Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies

Modeling of Sediment Yield at Kesem Dam and Identifying Soil and Water Conservation Measures

A thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Major Hydraulic Engineering)

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BY

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CERTIFICATION

I, the undersigned, certify that I have read the thesis entitled 'Modeling of Sediment Yield at Kesem Dam and Identifying Soil and Water Conservation Measures' and here by recommended for acceptance by the Addis Ababa institute of Technology in partial fulfillment for the requirement of the degree of Master of Science in Civil and Environmental Engineering majoring Hydraulic Engineering.

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DECLARATION AND COPYRIGHT

I, hereby declare that this thesis is my own original work and it has not been presented for a degree in any other University, and that all sources of material have been duly acknowledged.

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ABSTRACT

Soil erosion reduces not only soil productivity of the area but also reservoir capacity. The information on sources of sediment yield within a catchment can be used as a perspective on the rate of soil erosion occurring within that catchment. The objective of this study was to model and analyze the potential soil erosion of the catchment, to estimate the sediment yield of the watershed, and recommend appropriate soil and water conservation measures regarded as the best management activities of the watershed. A SWAT 2012 (Soil and Water Assessment Tool) model was selected for the simulation of the soil erosion and sediment yield of Kesem watershed which is located in Middle Awash sub basin, Ethiopia. Model calibration and validation were done after checking the performance of sensitive analysis. Twenty one parameters were identified for flow calibration and of which the Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (CN2) was the most sensitive one and twelve parameters were selected for sediment calibration of which an effective hydraulic conductivity (CH_K2) was the most sensitive for sediment. During flow calibration the R^2 and NS give as value of 0.68 and 0.67 respectively, and similarly for validation the R^2 and NS give as value of 0.65 and 0.60, respectively. For sediment calibration the R^2 and NS coefficient give as 0.77 and 0.64, respectively and sediment validation R^2 and NS give as 0.65 and 0.54, respectively. The calibration and validation results found were good and satisfactory for both flow and sediment. The total observed flow for study area at gauged station was 15.52m^3/s and the simulated flow by SWAT model was 14.15m^3/s and observed annual sediment yield generated from rating curve at selected gauging station was found 29.62ton/ha/yr and the simulated yield by SWAT model was 25.75ton/ha/yr. From the model simulated output, sub-basins 2, 7, 5, and 18 were found to be the severely eroded sub-basins with annual average sediment yield of 22.01t/ha, 19.29t/ha, 19.09t/ha and 18.93t/ha, respectively. While, sub-basins 12 and 13 were found to be the least sediment sources with annual average sediment yield of 0.03 t/ha and 0.06t/ha respectively. Six scenarios were developed to decrease sediment yield in the catchment and sediment management approach were proposed in the Kesem catchment.

***Keywords**: Kesem watersheds, Soil erosion, Sediment yield, SWAT model, Scenarios.*

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List of Abbreviations

ABA	Awash Basin Authority
AMC	Antecedent Moisture Condition
BMPs	Best Management Practices
DEM	Digital Elevation Model
EEPU	Ethiopian Electric Power Utility
FAO	Food and Agriculture Organization
GIS	Geographical Information System
ha	hectare
HRU	Hydraulic Response Unit
masl	meters above sea level
Mm^3	Million meter cube
m^3/s	Meter cube per second
MoWIE	Ministry of Water, Irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
ENMSA	Ethiopian National Meteorological Services Agency
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent bias
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
tons/ha/yr	Tonnes per hectar per year
WWDSE	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1 Background

Materials derived from bedrock through physical and chemical weathering processes are the main source of sediments. Soil erosion reduces not only soil productivity but also reservoir capacity (Duru, 2015). It can cause in lowering the capacity of land productivity temporarily or permanently. Vast areas of land now being cultivated may be rendered economically unproductive if the erosion of soil continues unabated. Erosion accelerates on-site and off-site problems. On-site effects mainly refer to soil nutrient losses. The most significant off-site effect of soil erosion is loss of water storage capacity because of sediment deposition in a reservoir. Sediment is detached from the soil surface both by raindrop impact and by the shearing force of flowing water. The detached sediment is transported down slope primarily by flowing water, although there is also a small amount of down slope transport by raindrop splash. Once runoff starts over the surface areas and in the streams, the quantity and size of material transported increases with the velocity of the runoff. At some point, the slope may decrease, resulting in a decreased velocity and hence a decreased transport capacity. The sediment is then deposited, starting with the large primary particles and aggregates. Smaller particles are transported further down slope, resulting in the enrichment of fines. The amount of sediment load passing the outlet of a catchment forms its sediment yield. Sediment yield which defined as the total sediment out flow from watershed is that includes both bed and suspended materials. Also it is a function of amount absolute or gross erosion in the watershed and the efficiency of stream system to transport eroded material out of the watershed. Therefore, sediment yields are closely related to soil erosion.

The estimation of sediment yield from the catchment is useful for reservoir sedimentation, river morphology, soil and water conservation planning, and also estimation of concentration and load of chemical adsorbed to sediment particles. Sedimentation in a reservoir can be defined by trap efficiency which is the ratio of the deposited sediment quantity to the total sediment inflow. Trap efficiency is a function of the volume and grain-size distribution of sediment, outlet works, and method of reservoir operation (Eizel-Din *et al*., 2010).

The information on sources of sediment yield within a catchment can be used as a perspective on the rate of soil erosion occurring within that catchment.

Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. Soil erosion leads to loss in soil fertility and sedimentation of water bodies with associated negative impacts. The negative changes in soil quality are a worldwide concern, particularly in developing countries where soil erosion is becoming a limiting factor in increasing or even sustaining agricultural productivity (Arekhi, 2008).

Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main factors that accelerate soil erosion in Ethiopia. The annual rate of soil loss in the country is higher than the annual rate of soil formation rate. Annually, Ethiopia losses over 1.5 billion tons of topsoil from the highlands to erosion which could have added about 1.5 million tons of grain to the country's harvest (Tamene, 2008). This indicates that soil erosion is a very serious threat to food security of people and requires urgent management intervention.

To circumvent the impacts of erosion, it is important to know the severity of the problem and the main controlling factors. Since different portions of the landscape vary in sensitivity to erosion due to differences in their geomorphological, geological, and vegetation attributes, it is also necessary to identify high erosion risk areas in order to plan site-specific management interventions. Depending on the prevailing erosion processes and controlling factors, the efficiency of soil conservation measures may vary. This calls for the assessment of the soil conservation potential of different management practices. This study was conducted in southern part of Afar Regional state in Ethiopia in order to analyze spatial patterns of soil erosion, assess rates of soil loss, and management alternatives. There is a severe soil erosion problem in the Upper Kesem watershed, particularly in the northern hills and in the gorges, where very steep slopes are being cultivated, for example, in some areas slopes with gradients of over 20%. These soil erosion and sediment load come from the upper stream of the watershed have a negative impact on the Kesem dam reservoir and downstream commend area. The objectives of this research were to use GIS and SWAT for the discretization of the catchments into small grid cells and for the computation of such physical characteristics of these cells as slope, land use and soil type, all of which affect the processes of soil erosion and deposition in the different sub-areas of a catchment.

1.2 Statement of the Problem

Soil erosion of Kesem Dam catchment is also substantial since the upper reaches of the catchment is intensely cultivated followed by steeper topography with an easily erodible soils and fairly low vegetation cover, down until the reservoir area. Deforestation, overgrazing and poor land management practices are some that accelerate the rate of soil erosion. The topography of Ethiopia in general and Kesem watershed in particular is undulating. Also agricultural activities are traditional and they use poor farming system which means local farmers commonly cultivate on the hilly sides causing easy topsoil wash away. These increases soil erosion and sediment transport in the watershed. The current level of degradation leading to erosion, and sedimentation are causing considerable loss of soil. As a consequence, the soils are becoming shallow, less fertile. Due to this, runoff and sediment coming from this watershed increase Kesem Dam reservoir siltation. Estimation of the spatial variability of sediment yield, identifying critical micro watersheds and evaluating various conservation measures in reducing runoff and sediment yield based on the simulation result of a physically based and spatially distributed SWAT (Soil and Water Assessment Tool) model is needed.

1.3 Objective of the Study

1.3.1 General Objective

The overall objective of this study is to model and analyze the potential soil erosion of the catchment and to estimate the sediment yield of the watershed and recommend appropriate soil and water conservation measures regarded as the best management activities of the watershed.

1.3.2 Specific Objectives

- To analysis the current and future soil erosion potential of the catchment
- To estimate sediment yield of the catchment
- To identify appropriate soil and water conservation measures in the catchments

1.4 Scope of the Study

The study mainly focuses on the estimation of catchment sediment yield at Kesem Dam and analysis of soil erosion potential using SWAT model for Kesem watershed. Model efficiency valuation and quantification of sediment yield and identification of sensitive areas of the watershed would be done. Generally, the purpose of this study is to estimate catchment sediment yield and how to reduce sediment deposing in the reservoir by using Soil and Water Assessment Tool model and recommend appropriate soil and water conservation measures in the catchments.

1.5 Thesis Outline

This thesis contained five chapters.

- Chapter one presented the introduction, statement of problem, objective that include general and specific objective and thesis out line
- Chapter two describes literature review related to the soil erosion, sediment yield and SWAT model descriptions
- Chapter three provides a description of the study area and data availability that include model input data collection and data analysis method presented in the detail
- Chapter four deals with discussion of the research founding
- The last chapter presented conclusion, recommendation, reference and appendix

2. LITERATURE REVIEW

2.1 Watershed management

Watershed is the geographical area drained by a watercourse, and watershed management as any human action aimed at ensuring a sustainable use of watershed resources (FAO, 2007). Watershed management involves examining the interaction among various natural processes and land use and managing land, water and the wider ecosystem of the watershed in an integrated way (FAO, 2017). According to the World Bank (Darghouth *et al*., 2008), the term 'watershed management' typically refers to management at the level of a micro or sub-watershed (whereas action at the level of the entire watershed system, sometimes across country boundaries and with a focus on institutional and policy issues, is usually called basin management).

Watersheds are usually delineated from surface topography, which include areas that provide water to the point through lateral flow over the surface and underground. It is also appropriate for most hydrological studies (Mulligan, 2004) and is widely used by many scientists. Scientific management of soil, water and vegetation resources on watershed basis is, very important to arrest erosion and rapid siltation in reservoirs, rivers and lakes. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme. Sharma *et al* (2003) and Suresh *et al* (2004) have found watersheds as appropriate units for prioritizing their study areas based on the soil erosion indexes.

2.2 Soil erosion

Soil erosion is one of the most serious environmental degradation problems that adversely affect many natural and human-managed ecosystems. In agricultural watersheds, soil erosion not only removes nutrient-rich top soil on site, but also degrades water quality as a result of transported sediments off site (Lal, 1998 and Zhu *et al.,* 2013). Therefore, it is a major cause of reduced agricultural productivity and water pollution.

Soil erosion is also the gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate its quality. In face of this, soil erosion due to running water has been one of the most pressing environmental problems throughout the world. The most commonly recognized forms of water erosion are splash erosion, sheet erosion, rill erosion, gully erosion and stream bank erosion. Soil erosion is a complex dynamic process by which productive surface soil are detached, transported and accumulated in a distant place resulting in exposure of sub-surface soil, and siltation in reservoir or natural stream (Verma *et al.,* 1995). The scientific approach for modeling of soil erosion and watershed management based on defined objective criteria is really important.

One important feature of soil erosion by water is the selective removal of the finer and more fertile fraction of the soil. A study by Bobe (2003) indicated that water erosion had accounted for about 55% of the 2 billion ha of the degraded soils in the world. There is no region of the globe where water erosion is not a threat to the long-term sustainability of mankind.

2.2.1 Factors affecting soil erosion

Erosion is controlled by many factors as described below:

2.2.1.1 Rainfall Intensity

The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall. According to Morgan (1995) soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills for which intensity is generally considered to be the most important rainfall Characteristics. Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms.

2.2.1.2 Topography

Soil erosion by water is a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. Naturally, the steeper the slope of a field, the greater would be the amount of soil loss by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment). Runoff velocity and effective depth of interaction between surface soil and runoff is increased with increase in slope. Some researchers, for instance (Bobe, 2004) indicated that soil erosion increases exponentially with increase in slope gradient.

2.2.1.3 Soil Erodibility

The term soil erodibility is limited to inter rill and rill erosion. It refers to the resistance of the soil to both detachment and transport by the eroding agent. Hudson (1996) defines erodibility as the specific property of soil, which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances. Generally soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. That is, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. Soil texture (particle size composition i.e. sand, silt, and clay), organic matter, structure, and permeability are major factors that affect soil erodibility. Soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content.

Soils high in silt and low in clay are highly erodible (Ringo, 1999). The high erodibility of silty soils is explained by their weak structural stability. They rapidly form surface sealing upon raindrop impact. Erosion is less on clayey soils due to their better aggregation. The large pores between sand particles permit rapid water movement hence reducing soil erosion. This researcher shows that erodibility decreases with increasing aggregate stability, as seal formation is delayed and infiltration increases. Large stable aggregate makes soil difficult to detach and transport, hence, it makes it more permeable to water.

2.2.1.4 Sealing and Crusting

Soil sealing is the formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling, or sedimentation, which is relatively impermeable to air and water (Bergsma *et al.*, 1996). It is due to the effect of raindrop on bare soil, which results in reduction of infiltration; and increase in runoff and the potential for the soil erosion. Sealing soils often generate more surface runoff, and therefore a greater hazard for rill erosion. Rainfall with a high cumulative energy causes sealing later, and to a smaller degree than lower cumulative rain energies.

Bobe, (2004) wrote that crust can be much more compact, hard and brittle when dry than the material immediately beneath it. He also put the relation between seal and crust as, all seals are crusts but not all crusts are seals. Crusts are characterized by increased soil surface strength and density that leads to reduced porosity due to change in pore size distribution and infiltration thereby leading to high runoff and erosion rate.

2.2.1.5 Vegetation Cover and Management

Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. Materials in contact with the soil surface reduce erosion more effective than a canopy. No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy. Besides, such materials slow the runoff, which increases the flow depth. This increased flow depth decreases detachability by cushioning the impact of the raindrops. Cover in contact with the soil surface also absorbs much of the flow’s eroding and transporting force, which greatly reduces erosion. Strips of dense mulch and grasses can induce deposition and filter sediment from the runoff.

2.3 Soil Erosion Modeling

Erosion modeling is based on understanding of the physical laws of landscape processes that occur in the natural environment. Erosion models can provide a better understanding of natural phenomena such as transport and deposition of sediment by overland flow and allow for reasonable prediction and forecasting. Many different models have been proposed to describe and predict soil erosion by water and associated sediment yield. They vary considerably in their objectives, time and spatial scales involved. Modeling soil erosion is a process of mathematically describing soil particle detachment, transport and deposition of land.

Jasrotia (2002) indicates that there are at list three reasons for modeling erosion as given below:

i. Erosion can be used as productive tool for assessing soil loss for conservation planning, project planning, and soil erosion inventories and for formulating regulations.
ii. Physical base mathematical models can predict where and when erosion is occurring thus helping the conservation plan target to reduce erosion.
iii. Models can be used as a tool for undertaking process and their interactions for setting reserve priorities.

2.4 Sediment Property and Sediment Load

Soil physical and chemical properties profoundly influence how soils function in an ecosystem and how they can best be managed (Brady and Weil, *et al*., 2008). Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Once the sediment particles are detached, they may either be transported by gravity, wind or/and water. When the transporting agent is water, it is called fluvial or marine sediment transport. The process of moving and removing from their original source or resting place is called erosion. In a channel**,** the water flow erodes the available material in the banks and/ or the stream bed until the flow is loaded with as much sediment particles as the energy of the stream will allow it to carry.

Usually, three modes of particle motion are distinguished: i) Rolling and/or sliding particle motion ii) Siltation or hopping particle motion iii) Suspended particle motion.

When the value of the bed-shear velocity just exceeds the critical value for initiation of motion, bed material particles will be rolling and/or sliding in continuous contact with the bed. For increasing values of the bed-shear velocity the particles will be moving along the bed by more or less regular jumps, which are called siltation. When the value of the bed-shear velocity begins to exceed the fall velocity of the particles, the sediment particles can be lifted to a level at which the upward turbulent forces will be of comparable or higher order than the submerged weight of the particles and as a result the particles may go into suspension. The suspended load may also include the fine silt particles brought into suspension from the catchment area rather than from streambed material (bed material load) and is called the wash load. A grain size of is frequently used to make the separation between bed material load and wash load. Based on energy considerations it can be shown that all particles with a fall velocity smaller than or equal to depth-averaged velocity can be transported in unlimited quantities, the latter being a typical feature of wash load transport.

Bed load and suspended load may occur simultaneously, but the transition zone between both modes of transport is not well-defined. Sediment transport by flowing water is strongly linked to surface soil erosion due to rain. The whole process can be seen as a continuous cycle of soil erosion, sediment transport, sediment deposition, soil erosion and sediment yield (in tones per km^2 per year) strongly depend on the local climatic (rain fall), soil, land (surface slope) and vegetation conditions. Proper land use and management can substantially reduce the problems related to sediment transport in rivers and reservoir.

The design of work (terracing, debris dams and slope fixation) can also help to control surface erosion.

2.5 Erosion and Sediment Transport in the Catchment

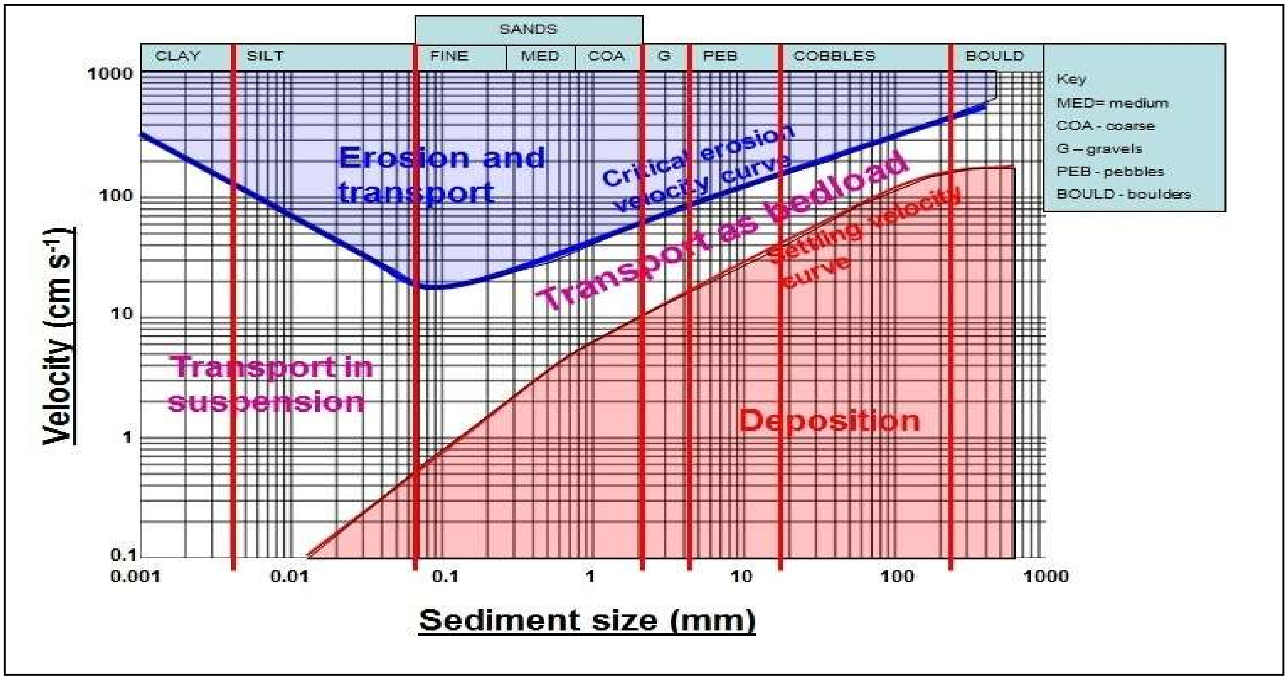
The sediment which is transported in catchment or rivers originates from soil erosion caused by water with heat and frost being significant assisting forces. Sources of Sediment transported in a river or the catchment (sheet, rill, and gully erosion), the tributaries, bed erosion, bank erosion including landslides and falling rocks. Sediment transport can take place in various forms, according to the hydraulic conditions provided by the flow, and according to the properties of the sediment. Bed load and suspended load are only rough and ready, but inaccurate, classifications of the phenomena taking place in the catchment or river. There is no clearly defined separation point between the two kinds of motion in nature.

There are three basic processes in erosion by water, namely, detachment, transport, and deposition. Detachment occurs when the erosive forces of raindrop impact and surface runoff exceed the soils' resistance to erosion. Transport of detached particles is by raindrop splash and flow. The sediment transported by the river flow is usually not uniformly distributed. Deposition occurs when the sediment load of a given particle type exceeds its corresponding transport capacity. The relative importance of these fundamental processes depends on whether the processes are leading to inter rill or rill erosion occurrence and on the levels of the controlling variables, such as the slope steepness and length, soil surface cover, amount of and intensity of rainfall, and conservation practice. Deposition occurs if sediment inflow from the inter rill areas exceeds the transport capacity of flow in the rills. If the sediment inflow is less than the transport capacity of flow, and if the flows erosive forces exceed the resistance of the soil to detachment, rill occurs.

Sediment yield models vary greatly in complexity from simple regression relationships linking annual sediment yield to climatic and physiographic variables, semi distributed physics based models such as a SWAT, to complex distributed simulation models (Garde and Ranga Raju, 2000). Formal erosion modeling or some other systems can be used to quantify erosion and sediment yield. Determining the sediment delivery ratio is a critical step in converting estimates of soil erosion within a basin into a quantitative value of sediment yield (Morris and Fan, 1998). Sediments and associated pollutants mobilized by sheet and rill erosion may be re-deposited by a variety of mechanisms prior to reaching stream channels, where transport processes are generally more efficient.

The sediment that is transported by the river has varying sizes in terms of diameter. In regions where the sediment transported in the river is relatively coarse consisting of sand, gravel or coarser particles it is possible to hydraulically determine the sediment yield (Basson, 2008). Sediment yield is the quantity of sediment that has been mobilised from a known catchment area size which is passing through a river channel's reference point in a given time interval. Sediment quantitative analysis is sometimes expressed as total sediment load in a stream. The sediment transport capacity is determined as function of hydraulic conditions and the shape of the stream cross section.

The faster the water is flowing, the larger the particles that can be kept in suspension and transported within the flowing water. However, as Swedish geographer Filip Hjulstrom discovered in the 1940s, the relationship between grain size and the likelihood of a grain being eroded, transported, or deposited is not as simple as one might imagine (Figure 1).



Source: Wikipedia

Figure 1 Relationships b/n particle size and the tendency to eroded, transported, or deposited at d/t current velocities

Anything smaller or larger requires a higher water velocity to be eroded and entrained in the flow. The main reason for this is that small particles, and especially the tiny grains of clay, have a strong tendency to stick together, and so are difficult to erode from the stream bed.

It is important to be aware that a stream can both erode and deposit sediments at the same time. At 100 cm/s, for example, silt, sand, and medium gravel will be eroded from the stream bed and transported in suspension, coarse gravel will be held in suspension, pebbles will be both transported and deposited, and cobbles and boulders will remain stationary on the stream bed.

