**ADDIS ABABA UNIVERISITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

# ESTIMATION OF CATCHMENT SEDIMENT YIELD USING SWAT MODEL (CASE STUDY GELANA RESERVOIR, RIFT VALLEY BASIN, ETHIOPIA)

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

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Addis Ababa, Ethiopia

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BY

MENGIST ABATE BEYENE

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## CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa institute of Technology a thesis entitled **Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gelana Reservoir, Rift Valley Basin, Ethiopia)** in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (major Hydraulic Engineering).

________________________________________

Dr. Yenesew Mengiste

(Supervisor)

________________________________________

Date

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I represent and warrant this is my original work, and does not infringe or violate any rights of others.

______________________________

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**ACKNOWLEDGMENT**

Above all I thank the almighty of GOD for his guidance and grace upon me during all my works and in all my life.

Secondly I would like to express my deepest gratitude appreciation to my advisor Dr. Yenesew Mengiste for her professional advice in the commencement of the study and valuable suggestions, encouragement and guidance of my research work. Furthermore, she has devoted her time and energy to advise me during the whole work and recommended valuable and constrictive comments to improve from starting proposal development to the finishing of the thesis. Also I would like to express my sincere thanks to Fitsum Teshome who has comment me on SWAT model output.

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## ABSTRACT

Sediment particles created from the land by soil erosion processes in the catchment are spread along with the flow of river. When the flow of river is obstructed and stored in reservoirs, the sediment settles, deposit and reduces its capacity. Sediment settle in a reservoir is a serious problem that threatens sustainability of the reservoir. The aim of this study was to estimate sediment yield in the reservoir, to investigate the spatial and temporal variation of sediment yield and to recommend appropriate sediment reduction measure. The Soil and Water Assessment Tool physically based semi distributed hydrological model is utilized for sediment yield estimation in the Gelana catchment (area of 644.28 km$^2$), located in Abaya-Chamo sub-basin, rift valley, Ethiopia. The model was calibrated, validated and assessed for evaluation to model using Nash–Sutcliffe coefficient and coefficient of determination at Tore gauged station. Model calibration and validation were done after checking the performance of sensitive analysis. The first most sensitive parameters were base flow alpha factor for bank of storage (ALPHA_BNK) for flow calibration and average slop steepness (HRU_SLP) for sediment calibration. For flow calibration the coefficient of determination and Nash-Sutcliffe coefficient give as 0.76 and 0.70 respectively. Similarly for flow validation the coefficient of determination and Nash-Sutcliffe coefficient give as 0.70 and 0.64 respectively. Sediment calibration the coefficient of determination and Nash-Sutcliffe coefficient give as 0.71 and 0.66 respectively. Sediment validation the coefficient of determination and Nash-Sutcliffe coefficient give as 0.80 and 0.64 respectively. Both the calibration and validation result indicated that good agreement between observed and simulated stream flow and sediment yield. The model simulated result shows that the average annual sediment yield is 89.14 ton/km$^2$/year at the dam site. Spatial and temporal variation of sediment yield were performed. The spatial variation of sediment ranges from 7.58 ton/ha to 53.17 ton/ha. Scenario was developed ($S_1$-$S_5$) for reduction of sediment yield in the Gelana reservoir.

Key words: Gelana catchment, sediment yield, SWAT, calibration and validation.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| DEM | Digital Elevation Model |
| ENMA | Ethiopia National Metrological Agency |
| ET | Evapotranspiration |
| FAO | Food and Agricultural Organization |
| GIS | Geographical Information System |
| Ha | Hectare |
| HRU | Hydrologic Response Unit |
| ITCZ | Intertropical Convergent Zone |
| Km | kilometers |
| MM | Millimeter |
| MoWIE | Ministry of Water Irrigation and Electricity |
| MUSLE | Modified Universal Soil Loss Equation |
| NGO | Non-governmental Organization |
| NSE | Nash Sutcliffe Simulation Efficiency |
| SCS | Soil Conservation Service |
| SNNPRS | South Nation Nationality People Reginal State |
| SWAT | Soil and Water Assessment Tools |
| SWC | Soil Water Conservation |
| SY | Sediment Yield |
| USDA | United State Development of Agriculture |

# 1. INTRODUCTION

## 1.1 Background and Justification

The estimation of sediment yield from the catchment is useful for reservoir sedimentation, river morphology, soil and water conservation planning, and also estimation of concertation and load of chemical adsorbed to sediment particles. Sediment yield defined as the total sediment out flow from watershed that includes both bed and suspended materials. 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. 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 smallest sediment particles may be transferred through the reservoir without settling whereas larger particles may be retained depending on how completely suspended sediment settles into the reservoir. During peak flow inflowing water with large volumes of sediment can enter a large reservoir and cannot be subsequently redistributed. Trap efficiency of a reservoir decreases with age as the reservoir capacity is depleted by sediment accumulation (Halcrow Water, 2001).

Sediment yields are closely related to soil erosion. Erosion is a natural process causing soil loss and generating sediment yield from catchment area even in the absence of human alterations of land cover. Soil erosion by water occurs in two phase process, consisting of the detachment of individual particles from the soil mass and their transport by erosive agents, and when sufficient energy no longer available to transport deposition occur (Morgan, 1998). Soil erosion not only the deposition of sediment transported by river into reservoir reduced the reservoir capacity, but also sediment deposition on river bed and banks causes widening of the flood plain during floods. It causes loose of fertile top soil cover, resulting in strong environmental impact and high economic costs by its effect on agricultural production, infrastructure and water quality (Lal 1998; Pimentel et al. 1995). Sediment yield reflects the influences of climate (precipitation), catchment properties (soil type, topography), land use/cover, and drainage properties (stream network form and density) (Walling, 1994). Sedimentation in catchment outlets such as reservoirs, lakes, ponds and dams is perhaps the most problematic outcome of soil erosion (Van Rompaey et al, 2001). High rates of sediment deposition at catchment outlets can reduce or totally eliminate water storage capacity (Vertstraen and peosen 1999). Various studies reported that sediment yield creates major problems in lakes, dams and reservoirs in Ethiopia (Setegn et al, 2008). Poor land use practices, inadequate management systems and lack of appropriate soil-conservation measures have added greatly to problems of soil erosion and sediment yield associated with the intense rainfall and steep terrain of the region.

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.

The rift valley of Ethiopia is greatly affected by soil erosion, land degradation and sediment transport. The water resources, land use and ecosystem of the valley have been affected by rapid population growth, overgrazing, deforestation, soil erosion, sediment deposition, and reduction of the water-storage capacity of lakes. Changes of land use and land cover through the expansion of agricultural land at the expense of forest and woodlands have been the major causes of soil erosion in the area (Jansen et al, 2007).

To tackle the problem of land degradation in Ethiopia, Government and non-Governments (NGO) launched massive afforestation and soil conservation schemes during the past few decades. However, despite its relatively long history, and the considerable investments made by the Government and NGO very little achievement had been recorded in terms of output, impact, and sustainability (Azene, 1996). In the study area rift valley basin especially Gelana sub-basin land degradation and poor agricultural practices are the most physical factor of soil erosion and sediment deposing in the downstream of the catchment. This study tries to characterize the catchment in terms of sediment yield using physically based SWAT model. The main objective of this study is to estimate the amount of sediment yield in the reservoir and appropriate reduction measure. Therefore, this study will provide enough information about the sediment variability and erosion status of each sub watershed which will be very essential for watershed development and management options, and decision makers will be beneficiaries on decision making based on scientific results.

## 1.2 Statement of Problem

All rivers contain sediment those can be considered a body of flowing sediment as much as one of flowing water. When a river is stilled behind a dam the sediment deposit to the bottom of the reservoir. As the sediment accumulate in the reservoir so the dam gradually loses its ability to store water for the purposes for which it was built. Every reservoir loses storage to sedimentation although the rate at which this happens varies widely. Sedimentation adversely affects the reservoir capacity. Though the ultimate destiny of all reservoirs is to become filled with sediment the length of time that this takes depends on the sedimentation rate and how well the problem is addressed both during the planning stage and while reservoir sedimentation is occurring.

The rift valley river watersheds suffer severe land degradation and soil erosion due to extended dry seasons in some parts of basin, torrential rain and geological nature, bringing large quantities of sediment in the drainage systems. In the study area Gelana reservoir sedimentation the one of problem due to the soil erosion and land degradation in the upstream.

## 1.3 General objective

The general objective of this study to estimate sediment yield in the reservoir, investigate sediment distribution and recommend appropriate reduction measures.

### 1.3.1 Specific objective

- ✓ To estimate sediment yield into the reservoir
- ✓ Assess the temporal and spatial variability of sediment yield in the catchment.
- ✓ To recommend appropriate reduction measure.

## 1.4 Research Question

- ➢ How much sediment yield produce from the catchment?
- ➢ How many sediment parameters are there the most sensitive?
- ➢ How to reduce the accumulation of sediment in the reservoir.

### 1.5 Scope of the Study

The scope of this study is limited to the estimation of catchment sediment yield using SWAT model. This study did not consider comparison of sediment yield by using another model and also not consider the impact of land use/land cover change on the sediment yield. 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 soil conservation measure.

### 1.6 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 presentation of the research founding. The last chapter presented conclusion, recommendation, reference and appendix.

# 2. LITRATURE REVIEW

## 2.1 Soil Erosion

Soil loss and sediment yield are two terms that have distinct meanings in erosion technology. Soil loss refers to the removal of soil material from its original position (Lentsoane, 2005), i.e., a particular slope or development. It can be defined as the detachment and movement of soil particles on a landscape profile or land facet distinguishing it from deposition and sediment transport in catchment (Nearing et al, 1994). The total sediment outflow from a catchment during any given time is the sediment yield of that catchment. It is that proportion of the soil loss that is not deposited before the catchment outflow or designated area or area of interest in the catchment (Lentsoane, 2005). It is therefore a net result of the complex process of detachment and transport by raindrops and flowing water (Nearing et al, 1994). It is thus acceptable to assume that for small catchments, or facets, the soil loss corresponds with sediment yield and is proportional for bigger catchments (Nearing et al, 1994). This is due to temporal and permanent deposition taking place within the catchment.

Spatial and temporal information on runoff, soil erosion, and sediment yield of a catchment can provide a useful perspective on the availability of water, rate of soil erosion, and soil loss in the catchment. The dynamics of the processes of soil erosion and sediment yield are influenced by the spatial and temporal characteristics of the input variables affecting them and by controls exerted by the land surface. The controls related to land surface include elevation, soil, vegetation cover, and underlying geology. The major classification of erosion type is by erosive agents, wind or water, which causes the erosion. The main types of erosion are rill erosion, sheet erosion and gully erosion. The sheet and rill erosion classification is based on a concept of progressive erosion severity.

Sheet erosion, which is a uniform removal of soil from the surface, is assumed to be the first phase of the erosion process, and sheet erosion rates are assumed to be low. As erosion becomes increasingly sever, rill erosion is assumed to begin. Rill erosion progresses to gully erosion, which produces deeply incised channels.

### 2.1.1 Factors affecting soil erosion

Several factors influence soil erosion which include climate, soil, topography, and vegetation and management practices. 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. The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity (Foster, 1988).

Soil erosion by water is also a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. As (Stern, 1990) put when the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport. The erodibility of the soil also affects soil erosion. The erodibility of the soil 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.

The other factor that contributes to soil erosion is soil sealing. 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 (Smitrh, 2005).

### 2.1.2 Rain drop band leaf drip erosion

The impact of falling drops of water has the capacity to detach soil particles from the land surface. The amount and sizes of the soil particles that can be detached with such an impact of falling water depends on the magnitude of the force of the drop or drip upon hitting the land surface. The raindrop and leaf drip may have varying forces of impact. The vegetative cover that determines whether rain falls as raindrop or leaf drip has an effect on the amount of the sediment produced.

According to (Smithers and Schulze, 2002), the vegetative canopy has an effect of reducing the rainfall energy impact on the soil surface whereby, even if most rainfall intercepted by vegetative canopy, eventually reaches the surface, it does so with much less energy than non-intercepted rainfall. It is reported by (Smithers and Schulze, 2002) that the raindrops intercepted by the canopy are either fractured into smaller drops with less energy, drip from leaf edges or run down crop stems to the ground. The total rain falling on the canopy cover may come to the ground through either falling or running down the stem in varying proportions. The main controlling parameters for the amount of erosion by raindrop and leaf drip include the fraction of land surface covered by canopy and the height of fall from the vegetative canopy. The fraction of land surface covered by canopy may vary throughout the year. This has a partial effect on the variation of sediment production during the year.

In addition, part of the ground may be covered by non-erodible surfaces. All these must be taken into consideration when determining raindrop and leaf drip erosion.

Many studies have been undertaken with the aim of developing methods for estimation of erosion by raindrop and leaf drip. Various empirical erosion models have different parameters that are used to account for vegetative canopy cover. In MUSLE, the cover management factor represented as (C), estimates the effect of ground cover conditions, soil conditions, and general management practices on erosion rates (Sadeghi et al., 2007). ACRU uses a parameter called canopy cover factor. SHETRAN uses an empirical equation to determine the rate of soil erosion by raindrop and leaf drip impact that relates the rate of detachment of soil to raindrop impact soil erodibility coefficient, proportion of ground nearly shielded by ground cover, proportion of ground shielded by ground level cover and momentum squared of raindrop and leaf drip reaching the ground per unit time per unit area. In order to illustrate the attempts that have been made to describe the erosion processes resulting from leaf drip and raindrop, the EUROSEM version (Morgan et al., 1998) of leaf drip and raindrop erosion processes will be presented.

According to (Morgan et al., 1998), the detachability of the soil by raindrop impact can be expressed as the weight of soil particles detached per unit of rainfall energy. Since there have been various research attempts to correlate the rainfall energy and the weight of the sediment that can be eroded, knowledge of the amount of energy of a falling drop or drip can aid in the prediction of the amount of soil that can be eroded from the ground with respect to various standard soil textures. The EUROSEM User Manual (Morgan et al., 1998) gives the soil detachability in grams per joule for common soil types ranging from clay to sand. Others have managed to define the rate of detachment by raindrop impact as being proportional to the square of rainfall intensity (Beasley et al., 1980).

### 2.1.3 Erosion and sediment transport by over land flow

Erosion is defined as the wearing a way of land surface by detachment and movement of soil and rock fragments through the action of moving water and other geological agents (ICOLD, 1998). The emphasis on the action moving water indicates the intrinsic ability of runoff to detach soil. Soil detachment by runoff contributes significantly to the sediment production process. Overland flow is characterized by sediment entrainment, transport and deposition.

According to (Pidwirny, 2008), entrainment is the process of particle lifting by the agent of erosion and there is a thin line between entrainment and detachment so much so that it is somehow hard to distinguish between entrainment and detachment. The latter is mostly influenced by fluid drag. In the EUROSEM User Manual (Morgan et al., 1998), soil detachment by flow and deposition during flow is expressed in terms of settling velocity and transport capacity. The rate of soil detachment due to overland flow on hill slopes of a catchment can also be determined from various empirical relationships that have been developed that aim to relate the rate of soil detachment to other dependent variables such as the shear stress, erodible soil thickness, vegetation cover, rock cover, canopy cover and other factors.

Once the particle is detached, then it is prone to be transported by any transporting medium mostly water and/or wind. Detachment and entrainment can occur in cyclic sequences depending on the prevailing flow conditions. (Pidwirny, 2008) states that an entrained particle tends to move on as long as the velocity of the medium is high enough to transport the particle horizontally. ( Pidwirny, 2008) further gives four different ways in which transport can occur in the transporting medium:

- Suspension is where the particles are carried by the medium without touching the surface of their origin. This can occur in air, water and ice.
- Saltation is where the particle moves from the surface to the medium in quick continuous repeated cycles. The action of returning to the surface usually has enough force to cause the entrainment of new particles. This process is only active in air and water.

- Traction is the movement of particles by rolling, sliding, and shuffling along the eroded surface. This occurs in all media of erosion sediment transport.
- Solution is a transport mechanism that occurs only in aqueous environment and it mainly involves the eroded material being dissolved and carried along in water as individual ions.

Particle weight, size, shape, surface configuration, and medium type are the main factors that determine which of these processes operate (Pidwirny, 2008).

## 2.2 Sediment Property

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition, the predominant material being quartz. 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:

Rolling and/ or sliding particle motion
Saltating or hopping particle motion
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 saltation. 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. Water seeping into the ground can contribute to landslides (sub surface erosion) which may become major sources of sediments for rivers. 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 km2 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.

### 2.2.1 Sediment Deposition

Once the particles have been detached and/or entrained, they continue to be transported in the given transporting media. Some of the particles become deposited while in transit. Deposition occurs when particle flow velocity is reduced and the forces propelling the particle to move are less than the forces of resistance to transport. The interaction between flow velocity and particle erosion, transport, and deposition is illustrated by ( Pidwirny, 2008) using Figure 2.1 ( Pidwirny, 2008) states that the curved line marked "erosion velocity" describes the velocity required to entrain particles from the surface and further explains that the entrainment of silt and clay needs greater velocities than larger sand particles owing to the fact that silt and clay have the ability to form cohesive bounds between particles. Therefore, greater flow velocities are required to break the bonds and move these particles.

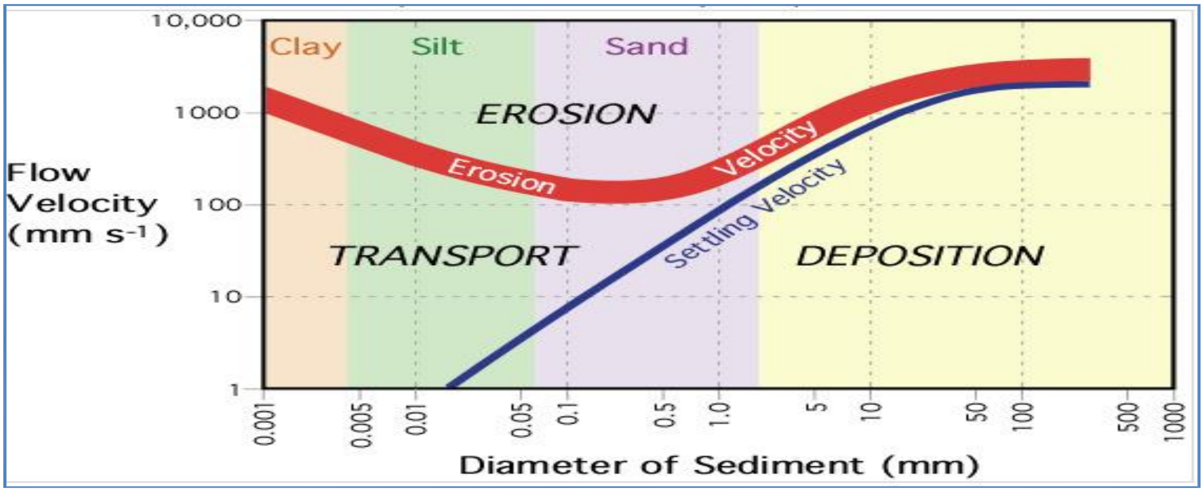


Figure 2. 1 The relationship between flow velocity and particle erosion transport and deposition (source physical Geography net) (pedwirny, 2008*)*

From Figure 2.1 above, the line labelled settling velocity shows at what velocity certain sized particles fall out of transport and are deposited (Pidwirny, 2008). The illustration shows the interaction between flow velocity, erosion, transport, settling velocity and deposition of particles of varying sizes in the form of clay, silt or sand.

