected stations (mm)

Year	Agarfa	Deloserbo	Gassera	Ginnir	Goba	Jarra	Robe
1987	915.5	935.5	837.06	1230.5	923.55	2325.92	860.8
1988	958.02	1077.5	850.93	1252.38	939.68	1137.1	877.46
1989	780.8	1031.1	765.02	911.3	875.56	2088.57	810.35
1990	984.42	707.3	881.85	892.35	967.41	1051.97	906.9
1991	735.8	720.3	511.52	772.9	665.65	841.46	589.69
1992	1050.5	1159.06	905.66	1354.8	993.24	1419.03	933.76
1993	964	984.4	818.83	1231.71	905.76	1415	842.1
1994	1022.3	918.8	857.77	837.48	946.15	1078.8	884.55
1995	856.67	1067.8	742.7	686.35	831.28	1625.4	763.8
1996	1291.4	1226	870.11	994.9	976.34	1152.5	916
1997	1517.9	884.5	871.43	1086.7	1235.33	1231.1	896.2
1998	1855.4	925.4	903.94	911.7	1224	981.5	934.31
1999	1400.43	1081.4	851.39	725.9	859.7	1202.7	877.85
2000	1363.5	936.8	752.39	697.32	938	942.2	785.58
2001	1345.94	1080.9	796.66	660.7	1233.1	940.19	819.3
2002	1215.3	944.2	630.77	810.7	799	760.01	648.7
2003	806.3	854.9	866.75	713.6	921.3	578.7	891.4
2004	1004.5	1138.71	859.69	840.6	974.19	659.3	895.88
2005	1044	838.42	657.16	939.48	881.65	859.22	713.48
2006	816.56	1436.14	958.21	1417.3	1382.47	1461.26	1053.7
2007	1108.1	1032.4	891.16	1084.21	1118.89	1571.44	973.02
2008	998.34	1029.69	804.85	1158.18	934.31	1006.88	827.7
2009	842.47	731.46	727.73	1360.7	684.95	1131.88	748.4
2010	1168.7	1246.47	1037.58	1700.6	803.19	1652.59	1071.81
2011	571.25	1013.03	747.95	1024.6	642.11	1155.51	769.2
2012	724.48	1149.07	831.69	1243.5	691.09	1310	855.3
2013	894.8	1343.26	981.62	1450.1	767.22	1556.39	1009.5
2014	552.65	794.94	804.15	1402.35	793.14	1089.6	739.84
2015	494.9	626.04	698.3	951.9	595.42	1177.67	773.51
2016	743.21	870.49	887.5	939.4	924.92	1193.12	861.93

Appendix15: Simulated Average Monthly Basin Values

Average Monthly Basin Values								
MONTH	RAIN (mm)	SNOW FALL (mm)	SURF Q (mm)	LAT Q (mm)	WATER YIELD (mm)	ET (mm)	SED YIELD (Ton/ha)	PET (mm)
1	27.5	0	4.28	0.91	47.02	14.49	0.24	73.09
2	10.26	0	0.14	0.36	21.78	13.64	0	78.53
3	51.68	0	2.13	0.6	13.24	39.82	0.15	89.48
4	138.27	0	10.92	1.8	24.01	66.84	0.28	85.61
5	140.7	0	10.36	2.8	44.7	60.87	0.28	76.48
6	82.02	0	9.83	2.19	52.71	38.32	0.28	67.31
7	82.81	0	6.58	1.65	47.28	38.65	0.19	71.14
8	82.96	0	5.1	1.92	44.15	37.12	0.15	73.73
9	158.93	0	11.06	2.88	54.37	46.24	0.36	74.98
10	193.31	0	16.63	4.44	87.79	47.74	0.51	72.52
11	84.02	0	7.12	2.81	94.05	32.36	0.25	63.88
12	28.96	0	1.86	1.33	74.08	22.26	0.08	65.89



Appendix16: Simulated Average Annual Basin Values

Average Annual Basin Values

Precipitation = 1081.2mm
Snow Fall = 0.00 mm
Snow Melt = 0.00 mm
Sublimation = 0.00 mm
Surface Runoff Q = 86.00 mm
Lateral Soil Q = 23.69 mm
Tile Q = 0.00 mm
Groundwater (Shal Aq) Q = 490.19 mm
Groundwater (Deep Aq) Q = 26.84 mm
Revap (Shal Aq => Soil/Plants) = 17.81 mm
Deep Aq Recharge = 26.73 mm
Total Aq Recharge = 534.69 mm
Total Water Yld = 604.63 mm
Percolation Out Of Soil = 511.38 mm
ET = 458.0 mm
PET = 890.7mm
Transmission Losses = 22.12 mm
Total Sediment Loading = 2.79 T/Ha