2.6 Soil Erosion and Sediment Yield Relationship

Sediment yield from a watershed is an integrated result of all water erosion and transport processes occurring in the entire contributing area (Lane *et al*., 2000). The relationships between erosion and sediment yield include the sediment delivery ration (SDR). Sediment delivery ratio denotes the ratio of the sediment yield (SY) at a given stream cross section to the gross erosion (AT) from the watershed upstream from the measuring point (Julien, 1998). Whereby, the following mathematical relationship is applied:

$$SY = (AT) * (SDR) \quad (1)$$

Equation 1 calculates the gross erosion therefore the sediment delivery ratio was being applied to compute the sediment yield. According to Julien (1998), the sediment delivery ratio is generally dependent on the size of the catchment area. Development of these sediment yield and drainage area relationships requires data on observed sediment yields to validate the relationship between the sediment yield and erosion.

The sediment delivery ratio can only be applied to catchments that are homogeneous with respect to hydrology, erosion and sediment characteristics on which the model results were verified on. According to Birkinshaw (2006) the sediment yield/catchment area relationships can be direct or inverse depending of catchment characteristics. Therefore the concept of sediment delivery ratio is applicable in catchments where reliable calibration was done and the catchment areas are homogeneous.

2.7 Reservoir Sedimentation

Sedimentation is a major problem of reservoir operation in Ethiopia. The reservoir sedimentation involves entrainment, transport and deposition. They originate from the catchments area, river system and settle in reservoirs. As a river enters the reservoir, its cross section of inflow is enlarged due to the effect of the backwater curve. Thus it causes a decrease in the water flow velocity; subsequently the sediment carrying capacity of water is reduced too. The major part, or all, of the sediment transported will deposit in the u/s part of the reservoir influenced by the back water curve. Reservoir sedimentation undergoes different processes of transportation and settling of sediment.

Due to different behavior of sediment particles in transportation and deposition, they have different impacts on the reservoir sedimentation pattern and storage losses. Thus, it is important to treat each type separately, so as to understand how they are deposited and transported in the reservoir. This is hardly needed in analyzing the reservoir sedimentation problem and providing the best measures. The rate of the reservoir sedimentation and form of the deposition is affected by the rate of sediment transport and the method of its deposition in reservoir.

2.7.1 Sedimentation Extent and Subsequent Effect on Dam Reservoir

Sedimentation problems generally occur at locations where the sediment transporting capacity of the hydraulic system is reduced due to the decrease of the steady (currents) and oscillatory (waves) flow velocities and related turbulent motions. Sediment yield is the amount of eroded sediment discharged by a stream at any given point. It represents the total amount of fluvial sediment exported by the catchment tributary to a measurement point, and is the parameter of primary concern in reservoir studies. Because, much eroded sediment is redeposited before it leaves a catchment, the sediment yield is always less than and often much less than, the erosion rate within that same catchment (Morris and Fan, 1997).

Many reservoirs which have been established for hydroelectric power, urban water supply and irrigation accumulate an alarmingly higher level of sediment than expected. Koka, Angereb, Legedadi, Gilgel Gibe-I and other reservoirs are threatened by this accelerated sedimentation. Consequences of reservoir sedimentation include the loss of storage capacity and its subsequent effects.

These effects include water supply shortages for human consumption, irrigation and hydropower; increased hydro-equipment maintenance and repair; a decline in water quality; the cost of removing sediment; blockage of navigational waters and loss of recreation opportunities. Aquatic ecosystems are modified by increased deposition of sediments and adsorbed or dissolved nutrients and chemicals, which commonly causes eutrophication which in turn negatively influences habitats of fish and other organisms. Some of the techniques suggested to reduce reservoir sediment concentration are technically less feasible as it requires design considerations during construction (which is difficult to implement for the existing dams). Removal of sediment is also economically demanding (Kebede, 2012). The deforestation and degradation of the Ethiopian Highlands have a negative impact on the downstream catchments (Awulachew *et al*., 2007; Hathaway, 2008).

Ethiopia is building and planning to build, many hydroelectric power dams hoping electricity will become the biggest export, replacing coffee. The Gilgel Gibe III hydroelectric power project, which will dam the Omo River, creating a reservoir with a live storage of about 11, 750 Mm^3 and a total surface area of 200 km^2 at normal operating level (889 masl) (EEPC, 2009). The reservoir is expected to be 155 km in total length with a catchment area of 34,150 Km^2.

High rates of sedimentation are anticipated in the Gilgel Gibe III reservoir, where one-third of its space is reserved for sediments to accumulate over time (Hathaway, 2008). Heavy sedimentation experienced by Ethiopia's existing dams is a very real risk to the lifespan of new dams. The soon to be constructed on Blue Nile 'Renaissance Dam', which will be the largest hydroelectric dam in the country, is expected to experience a high sedimentation rate. These sediments are currently being captured in the Egypt and Sudan dams but will soon be trapped by the Renaissance Dam.

The Gilgel Gibe I hydroelectric dam has a capacity of 917 Mm^3 water (Devi *et al*., 2007). Hathaway (2008) indicated that according to the 1997 Environmental Assessment on this reservoir, a high sedimentation load was anticipated. The expectation has proven to be true because investigation by Devi *et al* (2007) showed that the reservoir capacity has been reduced by annual sediment loads of 4.50x107 t $year^{-1}$ (from which Gilgel Gibe River contributes 277-437 t $year^{-1}$) which could occupy 3.75x107 $m^3 year^{-1}$. Based on the results of physico-chemical parameters and data obtained using the observational checklists, these researchers, estimated that the Gilgel Gibe I dam's volume will be reduced by half within 12 years and would be completely filled with sediments within 24 years unless timely remedial measures are taken. The dam was originally expected to serve at least for 70 years.

The Aba-Samuel dam in Addis Ababa provided one of the first electric power generating stations in the country. Sedimentation is so prolific that the reservoir's initial water carrying capacity has been reduced by half due to silt accumulation (4.45 tons of silt km^{-2}) and eutrophication (Devi *et al*., 2007). Another, estimate indicates that it is losing storage capacity at a rate of 664, 980 t per year for the 43 years following construction (Amare, 2005).

The Koka reservoir, supplied by the Awash and the Modjo rivers, was formed by the construction of the Koka dam in 1959 (with an original storage capacity 1650 Mm^3) for developing hydroelectric power for domestic use (Musa *et al*., 2005; Shahin, 1993). In 2000, Addis Ababa suffered power outages, even during the rainy season, after turbines at the Koka Dam became clogged with sediment (Hathaway, 2008). Impacts of the Koka reservoir sedimentation have been well documented. In Koka dam, 481 Mm^3 sediment has accumulated displacing an equivalent volume of water with an estimated economic loss of 60 million birr (displacement of 481 Mm^3 of water by sediments translates into an energy loss of 128 M KWh, considering the average energy price of 0.45 Birr/KWh) (Elias, 2003). Flood control capacity is being reduced due to sedimentation, limiting the amount of retained water during the rainy season.

Asmelash *et al* (2017) shows that the sediment outflow from Koka dam reservoir was about 11.2 million ton/yr, even though 20.3 million to/yr amount of sediment has been discharged to this reservoir, implying approximately 9.1 million ton/yr sediment is deposited into the reservoir. The average annual sediment yield of Tendaho Dam watershed was found to be about 5.34to/ha/yr. Out of which, 59.08 million ton/yr reaches at Tendaho dam reservoir (Asmelash *et al*., 2017).

2.8 Hydrological process

Water is present throughout the Solar System, and was part of the Earth from its formation. As shown schematically in Figure 2, the cycle starts when water on the surface of the Earth evaporates. Evaporation means the sun heats the water which turns into gas. Then, water collects as water vapor in the sky. This makes clouds. Next, the water in the clouds gets cold. This makes it become liquid again. This process is called condensation. Then, the water falls from the sky as rain, snow, sleet or hail. This is called precipitation. The precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate in to the ground, flow through the soil as subsurface flow, and discharge in to streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The water sinks into the surface and also collects into lakes, oceans, or aquifers. It evaporates again and continues the cycle.

Although the total volume of water in the global hydrologic cycle remains essentially constant, the distribution of this water is continually changing on continents, in regions, and within the local drainage basin. The hydrology of a region is determined by its weather patterns and by physical factors such as topography, geology and vegetation. Also, as civilization progresses, human activities gradually encroach on the natural water environment, altering the dynamic equilibrium of the hydrologic cycle and initiating new process and events.

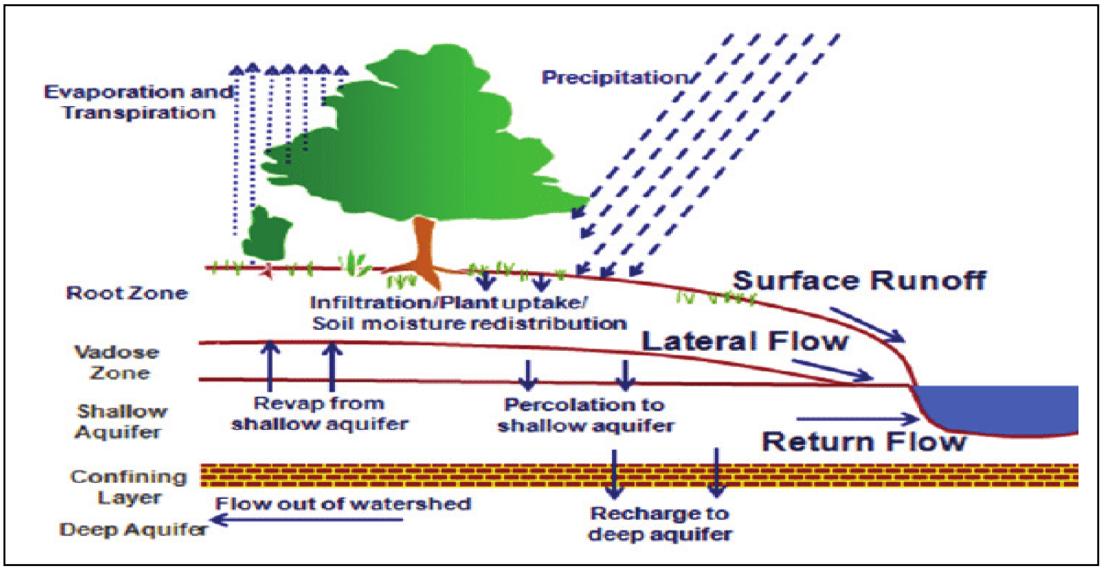


Figure 2 Hydrological process

2.9 Hydrological Model

Hydrologic models are widely used across the globe to simulate hydrologic process including quality and quantity of stream flow in a basin (Abbaspour, 2007). It is highly labor, time, and cost intensive for maintaining gauging stations to collect water quality and quantity from a number of locations for long-term (Fekete, 2007). Hence, it used to develop a means of extrapolating from those available measurements in space and time to ungauged catchments and into the future to assess the likely impact of future hydrological changes. Therefore, hydrologic models play a significant role in simulating a various hydrologic processes such as rainfall-runoff conceptualization, sediment yield, and water quality and quantity. A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes for which the modeling is made.

2.9.1 Types of Hydrological Model

Process-based distributed watershed models that provide a realistic approximation of the watershed system are valuable tools for quantification and spatial distribution of runoff and soil loss processes across the watershed (Bieger *et al.,* 2014). During recent years, there has been an increase in the development and use of these models (Yang and Wang, 2010). There are ranges of models that are available for simulating long-term trends of hydrologic processes at small and larger watershed scales.

Three main categories: Lumped, Semi-distributed & Distribute.

Lumped models: Parameters do not vary spatially within the basin & response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. Parameters do not represent physical features of hydrologic processes; model parameters – area weighted average. Not applicable to event based processes, discharge prediction at outlet only, simple and minimal data requirement, and easy use. Example SCS-CN based models; IHACRES, WATBAL etc.

Semi-distributed models: parameters are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. Mainly two types; i) Kinematic wave theory: simplified version of surface flow equations of physically based model, and ii) Probability distributed models: spatial resolution is accounted for by using probability distributions of input parameters across the basin. It is simplified versions of the surface or subsurface flow equations of physically based hydrologic models. Examples: SWMM, HECHMS, TOPMODEL, SWAT etc.

Distributed models: Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. The model approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. It requires large amount of data and highest accuracy in the rainfall-runoff modeling, if accurate data is available. Governing physical processes are modeled in detail.
The Distributed model requires high computational time, experts and Cumbersome. Examples: HYDROTEL, MIKE11/SHE, WATFLOOD etc.

One of the most widely applied watershed models is SWAT which has been extensively used for simulating hydrologic and water quality processes in watersheds with a wide range of scales and environmental conditions (Gassman *et al.,* 2007). Several past studies indicated that SWAT is capable of modeling data-scarce and ungauged watersheds with reasonable accuracy (Bieger *et al.,* 2014, Kumar *et al.,* 2015, and Mekonnen *et al.,* 2009). Therefore, SWAT model is selected as an appropriate model for this study.

2.10 Description of SWAT model

SWAT is a process-based, semi-distributed, and continuous-time watershed-scale model that is designed to simulate hydrology as well as erosion and transport of sediment, nutrients, and agricultural chemicals in large ungauged watersheds (Neitsch *et al.,* 2011). The model is capable of simulating main eco-hydrological processes including water flow, erosion, sediment, nutrient and pesticide transport, and plant growth.

In the SWAT model, the modeling or estimation of flow, sediment or nutrient transport of the watershed is done by dividing the watershed into sub basins and the land areas in the sub basins are also sub divided again into one or more land units, possessing similar land use, soil type and applied management strategies called hydrological response units (HRUs). HRUs represent lumped areas within a sub-basin with a unique combination of land use, soil type, and slope (Neitsch *et al.,* 2011).The HRUs are helpful for better estimation of the loadings (flow, sediment, pollutants) from the sub basins.

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

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. In land phase of the hydrologic cycle controls the amount of water, sediment, and nutrient and pesticide loadings to the main channel in each sub basin. The second division is the water or routing phase of the hydrologic cycle. In routing phase define the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

Land phase of the Hydrologic cycle: It Controls the amount of water, sediment, nutrient and pesticide loading to the main channel. The land phase of the hydrologic processes is simulated based on the water balance equation (Neitsch et al, 2005) and computed by water balance equation:

$$SW_t = SW + \Sigma(R_{day}-Q_i-E_a-P_i-QR_i) \ldots\ldots (2)$$

Where: SW, soil water content, t is time, R_{day}, amount of precipitation, Q_i, amount of surface runoff, E_a, amount of evapotranspiration, P_i, amount of percolation, QR_i, amount of return flow.

Estimation of surface runoff: the most commonly used method in SWAT model for estimating surface runoff is SCS curve number method (SCS, 1972).

$$Qsurf = \frac{(R_{day}-I_a)^2}{(R_{day}-I_a+S)} \ldots\ldots (3)$$

Where, Qsurf-accumulated runoff or rainfall excess (mm), Rday-rainfall depth for the day (mm), Ia-initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm), S -retention parameter (mm).

The retention parameter varies spatially due to changes in soil water content. The retention parameter is defined as:

$$S = 24.5 + \left[\frac{100}{CN} - 10\right] \ldots\ldots (4)$$

Where, CN -curve number for the day, the constant 25.4, in equation used to convert the gives S in to mm.

The SCS curve number depends upon soil type, land use/cover and Antecedent Moisture Conditions (AMC). The hydrologic soils are classified as A, B, C and D depends upon the infiltration and other characteristics. As the order increases from A to D, the runoff potential increases and the infiltration rate decreases. Group A have the lowest and group D have the highest runoff potential. Antecedent

Moisture Conditions (AMC) refers the moisture content present in the soil at the beginning of rainfall runoff event. Antecedent Moisture Conditions (AMC) classified based upon the soil moisture content: AMC-I (wilting point), AMC-II (average moisture and AMC-III (field capacity).

SWAT uses AMC-II for CN estimation. The values of curve number for different land use conditions and hydrologic soil groups are given by by Dhruva Narayana, (1993), this gives the curve number for antecedent moisture condition (AMC)-II i.e., for average condition.

Once SWAT decides the loadings of water and sediment to the main channel, the loadings are routed through the stream network of watershed using Muskingum routing method (Chow *et al.,* 1988).

Sediment component: SWAT computes erosion for each HRU caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE). Erosion and sediment yield estimation from SWAT for each sub basin using Modified Universal Soil Loss Equation (MUSLE), Williams (1975) given below.

$$Sed=118* (QSurf*qpeak*Ahru)\ 0.56*KUSLE*CUSLE*PUSLE*LSUSLE*CFRG \ldots\ldots\ldots (5)$$

Where, Sed is the sediment yield on a given day in metric tons, Qsurf is the surface runoff from the watershed in mm/ha, qpeak is the peak runoff rate in cubic meter per second, Ahru is the area of HRU, KUSLE is the USLE soil erodability factor, CUSLE is the USLE land cover and management factor, PUSLE is the USLE support practice factor, LSUSLE is the USLE topographic factor, and CFRG is the coarse fragment factor. In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

Sediment generation is calculated individually for each HRU and then summed to determine total sub-basin (Arnold *et al.,* 1998). Surface runoff (Q) is directly taken from the runoff calculation and peak runoff rate q_p calculated with a modified rational method, the rate of runoff will increase until the time of concentration, t = tc, when the entire sub-basin area is contributing to flow at the outlet.

The rational formula is,

$$q_{peak} = \frac{C*i*Area}{3.6} \quad (6)$$

Where, q_{peak} - peak runoff rate (m^3/s^{-1}), C - runoff coefficient, I - rainfall intensity (mm/h), Area - sub-basin area (km^2) and 3.6 is a unit conversion factor (Neitsch *et al*., 2005).

In land component, SWAT keep tracks the particle size distribution of eroded sediments and routes them through ponds, channels, and surface water bodies.

The sediment yield in the land is lagged and routed through grassed waterway, vegetative filter strips and ponds, if available, then reaching the stream channel. Thus, the sediment yield reaching the stream channel is the sum of total sediment yield calculated by MUSLE minus the lag, and the sediment trapped in grassed waterway, vegetative filter strips and/or ponds (Neitsch *et al.,* 2011).

Sediment routing is the function of peak flow rate and mean daily flow. When the watershed was delineated into smaller sub basin, each sub basins has at least one main routing reach. Therefore, the sediment from upland sub basins is routed through these reaches and then added to downstream reaches. To do this, SWAT uses the simplified version of Bagnold equation (Bagnold, 1977) and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity.

$$\text{Conc sed, ch, mx} = C_{sp} * V_{ch,pk}{}^{sp\ exp} \quad (7)$$

Where, *concsed,ch,mx* - maximum concentration of sediment that can be transported by water (ton/m^3 or kg/l), *Csp* and *sp* exp - coefficient and exponent of the equation defined by the user, and $V_{ch,\ pk}$ - peak channel velocity (m/s). The exponent *sp* exp normally varies between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation (Arnold *et al.,* 1995).

$$V_{ch,pk} = \frac{q_{ch,pk}}{A_{ch}} \quad (8)$$

$$q_{ch,pk} = prf * q_{ch} \quad (9)$$

Where, $q_{ch,\ pk}$ - peak flow rate (m^3/s), A_{ch} - cross-sectional area of flow in the channel (m^2), *Prf* - peak rate adjustment factor, and q_{ch} - average rate of flow (m^3/s).

The routing in the river reach starts off by comparing the maximum concentration of sediment above to the concentration of sediment in the reach at the beginning of the time step, conc*sed ch i*. If conc*sed, ch, i* > *concsed, ch, mx* deposition is the dominant process in the reach segment and the net amount of sediment deposited is calculated as in equation (10) below.

$$Sed_{dep} = (Conc_{sed,ch,i} - Conc_{sed,ch,mx}) * V_{ch} \qquad (10)$$

On the other hand, if conc*sed, ch, i* < *concsed, ch, mx* degradation is the dominant process in the reach segment and the net amount of sediment re-entrained is calculated as in equation (11) below.

$$Sed_{deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \qquad (11)$$

Where, Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), Concsed,ch,i is the amount of initial sediment concentration in the reach (kg/l or ton/m^3), Concsed,ch,mx is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m^3), K_{ch} is the channel erodibility factor (cm/hr/pa), C_{ch} is the channel cover factor and V_{ch} is the volume of water in the reach segment (m^3), sed_{dep} is the amount of sediment deposited in the reach (metric tons). The channel erodibility factor is conceptually similar to the soil erodibility factor used in the USLE equation. Channel erodibility is a function of properties of the bed or bank materials. In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility. The channel cover factor can be defined as the ratio of degradation from a channel with a specified vegetation cover to the corresponding degradation from a channel with no vegetation cover. The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface (Neitsch *et al.,* 2011).

Once the amount of degradation and deposition has been calculated by the above equations (10) and (11) respectively), then the final amount of sediment in the reach is determined by equation (12) and the amount of sediment transported out of the reach is calculated by equation (13) by the model.

$$\mathrm{Sed_{ch}} = \mathrm{Sed_{ch,i}} - \mathrm{Sed_{dep}} + \mathrm{Sed_{deg}} \qquad (12)$$

$$\mathrm{Sed_{out}} = \mathrm{Sed_{ch}} * \frac{\mathrm{V_{out}}}{\mathrm{V}} \qquad (13)$$

Where, Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons), Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), Sed_{out} is the amount of sediment transported out of the reach (metric tons), Sed_{ch} is the amount of suspended sediment in the reach (metric tons), V_{out} is the volume of outflow during the time step (m^3) and V_{ch} is the volume of water in the reach segment (m^3).

2.10.1 Model Efficiency Evaluation

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. The systematic and dynamic behavior of the model can be visualized by plotting simulated flow and observed flow on the same coordinate system. By looking at the graph a modeler can understand whether the model over predicted or under predicted and also the timing of the rising and falling limb of the hydrograph and give subjective decision on the performance of the model. But to quantitatively evaluate the model, we need mathematical measures of model performance.

Reasons to evaluate model performance (Krause *et al*., 2005),

1) To provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior;
2) To provide a means for evaluating improvements to the modeling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information, and representation of important spatial and temporal characteristics of the watershed;
3) To compare current modeling efforts with previous study results.

To assess the goodness-of-fit of the model, three methods were used during the calibration and validation periods. These are: - coefficient of determination (R^2), Percent bias (PBIAS), and the Nash-Sutcliffe efficiency coefficient (NS). These three statistical parameters are used to measure the model performance.

Coefficient of determination (R^2): measures the fraction of the variation in the measured data that is replicated in the simulated model results. It indicates how well the dispersion of the measured data is predicted by the model. Its value ranges between 0 and 1, with the zero being no correlation at all and the value of one indicates perfect match. R^2 is defined as (Krause et al., 2005) the squared value of the coefficient of correlation and is given by equation (14).

$$R^2 = \frac{\left[\sum_{i=0}^{n}\left(Q_{sim,i}-\overline{Q}_{sim}\right)\left(Q_{obs,i}-\overline{Q}_{obs}\right)\right]^2}{\sum_{i=0}^{n}\left(Q_{sim,i}-\overline{Q}_{sim}\right)^2\sum_{i=0}^{n}\left(Q_{obs,i}-\overline{Q}_{obs}\right)^2} \qquad (14)$$

Where, Q_{obs} is the observed (measured) stream flow on day i (m^3/s), Q_{sim} is the simulated stream flow on day i (m^3/s), and bars indicate averages.