The yellow band describes the relationship between erosion velocity and settling velocity for larger sized particles. The curves indicate that greater flow velocities are required to entrain larger sized particles from the stream’s bed and banks and also to make them fall out of transport and be deposited. The erosion velocity is slightly lower than the settling velocity for similar larger sized particles.

The complexity of the interaction is one of the reasons why a quantitative analysis of the sediment supplied to a stream from a watershed is usually difficult to perform as pointed out by (Julien, 1998). In other words, while it is possible to quantify sediment transport capacity. Sediment supply to streams or dams is affected by parameters such as deposition and entrainment, which cannot be accurately deciphered within the typically vast watershed areas encountered in practice.

Julien (1998) stated that physical processes involved in the spatial and temporal variations of all the parameters describing upland erosion from local rainstorms and bank erosion processes exacerbate the complexity of quantifying sediment supply.

### 2.2.1 Sediment transport capacity and sediment load

The transporting capacity is determined by the characteristics of the river channel and other factors. Every sediment particle that passes a given stream cross-section must satisfy the two conditions below (Julien, 1998):

- ✓ It must be eroded somewhere in the catchment above the cross section
- ✓ It must be transported by the flow from the place of erosion to the cross section

It was concluded from the above conditions that the rate of sediment transport depends on the transport capacity of the stream and availability of sediment. Julien (1998) went further to say that the amount of transported material in the stream therefore would depend on two groups of variables:

a) Characteristics and quantity of material made available for transport (characteristic variables): catchment topography, geology, rainfall intensity, magnitude and duration, weathering, vegetation, surface erosion, sediment supply from tributaries, mineralogy, soil type and land use.

b) Sediment transport capacity (defining variables): channel geometry, width, depth, shape, wetted perimeter, slope, vegetation, roughness, velocity distribution, turbulence and uniformity of discharge.

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.

Many attempts have been made to try to relate the quantity of material made available for transport, transport capacity and sediment sizes. Figure 2.2 below gives the general sediment transport capacity and supply relationship.

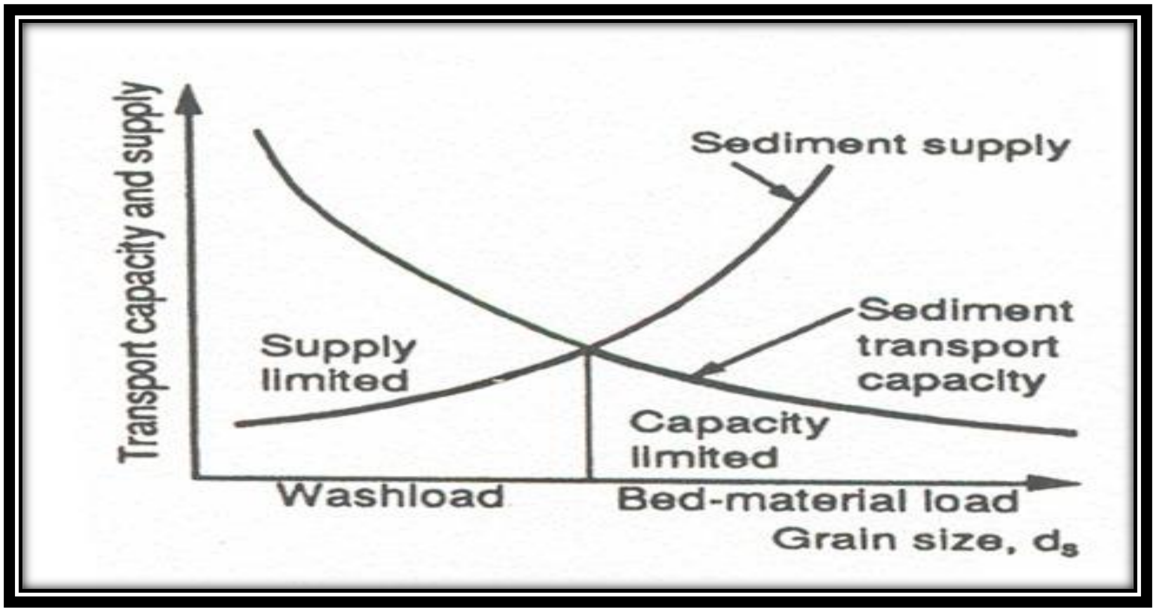


Figure 2. 2 Sediment transport capacity and supply relationship (Julien, 1998)

From Figure 2.2 it can be seen that for finer sized sediment, the transport capacity of the stream is much higher than the sediment supplied (up to some limiting grain size). The wash load is availability limited and it is therefore not possible to do a direct quantitative analysis of the sediment yield for a flow discharge on a particular river.

## 2.3 Erosion and sediment yield relationships

Not all sediment particles that are eroded from the catchment area upstream of a specified point along a river or at the reservoir manage to reach that specific point or the reservoir. The process of deposition described in paragraph is responsible for deposition of sediment before they get to the reservoir. While in most cases, the deposition would be as a result of limited transporting capacity of flow discharge, in some cases, it could be as a result of natural storages and ponds that trap the sediment within the catchment. While some deposited sediment become entrained back again into the transporting medium, there is still more chance that some sediment would still be deposited between the sediment source point and the hypothetical destination due to inadequate transport capacity.

One of the relationships that have been derived between erosion and sediment yield include the sediment delivery ration, $S_{DR}$. Sediment delivery ratio denotes the ratio of the sediment yield (SY) at a given stream cross section to the gross erosion ($A_T$) from the watershed upstream from the measuring point (Julien, 1998). Whereby, the following mathematical relationship is applied:

$$SY = (A_T)\,(S_{DR}) \qquad 2.1$$

Equation 2.1 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.

## 2.4 Watershed Parametrization

The erosion of soil from upland areas and deposition of sediment in low land and river banks is primarily governed by the hydrology and geomorphology of a watershed. The spatial variability of the topographic and the geomorphologic characteristics of watershed attributes to the variability of soil loss in the upland areas, and of sediment yield at the outlets of watersheds. Understanding the way in which topographic and geomorphologic factors, as well as hydrologic factors influence sediment yield is helpful in arranging the wise handling of sediment models and watershed management activities. Due to the fact that each watershed has its own distinct characteristics, the geomorphology and hydrology of one watershed varies from the other. Watersheds with a large drainage area and steep slopes are more likely to produce high sediment out flow as compared to the large sized watersheds with flat slopes. Additionally, the land cover situation of the watershed is another key factor. Watersheds with dense vegetation cover are more protected against erosion and sediment production. Similarly the hydrology of a watershed mainly rainfall characteristics, runoff and stream discharge is another fundamental factor to govern sediment production. The role of the different watershed factors in sediment production is interrelated with each other. For example, a watershed with a large drainage area, steep slopes and dense vegetation cover may generate less sediment yield as compared to a watershed with the same drainage area, flat slopes but less vegetation cover. In such case, the contribution from the variation of the slope and the vegetation condition determines the amount of the watershed's sediment supply. Because of the interdependency of parameters of a watershed, it is difficult to directly pinpoint a single parameter as the most governing factor for the amount of sediment yield (Habtamu, 2011).

## 2.5 Hydrological Model

Hydrological models are characterizations of the real world system. Modeling of the rainfall-runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 2000). Therefore, it is necessary 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. 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. (Beven, 2000) stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as usually, the transport of particles by rolling, sliding and saltating is called bed-load transport, while the suspended tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models to understand how the catchment responds to rainfall under different conditions.

### 2.5.1 Hydrologic Parameters

Hydrologic parameters are the main driving force behind the production and transportation of sediment load. Rainfall depth, intensity, surface runoff and stream flow are the major hydrologic factors that play a fundamental role in erosion generation and sediment transport. Rainfall initiates soil detachment and transportation, while surface runoff and peak flow transport the eroded soil as sediment load. Surface runoff and peak flow are estimated from available empirical formulae, while the stream flow component is measured physically. Nevertheless, for large basins with many river networks there is a limited amount of measured stream flow data available for each tributary and main river section. Therefore, physically based models like SWAT and other hydrologic models can help to simulate the surface runoff, peak flow and stream discharges, which can then be used as primary input for sediment modeling.

### 2.5.2 Soil and Water Assessment Tools (SWAT) Development and Interface

SWAT (Arnold et al. 1998) is a semi-distributed, time continuous watershed simulator operating on a daily time step. It is developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds. The major components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The program is provided with an interface in Arc GIS (Arc SWAT 2005, Winchell et al., 2008) for the definition of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data.

### 2.5.3 Theoretical Description of SWAT

The large scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further discredited into a series of hydrologic response units (HRUs), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated at each HRU and then aggregated for the sub basin by a weighted average. Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. For climate, SWAT uses the data from the station nearest to the centric of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method. The water in each HRU in SWAT is stored in four storage volumes: shallow soil profile (0-2m), snow shallow aquifer (typically 2-20m), and deep aquifer. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the rational formula (Chow et al., 1988). The watershed concentration time is estimated using manning's formula, considering both overland and channel flow. The soil profile is subdivided into multiple layers that support soil water processes including infiltration evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone. Down ward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer. Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal to $0c^0$ no percolation is allowed from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation.

The model computes evaporation from soils and plants separately. Potential evapotranspiration can be modeled with the Hargreves methods depending on data availability. Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index, and root depth, and can be limited by soil water content. Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by (Wischmeier and Smith, 1978). The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stoke's law (Chow et al.. 1988) and is calculated as a function of particle diameter squared. The depth of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth.

### 2.5.4 Hydrological component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation (Neitsch, et al, 2005).

$$Sw_t = Sw_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad 2.2$$

Where: $SW_t$ is the final soil water content (mm), Swo is the initial soil water content for day is (mm), t is the time (days), $R_{day}$ is the day precipitation (mm), $Q_{SURF}$ is the surface runoff (mm), Ea is the evapotranspiration (mm) $W_{SEEP}$ is the seepage from the bottom soil layer (mm) and $Q_{qw}$ is the groundwater flow on day (mm).

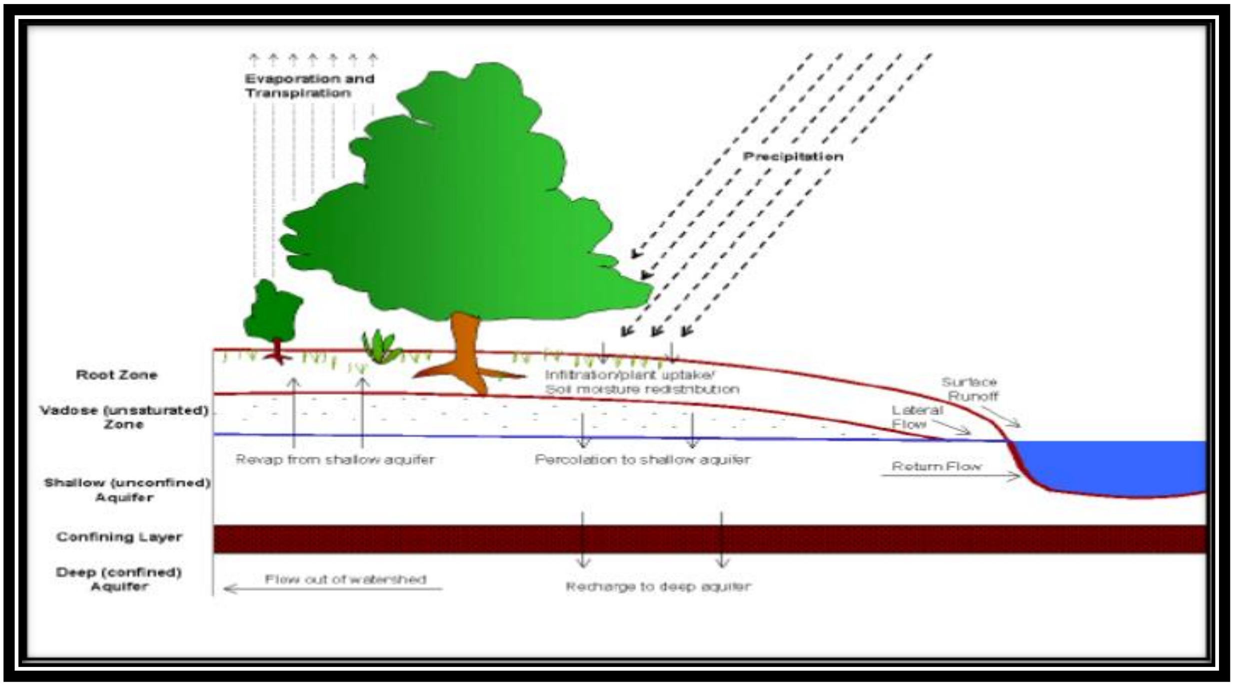


Figure 2. 3 Hydrological cycle component consider by SWAT (Neitsch et al.., 2005).

Generally, the model uses a digital elevation model (DEM) to delineate the watershed boundary and the watershed is divide into multiple sub-watersheds, the sub-watershed also subdivided in to hydrologic response units (HRUs) that consist of similar land use, slope, and soil characteristics (Arnold et al., 2012).The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management. Model outputs include surface runoff, evapotranspiration, groundwater, lateral flow, sediment, nutrient, and pesticide yields.

The SWAT model application is the following steps:

Data collection and preparation, sub-basin discretization, HRU definition, parameter sensitivity analysis, calibration and validation and uncertainty analysis.

SWAT model requires different procedures. The following are procedures necessary for modeling using SWAT.

Create new SWAT project, delineate the designated watershed for modeling, define land use, soil and slope data grids, determine the distribution of HRUs based on the land use and soil data, determine weather data, precipitation and temperature, write the SWAT input files requires access to data on soil, weather, land cover, plant growth, fertilizer and pesticide use, tillage, and urban activities, edit the input files if necessary, and Setup and run SWAT requires information on simulation period, PET estimation method and other options view SWAT output.

### 2.5.6 SWAT- CUP (SWAT Calibration Uncertainty Procedures)

Itis program designed to integrate various calibration/uncertainty analysis programs for SWAT using the same interface. The program can run SUFI2, GLUE, MoMc 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. It allows saving calibration iterations in the iteration history for later use. 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.

# 3. MATERIAL AND METHOD

## 3.1 Description of the Study Area

### 3.1.1 Location of Study Area

Gelana catchment is located in to Abaya-Chamo sub-Basin of rift valley lakes. The catchment found in southern part of the Ethiopia within the Oromia and South Nation Nationality people Regional States (SNNPRS). The catchment surrounded by $5^0$ 25’-6 $^o$18’ north and $37^0$ 50’-$38^0$ 20’ east about 450 kilometer south of Addis Ababa both in SNNPRS (Amaro special district) and Oromia regional state (Gelana district) to the south of Lake Abaya. The minimum elevation of the catchment at the dam site is 1633m and the maximum elevation is 3045m above sea level. When we go from the dam to the upstream the elevation is increase.

The Gelana dam is a type of earth fill embankment dam where located the coordinate of 405800E to 648800N UTM WGS 1984, close to Dima Tore gauged station. It has 25 meters height and 350 meters length. The reservoir capacity 52 million cubic meter of water. The full supply level of the reservoir is 1674.89 meter and the maximum water level is 1678.70 meter above sea level. The primary purpose of this dam is for irrigation in the downstream which located 30 kilometer from the dam. The total catchment area which contributed to the reservoir is 644.28km$^2$.

The Gelana irrigation area is found in the middle valley in the Gelana River. About 30 kilometer downstream of the dam site, a barrage is planned to be constructed from which two main canals will take off, one in the left side and in the other the right side of the river (Gelana dam final feasibility report, 2007).

The available flow is Gelana River which flows south from yirga chefe (upper valley) and enters a narrow gorge through which it descended down to the east edge of the Africa rift valley. Finally, the river travels through a seasonally flooded zone known as Bore swamp and eventually flow to Abaya Lake.

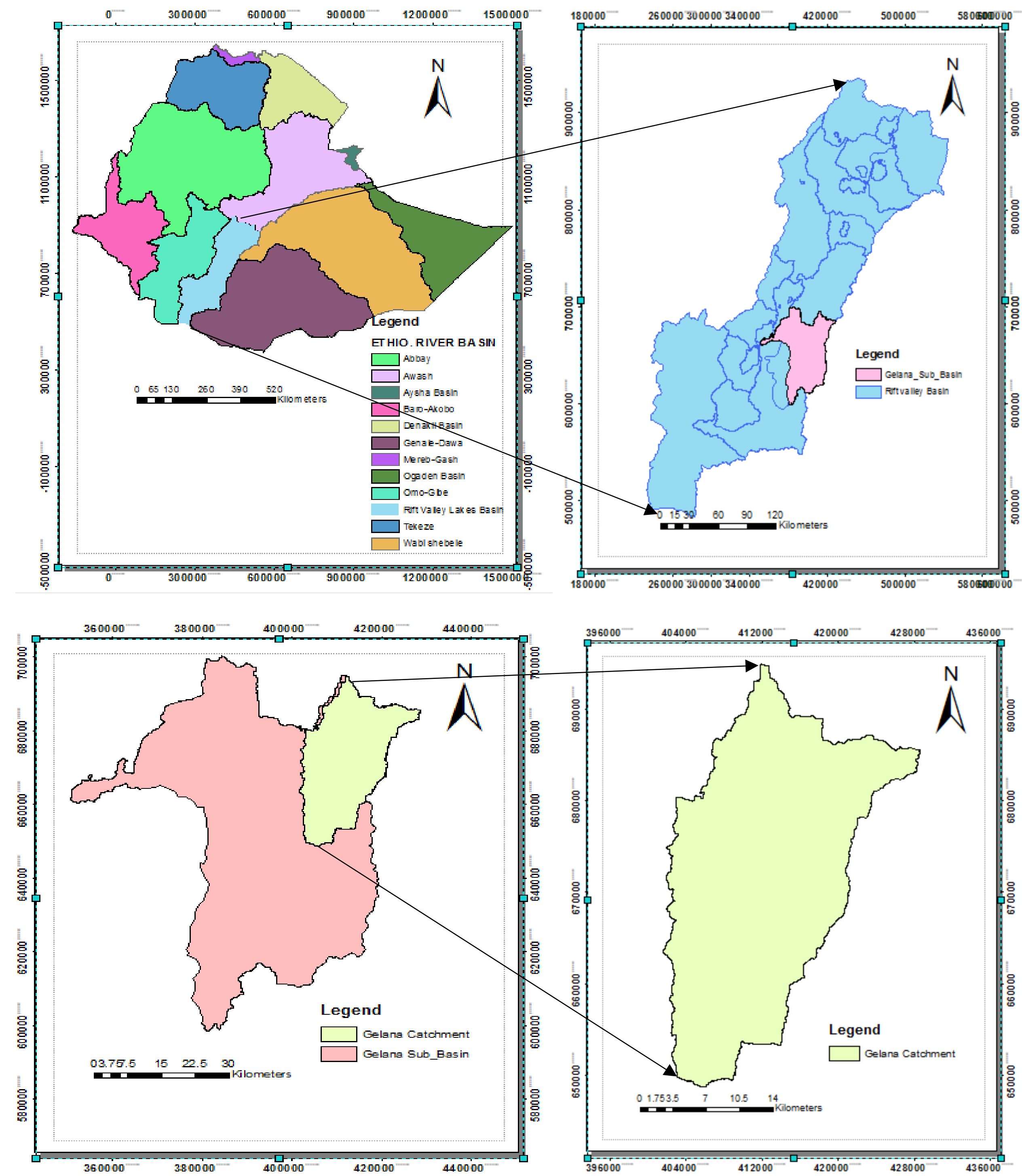


Figure 3. 1 Location of study area

### 3.1.2 Topography

Gelana catchment is left out due to poor soil, uneven topography and dense bush area along Gelana and Jelo River. The slope analysis is important to classified the capability of land, land use planning and conservation need. The result of slope analysis in the major part of the project is a gentle.