Nash-Sutcliffe efficiency coefficient (NS): used to assess the predictive power of the hydrological models. The value of NS varies from 1.0 (perfect fit) to -∞. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model. The NS value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data. According to Krause *et al*., (2005) the major disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and simulated values are calculated as squared values. This leads to an over estimation of the model performance during peak flows and an under estimation during low flows. This coefficient is calculated by equation (15) below.

$$E_{NS} = 1 - \frac{\sum_{i=0}^{n}(Q_{obsi}-Q_{simi})^2}{\sum_{i=0}^{n}\left(Q_{obsi}-\overline{Q}_{obs}\right)^2} \qquad (15)$$

Percent bias (PBIAS): It measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation (Moriasi *et al.,* 2007). Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta *et al*., 1999) and calculated by equation below.

$$PBIAS = \left[\frac{\sum_{i=0}^{n}(Q_{obs}-Q_{sim})}{\sum_{i=0}^{n}(Q_{obs})} * 100\right] \qquad (16)$$

PBIAS is the deviation of data being evaluated, expressed as a percentage.

Based on the compiled indicators, the performance of the model has been evaluated. The evaluation of the model accuracy based on performance rating: Very good, Good, Satisfactory and Unsatisfactory (Moriasi *et al*., 2007).

Table 1 Model performance rating

Rating	R2	NSE	PBIAS	
			Flow	Sediment
Very Good	0.75-1	0.75-1	< 10	< 15
Good	0.65 - 0.75	0.65 - 0.75	10-15	15-30
Satisfactory	0.5 - 0.65	0.5 - 0.65	15-25	30-55
Unsatisfactory	< 0.5	< 0.5	> 25	> 55

Adopted from Moriasi et al., 2007

2.11 SWAT- CUP (SWAT Calibration Uncertainty Procedures)

It is program designed to integrate various calibration/uncertainty analysis programs for SWAT using the same interface. The program can run SUFI2, GLUE, MCMC and Para Sol. The program guides the input files necessary for running a calibration program. Each SWAT-CUP project contains one calibration method and allows running the procedure many times until convergence is reached. SUFI-2 algorithm, in particular, is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources (Yang *et al*., 2008) and this algorism was used for this study.

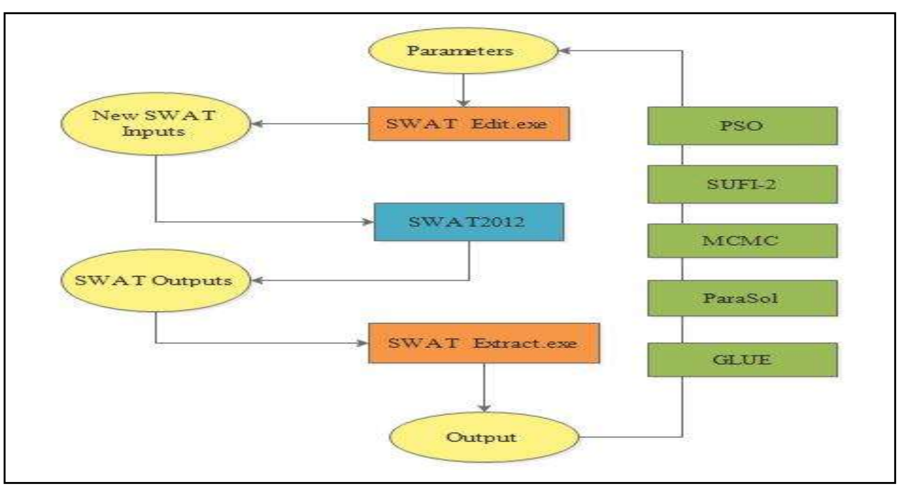


Figure 3 Structure of SWAT_CUP

3. METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

Kesem watershed is located at the southern end of the Afar depression (rift) in Afar regional state, 225km East of Addis Ababa and 40 Km NW of Metehara town (Fig 4). It lies in between UTM 37_WGS84 zone coordinates of 580000-608000mE and 9810000-1020000mN in western part of Sabure sub-catchment. Geographically the area is located 39° 54' E and 09° 09' N. The Kesem river catchment to dam site covers about 3018.5 km^2. It rises on the high Ethiopian plateau and descends the western scrap of the Great Rift Valley to join the Awash.

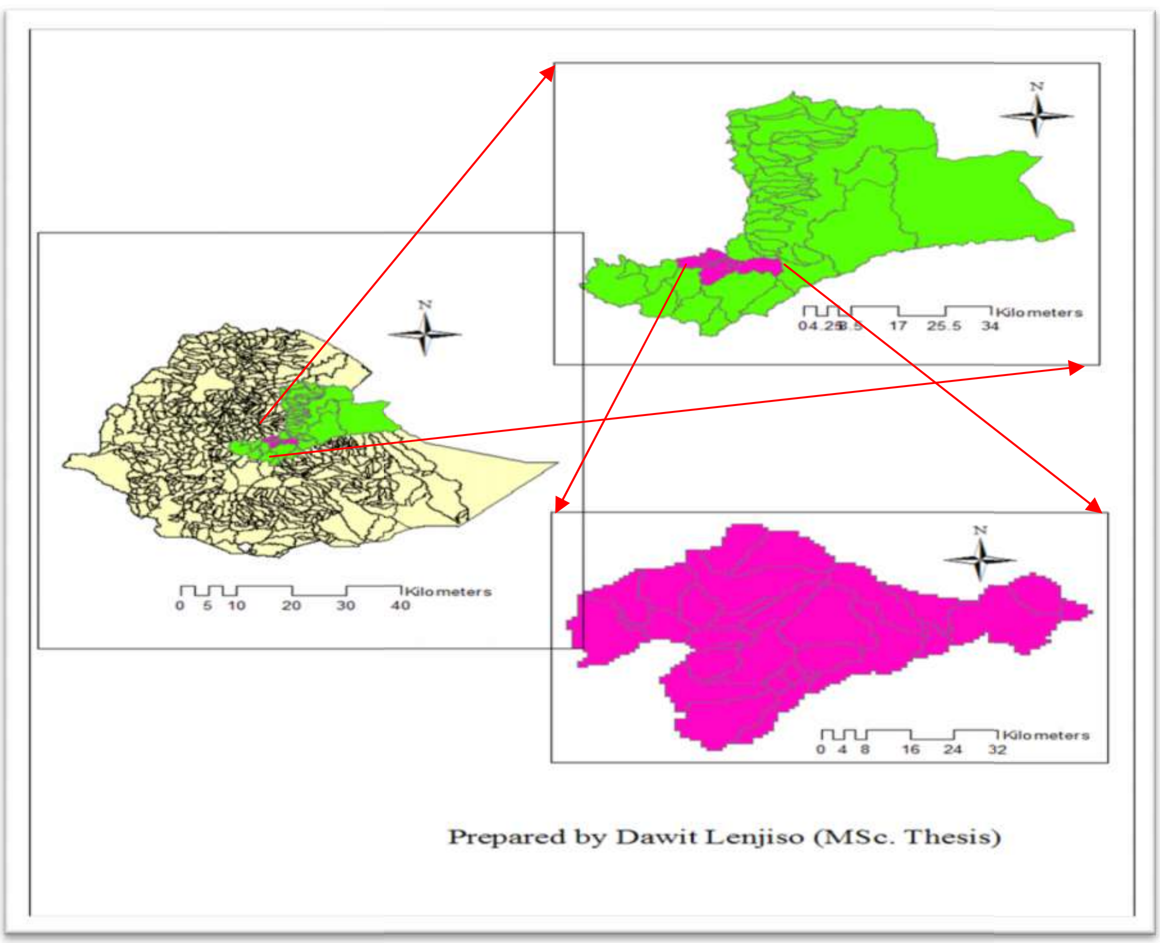


Figure 4 Location map of Kesem watershed

3.1.2 Climate

The area experience a typically tropical semi-arid climate with rainfall normally in the range 350mm to 800mm. Temperature varies from mean minima of 15ºc and 21ºc to mean maxima of 23ºc and 38ºc in December and June respectively; frost is unknown. Mean relative humidity are lowest in July 36% and highest in August 58%. Mean daily sunshine reported on an annual basis is 8.5hr. The overall pattern of rainfall is approximately 60% of the annual total falling as the main rains between July and September. There is, however, another minor and reliable period of rainfall peaking sometimes during the period March to May, these short rains account for a further 25% of the annual total.

3.1.3 Soil

The soil classification of the area silty soils predominates, comprising 49% of the surveyed area, as compared with 13% of the sandy and coarser soils and 20% of the clays. The miscellaneous land categories, some of which are also silty soils but unusable because of extreme topography, salinity or sodicity. The irrigable soils of the study area are all young alluvial soils, without any marked profile development (WWDSE, 2003).

3.1.4 Land Use and Land Cover

The land use condition in Awash catchments upstream of Kesem includes mainly of cultivated agricultural land, grass land, forest land, rural and urban settlements. In the upper most part where there is high rainfall, land use is complete in May with barley and teff. On the lower most part, however, rainfall is too unreliable and the sparse dry acacia scrub gives way to wide stretches of bare ground. The most common soil types are clay, sand, clay-loam, silt-clay-loam, sand-clay, and silt-clay. Land use and soil type have a direct impact on the flood amount, speed and potential to create damage that is why the study gives attention for land use and land cover of the sub basin. The main causes are poor farming practices characterized by a general lack of conservation measures, the cultivation of excessively steep-slopes, deforestation and over-grazing. Four main landscape units occur in the Kesem area. Irrigated agricultural development will be confined to the last of these units, the alluvial plains, which are generally flat or almost flat, with slopes of 2% or less down to the main drainage lines. In the west, towards the escarpment, slopes up to 4% occur with undulating or gullied micro relief; in the vicinity of water courses, the levees and/or small dunes often form an irregular micro relief of up to about 1 m amplitude.

3.2 Input Data

3.2.1 Data Collection

Before using and processing of any research, the primary task of the study was getting/collecting relevant information or data of the study area. To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The required data are spatial and time series data. Spatial data used are DEM, Land use/cover map, and soil map of the study area are collected from Ministry of Water, Irrigation, and Electricity. The SWAT needs good quality of DEM, Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The model estimates stream flow more accurately when using high-resolution topographic data, land use/land cover data, and soil data (Bosch *et al*., 2004). The time series data are Metrological (rainfall, temperature, sunshine hours, precipitation, and relative humidity) and Hydrological (flow and Sediment load) data and these data are collected from Ethiopian National Metrological Agency and Ministry of Water, Irrigation and Electricity respectively. The lengths of period of Metrological data also affect the SWAT model performance.

The model and software's used for modeling of soil erosion and sediment yield in the study area was Arc GIS 10.4.1 extension of SWAT 2012. Arc GIS 10.4.1 was used for input preparation of SWAT model, to extend the Arc SWAT model and to prepare the Thiessen polygon of the metrological stations in the watershed. SWAT- CUP for calibration and validation of data, and Microsoft EXCEL to analysis data.

3.2.1.1 Metrological Data

The metrological data required were: daily precipitation, daily maximum and daily minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. If any of these data was not available, which is very likely, SWAT can generate data using weather generator. For this monthly statistical values are needed from daily data values were needed to be generated from daily ones.

Precipitation: the daily precipitation of all gauging stations (Awara Melka, Arerti, Metehara, Shola Gebeya and Aleltu) was prepared in dbf format. Temperature: the daily temperature of two gauging stations (Shola Gebeya and Metehara) was prepared in dbf format. Solar radiation: the solar radiation of two stations (Shola Gebeya and Metehara) was prepared in dbf format. Relative humidity: The solar radiations of two gauging stations (Shola gebeya and Metehara) were prepared in dbf format and Wind speed: the wind speeds of two gauging stations (Metehara and Shola Gebeya) were prepared in dbf format. The selected principal stations were Metehara and Shola Gebeya gauging station and these data for the rest of the stations were generated by SWAT. More over these data were required when Penman Montheith equation is used to evaluate potential evapotranspiration. Weather simulation data: these data consists of monthly average values of all the values required by the SWAT model in order to generate daily values. All the above data were collected from Ethiopian National metrological agency for the period from (1986-2014).

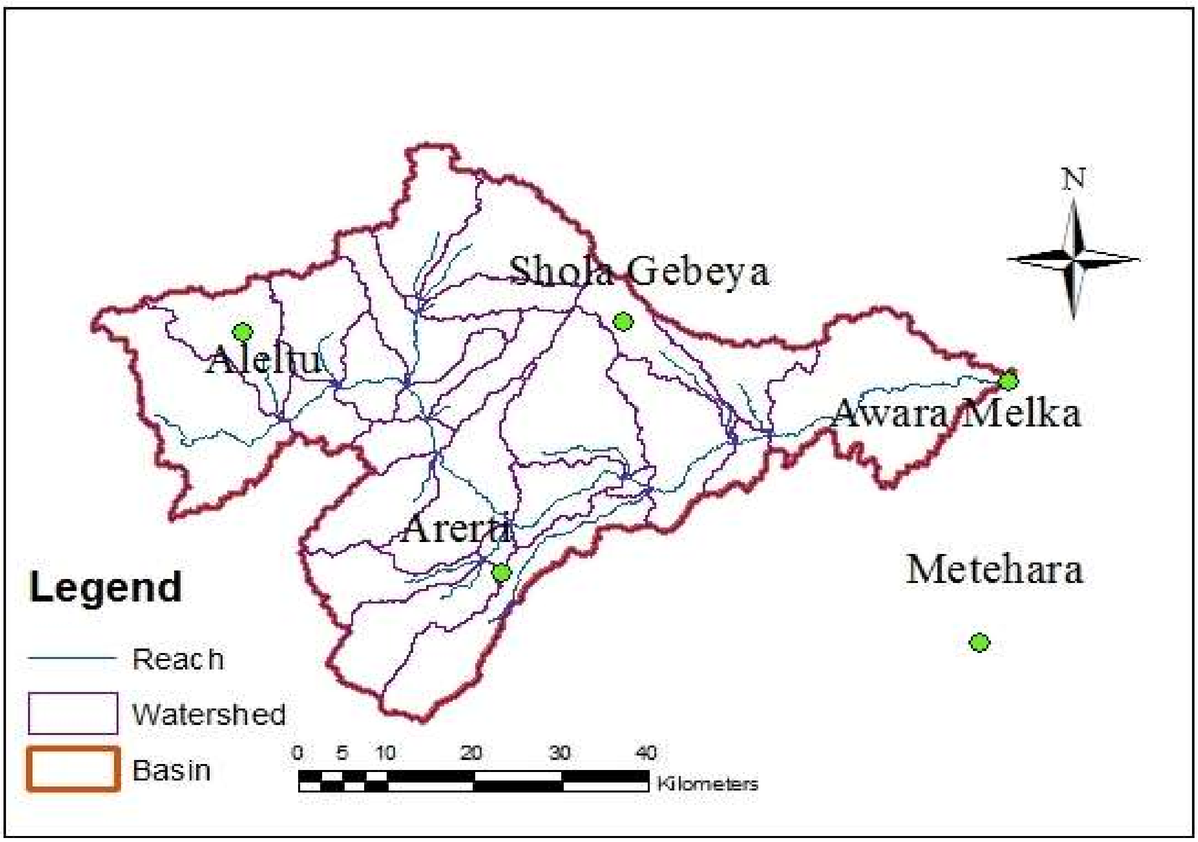


Figure 5 Location maps' of the selected metrological stations

Table 2 Metrological stations

S.No.	Station Name	Type of Station	Longitude (Decimal degrees)	Latitude (Decimal degrees)
1	Awara Melka	Precipitation	39.95	9.15
2	Aleltu	Precipitation	39.1551	9.206
3	Arerti	Precipitation	39.423	8.94
4	Shola gebeya	Precipitation, Temperatures (Max,min), Relative humidity, Solar radiation, and Wind speed	39.55	9.218
5	Metahara	Precipitation, Temperatures (Max,min), Relative humidity, Solar radiation, and Wind speed	39.919	8.86

3.2.1.2 Hydrological Data

Daily flow data is required for SWAT simulated result calibration and validation. This data was obtained from ministry of Water, Irrigation and Electricity, hydrological department from (1995-2009). Depending on the extent of calibration and validation, flow data was collected and arranged as per the requirement of SWAT model. The observed stream flow data was available at Awara Melka station. Here, it should be noted that the efficiency of the model during calibration and validation depends on the accuracy of the calculation. There is a site which has measured suspended sediment data in the Above the Kesem dam with a very short data. Depending on the observed suspended sediment data the remaining values were generated from sediment rating curve for sensitivity and calibration analysis.

3.2.1.3 Digital Elevation Model Data

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights.

DEM resolution affects the watershed delineation, stream network and subbasin classification in the SWAT model. It affects the number of sub-basins and HRUs. Jha *et al*., (2004) found that SWAT sediment predictions were sensitive to HRUs and sub-watershed configurations. According to (Chaubey *et al*., 2005) a decrease in DEM resolution resulted in decreased stream flow and watershed area. Since the runoff volume and total sediment load depends on the watershed area, the decrease in the DEM resolution resulted in large error in the predicted output. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and subbasin classification (Chaubey *et al*., 2005). The Kesem watershed was delineated and River networks were generated from Ethio_DEM. The DEM obtained for this study was obtained from Ministry of Water, Irrigation and Electricity and it has a resolution of 90m x 90m. Elevation of the study area ranges from 3489m amsl to 807m amsl.

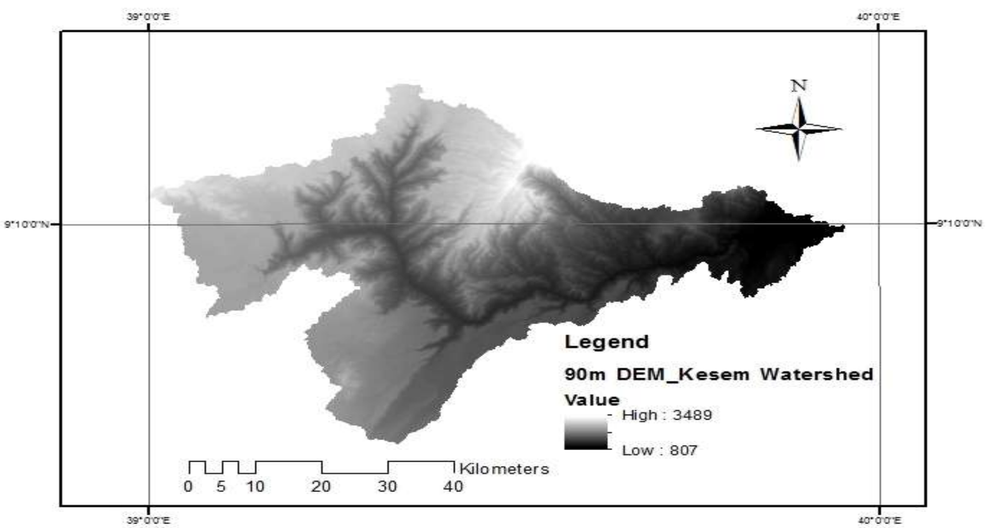


Figure 6 Digital Elevation Model map of the study area

3.2.1.4 Soil Map Data

Soil physical and chemical properties are other input required by SWAT's soil data base. The physical property of the soil in each horizon governs the movement of water, air through the soil profile and has major impact on cycling of water in hydrological response unit (HRU) and is used to determine water budget for the soil profile, daily runoff and erosion. Properties like soil texture (% clay, % sand, and % clay), organic content and bulk density were obtained from FAO database (FAO, 2002).

Different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity etc. which affects the water balance and sediment yield from the watershed. Therefore, using high spatial resolution soil map will increase the prediction accuracy of the model. It was observed that Lithic Leptosols and Vertic cambisols are the most dominant soils in the Sub-basin. Soil classification of the study area by SWAT is as follows.

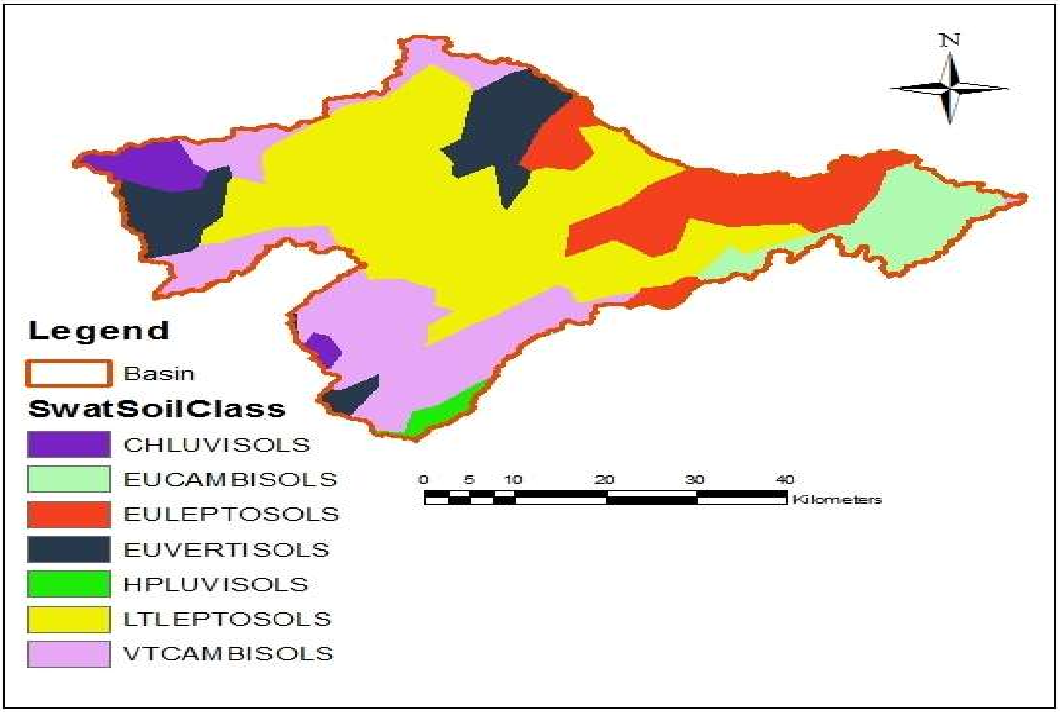


Figure 7 Soil Map data of the study area

Table 3 Soil distribution of the watershed

S.N	Soil type	SWAT code	Area (Ha)	Area (%)
1	Chromic luvisols	CHLUVISOLS	10,081.790	3.34
2	Eutric cambisols	EUCAMBISOLS	23,966.890	7.94
3	Eutric leptosols	EULEPTOSOLS	41,534.560	13.76
4	Eutric vertisols	EUVERTISOLS	31,784.805	10.53
5	Haplic luvisols	HPLUVISOLS	3,531.645	1.17
7	Lenthic leptosols	LTLEPTOSOLS	121,736.105	40.33
8	Vertic cambisols	VTCAMBISOLS	69,244.390	22.94
	Total		**301850**	**100**

3.2.1.5 Land use/covers data

Land use/land cover map data has also a significant effect on the hydrological modeling. It affects the runoff and sediment transport in the watershed. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interface. Agricultural land use is the dominant land use in the Kesem Watershed as shown in figure (8) below.