Topography in the central part of the study area is subdued with low gradients. Gradients up to about five present occur on the side slopes especially in the eastern margins. Micro-relief is particularly uneven along the course of the Gelana River where the terrain is broken by numerous drainage lines. The micro topography is also uneven to the west of the Bone River where there are very frequent termite mounds (Gelana dam final feasibility report, 2007).

### 3.1.3 Climate of the Study Area

The climate of Ethiopia is mainly controlled by seasonal migration of Inter-tropical convergence zone (ITCZ) and its associated atmospheric circulation but the topography has also an effect on the local climate. The traditional climate classification of the country is based on altitude and temperature shows the presence of five climatic zones namely: Wurch (cold climate at more than 3000 m altitude), Dega (temperate like climate-highland with 2500-3000 m altitude), Woina Dega (warm 1500-2500 m altitude), Kola (hot and arid type, less than 1500 m in altitude), and Bereha (hot and hyper-arid type) climate (NMSA, 2001).

Therefore the classification of the Gelana ranges from semi-arid in the lowland to humid in the highland of the catchment. The precipitation exceeds 2649.1 mm/year in the highlands area, whilst at the lowest altitude in the rift floor precipitation is often below 515.6 mm/year. The rain fall of this area characterized by a bimodal pattern with maximum peaks during April and May and during September and October in the season.

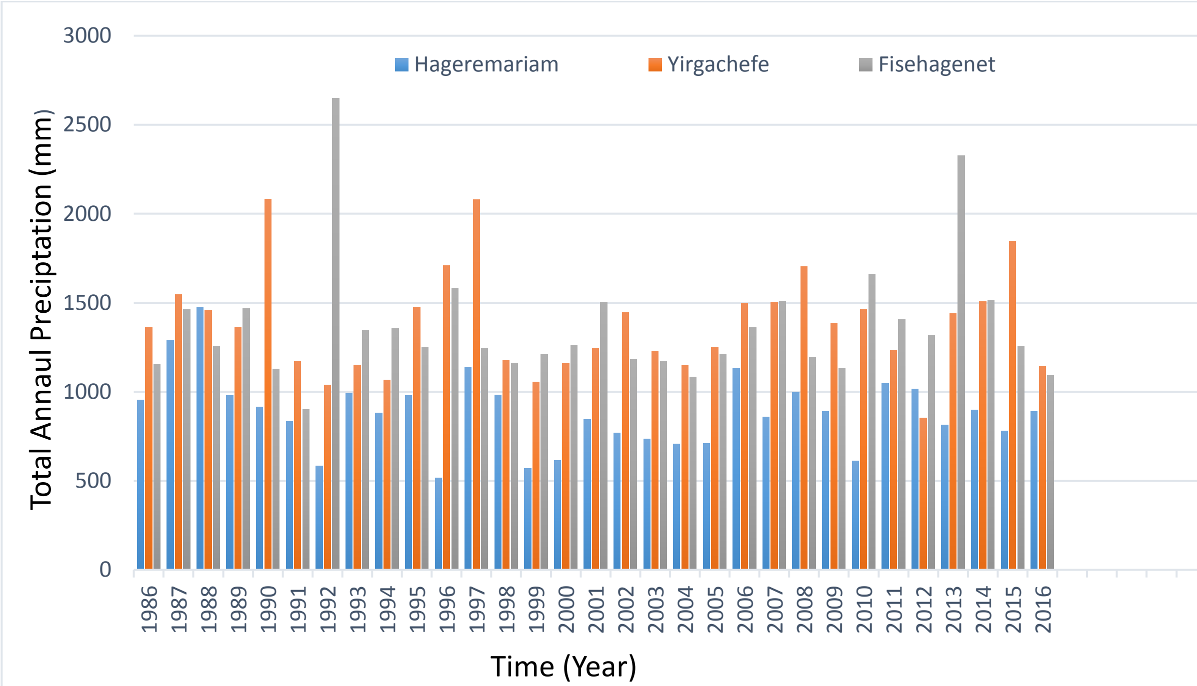


Figure 3. 2 Total annual precipitation of selection station at Gelana catchment

### 3.1.4 Geology

Ethiopian forms the part of the Arabo-Ethiopian swell which was uplifted during upper Eocene times. As a result of this uplift fissures formed, up which basaltic lavas were extruded. These lavas are known as trap series. The upper part of the basalts are interbedded with more silicic lavas, pyroclastic and lacustrine sediments. It is thought that the outcropping of lavas gave rise to the crustal collapse that formed the rift valley which followed after extrusion of the trap series. The cause of up swell is not known but it is almost certain that longitudinal arching cause weakness to develop, resulting and faulting. A subdued expression of this tectonic and volcanic activities is currently apparent as local thermal spring and occasional low to moderate intensity earthquakes.

The oldest rock in the Gelana catchment area are the Precambrian foliated biotitic and amphibole gneisses of the basement complex. These are found in the Amaro Mountains which form the western, fault controlled margin of the Gelana catchment and in the south of the catchment.

The basalt in the left and right abutment of the dam ranges from weathered and fractured to fresh. It consists of different flow layers ranging from amygdaloidal to massive aphanitic basalt. But no good exposure is found around the dam site to describe this lithology. Both abutment the basalt is overlain by thin veneer of insitu soil, a break down product of the underlying basaltic rock. The river channel across the dam axis is made up of clay deposit from stream suspension (Gelana dam final feasibility report, 2007).

### 3.1.5 Soil

The soil parent material are alluvial and colluvial deposit which in full the Gelana valley to considerable depth. The deposit originating from the western side are predominantly coarse while those originating from the basaltic rock of the eastern side are much finer. The deposits and other which occur from other sources lie superimposed on each other forming much layered soil and variable soil pattern. Extensive area of Eutric nitosols and Eutric camnisols with vertic properties occur to the east of Gelana river and extent southwards in to southern part of the study area. The west of the Bone River the soil predominantly coarse to medium textured nitosol. Elsewhere there are nitosols comprised of friable medium to fine textured material over impermeable clay at relatively shallow depths in the profile.

### 3.1.6 Land Use and Land Cover

In the Gelana catchment the land use and land cover are rapidly change due to high population growth in the basin. Agricultural land is dominant on the catchment. The vegetation cover is mostly a dry acacia thorn bush of varying density. This provides a certain amount of grazing for cattle and burnt to and encourage regeneration of grass. The densest vegetation is found adjacent to the Gelana where stands of dens riverine forest and bush occur. The area at the northern end of surveyed area is grassland which forms an important dry season grazing.

## 3.2 Data Collection and Analysis

### 3.2.1 Meteorological Data Collection and Analysis

The weather data were collected from Ethiopian National Metrological Agency (ENMA) which are one of input of SWAT model. The location of weather data for three station as shown below.

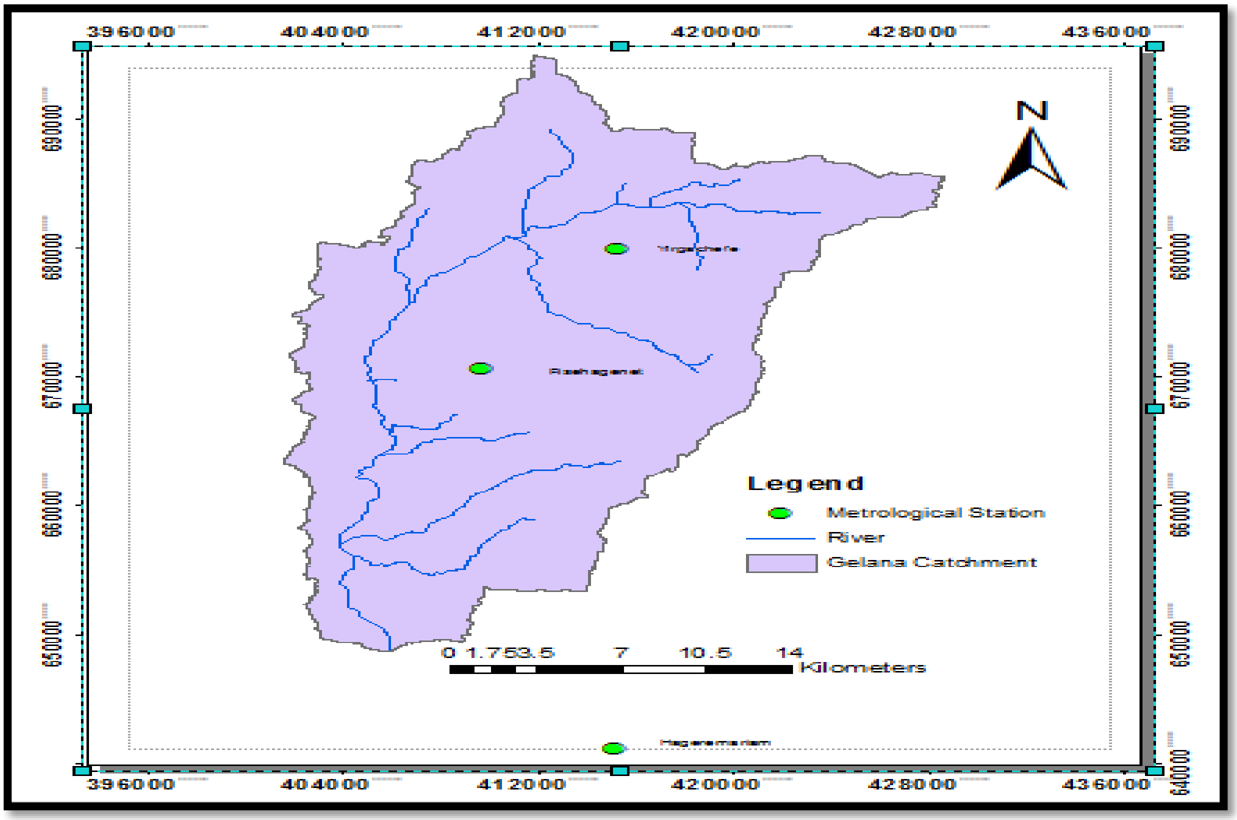


Figure 3. 3 Location of selection metrological station in Gelana catchment

*Table 3. 1* Metrological station with location in the Gelana catchment

| No | Station name | Latitude | Longitude | Elevation (masl) | Observation Period (year) | | |
|---|---|---|---|---|---|---|---|
| | | | | | precipitation | Max.Tem. | Min. Tem |
| 1 | Yirgachefe | 6.150667 | 38.2020 | 1856 | 1986-2016 | 1986-2016 | 1986-2016 |
| 2 | Fishagenet | 6.066700 | 38.1833 | 2240 | 1986-2016 | 1986-2016 | 1986-2016 |
| 3 | Hageremariam | 5.653200 | 38.2333 | 1861 | 1986-2016 | 1986-2016 | 1986-2016 |

The metrological data collection covers from 1986 to 2016 years. Metrological station also referenced using latitude, longitude and elevation data. The precipitation Gelana catchment is characterized by a bimodal pattern maximum precipitation during April, May and October.

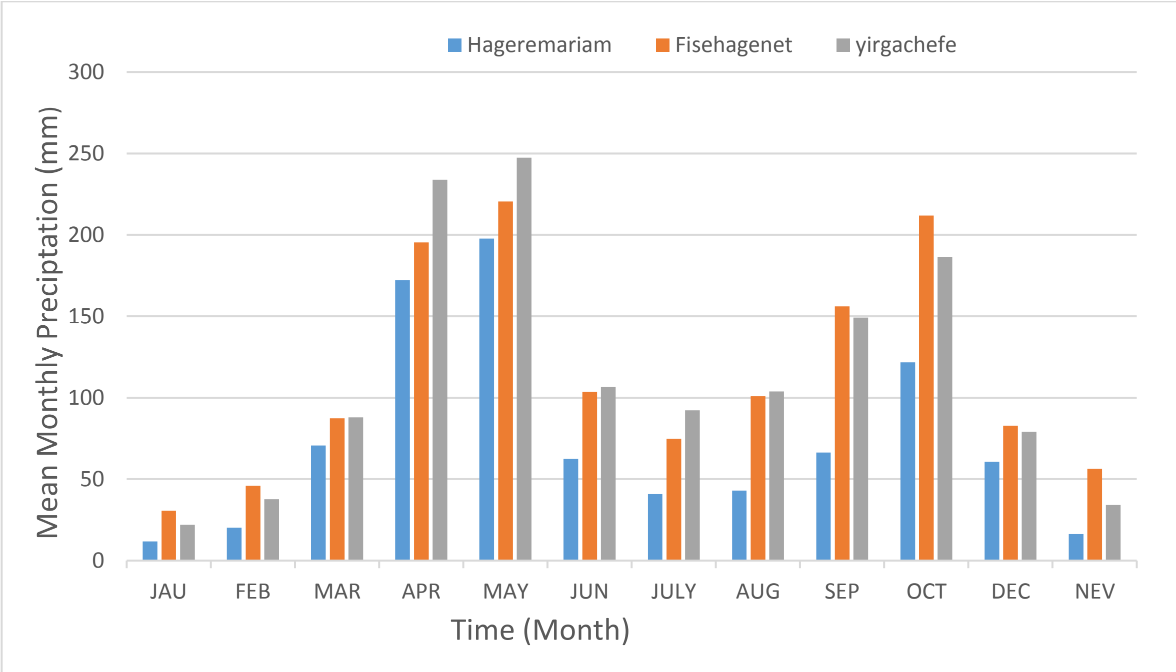


Figure 3. 4 Mean monthly precipitation on the selection station in the Gelana catchment

The maximum and minimum temperature represented the basin was also collected for three station the average monthly maximum and minimum temperature each station shown in the Figure 3.5 and 3.6 respectively.

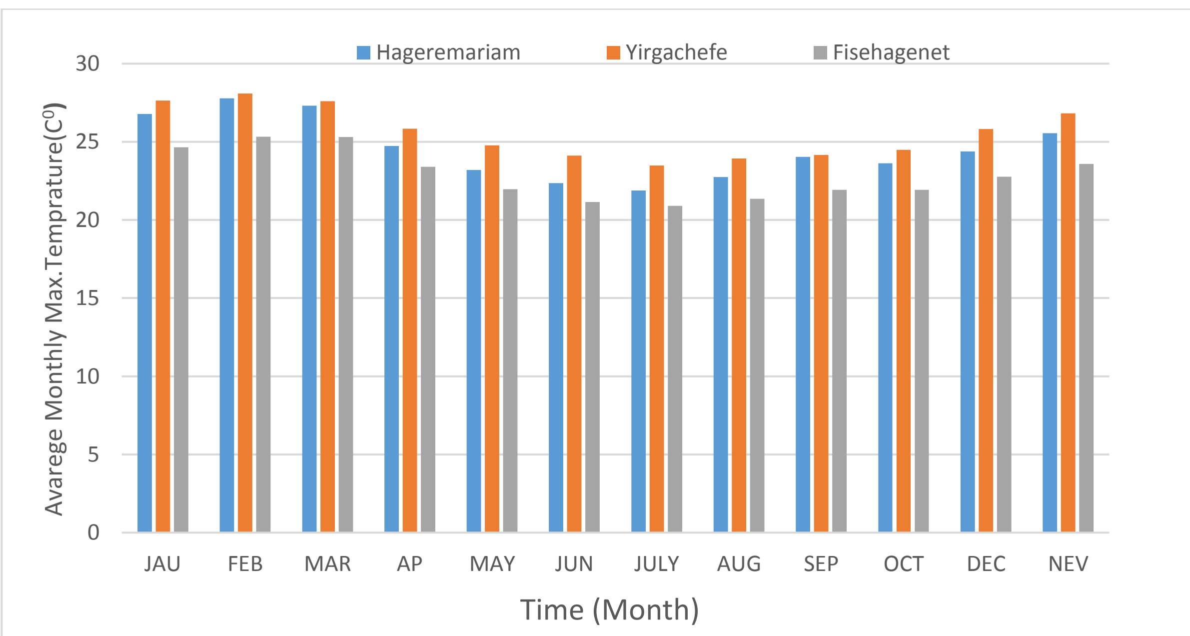


*Figure 3. 5* Mean monthly maximum temperature in the selected station Gelana catchment

The average monthly maximum temperature in the Gelana catchment varies from 20.9 $C^0$ to 28.09 $C^0$ in the lowland area and the average monthly minimum temperature varies from 8.25 $C^0$ to 13.54 $C^0$ in the high land of the catchment.

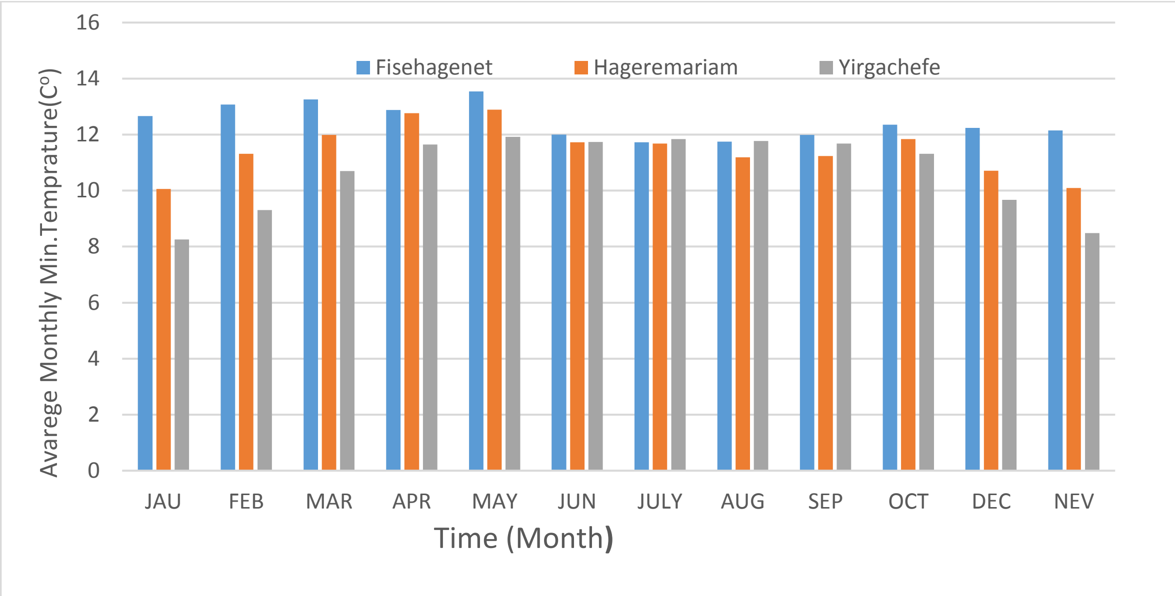


Figure 3. 6 Mean monthly minimum temperature in the selected station Gelana catchment

### 3.2.1.1. Metrological data Analysis

#### 3.2.1.1.1 Filling Missing data

All weather stations do not have fulfill observation data because some weather stations may have instrumental error or failures and others have lack of record observers. Therefore, it should be necessary to estimate or fill in this missing record. The missing precipitation station was estimated from the observation of precipitation at some other station as close to as evenly space around station with the missing record as possible.