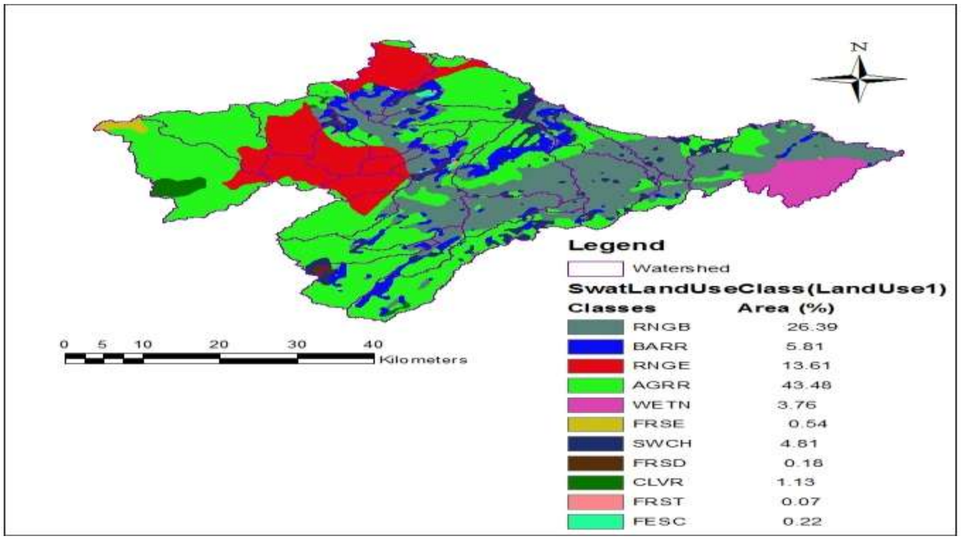


Figure 8 Land use/cover of the study area

Table 4 Land use/cover distribution of the watershed

S.N	Land use	SWAT code	Area(Ha)	Area (%)
1	Shrubland	RNGB	79,658.215	26.39
2	Sparsely vegetated	BARR	17,537.485	5.81
3	Grassland	RNGE	41,081.785	13.61
4	Cultivated	AGRR	131244.380	43.48
5	Wetland	WETN	11,349.560	3.76
7	Afro_Alphine	FRSE	1,629.990	0.54
8	Alemo swith grass	SWCH	14,518.985	4.81
9	Woodland	FRSD	543.330	0.18
10	Semi-desert grass land	CLVR	3,410.905	1.13
11	Natural Forest	FRST	211.295	0.07
12	Tropical plantation	FESC	664.070	0.22
	Total		**301850**	**100**

3.2.1.6Topography

The Kesem river catchment to dam site covers about 3018.5km^2 and extends from an altitude of almost 3489m to 807m elevation. It rises on the high Ethiopian plateau and descends the western scrap of the Great Rift Valley to join the Awash River. The most prominent feature of the Kesem Valley is the steepness of slopes linking the plateau of the north, west and south extremities of the catchment with the gorges of the central area. The channels of the Upper Kesem, being narrow and highly sinuous, feature in fine sediments. They cascade into narrow, flat-floored trenches where they braid amongst the boulder and cobble bed materials. For a large part of the central Kesem Catchment the valley floor broadens, up to half a kilometer wide. Often, in the upper parts of this section, traditional irrigated agriculture interposes between the channels and side slopes. For the final section of its course, the character of the catchment changes once more as it becomes constrained in narrow gorges and canyons, interrupted at irregular intervals by wider reaches which have become depositional areas for course fluvial sediments.

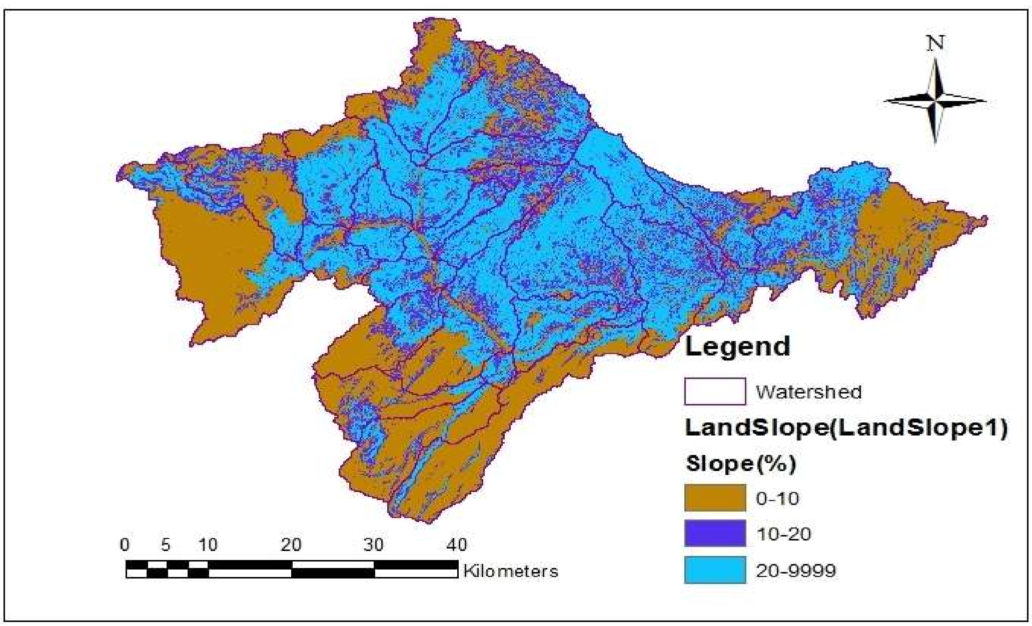


Figure 9 Slope classification of the study area

3.2.1.7 Sediment Data

3.2.1.7.1 Sediment Rating Curve

Sediment measurement in Kesem River above dam was taken by Ministry of Water, Irrigation and Electricity at gauge station was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step, the relationship known as sediment rating curve. Many researchers have also used sediment rating curve to estimate suspended sediment when measured data was not continuous or not valid (Asselman, 2000).

The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load and the general relationship can be written as equation (17).

The sediment rating curve usually express as a power function of discharge.

$$Qs = aQ^b \quad \text{...} (17)$$

Where: Qs is suspended sediment (ton/day), a and b is regration coefficient and exponent and Q is river discharge.

$$Qs = 0.0864*Cs*Q \quad \text{...} (18)$$

Where: Qs is sediment load (ton/day), Cs is sediment concentration (mg/l), Q river flow (m^3/s) and 0.0864 conversion factor.

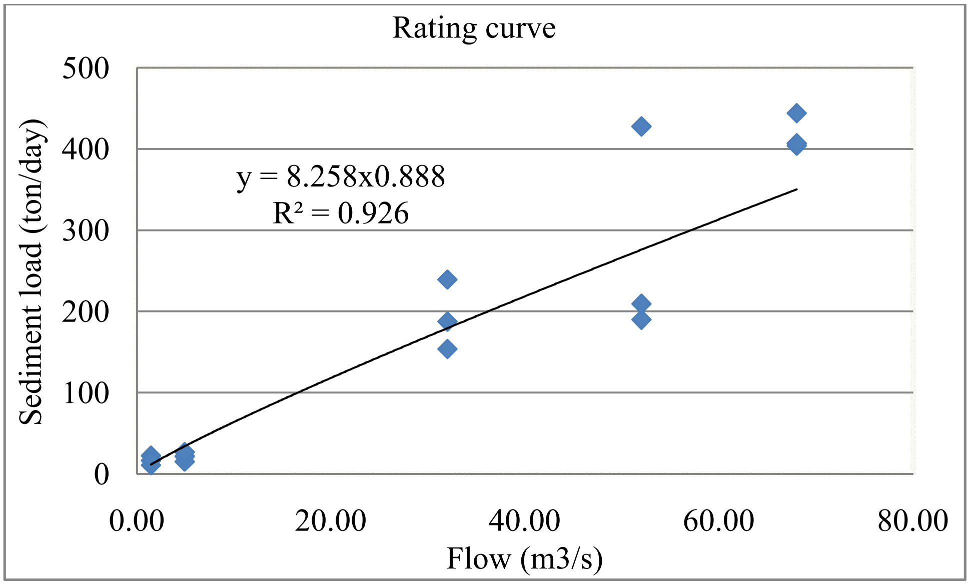


Figure 10 Sediment rating curve

Equation (18) only calculates sediment suspended load but the model simulated both suspended and bed loads. Most of the time the ratio of bed load to suspended load from 1:5 to 1:50 therefore, the bed load this study is 8% suspended load.

3.2.2 Data quality control

Engineering studies of water resources development and management depend heavily on meteorological and hydrological data.

These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. The quality control can be done by filling of missing data if there is any and double mass curve. This will help to identify if there are any gaps or unphysical peaks in data series and correct them before the data is used or input to the model. Otherwise, using the erroneous data as input to the model will give erroneous output from the model.

Filling missing rainfall data

Missed measured precipitation data may face to many problems in hydrologic analysis and design. Because of the cost associated with data collection and some natural and man-made conditions sometimes make it very difficult to have complete records of data at every stations clearly.

Conditions above mentioned sometimes prevent to obtain quantitative and qualitative data of the study area. For gauges that require periodic observation, the failure or absence of the observer to make the necessary visit to the gauge, destruction of recording gauges, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record. There are methods to estimate these missing values in the given stations. For this study missing values was estimated from other stations around the missed record station by considering the assumptions of at least three as close to and evenly spaced around the station with the missing record station as possible. Simple Arithmetic mean method was used where the mean monthly rainfall of all the index stations is within 10% of the station under consideration (station x) and calculated the missing data by equation 19. Whereas the mean monthly rainfall of one or more of the adjacent (index) stations differs from that of station x by more than 10% then the normal ratio method was used (equation 20).

$$P_x = \frac{1}{n}(P_A + P_B + P_C \dots\dots\dots + P_N) \quad (19)$$

$$P_x = \frac{1}{n}\left(\frac{N_X}{N_A}P_A + \frac{N_X}{N_B}P_B + \frac{N_X}{N_C}P_C \dots\dots\dots + \frac{N_X}{N_N}P_N\right) \quad (20)$$

Where, P_x is the precipitation for the station with missed record, P_A, P_B, P_C….P_N are the corresponding precipitation at the index stations and N_A, N_B, N_C, N_N and N_X are the long term mean monthly precipitation at the index stations and at station X under consideration respectively.

Areal Rainfall computation

Rain gauges represent point sampling of the areal distribution of a storm. In practice, hydrological analysis requires knowledge of the rainfall over an area. Arithmetic mean, Thiessen polygon, Isohyetal methods are some of the methods used to convert point (gauged) rainfall values at various stations into an average value over a catchment. However, Thiessen polygon is used for this study due to its simplicity and the average rainfall over the catchment is calculated by:

$$P_{av} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \cdots + P_nA_n}{A_1 + A_2 + A_3 + \cdots + A_n} \quad (21)$$

Where, P_{av} average areal rainfall (mm), P_1, P_2, P_3….P_n precipitation of station 1, 2, 3…n, respectively and A_1, A_2, A_3….A_n is area coverage of station 1, 2, 3…n respectively in the Thiessen polygon.

Hence, the multi-regression filling method was used to compute the missed data for analyzing rainfall data of study area. After selecting which station best matches with the records of the station in query using less percentage of missing data method, performing multi-regression between them gives the equation into which the given value should be calculated to get the estimated records of the missing data for the corresponding time period. In most cases missing data should be filled using multiple station as the missing may not be found as a whole only in one station, in such case either the rest unfilled will be in filled using monthly mean of already available (if they are short period) or another regression will be done with another station which has a record on those months and years. But, the data filled by this method was not used as input to the SWAT (Soil and Water Assessment Tool) model since the model itself has a built in function to fill in the missing data.

3.2.3 Data Analysis

The precipitation data must be checked for continuity and consistency before it is used for further analysis. Outlier test is also checked and no outlier exists in the data.

3.2.3.1 Homogeneity Test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station.

Therefore in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations daily rainfall records were carried out by non-dimensional equation:

$$Pi = \frac{\overline{P}_i}{\overline{P}} \quad \text{(22)}$$

Where: - Pi = Non dimensional Value of precipitation for the month i

$\overline{P}_i$ = Over years averaged monthly precipitation for the station i

$\overline{P}$ = Over year’s average yearly precipitation of the station

The selected stations were plotted for comparison with each other. Therefore, graphical sketch of non-dimensional plot of the stations that used for this study shows that of the stations are homogenous having a bi-modal rainfall pattern (Figure 11).

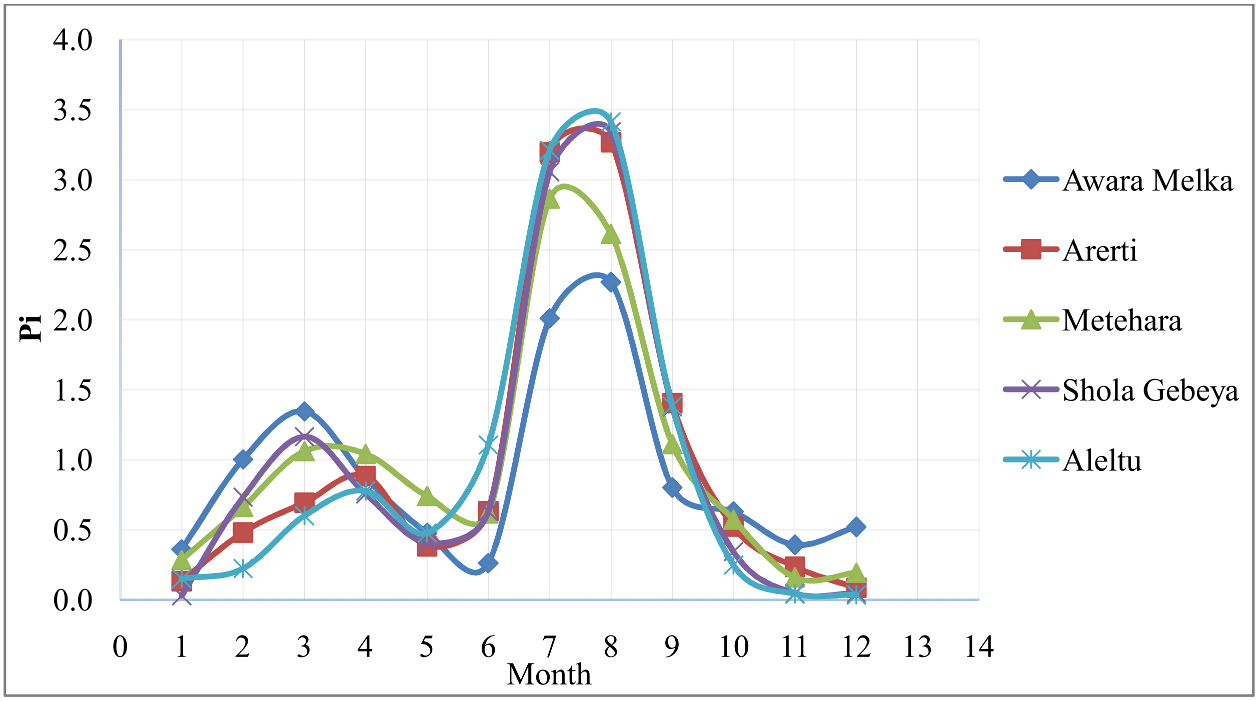


Figure 10 Non-dimensional plots of the selected stations within and around at the study area

3.2.3.2 Consistency Test

Consistency of time series data analyzed based on theory that a plot of two cumulative quantities that are measured for the same time period should be straight line and their proportionality unchanged, which is represented by slope.

Therefore, inconsistency of the record was done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique was used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge. If significant change in the system of the curve is observed, it should be corrected by:

$$P_x' = P_x * \frac{M'}{M} \quad (23)$$

Where, P_x' = Corrected precipitation at station x, Px = Original recorded precipitation at station x, M' = Corrected slope of the double mass curve, and M = Original slope of the double mass curve.

To check for consistency of the recorded data, the annual cumulative of individual stations were plotted against annual cumulative of group stations. According to the double mass curves analysis, all the stations were consistent. For illustration the double mass curves for some selected stations are presented below.

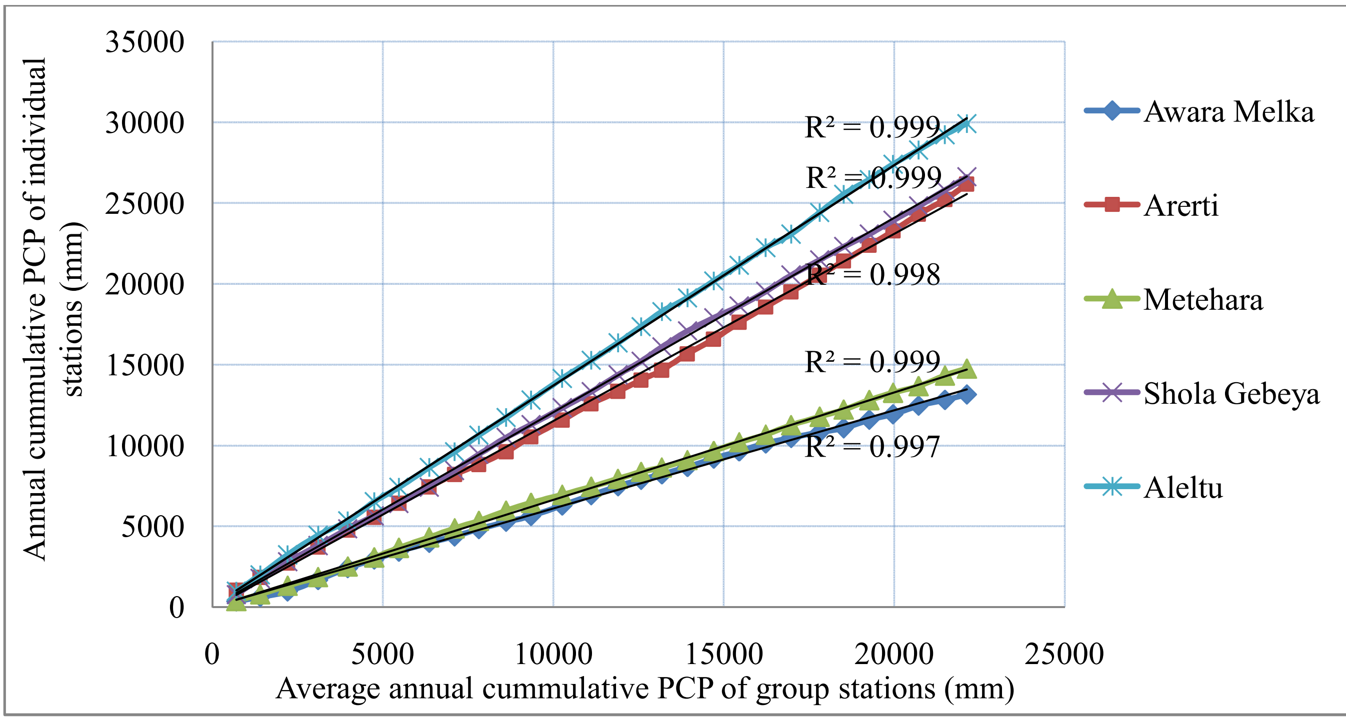


Figure 11 Double mass curve consistency checks for selected stations

3.2.3.3 Statistical parameters calculation for precipitation data

After the precipitation data was checked for quality and the appropriate station selected the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programme **pcpSTAT.exe**. This programme calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (userwgn.txt) (Liersch, 2003). At least seventy two (72) parameters were calculated by this programme which is needed in the weather generator of SWAT model. The programme can be found at (*http://swat.tamu.edu/software/links/*).

3.2.3.4 Statistical parameters calculation for Temperature data

The statistical parameters for temperature were calculated using the programme **Dew02.exe**. It is used to calculate the dew point temperature using minimum and maximum daily temperature and the average daily humidity. The data must be a dbf text file format with three columns. The first column stores the maximum daily temperature data, the second column the minimum temperature data, and the third column the average daily humidity data is used to generate maximum and minimum temperature, relative humidity, and dew point.

3.2.3.5 Weather data analysis

The rainfall data were collected from Ethipian National Metrological Agency (ENMA) for analysis. Mean monthly rainfall of the study area from (1986– 2014) is shown in figure below.

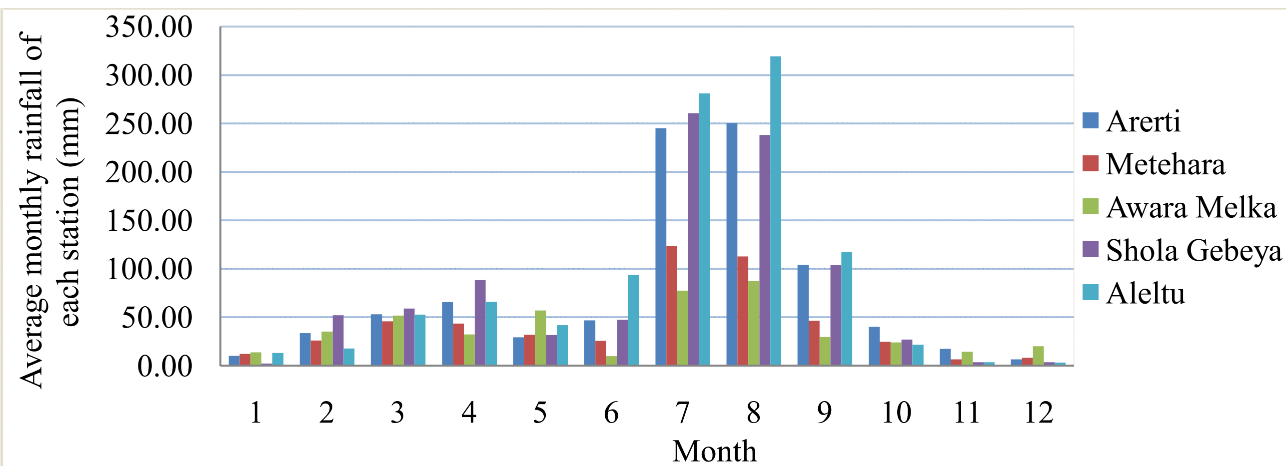


Figure 12 Mean monthly rainfall distributions at the study area

The precipitation at Kesem watershed is maximum during July, August and September.

The temperature data recorded at Shola Gebeya and Metahara stations (1986-2014) were used for further analysis. SWAT model as it requires the same length of year for both precipitation and temperature data. The daily maximum and minimum temperature was available with some missing data. The missing data was filled using linear interpolation only for checking the trend of the air temperature over time. Mean monthly max/min a temperature is shown in figure below.

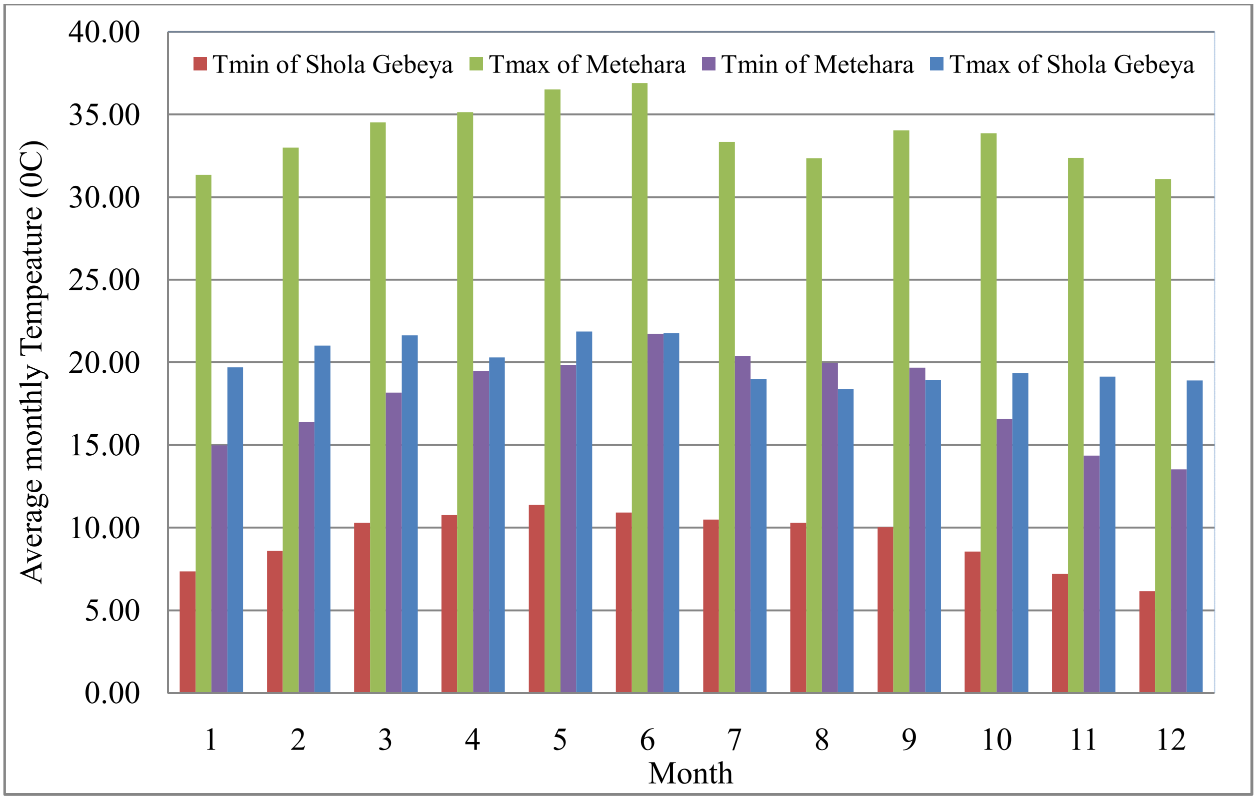


Figure 13 Mean monthly max/min temperatures of selected stations

3.3 Model

3.3.1 Conceptual Framework of the Model

The SWAT model is physically distributed and continuous time developed to predict the impact of land management practices on water, sediment and agricultural chemical yields from a watershed. The necessary data required to run the model was collected and prepared as to the requirement of the SWAT model format. The geospatial data such as the digital elevation map, land use/land cover map, soil map and the hydro-meteorological data such as the daily stream flow data (1995-2009), daily rainfall data (1986-2014), maximum and minimum daily air temperature data, relative humidity data, wind speed data, solar radiation data and sediment load/concentration data (1986-2014) are all collected and processed as per the input requirement format of the model. The conceptual framework is shown in figure 15 below.

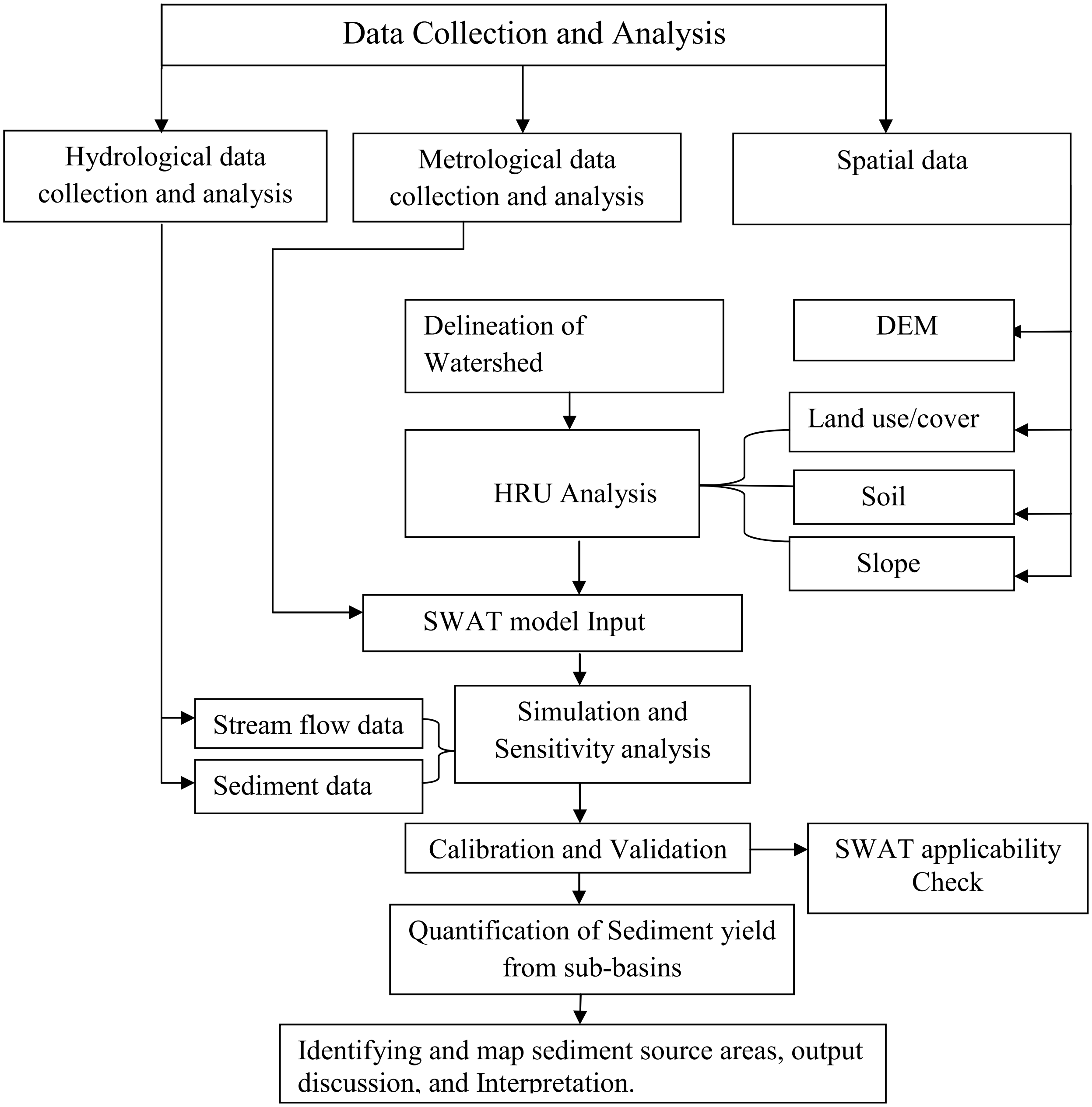


Figure 14 Conceptual framework of the model

3.3.2 Model input and Set up

3.3.2.1 SWAT Model input

Inputs including basin area and main channel length were determined by ArcSWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland manning's n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics. ArcSWAT processes mapped land use and soils data as well as a Digital Elevation Model (DEM) to create a set of default model input files.

SWAT requires specific statistics about watershed characteristics such as topography, land use and land cover, soil types, weather data and management practices. The model uses a two-level taste schemes; first basin and sub-basin delineation is performed based on topographic information, followed by further crumbling into HRUs using land use and soil type consideration in order to represent heterogeneous watershed properties. Climate inputs are required since they control water balance that drives all the processes simulated in the watershed. Management practice of a watershed is needed because it greatly influences the sediment transported from basins.

The spatially distributed data (GIS input) needed for the ArcSWAT interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on weather and river discharge were also used for prediction of stream flow and calibration purposes.

3.3.2.1.1 Digital Elevation Model (DEM)

Topography is defined by a DEM that describe the elevation of any point in a given area at a specific spatial resolution. A 90 m by 90 m resolution DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

3.3.2.1.2 Soil Data

SWAT model requires different soil textural and physio-chemical properties like soil texture (% clay, % sand, and % clay), organic content and bulk density were obtained from FAO database (FAO, 2002). Major soil types in the watershed are Lenthic Leptosols and Vertic Cambisols.

3.3.2.1.3 Land Use data

Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. Both soil and land use land cover data can be in shape file or grid format.

3.3.2.1.4 Weather Generator

Weather data are amongst the indispensable inputs for SWAT model. Accordingly weather data's such as daily data's of rainfall, temperature (minimum and maximum), Wind Speed, Relative humidity and solar radiation were analyzed and prepared according to the model requirement (in dbf format). There is lack of full and realistic long period of meteorological data in our country, which can be solved by the aid of Weather generator that solves the problem by generating data from the existing observed data. The weather generator requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. To generate the data, weather parameters values were developed by using WGN maker (Excel Macro Solver) and dew point temperature calculator DEW02 were used.

The weather generator parameters from the stations of Metehara, and Shola Gebeya are first loaded to the user weather generator database and the batch file containing the location and elevation of weather gauge stations are loaded sequentially. The missing Values in the existing data sets were filled with no dataset identifier (-99) and generated by the Program embedded in the model.

3.3.2.1.5 Discharge and Sediment yield data

Daily flow data and sediment concentration for Kesem watershed were obtained from Ministry of Water Irrigation and Electricity, Hydrology Department, Ethiopia. These daily river discharges at Awara Melka and sediment concentrations above dam gauge station were used for model calibration and validation.

3.3.2.2 SWAT Model set up

3.3.2.2.1 Watershed and Channel Delineation

The DEM is used to derive the watershed boundary, channel network, and sub basin size and distribution. The Kesem watershed was delineated with an outlet point at the out let of the watershed. The overall watershed was further broken down into sub-basins based on the algorithms provided by the SWAT model. As a consequence, these sub-basins influence the level of spatial complexity that is represented in the SWAT model. A sub-basin in SWAT is defined as the hydrologic area contributing to only one stream channel.

The first step in initializing a watershed simulation in SWAT model is to delineate the watershed and partition into sub basins. SWAT allows the user to delineate the watershed and sub basins using the Digital Elevation Model (DEM). DEM is a grid of square cells where each cell represents the elevation value at that location and the elevation value for each cell is an average of overall elevations inside the cell. The size of each cell determines the resolution of the DEM.

The watershed delineation tool uses and expands the Arc GIS, spatial analyst functions to perform watershed delineation (Neitsch et al, 2005) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub-basins and details of stream network depends on this threshold area (Winchell et al, 2007). The watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates a watershed area 3018.5 km^2 with 27 sub-basins (Figure 16).

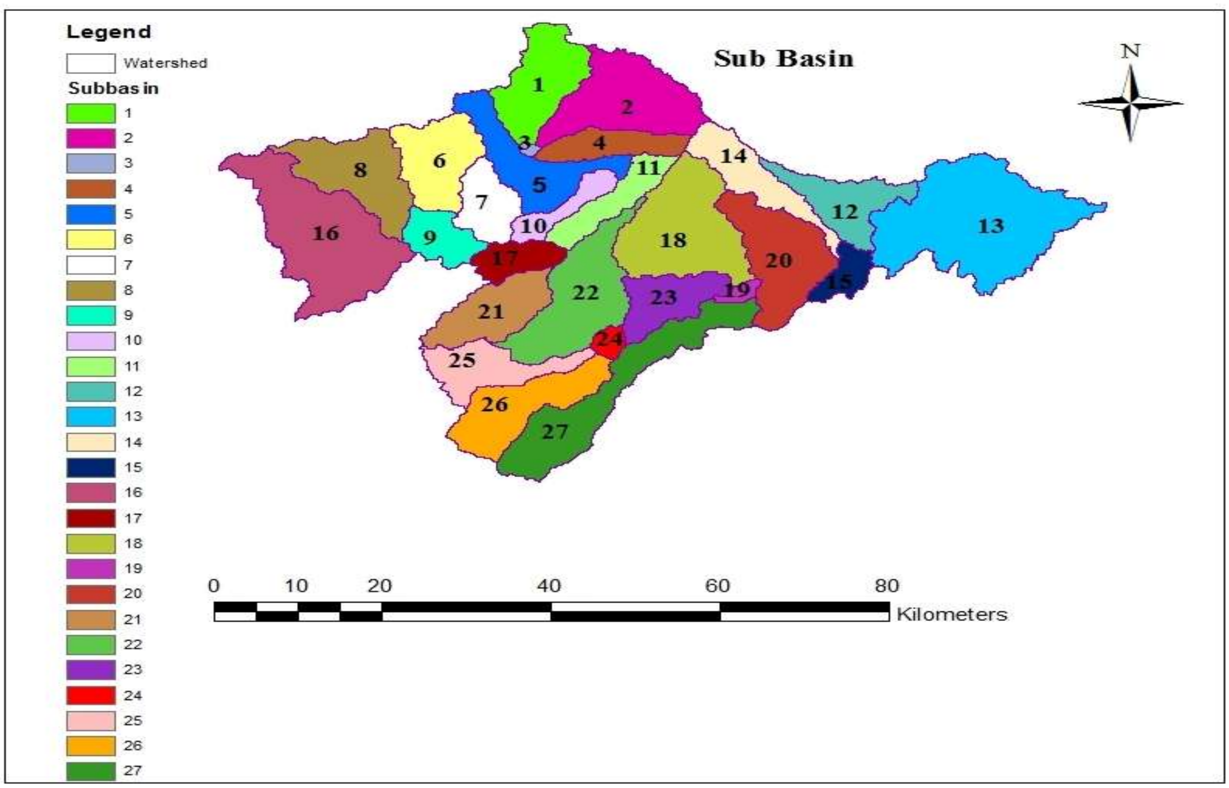


Figure 15 The delineated watershed and sub-basins by SWAT model

3.3.2.2.2 Hydrologic Response Unit Analysis

In SWAT, HRUs are defined as being unique occurrences of soil type, land cover, and slope class. Any parcels of land within one sub basin that share the same combination of these three features will be considered one HRU. All processes modeled by SWAT are done for each unique HRU in the watershed, independent of position within each sub basin. Multiple HRU slope discretization were selected for simplicity & saving time during parameterization of the HRU.

In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils, which cover less than the threshold level, are eliminated. The land use, soil and slope map of catchments were overlaid to produce a hydrologic response group by setting a thresh hold value of 10%, 20% and 10 % for land use, soil and slope domination to which land use percentage over the sub basin, soil over the land use and slope class percentage over the land use respectively were adopted in these study during HRU definition. Those thresholds were selected by considering the effect on the formulation of hydrologic response and for making the HRU formulation in a manageable amount.

3.3.2.2.3 Write Input Tables

After Hydrologic Response Units parameterization, the next step in SWAT model set-up is writing the input tables. In this section the prepared batch files containing the location and elevation of weather generator gauge stations, rainfall gauge stations, temperature gauge stations, relative humidity gauge stations, solar gauge stations and wind gauge stations were loaded sequentially. Then SWAT calls each metrological data’s related to each batch file and write it to the database for each sub-basin.

3.3.2.3 Sensitivity Analysis, Calibration and Validation of SWAT Model

After the model was set up the next step was run the model and the result from the simulation cannot be directly used for further analysis. Instead, the ability of the model to sufficiently predict the constituent stream flow and sediment yield should be evaluated through sensitivity analysis, model calibration and model validation (White & Chaubey, 2005).

3.3.2.3.1 Sensitivity Analysis

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed (Abbaspour, 2013). Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Model sensitivity is defined as the change in model output per change in parameter input. It is a process of testing and identifying model parameters that affects most the output from the model when changed. A parameter sensitivity analysis provides insights on which parameters contribute most to the output variance due to input variability (Holvoet *et al*., 2005). Therefore, a parameter is considered sensitive when the change in that parameter causes large change on model output. In general identifying sensitive parameters prior to model calibration helps us to allow the possible reduction in the number of parameters that must be calibrated thereby reducing the computational time required for model calibration.

Once the SWAT model for the Kesem Watershed was compiled using SWAT interface, a stream flow and sediment yield sensitivity analysis was performed on model parameters. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization. The sensitivity analysis was performed using SWAT interface for a period of (1995-2009).

The current version of model, SWAT2012, SWAT_CUP provides the algorithmic techniques for sensitivity analysis. In this study global sensitivity analysis was performed. Global sensitivity analysis performs the sensitivity of one parameter while the value of other related parameters are also changing. Global sensitivity analysis uses t-test and p-values to determine the sensitivity of each parameter. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance. This type of sensitivity can be performed after iteration. The main problem related to global sensitivity analysis is that it needs a large number of simulations (Abbaspour, 2013).

3.3.2.3.2 Model calibration and validation

Model calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty.

Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold *et al*., 2012). Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions. This implies the application of the calibrated model without changing the parameter values that were set during the calibration, when simulating the response for a period other than the calibration period (Refsgaard, 1997).

The model calibration and validation process were conducted by using the SUFI2 (Sequential Uncertainty Fitting Version 2 programme) in SWAT_CUP. SWAT_CUP is a computer programme for automatic calibration of SWAT models. The programme links SUFI2 procedures to SWAT. The auto-calibration procedure was supported by manual calibration for the values of parameters that were physically wrong. The values of parameters that are provided by SUFI2 during calibration as the best parameter value may not be physically correct or it may be outside recommended uncertainty range and needs to be adjusted manually to better match the existing situation.

3.3.3 Sediment modeling

For a watershed in which erosion and sedimentation process is significant, it is important to identify the source erosion and what causes it. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied (Lemma, 2015). In this study since there was a time limitation to conduct field investigation to the watershed of study, it aimed at applying SWAT (Soil and Water Assessment Tool) model to simulate the sediment yield from Kesem watershed. Therefore, a semi-distributed, physics-based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study.

4. RESULT AND DISCUSSION

4.1 Stream Flow Modeling

4.1.1 Parameters sensitive to flow

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive before running calibration by using Latin Hypercube (LH) and one-factor-at-a-time (OAT) methods of SWAT (Van Griensven et al., 2006). Flow sensitivity analysis was carried out for a period of eighteen years, which includes 3 years of warm-up period (1992-1994), the calibration period (from January 1, 1995 to December 31, 2004) and the validation period (from January 1, 2005 to December 31, 2009).

Twenty one (21) parameters were used as sensitivity analysis in different degree and 300 iterations has been done by SWAT_CUP sensitivity analysis for flow calibration. These parameters are used to calculate the amount of flow from the watershed. The parameter identification was done by using the monthly observed flow data. Table (5) shows all the parameters used in the sensitivity analysis with their Range values and Fitted Values for flow calibration.

The ranks of sensitive parameters selected depend on global sensitive analyses p-value and t-statistic. A t-stat and p-value is used to measure the sensitivity and relative significance of each parameter (Narsimlu *et al*., 2015). Here, t-stat provides a measure of sensitivity and hence larger in absolute values are more sensitive. On the other hand, P-value indicates the significance of the sensitivity and hence a value close to zero has more significance. Ranking in both cases (t-stat or p-value) give the same result i.e. a parameter will have the same rank whether it is ranked based on the t-stat or p-value. Therefore, the parameters, which have superior value of t-stat and smaller value of p-value, are most sensitive parameters (Abbaspour *et al*., 2017). However, attention was given to most sensitive parameters during model calibration process. In table (6), the rank for each parameter was assigned depending on p-value and t-stat.

Table 5 List of initially selected parameters used in flow sensitivity analysis

Parameters	Description of Parameters	Types of parameters	Range Values		Fitted Values
			Min	Max	
CN2	Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (Unit less)	Surface runoff	35	98	78
AlPHA_BF	Base flow alpha factor (days)	Ground water	0	1	0.22
GW_DELAY	Ground water delay (days)	Ground water	30	350	313.17
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Ground water	0	5000	3875
GW_REVAP	Ground water “revap” coefficient	Ground water	0.02	0.2	0.12
RCHRG_DP	Deep aquifer percolation fraction	Ground water	0	1	0.05
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	Ground water	6	14	10.98
SLSUBBSN	Average slope length	Geomorphology	10	150	138.89
ESCO	Soil evaporation compensation factor	Evapotranspiration	0	1	0.12
LAT_TTIME	Lateral flow travel time	Geomorphology	0	10	9.90
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	Soil water	0	1	0.23
HRU_SLP	Average slope steepness	Surface runoff	0	0.2	0.18
BLAI	Max leaf area index	Evapotranspiration	2	8	7.35
CANMX	Maximum canopy storage (mm)	Surface runoff	0	100	31.02
SOL_Z	Depth from soil surface to bottom of layer	Soil water	0	3500	2784
SOL_K	Soil conductivity (mm/hr)	Soil water	0	2000	1770
CH_N2	Manning's "n" value for the main channel	Channel process	0.01	0.3	0.25
CH_K2	Effective hydraulic conductivity in main channel (mm/hr)	Channel process	5	130	73.01
EPCO	Plant evaporation compensation factor	Evapotranspiration	0	1	0.5
SURLAG	Surface runoff lag coefficient	Surface runoff	1	12	3.34
OV_N	Manning's “n”value for overland flow	Surface runoff	0.01	30	9.12

Table 6 Rank of each parameter depending on t-test and p-value

Parameter Name	t-Stat	P-Value	Rank
CN2.mgt	-21.43	0.000	1
RCHRG_DP.gw	-3.28	0.001	2
SOL_K(..).sol	-2.56	0.011	3
CH_K2.rte	-2.13	0.034	4
HRU_SLP.hru	-1.64	0.102	5
SOL_Z(..).sol	1.57	0.118	6
GW_DELAY.gw	-1.55	0.122	7
CANMX.hru	1.44	0.152	8
SURLAG.bsn	1.33	0.185	9
LAT_TTIME.hru	1.14	0.254	10
ALPHA_BF.gw	-0.85	0.395	11
SLSUBBSN.hru	-0.79	0.429	12
CH_N2.rte	-0.61	0.541	13
OV_N.hru	0.59	0.557	14
EPCO.hru	-0.56	0.574	15
BLAI{..}.plant.dat	0.50	0.617	16
GW_REVAP.gw	0.49	0.623	17
REVAPMN.gw	-0.49	0.626	18
ESCO.hru	-0.47	0.636	19
SOL_AWC(..).sol	0.13	0.900	20
GWQMN.gw	0.03	0.974	21

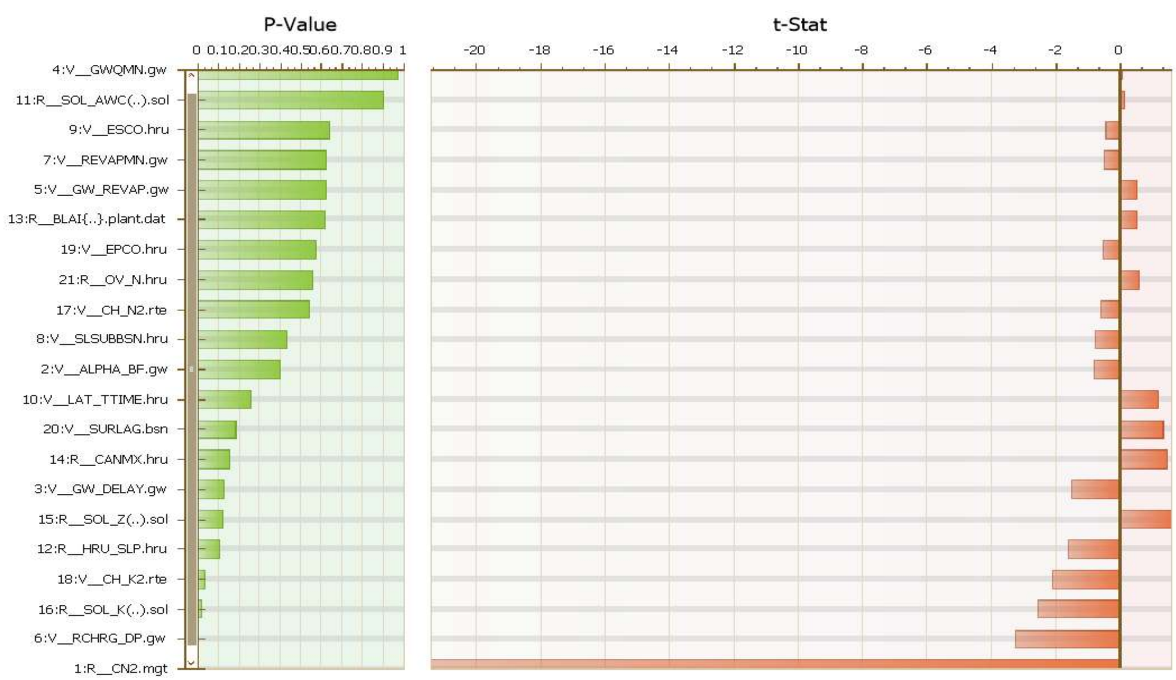


Figure 16 Global sensitive parameters (p-value) and (t-stat) for flow

Figure (17) shows that p-value and t-stat respectively. According to the result from the global sensitivity analysis, Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (CN2) was found to be the most sensitive parameter followed by deep aquifer percolation fraction (RCHRG_DP), Soil conductivity (SOL_K), and Effective hydraulic conductivity in main channel (CH_K2).