Missing data filling method are: arithmetic mean method, normal ration method, inverse distance weighing method and regression method. Arithmetic mean method can be used to fill the missing data when the normal annual precipitation is below or equal to 10% of the station which data are being recorded. The normal ration method is used when the normal annual precipitation any of index station different from that of precipitation station by more than 10%. When there is no normal annual precipitation for the station, inverse distance weighing method can be used to fill the missing data. Another method is regression/Excel STAT used to fill the missed data from nearest station to another station. For this study arithmetic mean and normal ratio method used. According to Richard H. (1998) the two formulas are described below.

Arithmetic mean method

$$\mathbf{P_X = \frac{(P1+P2+P3 \ldots Pn)}{N}} \qquad 3.1$$

Where:

$P_x$ = the precipitation from the station with the missed record $P_1$, $P_2$, $P_3$ … $P_n$ are the corresponding index station.

N = number of index station

The normal ration method is used when the surrounding gauged have the normal annual precipitation exceeded 10% consider gauged.

$$P_X = \frac{Nx}{N} \left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \cdots \frac{Pn}{Nn}\right. \qquad 3.2$$

Where:

Px = Missing value precipitation to be computed

P1, P2, P3 …Pn = Rain fall neighboring station during missing period

N1, N2, N3 … Nn = Average value of rain fall for the neighboring station

N = Number of station used to in the computation

Nx = Average value of the rainfall for the station in question for the recording period

#### 3.2.1.1.2 Check Consistency of the selection Station

If the condition relevant to the recording of rain gauged stations have significant change during the period of record, inconsistency would arise in rain fall data of a station. There are a lot of factors that affect the consistency of precipitation record at a given weather station. To check a given weather station data time series observational data is relatively consistent and homogeneous and the periodic data are proportional to an appropriate simultaneous period. This station data proportionality can be tested by double mass curve analysis in which accumulated rainfall/precipitation data is plotted against the mean value of all neighborhood stations. Double mass curve method helped in determining the best realistic correlation of stations located near or within watershed. This technique is based on the principle that when each recorded data comes from the same parent population they are consistent (Subramanya, 2008). It should be corrected as:

$$Pcx = Px\left(\frac{Mc}{Ma}\right) \quad 3.3$$

Where:

$P_{cx}$ = correct precipitation at any time $t_1$ at station x

$P_x$ = original record precipitation at any time $t_1$ at station x

Mc = correct slop of the double mass curve

Ma = original slop of double mass curve

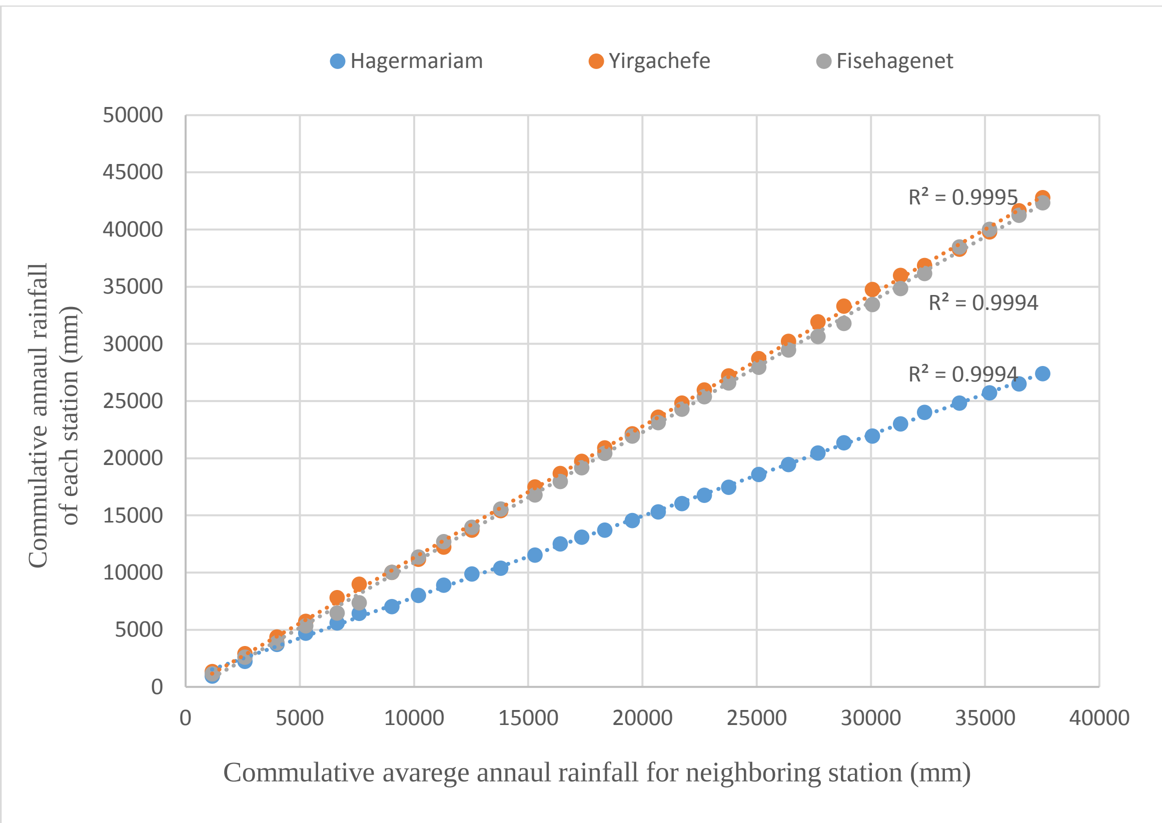


Figure 3. 7 Double mass curve plot for selected metrological station

#### 3.2.1.1.3 Checking Homogeneity of Selection Station by Non- Dimensional Parametrization

The homogeneity of parameters analysis is important to the variation of the statistical properties of the time series. The causes of variation can be either human or natural. These include alterations to land use and relocation of the observation station. Therefore, in order to select the representative meteorological station for the analysis of rainfall estimation, checking homogeneity of group stations are important and the homogeneity of the selected gauging stations monthly rainfall records were carried out by non-dimensional.

$$P_i = \frac{\overline{P_i}}{\overline{P}} * 100 \qquad 3.4$$

Where:

Pi is non- dimensional value of precipitation for the month in the station i

$\overline{Pi}$ is over year's average monthly precipitation for the station i

$\overline{P}$ is over year average yearly precipitation for station i

The selection station are plotted for compares for each other and the same- mode and pattern of the stations are observed and hence group station selected are homogenies.

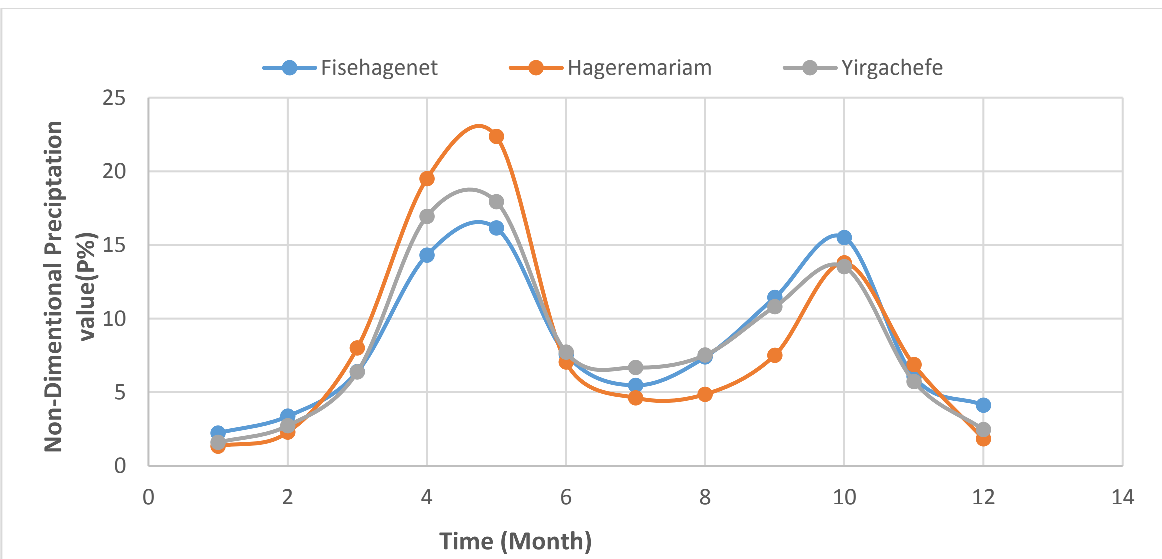


*Figure 3. 8 Homogeneity test for selected weather station at Gelana catchment*

### 3.2.2 Hydrological Data Collection and Analysis

The hydrological data was required for performing sensitivity analysis, calibration and validation of the model. Observed daily stream flow data for Gelana catchment at Tore gauge station was obtained from Ministry of Water, Irrigation and Electricity (MoWIE) hydrology department the period of 1989-2015 years for SWAT simulation result of calibration and validation. The daily observed stream flow data changed to monthly stream flow data by using excel. The stream flow data should be consistent, stationary and homogenous. Monthly stream flow data from a period of 1989-2006 were used for model calibration and from 2007-2015 were used for mode validation. Unlike rainfall, stream flow shows strong serial correlation the value on one day is closely related to the value on the previous and following days especially during the period of low flow or recession. The runoff generated due to the small rainfall occurs on December to March and heavy rainfall on April to May and September to October is the main cause of variation of flow in the study area (Source: master plan study of Rift Valley Basin).The gauging station has good stream flow records with a small number of missing data in the study baseline.

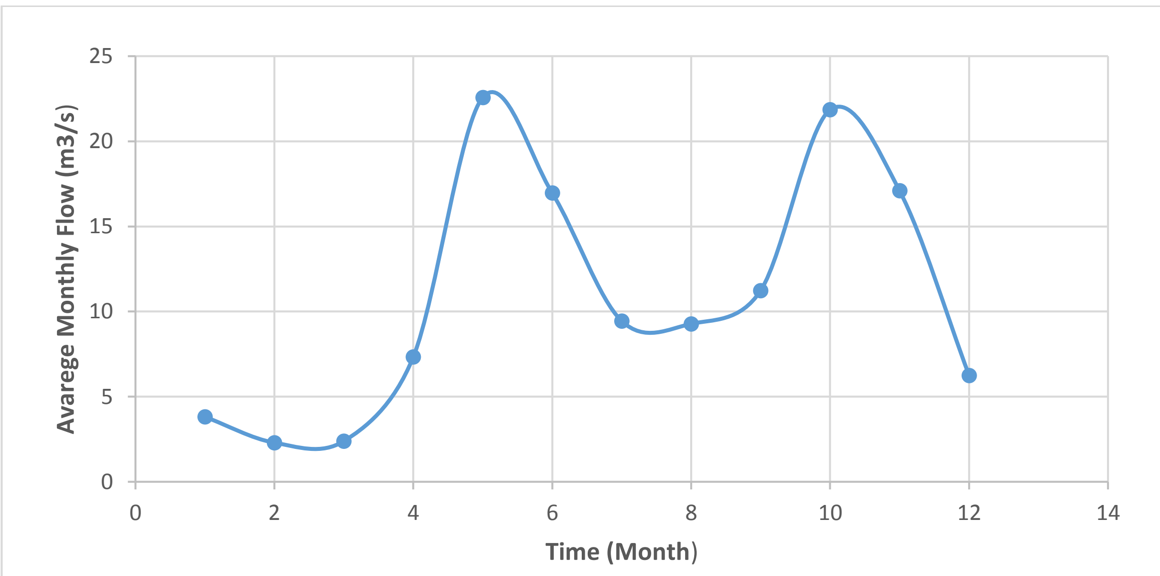


Figure 3. 9 Monthly average stream flow at Tore gauged station (1989-2015)

### 3.2.3 Sediment Data

Sediment data collected from Ministry of Water Irrigation and Electricity (MoWIE) for hydrology department, rift valley basin Gelana catchment at Tore gauged station but this data was not enough to calibration and validation of SWAT model. To fill this gaps, developed sediment rating curve is one of the option. Many researchers have also used sediment rating curve to estimate suspended sediment when measured data or not valid (Asselman, 2000). Sediment rating curve expresses the average relation between river discharge and suspended sediment concentration for a certain existing data. The sediment rating curve usually express as a power function of discharge.

$$Qs = aQ^b \qquad 3.5$$

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

The sample of suspended sediment measured by (mg/l) to convert sediment load (ton/day) by using the following formula.

$$Qs = 0.0864*Cs*Q \qquad 3.6$$

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

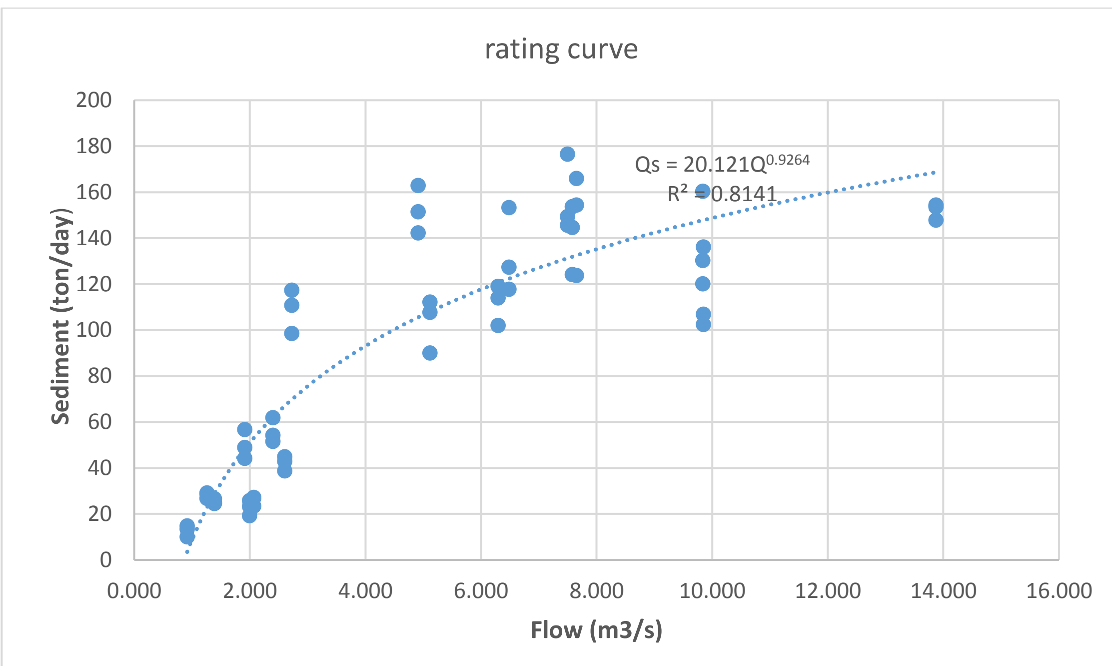


Figure 3. 10 Sediment rating curve Gelana catchment at Tore gauged station

The above equation calculated to only sediment suspended load but the model simulated both suspended and bed loads. According to (Rakoczi, 1987) most of the time the ratio of bed load to suspended load from 1:5 to 1:50 therefor, the bed load this study is 8% suspended load.

### 3.2.4 Spatial Data Collection and Analysis

The spatial data which are including Digital Elevation Model (DEM), land use land cover map and soil map were collected different sources. The DEM and land use land cover collected from Ministry of Water, Irrigation and Electricity (MoWIE) GIS department and soil map form FAO soil.

#### 3.2.4.1 Digital Elevation Model (DEM)

Digital Elevation model (DEM) is one of the main inputs of the SWAT (Soil and Water Assessment Tool) model. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRU). The resolution of the Digital Elevation Model (DEM) is the most critical input parameter when developing a SWAT model (Gassman et al., 2007).

DEM resolution affects the watershed delineation, stream network and sub basin classification in the SWAT model. It affects the number of sub-basins and HRU. The number of sub watersheds in the sub basin affects the predicted sediment yield for a watershed (Bingner et al., 1997). (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. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and sub basin classification (Chaubey et al., 2005).

In general, the quality of the DEM data strongly affect the final output of the hydrological model (Defourny et al., 1999). Therefore, it is wise to use the finest available DEM data for model application.

For this study the Ethiopia digital elevation model (DEM) collected from Ministry of Water, Irrigation and Electricity with a spatial resolution of 30 m by 30 m. The projected map was used in the watershed delineation in Arc SWAT which is the interface in the ArcMap to use it in SWAT model. The minimum elevation at the dam site is 1633m and the maximum elevation is 3045m above sea level when we go from the dam to the upstream the elevation is increase.

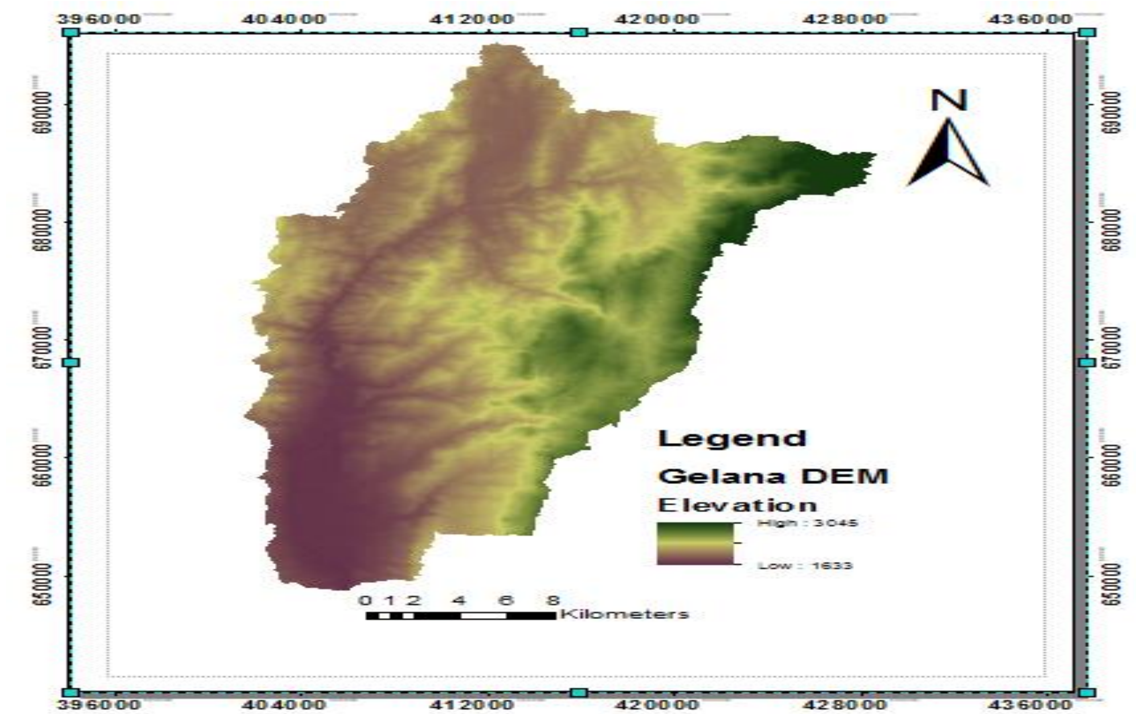


Figure 3. 11 Digital elevation model of the Gelana catchment

### 3.2.4.2 Land Use/ Land Cover

The land use is one of the most important data that affect runoff, evapotranspiration and surface erosion in a watershed. It is one basic input data for SWAT model to describe the hydrological response units (HRU). The land use map of the study area was obtained from Ministry of Water Resources Irrigation and Electricity in the GIS department from the study of rift valley river basin. The reclassification of the land use map was done to represent the land use according to the specific land cover types and the respective crop parameter was selected from SWAT database. A look up table that identifies the four letter SWAT code for the different categories of land cover/land use were prepared so as to relate the grid values to SWAT land cover/land use classes.