4.1.2 Stream Flow Calibration and Validation

The calibration and validation was done by using observed stream flow data at Awara Melka station. The stream flow data was available at this station from January 1, 1995 to December 31, 2009. Out of those total stream flow data two-third used for calibration purpose and one–third used for validation purpose. The calibration period was carried out for ten years that is from January 1, 1995 to December 31, 2004 and the validation period carried out five years from January1, 2005 to December 31, 2009. The simulated flow was calibrated manually using the separated observed surface flow gauged at the outlet of the sub watershed. The calibration processes considered the parameters and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained.

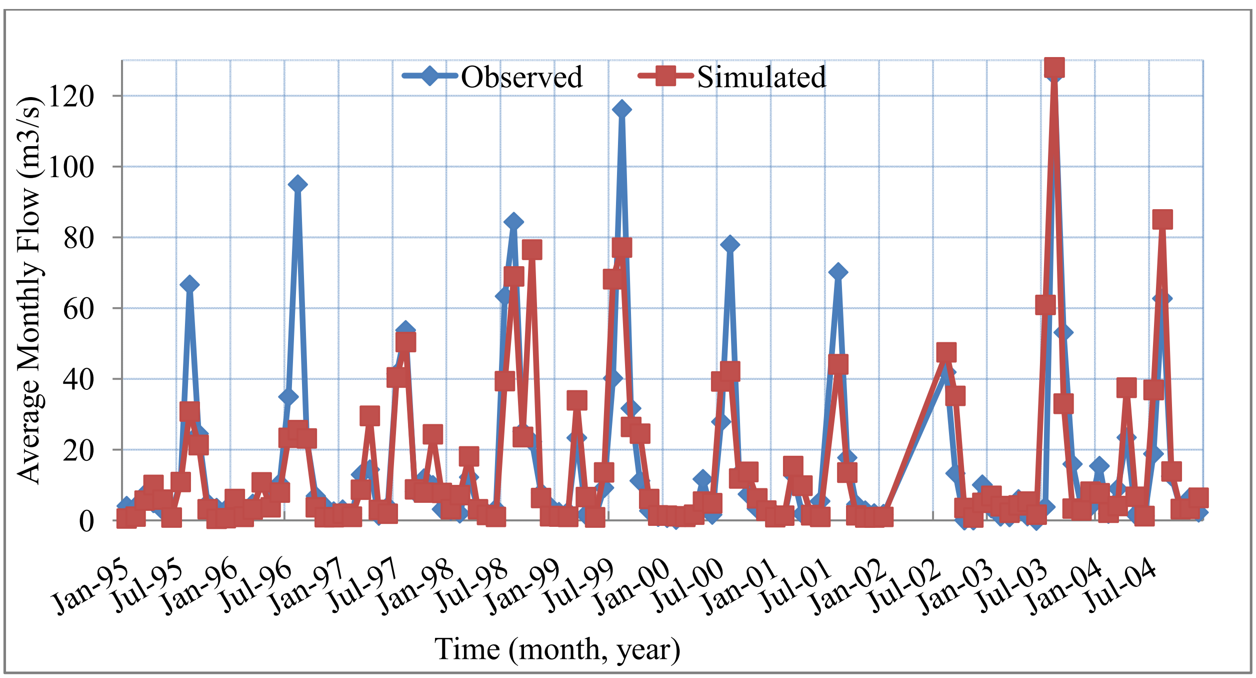


Figure 17 Mean monthly simulated and observed flow calibration by Excel

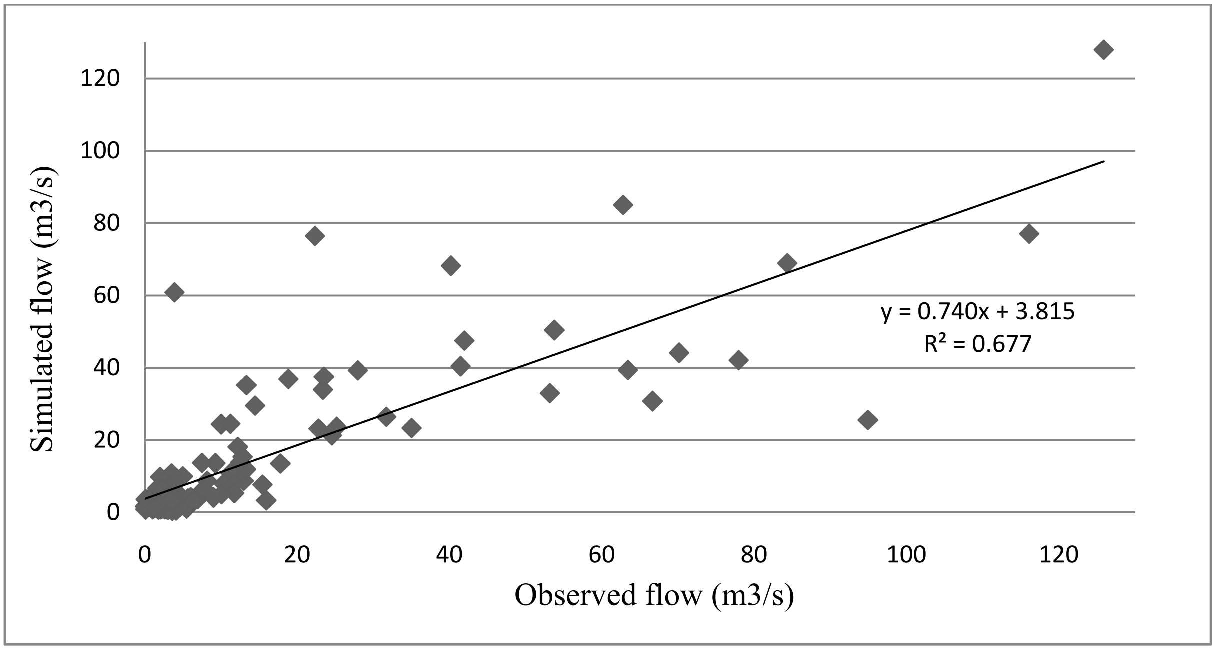


Figure 18 Goodness-of-fit for observed and simulated monthly flow calibration period

The model goodness-of-fit was evaluated and the model performance after adjusting all the parameters. Calibration resulted after simulation found Correlation coefficient (R2) of 0.68, Nash Sutcliffe model efficiency (NSE) of 0.67, and Percent of biased (PBIAS) of 0.5.

Hence it is necessary to validate the stream flow to have a better estimation of the soil loss. The validation was done based on monthly basis from (2005-2009) without any parameter adjustment. The model with calibrated parameters was validated by using an independent set of measured flow data which were not used during model calibration to observe how much the simulation similar to the measured one. The figure (20) shows that the simulated flow line similarly follows the pattern of the measured flow line except deviation in some points.

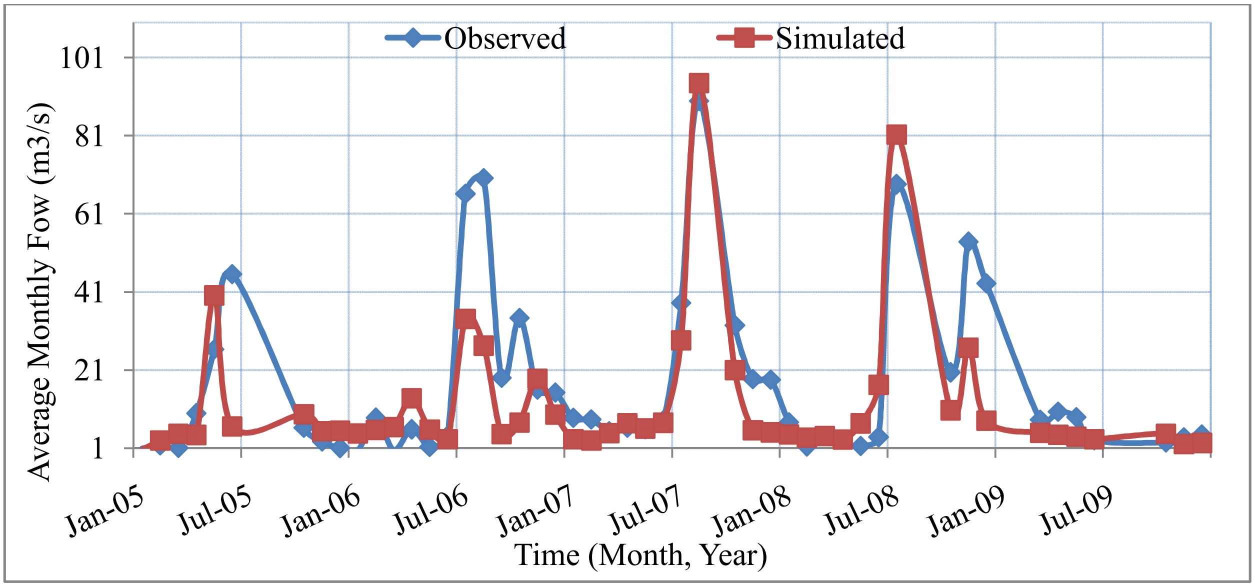


Figure 19 Monthly simulated and observed flows validation by Excel

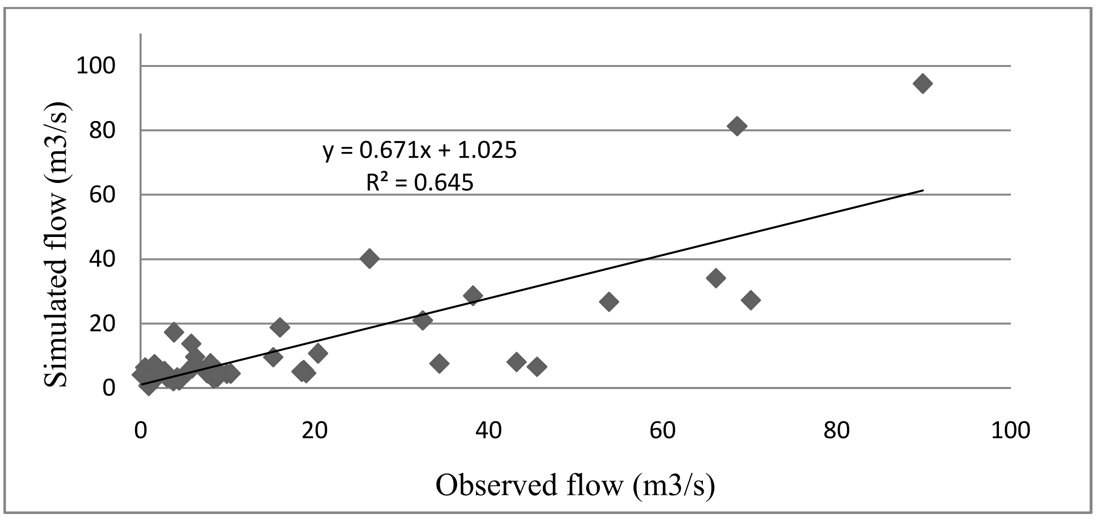


Figure 20 Goodness-of-fit for monthly observed and simulated flow validation period

The above graphical representations clearly show that, there is satisfactory agreement between model simulation and observed flow. Accordingly, match between monthly measured and simulated flows in the validation period were demonstrated by the Correlation coefficient (R2) of 0.65, Nash Sutcliffe model efficiency (NSE) of 0.60, and Percent of biased (PBIAS) of 26.8.

The performance remarks given in the following table (7) are based on the classification given by (Moria et.al. 2007). The model under estimate the stream flows from (1995-2001) and over estimate from (2002-2004) during calibration period. Similarly, under estimate the stream flows from (2005-2006) and over estimate from (2007-2008) during validation period.

Table 7 Evaluation of stream flow during calibration and validation periods

Monthly time step simulation	Mean monthly stream flows (m^3/s)		Model performance			Performance Remarks		
	Observed	Simulated	R^2	NSE	PBIAS	R^2	NSE	PBIAS
Calibration Period (1995-2004)	15.00	14.92	0.68	0.67	0.5	Good	Good	V.good
Validation Period (2005-2009)	16.75	12.26	0.65	0.60	26.8	Satisf.	Satisf.	Satisf.

4.2 Sediment Yield Modeling

4.2.1 Parameters sensitive to sediment

The parameters included in the table below were affecting the soil erosion simulation to some extent. These sediment parameters are used to compute the amount of sediment from a catchment (from upland) and from the channel (in stream sediment).

Table 8 List of initially selected parameters used in sediment yield sensitivity analysis

S/N	Parameters	Description of parameters	Range (Min-Max)	Fitted value
1	SPCON	Linear re-entrainment parameter for channel sediment routing	0.0001-0.01	0.0069
2	SPEXP	Exponential re-entrainment parameter	1 - 1.5	1.002
3	USLE_C	USLE cover and management factor	0.001 – 0.5	0.248
4	SLSUBBSN	Average slope length	10 – 150	19.23
5	HRU_SLP	Average slope steepness	0 - 1	0.0036
6	RSDIN	Initial residue cover [kg/ha]	0 - 10000	3625
7	BIOMIX	Biological mixing efficiency	0 - 1	0.079
8	USLE_P	USLE support practice factor	0 - 1	0.233
9	CH_COV1	Channel erodibility factor	-0.05 – 0.6	0.26
10	CH_COV2	Channel cover factor	-0.001 – 1	0.008
11	USLE_K	USLE soil erodibility factor	0 - 2000	1108.3
12	CH_K2	Effective hydraulic conductivity(mm/h)	5-130	13.210

To see which parameter is highly sensitive to sediment from the list of parameters in Table 8 Global sensitivity analysis was applied. Twelve parameters that directly affect the sediment yield and sediment transport in the watershed were analyzed and the result is tabulated in Table 9 below.

Table 9 Lists of parameters sensitive to sediment and their rankings

Parameter Name	t-Stat	P-Value	Rank
CH_K2.rte	18.81	0.00	1
HRU_SLP.hru	-9.88	0.00	2
BIOMIX.mgt	-4.65	0.00	3
SLSUBBSN.hru	-2.99	0.00	4
USLE_P.mgt	-1.46	0.15	5
RSDIN.hru	1.34	0.18	6
USLE_C{..}.plant.dat	-1.10	0.28	7
CH_COV2.rte	-0.93	0.36	8
USLE_K(..).sol	-0.82	0.42	9
SPEXP.bsn	-0.81	0.42	10
SPCON.bsn	0.55	0.59	11
CH_COV1.rte	-0.26	0.80	12

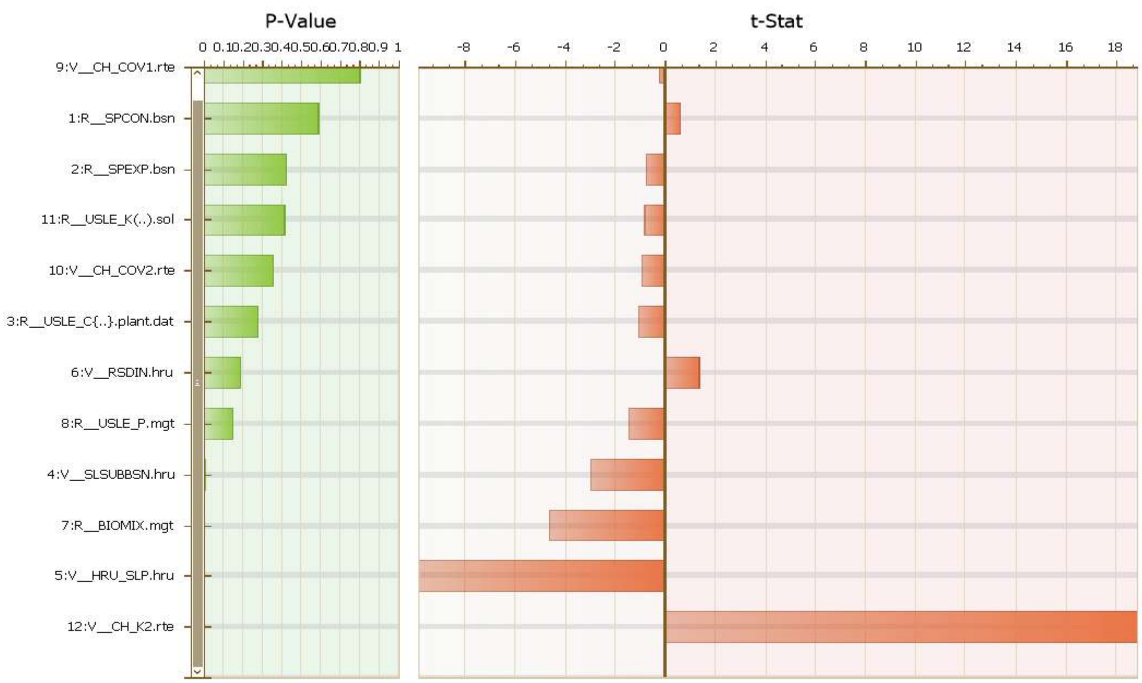


Figure 21 Global sensitive parameters (p-value) and (t-stat) for sediment

The sensitivity of the parameter decreases with increasing rank number value and therefore, parameters at the bottom of the table are less sensitive.

Accordingly, the most sensitive parameters for sediment yield were: Effective hydraulic conductivity (CH_K2), Average slope steepness (HRU_SLP), Biological mixing efficiency (BIOMIX), and Average slope length (SLSUBBSN.

4.2.2 Sediment yield Calibration and Validation

After sensitivity analysis, the next step was calibrating sediment yield of the watershed. 3 years (1992-1994) was used for model warm up. So that model was calibrated (1995-2004). The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis that has identified sensitive parameters and has effect on the simulated result when changed for sediment yield of the watershed, by varying iteratively within the allowable ranges of the parameters.

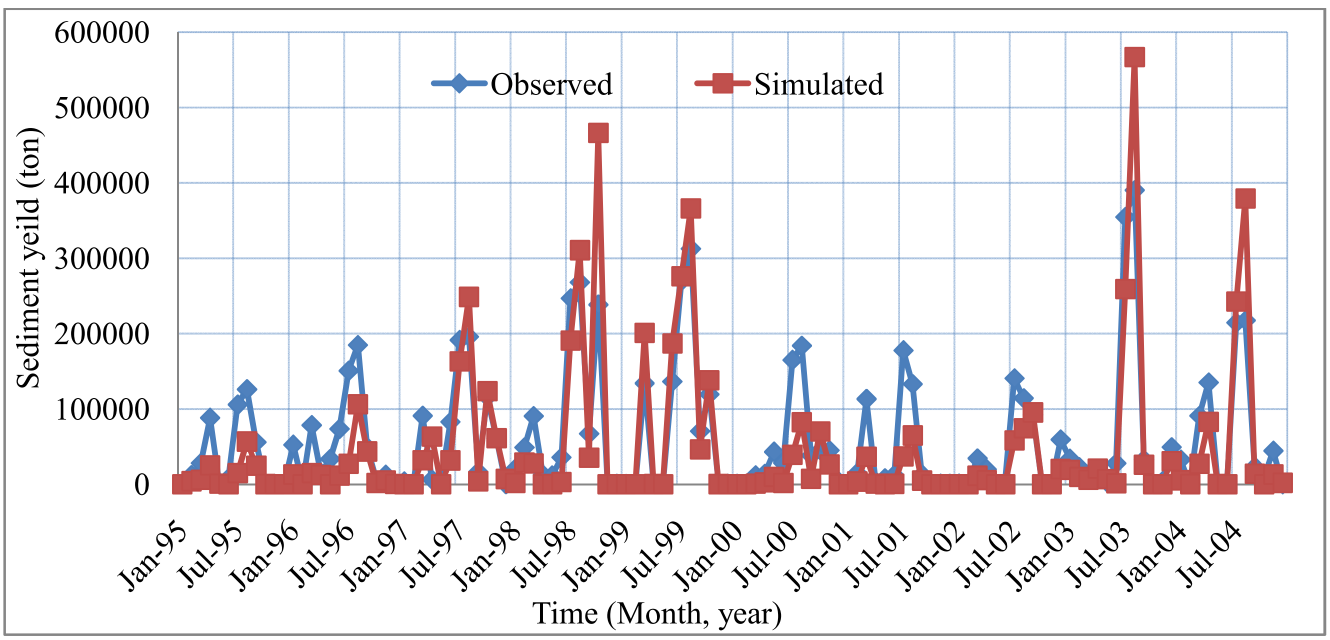


Figure 22 Monthly observed and simulated sediment yield calibration period by excel

As shown in figure above the model overestimate the peak monthly sediment yield from (1997-1999) and (2003-2004).

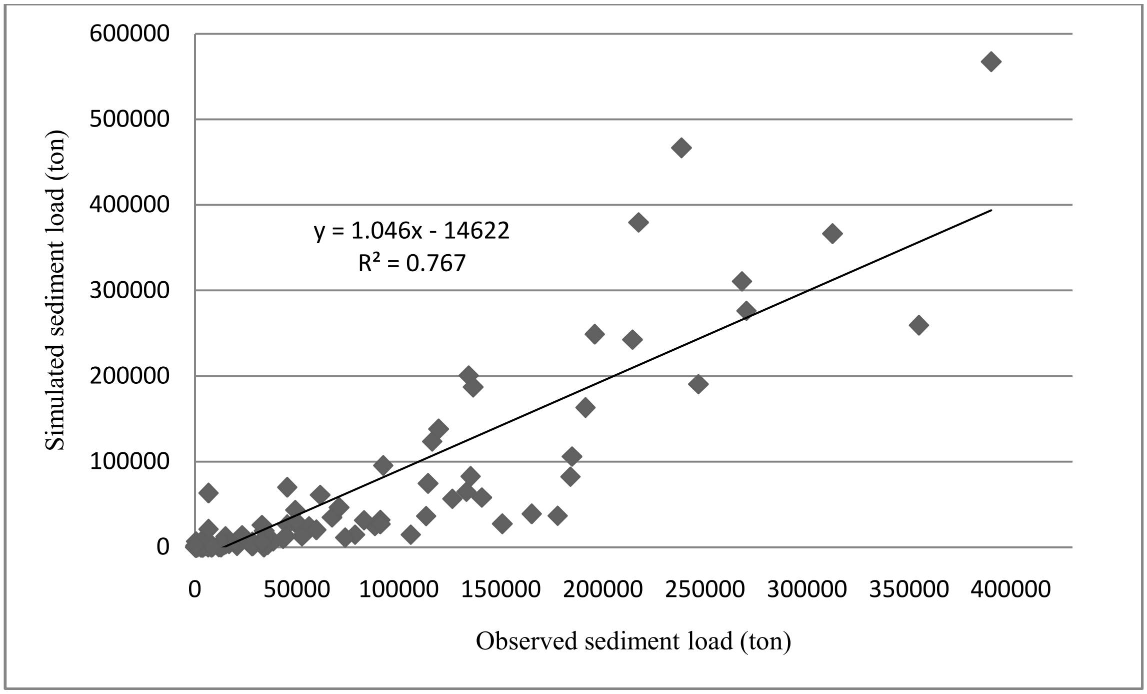


Figure 23 Goodness-of-fit for observed and simulated sediment yield calibration period

The observed and the simulated values of the sediment yield were plotted against each other to determine the goodness-of-fit criterion of coefficient of determination (Figure 24). Calibration resulted after simulation found Correlation coefficient (R2) of 0.77, Nash Sutcliffe model efficiency (NSE) of 0.64, and Percent of biased (PBIAS) of 19.8.