SWAT calculated the area covered by each land use. The following table show that land use/ land cover with area.

Table 3. 2 SWAT land use land cover classification of Gelana catchment

| No. | Description | SWAT Code | Area (ha) | % of total Area |
|---|---|---|---|---|
| 1 | Agricultural Land-Generic | AGRL | 53677.89 | 83.32 |

| | | | | |
|---|---|---|---|---|
| 2 | Forest-Evergreen | FRSE | 10203.11 | 15.84 |
| 3 | Residential-Low Density | URLD | 257.77 | 0.40 |
| 4 | Forest-Mixed | FRST | 151.85 | 0.24 |
| 5 | Forest-Deciduous | FRSD | 137.01 | 0.21 |

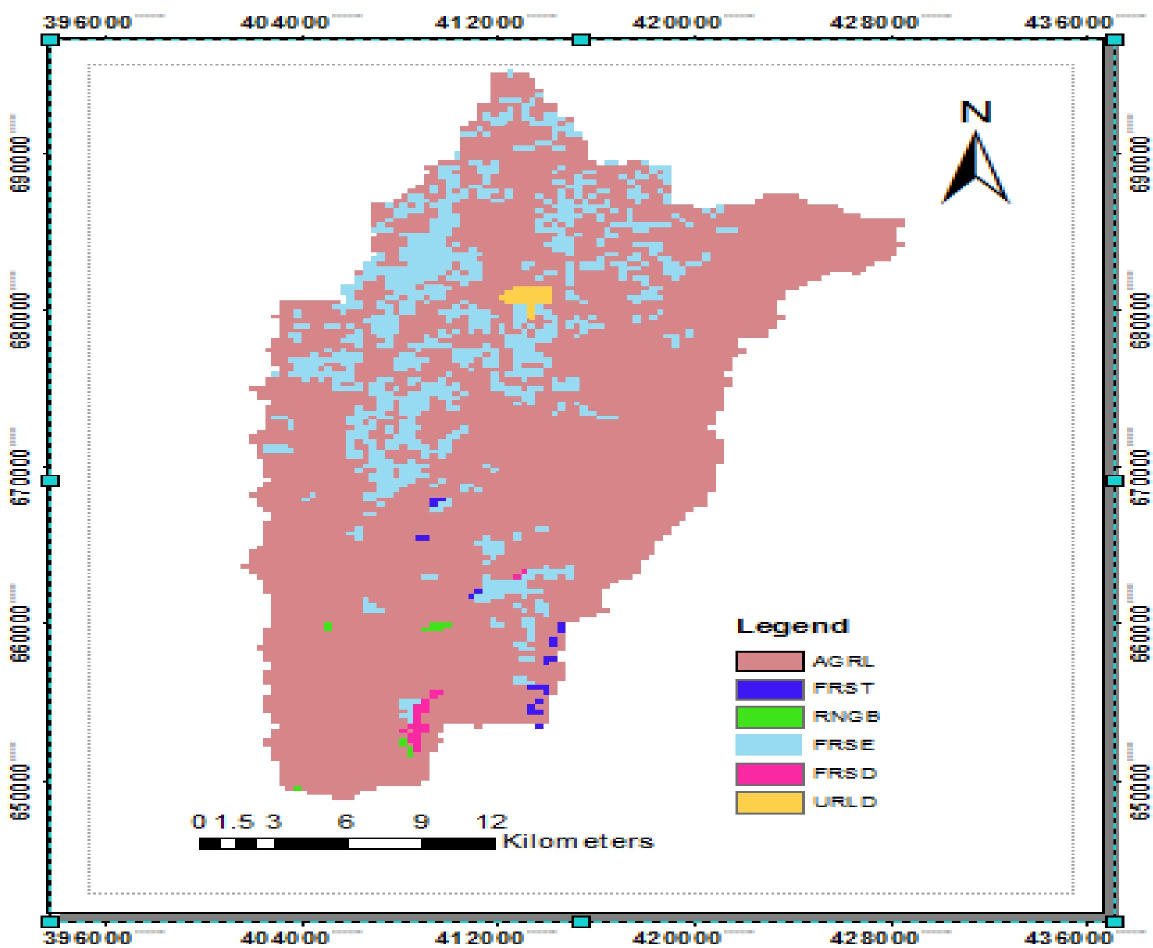


Figure 3. 12 Land use and land cover reclassified by SWAT

**3.2.4.3 Soil Data**

One of highly contribute for hydrological response unit in SWAT model is soil data. Soil data is another important spatial input data for SWAT model. SWAT model required different soil texture and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. The major aim of soil classification to convert user's soil into SWAT database or grid properties. The soil type found in the Gelana catchment is not found in the SWAT database. Therefor SWAT does not consider of Gelana catchment. To fulfill this gap new soil and their properties were added to the soil database by using soil data base editor. The data were obtained from FAO world soil database. To connect the soil map with SWAT model user soil database which contains textural and chemical properties of soils was prepared for each soil layers and added to the SWAT user soil databases using the data management append tool in ArcGIS. The following table (3.3) show that symbol and area coverage of the soil types in the Gelana catchment.

Table 3. 3  SWAT soil classification in Gelana catchment

| No | Soil type | Area (ha) | % of total area |
|---|---|---|---|
| 1 | Eutric Nitosols | 56011.73 | 86.94 |
| 2 | Eutric Cambisols | 8415.91 | 13.06 |
| Total | | 64427.63 | 100.00 |

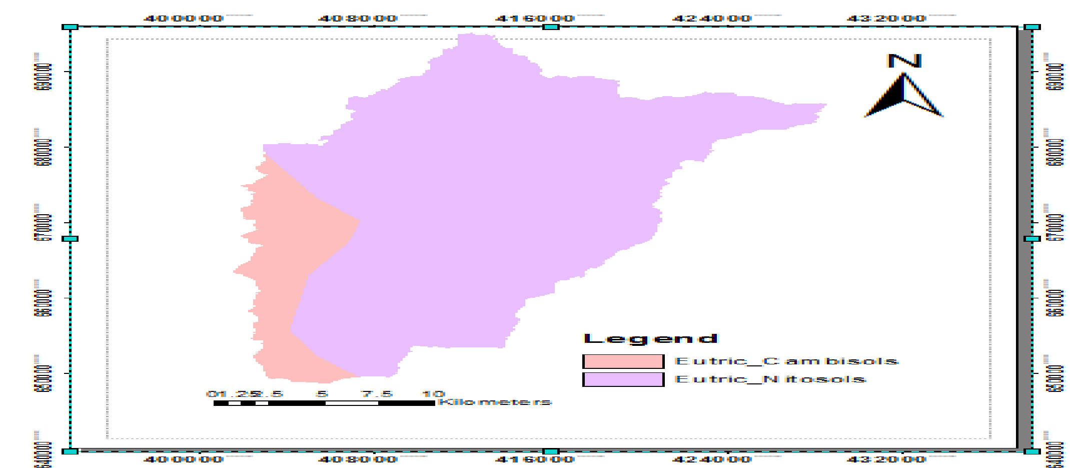


Figure 3. 13  Soil type in the Gelana catchment

### 3.2.4.4 Slope

The slop of Gelana catchment derive from DEM input therefore, the model uses this slope for the development of hydrological response unit in addition to land use and soil input parameter. Arc SWAT allows to slope class when defining hydrological response unit. There are possibility to choose simply a single slope class or multiple slope class. For this study consider slope class for Gelana catchment class one 0-5%, class two 5-10% class three 10-15% class four 15-20% class five greater than 20% . The following table and figure are show that slope classification in the Gelana Catchment.

Table 3. 4 Slope and area contribution in the Gelana catchment

| No | Slope | Area contribution at outlet | |
|---|---|---|---|
| | | Area (ha) | Area (%) |
| 1 | 0-5 | 3836.32 | 5.95 |
| 2 | 5-10 | 11401.02 | 17.70 |
| 3 | 10-15 | 13473.90 | 20.91 |
| 4 | 15-20 | 11967.55 | 18.58 |
| 5 | >20 | 23748.84 | 36.86 |

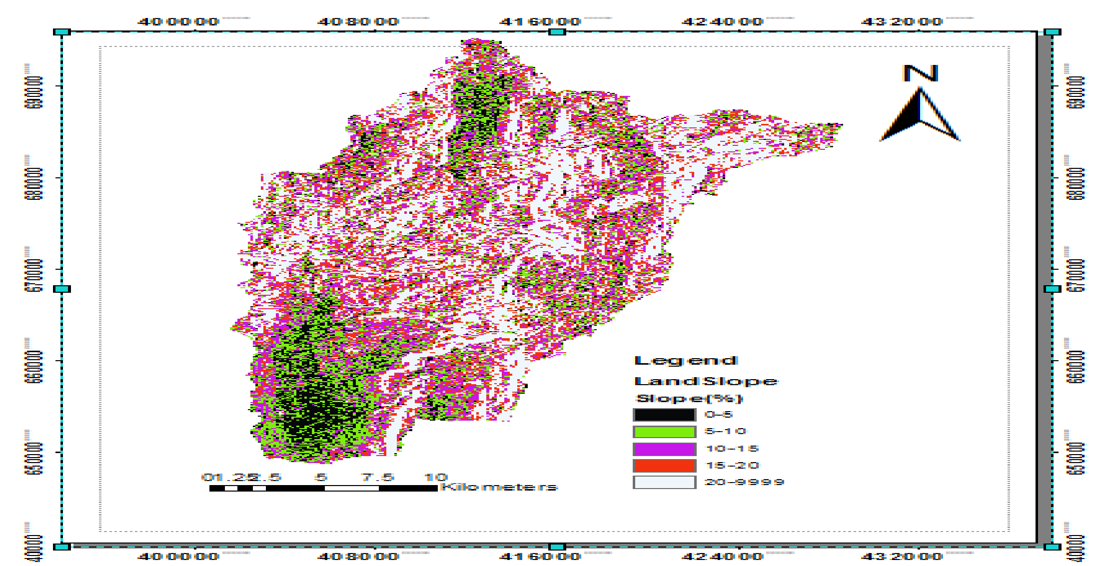


Figure 3. 14 Slop of Gelana catchment

### 3.3 Methodology

The methodology of this study is used to SWAT model. SWAT model is physical distribution and continues time developed to predict the impact of land management practices on water, sediment and agricultural chemical yield from watershed. SWAT model required different input data such as digital elevation map, land use/ land cover map, soil map, daily rain fall data (1986-2016), daily minimum and maximum air temperature data (1986-2016) daily stream flow (1989-2015) data and sediment concentration sampling data which were collected from different organization.

The component of this methodology are:

- ✓ Data collection
- ✓ Data processing and analysis
- ✓ Running the model
- ✓ Selecting sensitive parameters
- ✓ Calibration of the model
- ✓ Validation of the model
- ✓ Discuses output model result

The detail methodology explained in the following flow chart

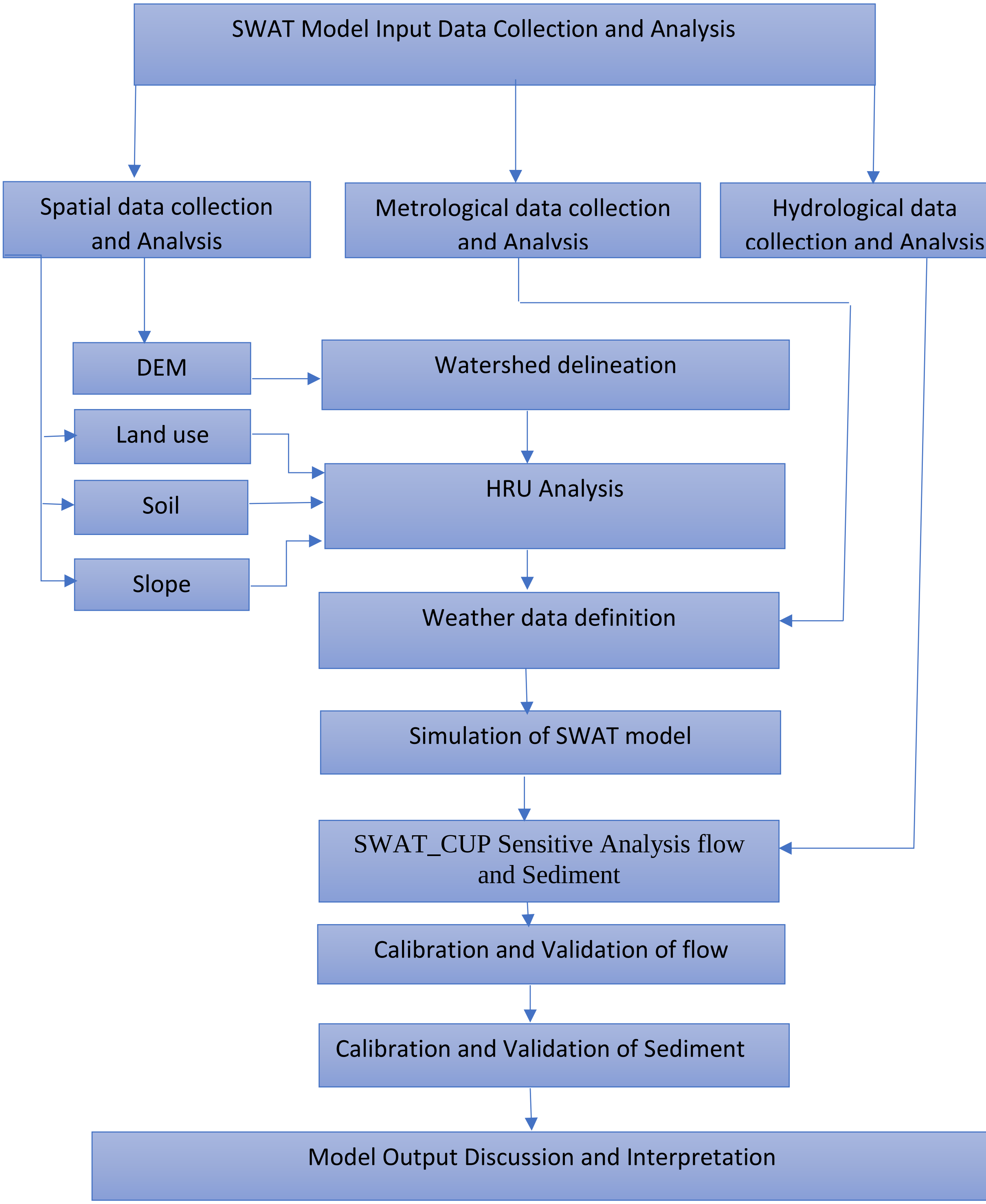


Figure 3. 15 Conceptual framework of the flow and sediment yield estimation

### 3.3.1 Description of SWAT Model

The Soil and Water Assessment Tool (SWAT) model was developed by the USDA Agricultural Research Service. This model is a watershed scale model that can predict the impact of changes in land management to water and sediment. It is physically based requiring specific information about soil, topography, weather, and land management practices within the watershed (Arnold et al., 1998). SWAT is a useful tool because watersheds that do not have any monitoring data can be modeled. It also can simulate large watersheds in a relatively short period of time (Arnold et al., 1998).

The SWAT/ArcView interface was developed by the black land research center. This extension allows SWAT input files to be generated and output files to be analyzed using ArcView's spatial capabilities. With this interface the three main advantages are:

Create input files using ArcView grids and tables,
Run SWAT without exiting the interface, and
Display the output using ArcView tables, graphs, and map views.

The Soil and Water Assessment Tool is a physically based and semi-empirical model. It is based on physical laws but it also permits the addition of measurements and their use for simulations. The spatial areas that can be modeled range from hundreds to thousands of square kilometers.

Unlike Arc Hydro or WSDT, the SWAT model takes into account many parameters impacting on hydrology and simulates the flow and the transport of sediments or polluting elements. It has been developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soil, land use, and management conditions over long periods of time (Di Luzio et al., 2002).

Developed by the Backland research Centre the SWAT model was originally written and made compatible with GRASS (Srinivasan and Arnold, 1994). A new version in Arc Macro Language compatible with Arc Info has been created (Bian et al., 1996) and then in Avenue, compatible with ArcView (Di Luzio et al., 1997): AVSWAT. A new improvement is still in progress it concerns an improved interface for ArcGIS 8.x in Visual Basic (Olivera et al., 2003). The version used is AVSWAT: this version provides an ArcView 3 extension and a graphical user interface.

### 3.3.2 Hydrological Component of SWAT

The Simulation of the hydrology of a watershed is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water and sediment loadings to the main channel in each sub watershed. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water and sediments through the channel network of the watershed to the outlet. In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation (Neisch et al, 2005).

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad 3.7$$

Where: $SW_t$ is the final water content (mm), $SW_O$ is the initial soil water content on day i (mm), $R_{day}$ is the amount of precipitation on day i (mm), $Q_{surf}$ is the amount of surface run of on day i (mm), $E_a$ is the amount of evapotranspiration on day i (mm), $W_{seep}$ is the amount of water entering the vadose zone from the soil profile on day i (mm), $Q_{gw}$ is the amount of ground water flow on day i (mm) and t is time (day).

More detailed descriptions of the different model components are listed in (Arnold et al., 1998), (Neitsch et al.,2005). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The surface runoff in the catchment is estimated by the model using SCS curve number method shown in equation (3.8) (USDA SCS, 1972):

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{R_{day} + 0.8S} \quad 3.8$$

Where: $Q_{surf}$ is the accumulated runoff or rainfall excess (mm), $R_{day}$ is the rain fall depth for the day (mm), S is the retention parameters (mm). The retention parameters defined by the following equation:

$$S = 25.4\left(\frac{100}{CN} - 10\right) \quad 3.9$$

Where: CN is the curve number for the day

SWAT includes two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant evapotranspiration. The soil moisture method equation (3.10) over estimates runoff in shallow soils. But calculating daily CN as a function of plant evapotranspiration, the value is less dependent on soil storage and more dependent on antecedent climate.

$$S = S_{max} * \left(1 - \frac{SW}{[SW + \exp(w_1 - w_2 * SW)]}\right) \quad 3.10$$

Where: S is the retention parameter for a given day (mm), $S_{max}$ is the maximum value that the retention parameter can have on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm) and $w_1$ and $w_2$ are shape coefficients. The maximum retention parameter value, $S_{max}$ is calculated by solving the following equation using $CN_1$.

$$S_{max} = 25.4\left(\frac{100}{CN_1} - 10\right) \quad 3.11$$

When the retention parameter varies with plant evapotranspiration, the following equation is used to update the retention parameter at the end of every day:

$$S = S_{prev} + E_a * \exp\left(\frac{-Cncoef - S_{prev}}{S_{max}}\right) - R_{day} - Q_{surf} \quad 3.12$$

Where: $S_{prev}$ is the retention parameter for previous day (mm), $E_a$ is the potential evapotranspiration for the day (mm/day), Cncoef is the weighing coefficient used to calculate the retention coefficient for daily curve number calculation dependent on plant evapotranspiration, $S_{max}$ is the maximum the retention parameters can achieve on any given day (mm), $R_{day}$ is rain fall depth on the day (mm), and $Q_{surf}$ is the surface runoff (mm). The initial value retention parameter is defined as: $S = 0.9S_{max}$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. SCS defines three antecedent moisture conditions: I -dry (wilting point), II - average moisture, and III - wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions, the curve numbers for moisture conditions I and III are calculated with equations (3.13 and 3.14).

$$\mathrm{CN_1} = \mathrm{CN_2} - \left(\frac{20*(100-\mathrm{CN_2})}{100-\mathrm{CN_2}+\exp[2.533-0.063(100-\mathrm{CN_2})]}\right) \quad 3.13$$

$$\mathrm{CN_3} = \mathrm{CN_2} * \exp[0.00673 * (100 - \mathrm{CN_2})] \quad 3.14$$

Typical curve numbers for moisture condition II are listed in various tables (Neitsch *et al*, 2005). The values are appropriate for a 5 % slope. Williams (1995) developed an equation to adjust the curve number to a different slope as shown in equation (3.15):

$$CN_{2(s)} = \left(\frac{CN_3-CN_2}{3}\right) * [1 - 2exp(-13.86 * slp)] + CN_2 \quad 3.15$$

Where: $CN_1$ is the antecedent moisture condition I curve number,$CN_2$ is the antecedent moisture condition II curve number, $CN_3$ is the antecedent moisture condition III curve number for the default 5% slop, $CN_{2(s)}$ the moisture condition II curve number adjusted the slop and slp is the average present slop of sub basin.