The SWAT model was validated for sediment from (2005-2009) using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

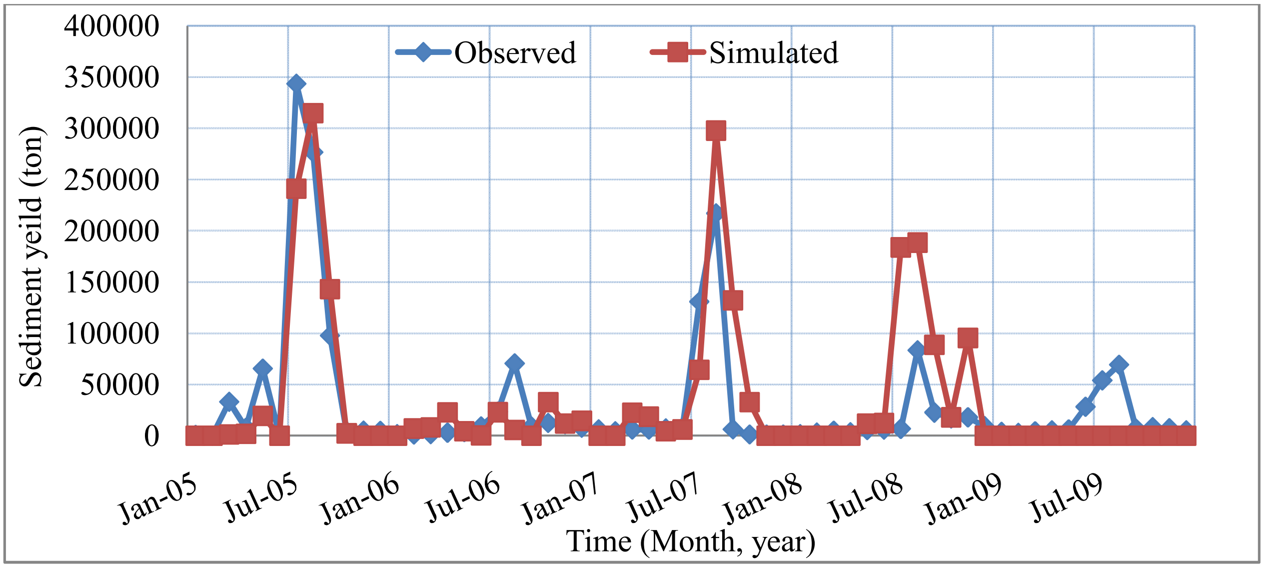


Figure 24 Monthly observed and simulated sediment yields validation period by Excel

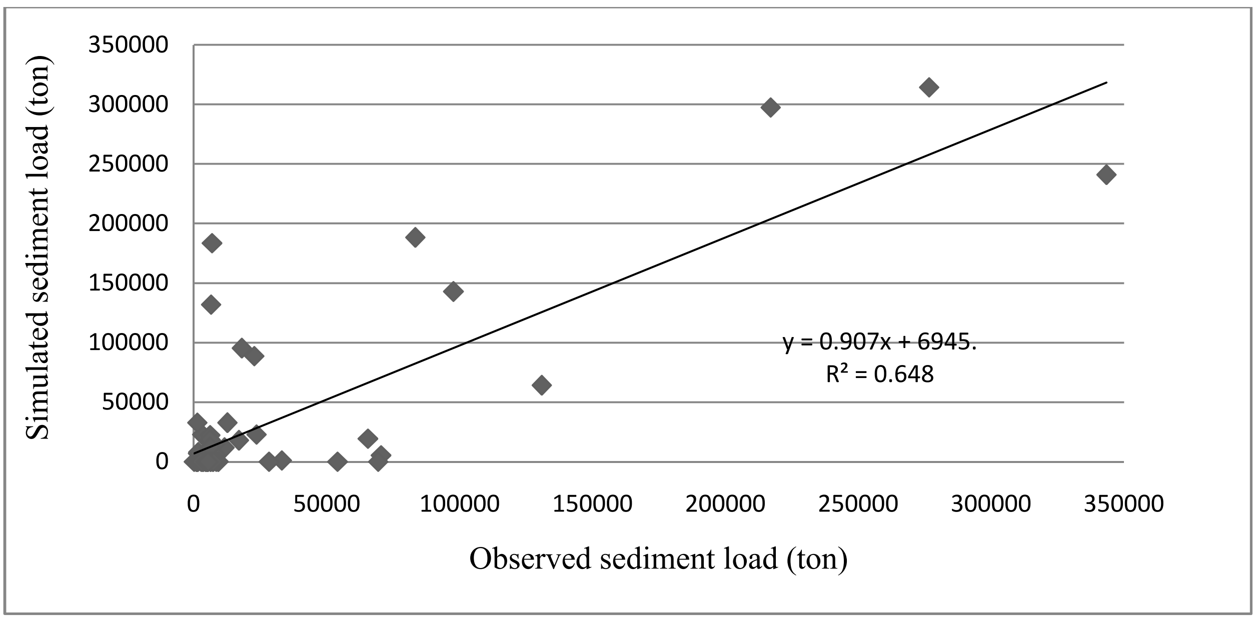


Figure 25 Goodness-of-fit for observed and simulated sediment yield validation period

The goodness-of-fit for simulated and observed sediment during validation period were plotted (Figure 26). The statistical values in the monthly basis of sediment yield estimation in the validation period results (R^2= 0.65, NSE= 0.54 and PBIAS=-14.2). The model overestimated the peak monthly sediment yield from (2007-2008) Figure 25 above.

Table 10 Evaluation of sediment yield during Calibration and Validation periods

Monthly time step simulation	Average monthly sediment load (ton/month)		Model performance			Performance Remarks		
	Observed	Simulated	R^2	NSE	PBIAS	R^2	NSE	PBIAS
Calibration (1995-2004)	59714.47	47878.78	0.77	0.64	19.8	V.good	Good	Good
Validation (2005-2009)	29598.61	33798.49	0.65	0.54	-14.2	Good	Satisf.	V.good

4.3 Soil loss simulation and identification of sediment source areas

After the model was calibrated and validated, it was run for a period 18 years (1992 - 2009), then the overall simulated output can be used for further application and sediment source areas were identified Watershed.

The total observed Stream flow at study area gauged station was 15.52m^3/s and the simulated of Stream flow by SWAT model is 14.12m^3/s. The total annual sediment yield from catchment into the reservoir calibration and validation period was estimated by SWAT model is 7,773,363 ton. The total catchment area of the study area is 301850 ha. Therefore, the annual specific sediment yield from the catchment can be calculated as the total sediment yield divided by the area of the catchment which is equal to 25.75 ton/ha/year. From Kesem irrigation project feasibility study sediment yield estimated is 23 - 27 ton/ha/yr (Sir M Macdonald, 1986). Modeling of sediment yield for upper Awash, estimation of average annual sediment yield is 44.88ton/ha/yr (Tarik A, 2017).

The model is good result for the estimation of catchment stream flow and sediment yield in the study area. The SWAT model had 75 capabilities to identify areas within a watershed with high erosion and sediment yield. This helps to prioterize and formulates development and conservation plans in order to use available economic resource optimally. Since the erosion process occurred in the watershed is believed to be the major source of sediment load, it is important to give due attention for appropriate watershed development or soil and water conservation at least for those places which are major cause for higher sediment yield.

27 sub-basins are classified as per the model. Accordingly the highest average soil loss was 22.01 tons/ha and it was observed from sub basin 2. The lowest average soil loss was 0.03 tons/ha and it was observed from sub basins number 12. The rest sub watersheds were categorized between the highest and lowest soil loss rate. As it was observed in the simulation soil loss was strongly related with soil type, land use and slope gradient. Highest soil loss was correlated with Vertic cambisols, Lenthic leptosols, and Eutric Vertisols soil types with shrub land use, cultivated land use, and sparsely vegetated land use system and slope gradient greater than 20%. Lowest rate was observed from Eutric leptosols and Eutric cambisols soil type with Wetland use and shrubland use system and slope gradient 0-10%. The slope gradient created opportunity for the runoff to get high velocity.

Sediment yield of a watershed is the summation of suspended and bed load. The analysis described below is suspended sediment load.

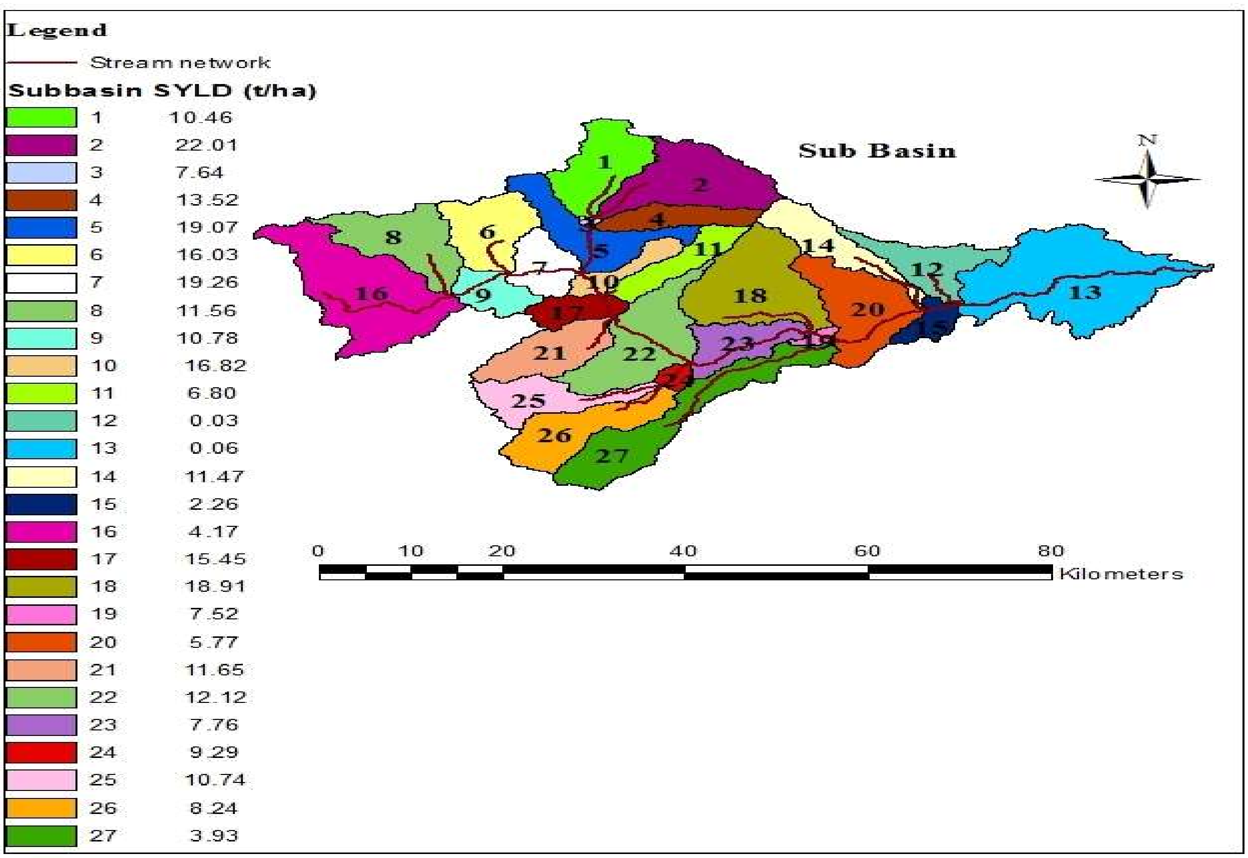


Figure 26 Average annual soil loss rates of sub-basins

4.4 Identification of sub basins

The identification of sub basin of this study was done based on estimated mean annual soil loss. Rank was assigned based on the amount of mean soil loss in which the first rank was given to the sub watershed with maximum soil loss. Other ranks were assigned in decreasing order of soil loss intensity where the last rank goes to the sub watershed with the least soil loss.

Table 11 Ranked sub-basins in terms of soil loss rates

Sub Watershed	Average Annual Soil loss (t/ha)	Rank	Area (ha)	Area (%)
2	22.01	1	16965.0	5.62
7	19.26	2	7063.2	2.34
5	19.07	3	12002.0	3.98
18	18.91	4	20625.0	6.83
10	16.84	5	4455.0	1.48
6	16.03	6	11402.0	3.78
17	15.45	7	4894.0	1.62
4	13.52	8	6588.5	2.18
22	12.12	9	17657.0	5.85
21	11.65	10	10487.0	3.47
8	11.56	11	13803.0	4.57
14	11.47	12	9530.5	3.16
9	10.78	13	5813.4	1.93
25	10.74	14	9413.8	3.12
1	10.46	15	12590.0	4.17
24	9.29	16	1559.2	0.52
26	8.24	17	12909.0	4.28
23	7.76	18	8340.6	2.76
3	7.64	19	364.5	0.12
19	7.52	20	1112.1	0.37
11	6.80	21	7118.3	2.36
20	5.77	22	15557.0	5.15
16	4.17	23	26544.0	8.79
27	3.93	24	18742.0	6.21
15	2.26	25	3671.7	1.22
13	0.06	26	33050.0	10.95
12	0.03	27	9600.9	3.18

Accordingly the rank was classified based on the soil loss rate. Accordingly, the highly eroded was from sub basin 2, 7, 5, 18 and its average annual sediment yield was 22.01 t/ha, 19.29 t/ha, 19.07 t/ha, 18.91 t/ha respectively.

And low sediment yield was from sub basin 12 and 13 it were 0.03 t/ha and 0.06 t/ha respectively. The average annual of sediment yield of Tendaho sub-basins ranges between 26.66ton/ha ton 0.02ton/ha (Asmelash *et al*., 2017).

These highly eroded sub basins are found in steep slope, heavy clay soil which is poor infiltration capacity soil and agricultural land use with poor conservation. These factors were responsible for aggravating the soil loss rate of the sub watersheds. Hence mitigation measures should be proposed based on the soil loss rate problem.

As per the research conducted by Hurni (1983), the range of the tolerable soil loss level for the various agro-climatic zones of Ethiopia was found to be 2 to 18 t/ha. Therefore, more of Kesem dam sub basins were found in the range of the tolerable soil loss level. But, the annual soil loss rate at some sub-basins of Kesem dam watershed was above this tolerable limit. In addition, based on the relative soil erosion and sediment delivery of the sub-basins, the authors have classified the sediment delivery of the sub-basins into four classes (Table 12), for quick mitigation and decline of the sediment yield at Kesem dam reservoir.

Table 12 Eroded soil delivery classes of sub-basins

Sediment yield interval (t/ha/yr)	Erosion class
Greater than 18	Highly eroded
10–18	Moderately eroded
2 – 10	Acceptable erosion
0–2	Negligible erosion

The spatial location of the sediment yield classes of sub-basins based on the classification of table above (Table 12) are mapped as shown in Figure 28.

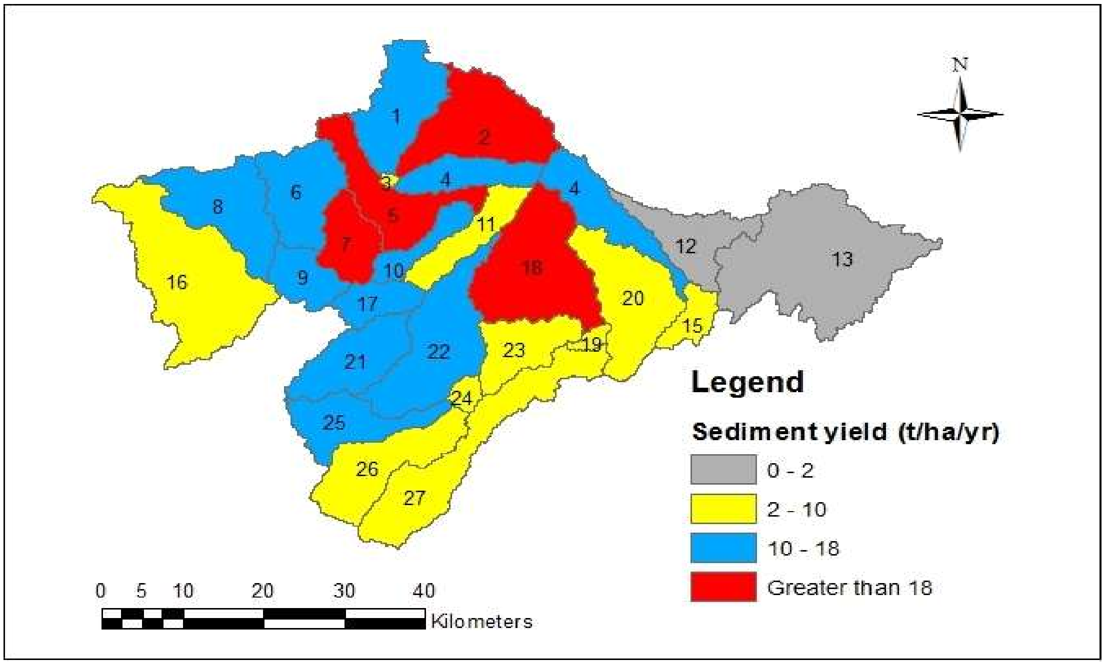


Figure 27 Spatial distribution of sediment yield of Kesem dam watershed sub-basin

The sediment yield from a given watershed is dominantly related to rainfall and runoff, soil erodibility, slope length and steepness, cropping and management of the soil, and any supporting practices implemented to prevent erosion (Dilnesaw and Bonn, 2006).

4.5 Scenarios developing and Mitigation measures

Changes in land use/land cover affect the hydrological cycle, biodiversity, radiation budgets and other processes. These changes on the other hand affect the storm runoff and sediment transport in the catchment. Therefore, analyzing the effect of land use/land cover change on the hydrology and sediment transport is one of the essential parts of this study. To do this it is necessary to develop scenarios that reflect the changes made to the watershed land use. Scenario analysis enables us to apply improved management practices and decision making.

The scenarios may be developed based on future land use plan in the watershed if there is any. But, in the absence of future master plan, the scenarios can be developed by changing the land use by a specified percentage and quantify the changes caused by the conversion of one land use type to the other.

The dominant land use in the study area is Agricultural land. Therefore, scenario development was made by changing the agricultural land to different land uses in the watershed to see scenario and two best Management Practices (BMP): applying grass strip area between a slope of 0 to 25% and terracing (Stone bunding) area between a slope of 0 to 25%. Therefore, six scenarios were compared to the baseline i.e. the original land use. These scenarios were developed to evaluate the sediment yield change from the watershed.

The scenarios are:

Scenario_0 = Initial land use

1. Scenario_1: 10% of agricultural land is changed to sparsely vegetated land grassland
2. Scenario_2: 10% of agricultural land is changed to shrubland
3. Scenario_3: 20% of agricultural land is changed to shrubland
4. Snenario_4: 30% of agricultural land is changed to Shruband
5. Snenario_5: 40% of agricultural land is changed to shrubland
6. Scenario_6: 50% of agricultural land is changed to shrubland

As I had checked by changing different land use existed my study area, the above developed scenario shows that small reduction of sediment yields in the catchment. Therefore, it is preferable to apply another best management practices like aforestation, applying grass strip and terracing (Stone bunding) area between a slopes of 0 to 25% was recommended. Applying grass strip and terracing (stone bunds) in low slope areas of the catchment could give potential effect of BMPs (Betrie *et al*., 2011).

Table 13 Summary of scenario development result

Scenarios	Period (1992-2009)		
	Average sediment yield (tons/ha/yr)	Difference	Sed. Change (%)
S0	18.10	-	-
S1	18.09	-0.01	-0.06
S2	18.07	-0.03	-0.17
S3	18.03	-0.07	-0.39
S4	17.99	-0.11	-0.61
S5	17.87	-0.23	-1.3
S6	17.80	-0.30	-1.7

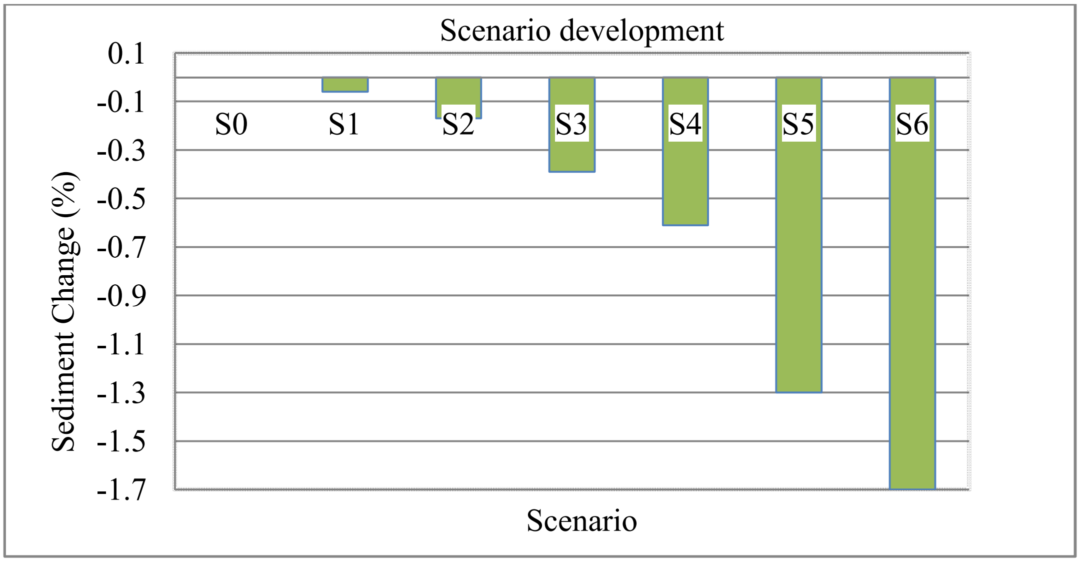


Figure 28 Comparison of change of sediment yield

A comprehensive watershed management usually has multiple objectives such as controlling damaging runoff and managing and utilizing the same for useful purpose on one hand, and controlling erosion and reducing the effect of sedimentation on the other hand. As seen in scenarios developed by changing land uses, there no is great difference in reduction of soil erosion.

Therefore, it is mandatory to apply other conservation measures in the area. In the upstream watershed of a reservoir, basic management measures are commonly taken to reduce soil erosion and sediment yield entering into the reservoir. Among these basic management measures; flood interception and diversion works, gully head protection works, check dams, silt trapping dams, closing off hillsides, reforestation, contour farming and terracing, rotation cropping of grain and grass, intercropping and inter planting are best pretention method if it applied to the study area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The SWAT model was found to be useful in identifying effect of soil erosion and sediment yield in Kesem watershed. The model performance in Kesem sub basin was good in predicting stream flow and sediment yield despite scarce data of observed suspended sediment load.