The peak runoff is estimated by SWAT model by using modified rational method shown in equation 3.16).

$$q_{peak} = \frac{a_{lc}*Q_{surf}*Area}{3.6*t_{conc}} \quad 3.16$$

Where: $q_{peak}$ is the peak runoff rate ($m^3$ /s), $a_{lc}$ is the fraction of daily rain fall that occur during the time of consternation, $Q_{surf}$ is the surface runoff (mm), $t_{conc}$ is the time of concentration for the sub basin (hr.) and 3.6 is the conservation factor.

### 3.3.3 SWAT Model for Sediment Yield

The SWAT model can be used for sediment yield predictions for planning and management of water resources and reservoir sediment controls at the catchment scale. The modeling method is applicable to temporal and spatial analysis of sediment yields of which the results are essential for reservoir management strategies. SWAT can also be a potential tool in predicting sediment yield especially at the catchment scale because it considers spatial and temporal variation based on different potential physical variables. The model can also provide a better understanding of sediment transport and deposition processes by overland flow and allow reasonable prediction and forecasting. Sediment yield is the sum of the sediments produced by overland flow, gully, and stream channel erosion in a catchment. The main factor controlling sediment yield in general is the transport capacity of runoff (Mutchler et al., 1988). Sediment transport in the channel network is a function of degradation and aggradation (Neitsch et al., 2005). The current version of the model routes the maximum amount of sediment in a reach as a function of the peak channel velocity and estimates sediment yield for each HRU using MUSLE (Williams, 1975).

$$\text{Sed} = 11.8\text{Q}_{\text{surf.areahu}}\ \text{C}_{\text{USLE}}\ \text{P}_{\text{USLE}}\ \text{LS}_{\text{USLE}}\ \text{CFGR} \qquad 3.17$$

Where: Sed is the sediment yield on a given day (metric tons) $Q_{surf}$ is the surface runoff volume (mm/ha), .$Q_{peak}$ is the peak runoff rate ($m^3$/s), $area_{hu}$ is the area of the HRU (ha), $K_{USLE}$ is the USLE soil erodibility factor, $C_{USLE}$ is the USLE cover and management factor, $P_{USLE}$ is the USLE support practice factor, $LS_{USLE}$ is the USLE topographic factor and CFRG is the coarse fragment factor.

The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity and is calculated by equation 3.18.

$$Conc_{sed,ch,mx} = C_{sp} V_{ch,pk}^{spexp} \qquad 3.18$$

Where: Csed,ch,mx is the maximum concentration of sediment that can be trans -ported by the water (ton/m3or kg/l), Csp is a coefficient defined by the user, Vch,pk, is the peak channel velocity (m/s), and spexp is exponent parameter for calculating sediment reentrained in channel sediment routing that is defined between 1.0 and 2.0.

The maximum concentration of sediment calculated by equation 3.18 in the reach is compared to the concentration of sediment in the reach at the beginning of the time step, $conc_{sed,\ ch,i}$. If $conc_{sed,i}$ greater than $conc_{sed,ch,mx,}$ deposition is the dominant process in the reach segment and the net amount of sediment deposited is calculated by equation 3.19. If $conc_{sed,ch,i}$ less than $conc_{sed,ch,mx,}$ degradation is the dominant process in the reach segment and the net amount of sediment re-entrained is calculated by equation 3.20.

$$sed_{dep} = \left(conc_{sed,ch,i} - conc_{sed,ch,mx}\right) v_{ch} \qquad 3.19$$

$$sed_{deg} = \left(conc_{sed,ch,i} - conc_{sed,ch,mx}\right) V_{ch} K_{CH} C_{CH} \qquad 3.20$$

Where: $sed_{dep}$ is the amount of sediment deposited in the reach segment (metric tons), $sed_{deg}$ is the amount of sediment restrained in the reach segment (metric tons), Vch is the volume of water in the reach segment ($m^3$), $K_{CH}$ is the channel erodibility factor (cm/hr/Pa) and CCH is the channel cover factor.

The final amount of sediment in the reach is determined from equation 3.22

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg} \quad 3.21$$

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). The amount of sediment transported out of the reach is calculated by equation 3.22.

$$Sed_{out} = Sed_{ch} \frac{Vout}{Vch} \quad 3.22$$

Where: $sed_{out}$ is the amount of sediment transported out of the reach (metric tons), $V_{out}$ is the volume of outflow during the time step ($m^3$).

### 3.3.4 SWAT Model Setup

#### 3.3.4.1 Watershed Delineation

Arc SWAT uses Digital Elevation Model (DEM) data to automatically delineate the watershed into several hydrologically connected sub-watersheds. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the land use land cover map, soil map and the DEM were projected into the same projection which is a projection parameters for Ethiopia. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold based stream definition option were used to define the minimum size of the sub-basins. The Gelana basin was delineated with an outlet point at Tore gauge station and at the out let of Gelana catchment (Gelana reservoir). The overall watershed was further classified into sub-basins based on the algorithms provided by the SWAT model. Sub-basin defined as the hydrological area contributing to only one steam channel. As a consequence these sub-basins influence the level of spatial complexity that is represented in the SWAT model. Stream channels were defined as DEM cells having at least a

64427.778 hectare contributing area. The contributing area resulted in 25 sub-basin for being delineated. The contributed area affected by the slope. The slope is increase from outlet to end of upstream catchment.

#### 3.3.4.2 Hydrological Response Unit (HRU)

The SWAT model require defining unique sub-basin called hydrological response unit (HRU) which consists of three components land use, soil and slope delineation. The hydrological response unit analysis tool in Arc SWAT helps to load land use, soil layers and slope map to the project. The delineated watershed by Arc SWAT and the prepared land use and soil layers were overlapped. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. The land use /land cover, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties made to be overlaid for HRU definition.

The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Subdividing the sub watershed into areas having unique land use, soil and slope combinations makes it possible to study the differences in evapotranspiration and other hydrologic conditions for different land cover, soil and slope.

The land use, soil and slope datasets were imported overlaid and linked with the SWAT 2012 databases. To define the distributions of HRUs multiple HRU definition options were tested. For multiple HRU definition 5 percent land use/land cover, 10 percent soil and 10 percent slope threshold were used. Finally, the Gelana catchment was created 212 HRU.

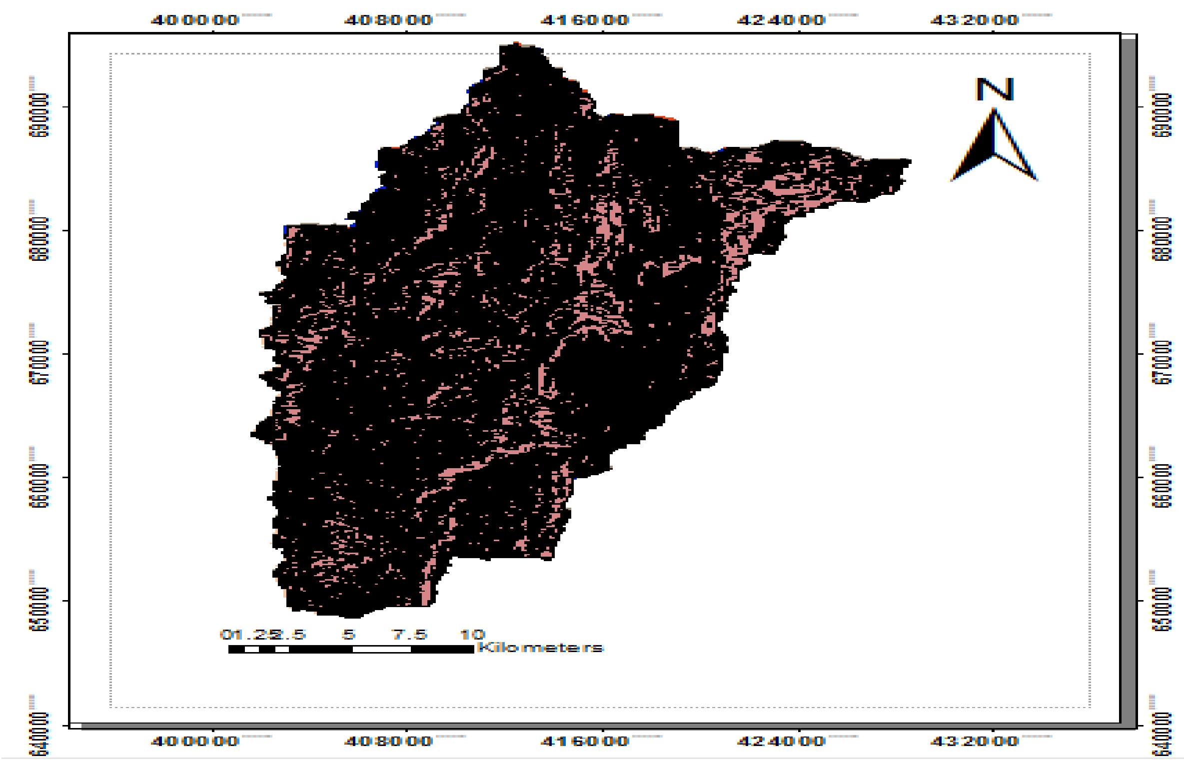


Figure 3. 16 HRU in Gelana catchment

### 3.3.4.3 Write Input Table

The Arc SWAT program built database file that contained information needed to generate default input for running of SWAT model (Arnold et al, 1998). The input data needed include the Digital Elevation Model (DEM), soil data, land use and weather data river discharge and sediment data for estimation, prediction sediment yield and calibration purposes.

### 3.3.4.4 Edit SWAT input

The Edit SWAT allows to edit the input SWAT model database and the watershed database file containing the current input for SWAT model. This step of model set up used to modify soil parameters, land use type and slope etc. But there is no edit data for this study.

### 3.3.4.5 SWAT Simulation

The SWAT simulation allows to run the SWAT model, perform sensitivity analysis, calibration and validation was carried out.

#### 3.3.4.6 Sensitive Analysis Calibration and Validation

##### 3.3.4.6.1 Sensitive Analysis

Sensitivity analysis is the method through which parameters are weighed and ranked to determine which parameters are the most critical in effecting specific model outputs. It describes as how model output varies when given input variables are varied. It allows in a particular identify those model parameters that exert the highest influence on model calibration or on model predictions. The model sensitivity is defined as the ratio of the change in model output to a change in parameter input. Sensitivity analysis and calibration are usually not easy with a large number of parameters. Thus, one important aim of parameter sensitivity analysis is to reduce the number of input parameters thereby reducing the computation time for the calibration.

Sensitivity parameters can determine which parameters in the watershed are most sensitive and these parameters need to be adjusted based on the sensitivity analysis. The model calibration requires identifying the controlling parameters and parameter precision (Ma et al., 2000). Sensitivity analyses are performed in different ways: local, which involves changing values one at a time, and global, which is the ability to change all the parameter values simultaneously because the sensitivity of each parameter depends on the other related parameters the results may vary.

As the SWAT model relies on numerous parameters to represent the various hydrological, climatic, soil and plant processes within a watershed the calibration of the model for a specific study area is a challenging task, accentuated by the fact that many of these calibration parameters may be correlated to each other. Therefore many researchers like (Vandenberghe et al., 2002) have proposed that a sensitivity analysis should be performed before model calibration to identify the most sensitive parameters and just use these in the subsequent calibration.

##### 3.3.4.6.2 Calibration

Calibration is the process whereby model parameter are adjusted to make the model output match with observed data. When simulated outputs like streamflow are close to observed outputs, the model is said to be properly calibrated. There are three calibration approaches widely used by the scientific study. These are the manual calibration, automatic calibration and a combination of the two. The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman et al., 2007). (Coffey et al. 2004) presented nearly 20 different statistical tests that can be used for evaluating SWAT stream flow output during a manual calibration process. They recommended using the Nash-Suttcliffe simulation efficiency NSE and regression coefficients $R^2$ for analyzing monthly output and median objective functions, sign test, autocorrelation and cross-correlation for assessing daily output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by (Spruill et al. 2000).

(Eckhartd and Arnold 2001) outlined the strategy of imposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT. Subsequently an automatic calibration of the version SWAT-G of the SWAT model with a stochastic global optimization algorithm and shuffled complex evolution algorithm is presented for a mesoscale catchment. Automated techniques involve the use of Monte Carlo or other parameter estimation schemes that determine automatically what the best choice of values are for a suite of parameters, usually on the basis of a large set of simulations, for a calibration process (Gassman et al., 2007). Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is less subjective and due to extensive search of parameter possibilities can give results better than if done manually.

#### 3.3.4.6.3 Validation

After the model calibrated, the accuracy of the model was evaluated during the validation processed using the help of the data, which were not used during the calibration of the model. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios (Dilnesaw, 2006).

#### 3.3.4.6.4 Model Performance Evaluation

The performance SWAT was evaluated using the statistical measures to determine the quality and reliability of simulate when compare to observed values. The performance of model in simulating stream flow and sediment yield is evaluated using SWAT-CUP. The selection and use of specific efficiency criteria and the interpretation of the results can be a challenge for even the most experienced hydrologist since each criterion may place different emphasis on different types of simulated and observed behaviors. For this study coefficient of determination ($R^2$) and Nash-Sutcliffe Efficiency (NSE) was choose for the criteria of model performance.

The coefficient of determination ($R^2$) is an indicator of strength of relationship between observed and simulation value. The values of $R^2$ range from 0.0 to 1.0 with higher value indicated better agreement (Legates & McCabe, 1999). The value of $R^2$ is 0.0 indicated that none of the variance in measured data that is replicated in the simulated model value. On the other hand the value of $R^2$ is 1.0 indicated that all the variance in the measured data replicated by model simulation.

The following formula used to calculate $R^2$.

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - O_m)*(S_i - S_m)}{\sqrt{\sum_{i=1}^{n}(O_i - O_m)^2} * \sqrt{\sum_{i=1}^{n}(S_i - S_m)^2}} \qquad 3.23$$

Where: $R^2$ is coefficient of determination, O is observed hydrologic variable, $O_m$ is mean observed hydrologic variable, $S_i$ is model simulated output, $S_m$ is mean of the model simulations and N is total number of observation.

Nash-Sutcliffe Efficiency (NSE) is determines the relative magnitude of the residual variance compared to the measured data variance is calculated as follows (Nash, Sutcliffe 1970).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - O_m)^2} \qquad 3.24$$

Where: S is model simulated output, O is observed hydrologic variable, $O_m$ is mean of the observations that NSE uses as a benchmark against which performance of the hydrologic model is compared and n is total number of observations.

NSE indicates how well the plot of observed versus simulated data fits the one ratio to one line. According to (Moriasi, et al. 2007) NSE ranges from negative infinity to 1.0, where NSE is 1.0 shows that a perfect model. NSE 0.0, implies the observed mean is as good a predictor as the model. Generally the value between 0.0 and 1.0 acceptable model performance where below 0.0 is not acceptable performance. According to (Moriasi, et al. 2007) a model performance considering with monthly time steps can be evaluated as very good when NSE greater than seventy five present and satisfactory when less than fifty present.

# 4. RESULT AND DISCUSSION

## 4.1 Sensitive Parameters

For the Gelana catchment both flow and sediment sensitive parameters were carried out at Tore gauged station. According to Abbaspour et al, 2007 the flow and sediment sensitive parameters are separately. Some parameters are sensitive to both flow and sediment, others are only flow or sediments. Therefore, it should be tested independently.

### 4.1.1 Flow Sensitive Parameters

Before running the calibration, we analyzed the sensitivity of the parameters by using the Latin hypercube one-factor-at-a-time (LH-OAT) method of SWAT (Van Griensven et al., 2006). It is important to global and local sensitive analysis method and efficient ranking order of parameters. Twenty one sensitive parameters selected and 500 iterations have been done by SWAT-CUP at Tore gauged station. The parameter identification was done by using monthly flow data from 1989 to 2015. Table (4.2) shows that the rank of flow sensitive parameters are described. The rank of sensitive parameters selected depend on global sensitive analyses p-value and t-statistic. A p-value used to determine the significant of sensitivity which is the p-value close to zero is more sensitive and the t-stat used to identify a measure of sensitivity each parameters that is the largest absolute value of t-stat is more sensitive (EAWAG, 2013). Figure (4.1) shows that p-value and t-stat respectively. Therefore, the highest flow sensitive parameter is base flow alpha factor for bank of storage (ALPHA- BNK) (p-value=0.00006), the next sensitive parameters are Effective Hydraulic conductivity (CH-$N_2$), Ground water revap coefficient (GW-REVAP), saturated hydraulic conductivity (SOL-K), and Soil evaporation compensation factor (ESCO). Table (4.1) shows the most flow sensitive parameters.

Table 4. 1 Calibrated parameter for flow

| No | Parameters | Description of Parameters | Rang | | Fitted value | Rank |
|---|---|---|---|---|---|---|
| | | | Min. | Max. | | |
| 1 | ALPHA_BNK | Base flow alpha factor for bank of storage | 0 | 1 | 0.085 | 1 |
| 2 | CH_N2 | Effective hydraulic conductivity | -0.01 | 0.3 | 0.2 | 2 |
| 3 | GW_REVAP | Ground water revap coefficient | 0.02 | 0.2 | 0.19 | 3 |
| 4 | SOL_K | Saturated hydraulic conductivity | 0 | 2000 | 970 | 4 |
| 5 | ESCO | Soil evaporation compensation factor | 0 | 1 | 0.41 | 5 |

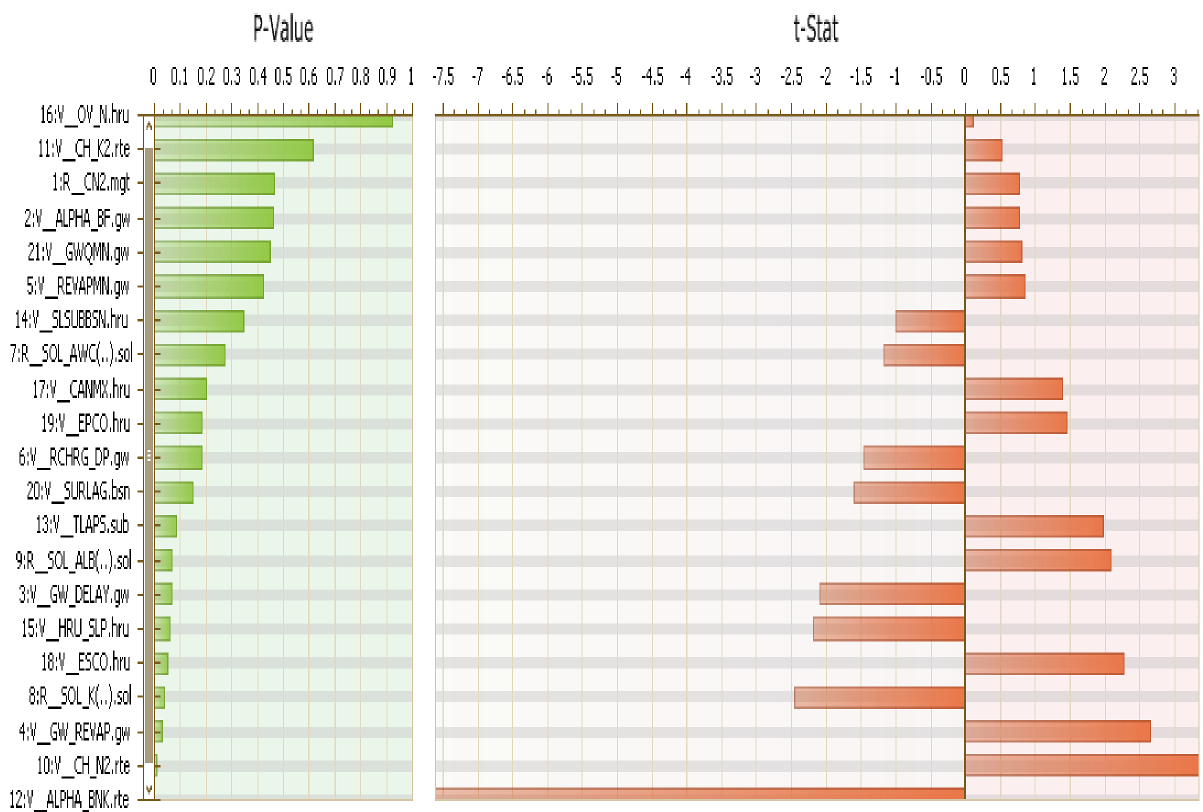


Figure 4. 1 Global sensitive parameters (p-value) and (t-stat) in study area

Table 4. 2 Flow sensitive parameters

| No | Parameters | Description of Parameters | p-value | t-stat | Range | | Rank |
|---|---|---|---|---|---|---|---|
| | | | | | Min. | Max. | |
| 1 | ALPHA_BNK | Base flow alpha factor for bank of storage | 0.00006 | -7.609 | 0 | 1 | 1 |
| 2 | CH_N2 | Effective hydraulic conductivity | 0.0101 | 3.349 | -0.01 | 0.3 | 2 |
| 3 | GW_REVAP | Ground water revap coefficient | 0.0291 | 2.653 | 0.02 | 0.2 | 3 |
| 4 | SOL_K | Saturated hydraulic conductivity | 0.0396 | -2.454 | 0 | 2000 | 4 |
| 5 | ESCO | Soil evaporation compensation factor | 0.0532 | 2.266 | 0 | 1 | 5 |
| 6 | HRU_SLP | Average slop steepness | 0.0603 | -2.186 | 0 | 1 | 6 |
| 7 | GW_DELAY | Ground water delay(days) | 0.0696 | -2.094 | 0 | 500 | 7 |
| 8 | SOL_ALB | Moist soil albedo | 0.0704 | 2.086 | 0 | 0.25 | 8 |
| 9 | TLAPS | Temperature lapse rate | 0.0846 | 1.967 | -10 | 10 | 9 |
| 10 | SURLAG | Surface runoff lag time | 0.1493 | -1.595 | 0.05 | 24 | 10 |
| 11 | RCHRG_DP | Deep aquifer percolation fraction | 0.1822 | -1.460 | 0 | 1 | 11 |
| 12 | EPCO | Plant uptake compensation factor | 0.1857 | 1.447 | 0 | 1 | 12 |
| 13 | CANMX | Maximum canopy storage | 0.2017 | 1.390 | 0 | 100 | 13 |
| 14 | SOL_AWC | Available water capacity on the soil layer(mm $H_2O$/mm soil) | 0.2732 | -1.176 | 0 | 1 | 14 |
| 15 | SLSUBBSN | Average slop length | 0.3445 | -1.004 | 10 | 150 | 15 |
| 16 | REVAPMN | Threshold depth of water in the shallow(mm) | 0.4223 | 0.845 | 0 | 500 | 16 |
| 17 | GWQMN | Threshold depth of water in the shallow aquifer for return flow occur(mm) | 0.4468 | 0.800 | 0 | 5000 | 17 |
| 18 | ALPHA_BF | Base flow alpha factor(mm) | 0.4635 | 0.769 | 0 | 1 | 18 |
| 19 | CN2 | SCS runoff curve number | 0.4662 | 0.764 | 35 | 98 | 19 |
| 20 | CH_K2 | Effective hydraulic conductivity | 0.6137 | 0.525 | -0.01 | 500 | 20 |
| 21 | OV_N | Meaning n value for over land flow | 0.9211 | 0.102 | 0.01 | 30 | 21 |

### 4.1.2 Sediment Sensitive Parameters

Fourteen sediment sensitive parameters consider, out of those parameters only six parameters are most significant for monthly sediment simulate analysis. Table (4.3) shown that sediment sensitive parameter.

Table 4. 3 Sediment sensitive parameters

| No | Parameters | Description of parameters | P-value | t-stat | Rang | | Rank |
|---|---|---|---|---|---|---|---|
| | | | | | Min. | Max. | |
| 1 | HRU_SLP | Average slop steepness | 7.736E-61 | -32.622 | 0 | 1 | 1 |
| 2 | LAT_SED | Sediment concentration in the lateral flow and ground water flow | 1.796E-42 | -23.475 | 0 | 5000 | 2 |
| 3 | CN2 | Soil conservation service run off curve number | 1.403E-28 | -15.619 | 35 | 98 | 3 |
| 4 | SLSUBBSN | Average slop length | 5.410E-4 | 3.575 | 10 | 150 | 4 |
| 5 | SPEXP | Exponent parameter for calculating sediment reentrained in channel sediment routing | 0.034 | 2.153 | 1 | 1.5 | 5 |
| 6 | GWQMN | Threshold depth of water in the shallow aquifer fore return flow to occur | 0.053 | -1.957 | 0 | 5000 | 6 |
| 7 | CH_ERODMO | Jan. erodibility factor | 0.134 | -1.511 | 0 | 1 | 7 |
| 8 | BIOMIX | Biological mixing efficie | 0.401 | 0.843 | 0 | 1 | 8 |
| 9 | USLE_P | USLE equation support pra | 0.444 | 0.768 | 0 | 1 | 9 |
| 10 | CH_COV1 | Channel erodibility factor | 0.461 | -0.740 | -0.05 | 0.6 | 10 |
| 11 | CH_COV2 | Channel cover factor | 0.601 | -0.523 | -0.001 | 0.1 | 11 |
| 12 | SPCON | Liner parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing | 0.761 | 0.305 | 0.0001 | 0.01 | 12 |
| 13 | RSDIN | Initial residue cover | 0.843 | 0.198 | 0 | 10000 | 13 |
| 14 | USLE_K | USLE equation soil erodibility (k) factor | 0.883 | -0.147 | 0 | 2000 | 14 |

The most sensitive parameter in this study are average slop steepness (HRU_SLP), sediment concentration in the lateral flow and ground water flow (LAT_SED), soil conservation service run off curve number (CN2), average slop length (SLSUBBSN), exponent parameter for calculating sediment reentrained in channel sediment routing (SPEXP) and threshold depth of water in the shallow aquifer fore return flow to occur (GWQMN). Table 4.4 shows calibrated value for sediment

Table 4. 4 Calibrated parameters for sediment

| No | Parameters | Description of Parameters | Rang | | Fitted value | Rank |
|---|---|---|---|---|---|---|
| | | | Min. | Max. | | |
| 1 | HRU_SLP | average slop steepness | 0 | 1 | 0.00095 | 1 |
| 2 | LAT_SED | sediment concentration in the lateral flow and ground water flow | 0 | 5000 | 810.70 | 2 |
| 3 | CN2 | Soil conservation service run off curve number | 35 | 98 | 78.01 | 3 |
| 4 | SLSUBBSN | Average slop length | 10 | 150 | 147.15 | 4 |
| 5 | SPEXP | Exponent parameter for calculating sediment reentrained in channel sediment routing | 1 | 1.50 | 1.14 | 5 |
| 6 | GWQMN | Threshold depth of water in the shallow aquifer fore return flow to occur | 0 | 5000 | 2.46 | 6 |

## 4.2 Calibration and Validation

### 4.2.1 Flow Calibration

SWAT 2012 model was calibrated and validated using measured stream flow data at Tore gauged station. The total available stream flow at this station from the period Janaury1989 to December 2015. 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 eighteen years that is from January 1989 to December 2006 and the validation period carried out nine years from January 2007 to December 2015. The result of calibration as shown the following Figure (4.2) the coefficient of determination ($R^2$) is 0.76 and Nash Sutcliff Efficiency (NS) is 0.70.

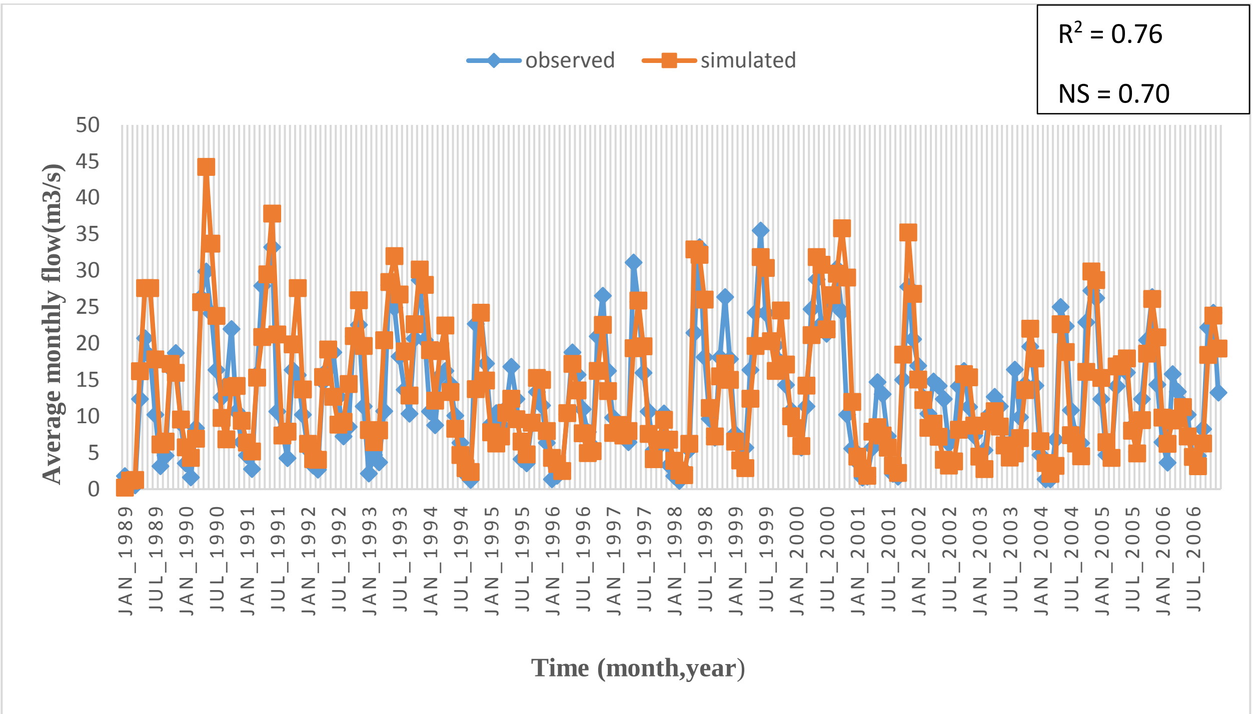


Figure 4. 2 Measured and simulated monthly flow for calibration

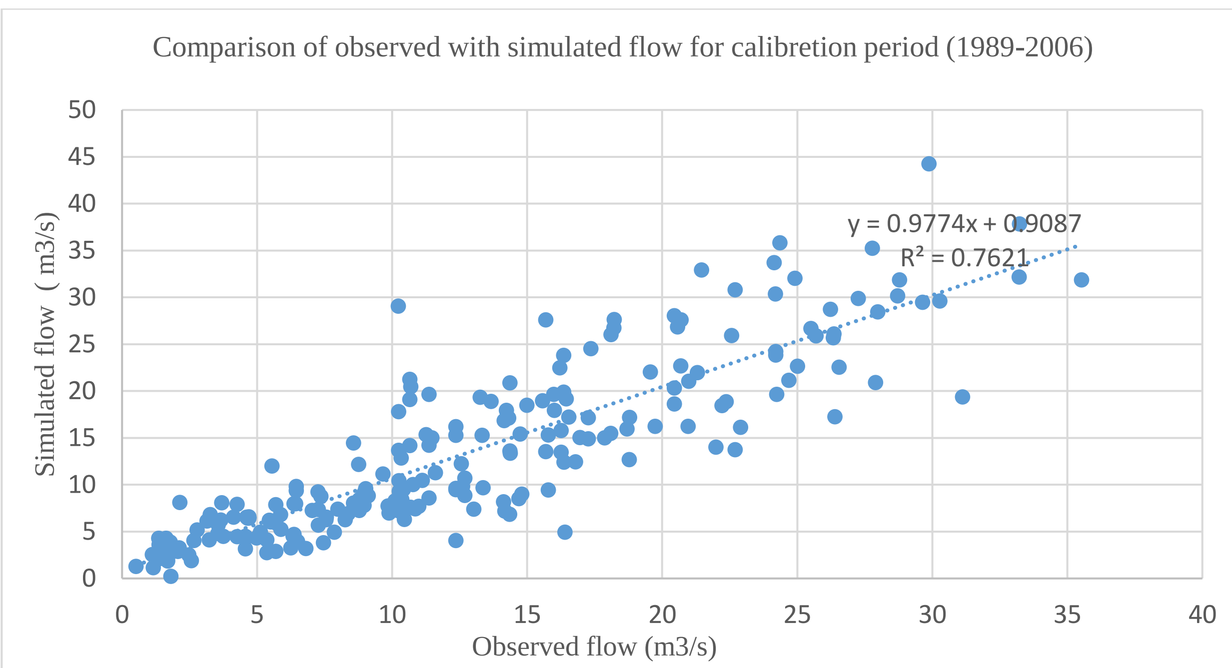


Figure 4. 3 Fit line of measured and simulated flow for calibration

Table 4. 5 Observed and simulated flow calibration

| Time (year) | Average Flow ($m^3/s$) | | Model Efficiency(Monthly) | |
|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | NS |
| 1989-2006 | 12.86 | 13.48 | 0.76 | 0.70 |

### 4.2.2 Flow Validation

Model validation results is necessary to increase user confidence. It involves re-running the model using the input data and without any adjustment of calibration parameters at different time period. Therefore, for this study the model validation carried out monthly flow from January 2007 to May 2015. The coefficient of determination ($R^2$) is 0.70 and Nash Sutcliffe Efficiency (NS) is 0.64.

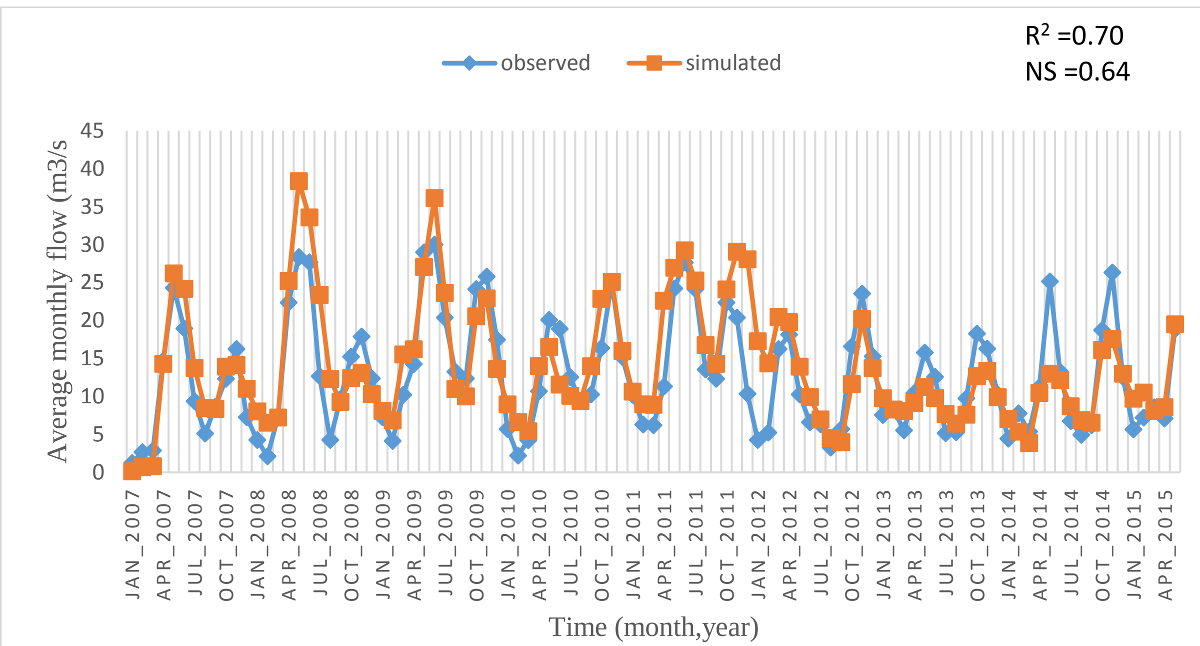


Figure 4. 4 Measured and simulated flow for validation

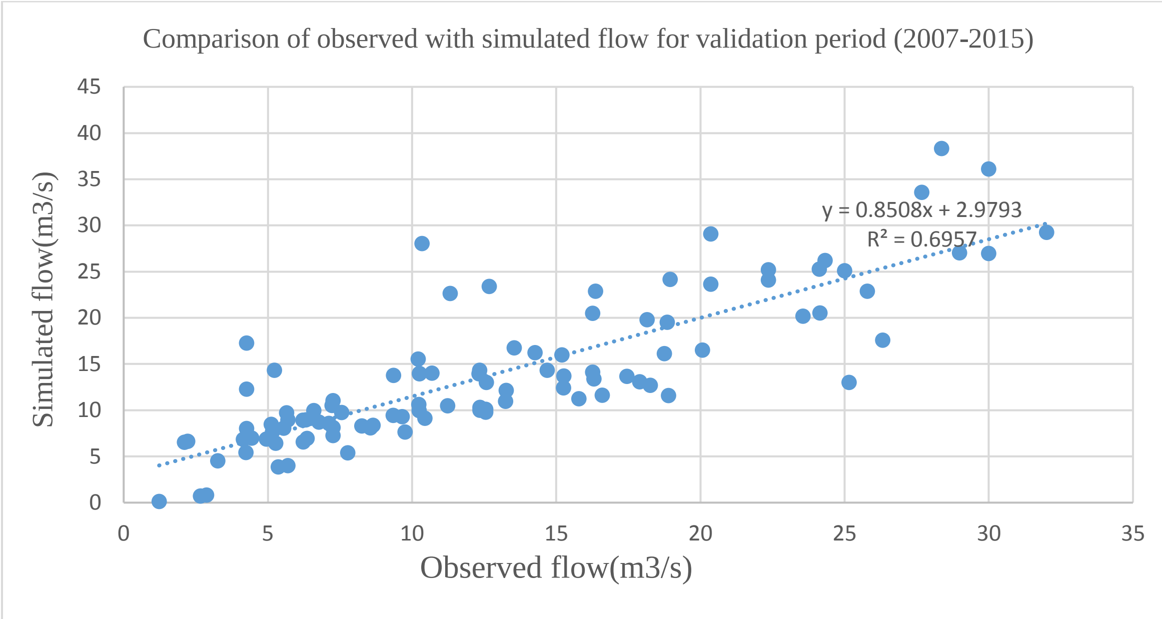


Figure 4. 5 Fit line of observed and simulated flow for validation period

Table 4. 6 Observation and simulation flow validation

| Time (year) | Average Flow (m³/s) | | Model Efficiency (Monthly) | |
|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | NS |
| 2007-2015 | 12.80 | 13.87 | 0.70 | 0.64 |

### 4.2.3 Sediment Calibration

SWAT model were calibrated for monthly sediment yield where after calibration and validation of stream flow at the Gelana Tore gauged station. The observed sediment data based on the rating curve of Tore gauged station at the dam site. The modeling was comparing observed sediment with model simulated sediment for the calibration period from 2003 to 2008. The SWAT model performance evolution simulation monthly sediment yield at Tore gauged station. The coefficient of determination ($R^2$) value is 0.71 and Nash- Sutcliff model efficiency (NSE) value is 0.66. The graphical comparison of measured and simulated sediment yield shown in figure 4.6 and 4.7.