The stream flow calibration and validation period is from (1995-2004) and (2005-2009) respectively. As it showed in the model performance efficiency evaluation, coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) are found to be 0.68 and 0.67 respectively in calibration, 0.65 and 0.60 respectively in validation for flow analysis. Sediment data taken from the rating curve equation is from 1995 to 2009. The model calibration period is 1995 to 2004 and the validation period is 2005 to 2009. Similarly, Sediment model performance efficiency, coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) are found to be 0.77 and 0.64 for calibration and 0.65 and 0.54 for validation respectively. This shows the SWAT model simulate well stream flow and sediment yield/load in Kesem sub-basin.

The study area covers 3018.5km^2 which is subdivided into 27 sub basins, sub basins were further divided into 219 HRU based on 10% land use, 20% soil and 10% slop classification. The important parameters were identified for calibration based on the sensitivity analysis using the SWAT model. Accordingly, the global sensitivity analysis showed that flow is most sensitive to CN2, RCHRG_DP, SOL_K and CH_K2 and the most sensitive sediment parameters are CH_K, HRU_SLP, BIOMIX and SLSUBBSN.

The total annual sediment yield generated from rating curve at selected gauging station was found 29.62ton/ha/yr and the simulated yield by SWAT model is 25.75ton/ha/yr. From the model simulated output, sub-basins 2, 7, 5, and 18 were found to be the severely eroded sub-basins with annual average sediment yield of 22.01t/ha, 19.29t/ha, 19.09t/ha and 18.93t/ha, respectively. While, sub-basins 12 and 13 were found to be the negligible/least sediment sources with annual average sediment yield of 0.03 t/ha and 0.06t/ha respectively. Based on scenario developed best management practices were applied in the study area.

5.2 Recommendation

- There is no well functioned hydro-meteorological station in and nearest to the watershed. Due to this there is short of stream flow and sediment yield record of observation data was used in this study. Using longer period of flow and sediment data will improve the model result.
- An improved model results depends on accurate and quality of input data. The constraints in conducting this research work were lacks of well and continuous recorded meteorological and hydrological data in and around the watershed, continuous measured sediment data, especially sediment data on the daily basis. Sediment data used were generated from sediment rating curves developed for this study. Therefore, observed sediment yield and simulated sediment yield by the SWAT model were derived based on sediment rating curve. Good result can be obtained if continuous and detailed sediment concentration data are used. Hence, responsible bodies should give due attention to minimize problem such as time and frequency of sampling, method of sampling and proper record of sediment concentration data with its respective measured flow data.
- Nonfunctional meteorological and hydrological stations are recommended to be maintained or replaced early and additional gauging stations for data accuracy are recommended in the area.
- Whenever natural resource management and conservation works are planned, the area should be treated based on the severity of erosion problem, which is based on erosion severity class of sub watersheds. In this study, sub-watersheds that produce the highest sediment yield are 2, 7, 5, 18 and the like. Accordingly, attention should be given to those sub-watersheds that contribute more sediment yield to the reservoir and conservation measures such as contour farming and terracing, changing land uses, reforestation and construction of check dams should be applied to these areas.

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APPENDICES

Appendix A

Year	Matahara	Arerti	Awara Melka	Aleltu	Shola gebeya
1986	375.10	1039.60	351.30	975.50	770.50
1987	423.50	800.80	269.90	1002.60	997.70
1988	525.50	875.20	341.00	1241.30	1039.60
1989	536.98	997.70	719.20	1213.50	997.70
1990	652.80	1039.60	732.30	890.30	1039.60
1991	556.10	800.80	528.50	1188.60	800.80
1992	598.50	877.10	488.90	888.20	770.50
1993	649.40	1005.36	550.50	1236.20	997.70
1994	556.20	767.80	395.70	970.20	1039.60
1995	458.00	623.90	445.60	1030.90	997.70
1996	634.30	790.80	450.60	1080.70	1039.60
1997	484.06	912.36	359.90	1087.90	800.80
1998	495.10	1039.80	664.20	1340.70	1039.60
1999	494.50	1011.40	627.00	1123.70	997.70
2000	493.20	765.40	550.70	1076.10	1039.60
2001	427.10	701.30	406.90	1007.50	845.40
2002	276.50	617.40	327.90	929.30	885.70
2003	455.60	1005.30	450.50	851.90	989.60
2004	559.80	906.40	528.80	1044.80	814.80
2005	544.40	1050.10	445.50	975.30	727.00
2006	467.60	944.10	496.30	1079.30	898.60
2007	590.95	931.10	341.00	848.40	1007.70
2008	516.80	1041.30	341.00	1340.70	945.70
2009	444.20	878.00	255.10	1123.70	829.20
2010	588.10	964.12	518.80	913.30	770.50
2011	455.79	891.60	341.00	949.50	845.40
2012	405.80	1031.80	534.70	880.80	885.70
2013	663.75	913.40	352.80	947.90	989.60
2014	419.50	959.50	334.50	680.00	814.80

Appendix A.1 Annual rainfall of selected station

Month	Metahara	Arerti	Awara Melka	Aleltu	Shola Gebeya
1	12.32	10.31	13.92	13.25	2.40
2	26.15	33.63	35.19	17.86	52.04
3	45.86	53.19	51.81	52.63	58.96
4	43.53	65.60	32.42	65.94	88.33
5	32.09	29.23	56.95	41.88	31.71
6	25.74	46.95	9.79	93.76	47.63
7	123.69	244.98	77.40	281.11	260.47
8	112.86	250.36	87.28	319.24	238.16
9	46.53	104.25	29.84	117.38	103.94
10	24.78	40.08	24.23	21.86	26.89
11	6.65	17.55	14.62	3.61	3.58
12	8.38	6.73	20.02	3.16	3.78

Appendix A.2 Average monthly Rainfall of selected stations (1986-2014)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1986	30.9	33.6	34.4	34.4	36.5	34.9	32.8	33.6	34.5	33.9	33.1	31.1	**33.63**
1987	30.3	33.6	33.2	33.6	33.7	36.9	36.4	33.3	35.7	34.7	33.1	31.8	**33.84**
1988	31.0	33.8	35.6	35.4	37.3	37.0	32.1	31.7	32.7	33.2	31.6	30.3	**33.48**
1989	29.7	30.7	33.4	31.1	35.8	36.0	32.8	33.3	33.8	34.2	32.4	30.1	**32.79**
1990	31.2	29.6	30.9	32.7	37.0	37.7	32.7	32.7	33.6	34.1	32.7	30.8	**32.98**
1991	32.6	32.2	34.6	34.1	34.9	36.7	32.3	31.3	33.9	33.8	31.8	31.0	**33.26**
1992	30.4	29.8	35.1	35.3	36.0	36.4	32.8	30.9	32.3	32.7	31.8	31.5	**32.92**
1993	30.2	28.9	34.9	33.5	33.6	36.8	33.1	33.1	34.2	33.9	32.7	31.3	**33.03**
1994	31.4	33.0	35.3	36.5	36.3	36.3	32.1	31.7	32.3	33.5	31.0	30.1	**33.29**
1995	31.1	33.4	32.5	34.8	36.9	37.7	33.2	32.4	33.5	34.6	33.0	32.5	**33.79**
1996	31.6	34.2	34.4	34.3	34.3	34.7	32.3	32.4	34.1	34.3	31.9	31.5	**33.32**
1997	31.6	32.1	35.3	34.1	36.8	36.3	33.1	33.3	35.9	32.0	30.3	30.3	**33.43**
1998	29.9	32.9	33.9	36.0	37.0	38.1	34.3	31.5	33.8	32.9	32.3	31.1	**33.62**
1999	31.9	34.8	32.8	36.2	37.2	36.9	31.9	32.0	33.6	31.9	31.3	30.4	**33.39**
2000	31.8	33.2	35.1	35.7	36.8	37.3	33.2	31.2	33.7	32.7	31.7	31.1	**33.61**
2001	30.1	32.9	33.7	35.9	37.9	36.4	33.0	31.3	34.9	34.8	32.7	31.7	**33.76**
2002	30.9	33.9	34.5	36.3	38.3	37.8	36.6	33.6	35.4	35.3	33.5	31.3	**34.78**
2003	31.3	34.8	35.6	35.8	38.1	36.8	32.9	31.6	33.6	35.2	33.1	30.9	**34.13**
2004	32.3	32.5	34.1	33.3	37.8	36.9	33.3	33.1	34.7	33.4	32.6	31.3	**33.77**
2005	31.6	35.0	34.9	35.8	34.4	36.6	32.2	33.5	35.0	34.9	33.2	31.7	**34.05**
2006	32.7	34.0	34.3	34.9	37.3	37.9	33.7	31.7	34.4	34.4	32.5	29.9	**33.96**
2007	31.1	34.0	35.3	34.7	37.4	36.6	33.6	31.0	33.0	33.9	31.9	31.0	**33.61**
2008	32.4	32.0	36.1	36.0	36.0	36.1	32.8	32.0	34.7	34.2	30.2	31.0	**33.62**
2009	31.2	34.0	36.5	36.1	37.9	38.3	34.8	33.6	36.1	33.7	33.5	31.5	**34.76**
2010	31.9	32.5	33.0	35.9	35.8	37.2	33.4	32.2	33.7	35.6	33.2	31.5	**33.82**
2011	32.7	34.7	34.3	37.2	36.6	37.0	35.0	32.8	33.1	34.6	32.8	31.3	**34.33**
2012	32.5	33.9	36.1	36.3	37.4	37.2	32.8	31.8	33.7	34.1	33.6	31.9	**34.26**
2013	31.5	34.3	36.2	36.9	37.3	34.3	32.0	32.2	33.8	33.7	32.3	30.9	**33.78**
2014	32.0	33.4	35.3	36.1	36.5	38.0	35.9	33.8	34.0	32.3	33.0	31.5	**34.32**

Appendix A.3 Average monthly and yearly maximum temperature of Metahara station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1986	9.8	18.4	17.6	19.9	19.8	20.9	19.4	19.7	18.6	15.6	13.8	13.6	**17.23**
1987	13.6	15.0	19.3	17.2	18.7	22.9	22.1	20.2	20.2	17.8	12.7	13.6	**17.79**
1988	16.7	18.8	17.9	20.0	19.1	22.3	20.6	19.4	19.4	16.7	10.0	12.1	**17.74**
1989	13.0	15.9	17.8	18.7	16.0	19.8	19.9	19.4	19.0	15.2	14.5	18.0	**17.27**
1990	14.7	18.8	17.6	17.6	20.2	22.6	20.0	19.9	19.8	15.1	14.7	12.2	**17.75**
1991	16.4	18.2	19.5	18.7	19.2	21.7	20.4	19.8	19.5	15.7	12.8	13.6	**17.95**
1992	16.9	19.1	20.5	20.3	19.8	21.5	20.3	19.9	18.6	16.8	15.0	16.8	**18.78**
1993	17.3	16.3	15.5	19.7	19.4	21.9	20.3	20.3	20.6	18.3	14.3	12.2	**18.01**
1994	11.9	14.8	20.1	20.8	19.9	21.8	19.6	19.5	18.5	15.4	14.3	13.0	**17.46**
1995	12.4	17.4	18.7	19.7	19.8	21.1	21.2	20.0	18.9	17.0	13.2	17.1	**18.04**
1996	17.7	15.2	19.7	18.5	19.6	21.4	20.2	20.1	19.9	15.4	13.3	11.6	**17.73**
1997	16.2	12.8	19.1	19.4	19.5	20.6	20.1	20.3	20.1	19.0	18.6	14.4	**18.39**
1998	18.1	19.6	20.1	20.4	21.2	23.2	21.4	19.9	20.3	17.8	12.6	10.0	**18.72**
1999	14.1	14.8	18.9	18.7	19.5	21.1	18.9	19.2	19.6	17.6	12.6	12.0	**17.28**
2000	12.1	12.1	16.5	19.3	20.7	22.4	19.8	19.7	19.7	16.9	14.7	12.7	**17.23**
2001	13.5	14.9	19.0	18.2	21.0	22.2	20.0	20.1	18.6	17.9	13.9	14.3	**17.81**
2002	16.6	15.7	20.1	20.0	20.5	22.3	21.8	20.0	19.1	17.7	14.4	18.0	**18.87**
2003	16.0	17.1	19.3	20.5	19.2	21.2	20.4	19.6	20.0	16.3	16.0	14.0	**18.30**
2004	18.2	15.4	16.1	19.3	18.3	21.9	20.3	20.6	19.9	16.7	15.5	15.8	**18.16**
2005	15.4	15.7	19.3	18.6	20.3	21.7	20.3	20.2	20.9	16.2	14.5	10.5	**17.79**
2006	15.7	18.2	17.8	19.3	19.8	21.9	20.6	20.5	20.2	18.8	15.6	16.2	**18.71**
2007	16.7	17.9	17.3	19.5	21.5	22.4	20.7	19.6	20.3	15.6	14.7	10.5	**18.04**
2008	14.1	14.3	13.3	18.9	20.2	21.4	20.0	19.8	20.3	16.6	13.8	11.0	**16.99**
2009	13.5	16.0	17.9	19.4	19.4	21.2	20.9	20.3	20.0	17.5	14.0	18.1	**18.19**
2010	15.2	18.3	18.0	20.5	21.6	22.5	20.9	20.5	19.7	15.9	14.7	12.1	**18.32**
2011	14.6	15.9	16.3	20.6	20.8	21.2	21.0	20.0	20.4	14.7	16.9	11.5	**17.81**
2012	13.2	14.0	16.2	20.7	19.3	22.2	19.8	19.6	19.9	14.5	14.3	13.8	**17.29**
2013	14.0	20.5	19.6	20.4	21.5	20.5	19.6	20.4	18.7	16.6	15.5	11.0	**18.16**
2014	14.6	18.3	18.3	19.7	20.5	20.9	21.4	20.4	19.9	16.3	15.3	11.6	**18.08**

Appendix A.4 Average monthly and yearly minimum temperature of Metahara station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1986	19.8	21.1	20.6	20.5	22.2	21.8	18.5	17.8	18.4	19.3	18.7	18.2	19.73
1987	18.8	20.7	22.0	20.8	22.2	21.1	18.2	17.8	18.4	18.7	18.8	18.8	19.67
1988	20.0	20.3	22.2	21.5	21.5	20.6	19.0	18.1	19.1	19.4	18.2	18.5	19.86
1989	19.2	20.8	22.0	21.6	22.8	23.4	18.7	18.3	19.5	18.7	19.4	18.3	20.29
1990	19.7	19.9	19.5	20.3	20.7	21.7	18.7	20.7	18.7	19.5	19.0	18.8	19.77
1991	19.5	21.3	20.4	22.1	21.8	21.8	19.1	18.3	18.4	19.4	19.3	19.1	20.06
1992	19.7	21.1	20.6	20.5	22.2	21.8	18.5	17.8	18.4	19.3	18.7	18.2	19.72
1993	18.9	20.7	22.0	20.8	22.2	21.1	18.2	17.8	18.4	18.7	18.8	18.8	19.68
1994	20.0	20.3	22.2	21.5	21.5	20.6	19.0	18.1	19.1	19.4	18.2	18.5	19.86
1995	19.2	20.8	22.0	21.6	22.8	23.4	18.7	18.3	19.5	18.7	19.4	19.2	20.29
1996	19.7	19.9	19.5	20.3	20.7	21.7	18.7	20.7	18.7	19.5	19.0	18.8	19.78
1997	20.1	21.4	20.4	22.1	21.8	21.8	19.1	18.3	18.4	19.4	19.3	19.1	20.07
1998	20.2	21.6	22.5	20.6	22.5	21.7	18.6	17.9	19.3	19.5	20.4	19.7	20.35
1999	20.1	21.7	22.0	21.8	21.9	21.7	18.5	17.7	18.5	18.6	19.0	18.9	20.02
2000	19.9	21.1	21.7	16.6	22.1	22.3	19.8	18.1	18.8	18.5	19.7	19.0	20.00
2001	19.8	21.6	23.3	20.4	21.4	21.9	21.1	19.1	19.8	20.9	19.9	18.7	21.03
2002	20.2	21.6	22.5	20.5	22.7	20.0	18.7	18.4	19.4	19.9	19.5	19.2	20.15
2003	20.3	21.7	22.0	21.9	21.9	21.7	18.5	18.7	18.5	19.6	19.0	18.7	20.10
2004	19.9	21.8	22.1	22.9	21.8	22.1	21.1	19.1	19.8	20.9	19.6	18.9	21.13
2005	19.8	21.6	23.3	20.1	21.1	21.3	18.7	18.4	19.4	19.9	19.5	19.2	20.19
2006	19.8	21.1	20.6	20.5	22.2	21.8	18.5	17.8	18.4	19.3	18.7	18.2	19.73
2007	18.8	20.7	22.0	20.8	22.2	21.1	18.2	17.8	18.4	18.7	18.8	18.8	19.67
2008	20.0	20.3	22.2	21.5	21.5	20.6	19.0	18.1	19.1	19.4	18.2	18.5	19.86
2009	19.2	20.8	22.0	21.6	22.8	23.4	18.7	18.3	19.5	18.7	19.4	18.8	20.39
2010	19.3	19.9	19.5	20.3	20.7	21.7	18.7	20.7	18.7	19.5	19.0	18.8	19.74
2011	19.7	21.3	20.4	22.1	21.8	21.8	19.1	18.3	18.4	19.4	19.3	19.1	20.03
2012	20.1	21.6	22.5	20.6	22.5	21.7	18.6	17.9	19.3	19.5	20.4	19.7	20.35
2013	20.2	21.7	22.0	21.8	21.9	21.7	18.5	17.7	18.5	18.6	19.0	18.9	20.03
2014	20.1	20.4	21.3	11.3	22.1	22.3	19.8	18.1	18.8	19.1	19.5	18.9	19.33

Appendix A.5 Average monthly and yearly maximum temperature of Shola gebeya station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1986	8.0	9.7	10.3	11.0	11.9	11.0	10.7	10.5	10.2	9.6	7.2	7.7	9.80
1987	7.6	9.9	10.8	11.3	11.9	11.3	10.4	10.1	10.1	8.1	7.2	5.6	9.51
1988	8.2	7.3	9.2	10.4	11.5	10.7	10.0	10.3	10.3	8.2	7.0	6.1	9.12
1989	7.4	9.2	11.0	10.7	11.0	11.4	10.7	10.7	10.2	8.8	7.1	6.3	9.62
1990	7.5	9.4	9.2	9.9	10.4	11.3	10.5	10.4	10.2	9.0	7.1	6.9	9.30
1991	7.7	8.2	9.7	11.4	11.5	10.8	10.6	10.5	10.1	7.9	7.9	5.3	9.45
1992	7.9	9.7	10.3	11.0	11.9	11.0	10.7	10.5	10.2	9.6	7.2	7.7	9.79
1993	7.6	9.9	10.8	11.3	11.9	11.3	10.4	10.1	10.1	8.1	7.2	5.6	9.50
1994	8.3	7.3	9.2	10.4	11.5	10.7	10.0	10.3	10.3	8.2	7.0	6.1	9.13
1995	7.4	9.2	11.0	10.7	11.0	11.4	10.7	10.7	10.2	8.8	7.1	7.1	9.62
1996	7.5	9.4	9.2	9.9	10.4	11.3	10.5	10.4	10.2	9.0	7.1	6.9	9.30
1997	6.5	8.0	9.7	11.4	11.5	10.8	10.6	10.5	10.1	7.9	7.9	5.3	9.18
1998	7.4	7.3	9.4	10.5	11.8	10.6	10.6	10.5	10.1	8.5	7.2	7.3	9.27
1999	6.8	8.7	11.0	10.8	11.5	10.9	10.4	10.5	10.0	8.9	7.6	5.1	9.34
2000	5.9	8.2	10.5	10.6	11.4	11.0	10.6	9.9	9.9	7.5	7.1	6.8	9.73
2001	8.4	8.4	11.8	11.1	11.1	10.5	10.7	10.1	9.8	9.4	8.3	7.3	10.25
2002	6.5	7.2	9.4	10.5	11.8	10.6	10.0	9.8	9.5	7.8	6.4	5.2	9.19
2003	8.5	8.4	11.8	11.2	10.8	10.0	10.0	9.8	9.5	7.8	6.4	5.2	9.31
2004	5.9	8.2	10.2	9.8	11.3	11.1	10.7	10.1	9.8	9.4	7.7	6.0	9.65
2005	8.4	8.4	11.8	11.2	10.8	10.0	10.0	9.8	9.5	7.8	6.4	5.2	9.11
2006	8.0	9.7	10.3	11.0	11.9	11.0	10.7	10.5	10.2	9.6	7.2	7.7	9.80
2007	7.6	9.9	10.8	11.3	11.9	11.3	10.4	10.1	10.1	8.1	7.2	5.6	9.51
2008	8.2	7.3	9.2	10.4	11.5	10.7	10.0	10.3	10.3	8.2	7.0	6.1	9.12
2009	8.0	9.2	11.0	10.7	11.0	11.4	10.7	10.7	10.2	8.8	7.1	6.4	9.89
2010	6.7	9.4	9.2	9.9	10.4	11.3	10.5	10.4	10.2	9.0	7.1	6.9	9.24
2011	7.5	8.2	9.7	11.4	11.5	10.8	10.6	10.5	10.1	7.9	7.9	5.3	9.28
2012	6.5	7.2	9.4	10.5	11.8	10.6	10.6	10.5	10.1	8.5	7.2	7.3	9.19
2013	7.4	8.7	11.0	10.8	11.5	10.9	10.4	10.5	10.0	8.9	7.6	5.1	9.39
2014	6.8	8.3	10.7	11.3	11.4	11.0	10.6	9.9	9.9	2.3	7.2	6.5	9.24

Appendix A.6 Average monthly and yearly minimum temperature of Shola gebeya station

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	11.89	2.5988	8.8449	0.0319	0.4528	1.77
Feb.	25.7	4.2098	6.8183	0.0589	0.6716	4.47
Mar.	44.33	5.4738	5.5595	0.1214	0.3963	5.47
Apr.	43.59	5.2412	7.6193	0.1941	0.4781	8.37
May.	32.09	3.8097	6.5839	0.1494	0.4589	6.9
Jun.	26.51	2.987	5.0572	0.1648	0.3827	6.53
Jul.	120.32	7.62	3.0564	0.4524	0.5098	15.23
Aug.	112.03	7.1964	3.1788	0.4614	0.5241	15.9
Sep.	47.7	4.7951	6.0053	0.2769	0.454	10.5
Oct.	23.92	3.8598	8.0231	0.0667	0.434	3.53
Nov.	6.89	1.7021	11.3261	0.035	0.2791	1.43
Dec.	8.36	2.1912	11.4119	0.0259	0.3415	1.37

Appendix A.7 Statistical analysis of daily precipitation data of selected station

Month	tmp_max	tmp_min	hmd	dewpt
Jan	19.78	7.43	69.16	8.98
Feb	21.09	8.65	66.69	9.6
Mar	21.6	10.36	67.54	10.65
Apr	20.38	10.8	70.09	10.66
May	21.87	11.39	68.5	11.41
Jun	21.72	10.92	68.17	11.04
Jul	19	10.51	74.14	10.61
Aug	18.42	10.3	75.01	10.36
Sep	18.98	10.07	72.79	10.16
Oct	19.4	8.56	69.58	9.25
Nov	19.25	7.64	70.71	9.12
Dec	19.17	7.07	70.12	8.76

Appendix A.8 Statistical analysis of daily temperature data of selected station

(Written by Stefan Liersch August 2003)