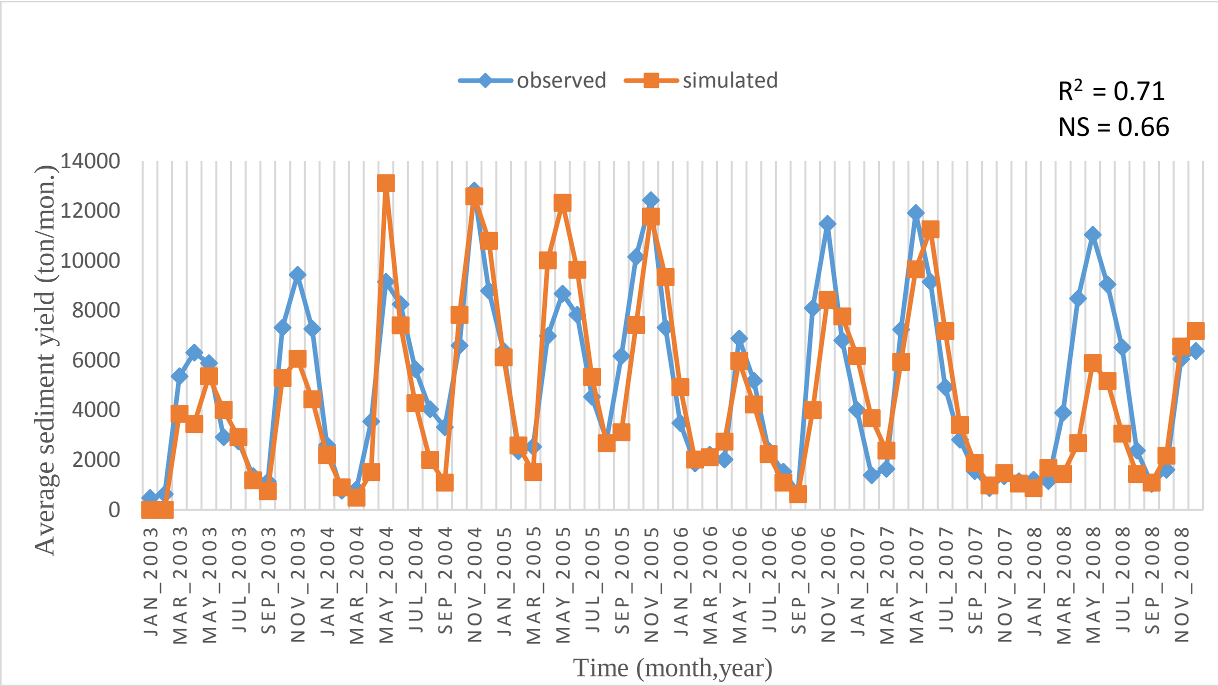


Figure 4. 6 Observed and simulated sediment for calibration

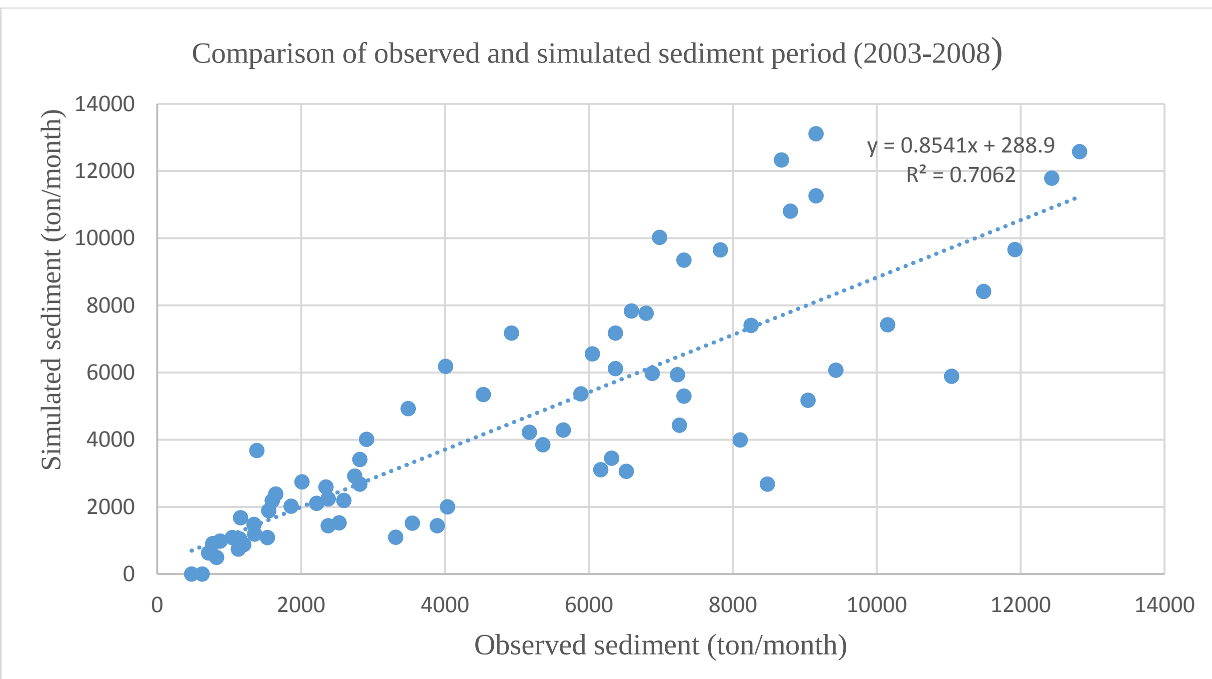


Figure *4. 7* Fit line observed and simulated sediment for calibration period

Table 4. 7 Observation and simulation sediment calibration

| Time (year) | Average monthly sediment (ton/month) | | Model efficiency(Monthly) | |
|---|---|---|---|---|
| | Observed | simulated | $R^2$ | NS |
| 2003-2008 | 4926.09 | 4496.03 | 0.71 | 0.66 |

### 4.2.4 Sediment Validation

SWAT model monthly sediment validation was done after sediment calibration without further parameter adjustment. The model monthly validation period is different from the calibration period. Validation was performed for three years from January 2009 to December 2011. The correlation coefficient ($R^2$) is 0.80 and Nash-Sutcliffe Efficiency (NS) is 0.64. Those value show that a good agreement between observed and simulated sediment. Finger 4.8 and 4.9 shows the model monthly observed and simulated for validation and the fitted line observed and simulated sediment for validation period respectively.

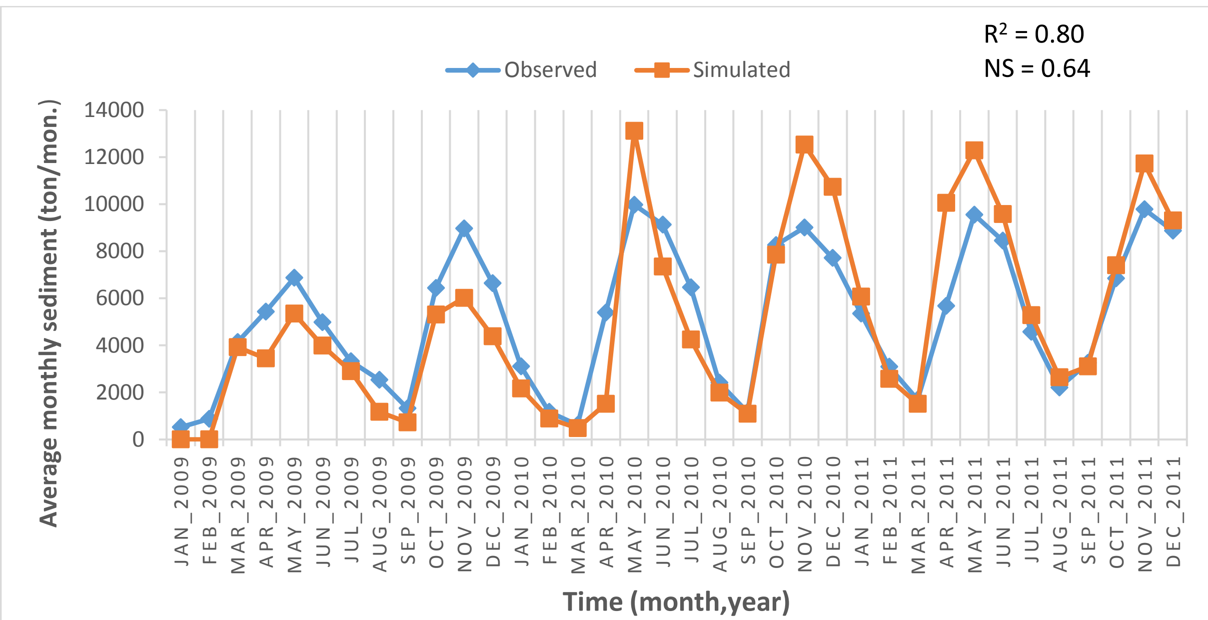


Figure 4. 8 Observed and simulated sediment for validation

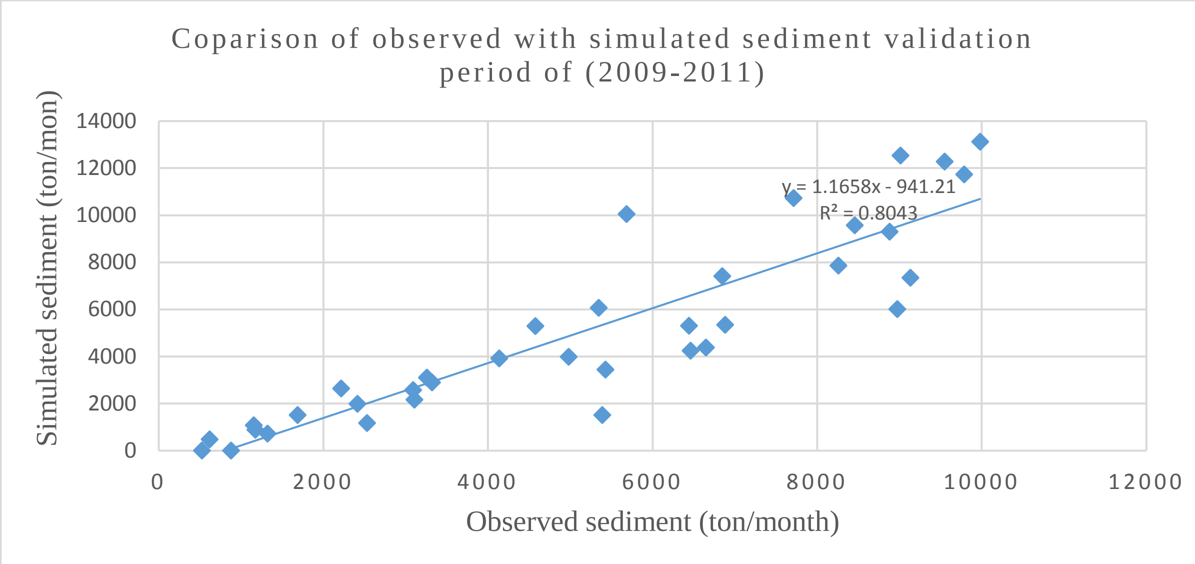


Figure 4. 9 Fit line observed and simulated sediment for validation period.

Table 4. 8 Observation and simulation of sediment for validation

| Time (year) | Average monthly sediment (ton/month) | | Model efficiency (Monthly) | |
|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | NS |
| 2009-2011 | 5161.33 | 5075.57 | 0.80 | 0.64 |

After calibration and validation of the model the total observed and simulated of sediment yield in the Gelana catchment at the dam site during calibration period are 354,678.60 ton and 323,714.10 ton respectively. Therefore, SWAT model is good result for the estimation of catchment sediment yield in the study area. The result indicated that the model simulation almost similar to the observed sediment yield.

The total annual sediment yield from catchment in to the reservoir during calibration and validation period was estimated using SWAT model is 57,429.59 ton. Based on this result 57,429.59 ton/year sediment enter into the reservoir. The total catchment area of this study is 644.28 km$^2$. 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 89.14 ton/km$^2$/year. Sedimentation modeling for Ribb dam (catchment area 844km$^2$), estimation of the average annual sediment yield is 72.79

ton/km$^2$/year (Tensay, 2011) and sediment management in Gibe I reservoir (catchment area 3602km$^2$), estimation of average annual sediment yield is 106.178 ton/km$^2$/year (Tufa, 2016).

### 4.3 Temporal variation of sediment

The temporal variation of sediment yield characteristic of the entire sub-catchment has been computed with SWAT model. Catchment sediment yield is a function of catchment size, land use, soil type, slop and climate. After calibration and validation of flow and sediment at Tore gauged station the comparison between sediment yield catchment discharge and rainfall are direct relationship which is the higher rainfalls will have the higher runoff and sediment yield.

The maximum sediment deposing recorded in the period of 1997 but for the next three years (1998-2000) highly reduce sedimentation. From the beginning of 2001 to 2016 the rate of sediment yield increase. According to (Derege et al., 2011), the cultivated area in the rift valley basin wide spread for the last two decade. Therefore, sediment yield vary from season to season due to wide spread of cultivated area and uneven distribution rainfall in the basin. Table 4.9 the temporal variation of sediment in the Gelana reservoir.

Table 4. 9 Temporal variations of sediment

| No | Year | Sediment (ton) | No | Year | Sediment (ton) |
|---|---|---|---|---|---|
| 1 | 1989 | 33309.64 | 15 | 2003 | 37291.50 |
| 2 | 1990 | 68559.90 | 16 | 2004 | 64196.80 |
| 3 | 1991 | 22770.89 | 17 | 2005 | 81874.00 |
| 4 | 1992 | 11952.90 | 28 | 2006 | 46085.20 |
| 5 | 1993 | 18895.40 | 19 | 2007 | 55070.70 |
| 6 | 1994 | 24453.49 | 20 | 2008 | 39195.90 |
| 7 | 1995 | 45521.17 | 21 | 2009 | 37182.00 |
| 8 | 1996 | 51192.31 | 22 | 2010 | 63922.80 |
| 9 | 1997 | 83159.91 | 23 | 2011 | 81474.00 |
| 10 | 1998 | 21644.00 | 24 | 2012 | 48922.23 |
| 11 | 1999 | 10892.90 | 25 | 2013 | 51694.31 |
| 12 | 2000 | 16142.40 | 26 | 2014 | 63620.90 |
| 13 | 2001 | 35037.66 | 27 | 2015 | 67529.32 |
| 14 | 2002 | 39297.50 | 28 | 2016 | 69575.30 |

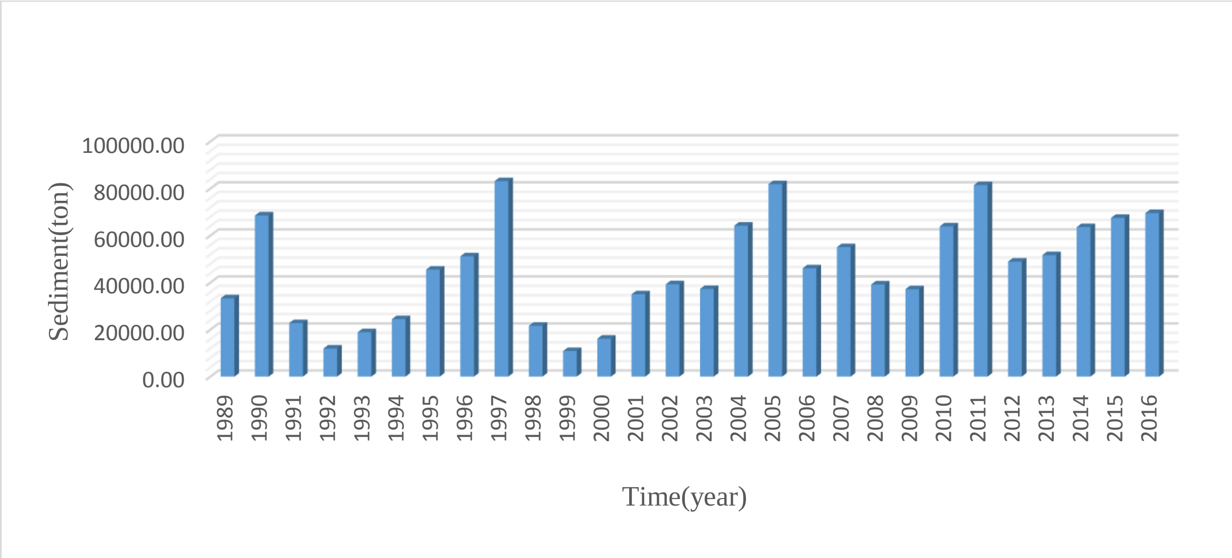


Figure 4. 10 Temporal variation of sediment hectograph

Rainfall runoff is highly contribute to the process of detachment, transport and deposing of sediment particles. The beginning of rain season rapidly increase sediment yield. The higher value of sediment yield observed during May and October which has higher rainfall intensity.

### 4.4 Spatial variation of sediment

Identification and ranking of critical erosion prone areas is an important consideration for policy makers to implement best management strategies that are more sustainable in future for long term used of these natural resources (Kumar and Mishra, 2014). After the model calibration and validation of sediment identify the model simulation of the spatial sediment distribution on the Gelana catchment. Table 4.10 and Figure 4.11 show the spatial distribution of sediment in the Gelana catchment. The maximum annual sediment generation in the sub-catchment 17, sub-catchment 15 and the minimum annual sediment generation in the sub-catchment 8 sub-catchment 19 and sub-catchment 24. Therefore, sub-catchment 15 and 17 are the most erodible area.  The average annual sediment distribution ranges from 7.58 ton/ha to 53.17 ton/ha. According to Zelalem (2016), the runoff sediment yield modeling using Soil and Water Assessment Tool for management planning of Mojo watershed Ethiopia, shows the estimated soil loss rate from different sub-watershed ranges from 2 t/ha/year to 204 t/ha/year. The sediment yields for sub-catchment of this study was different; this is due to the combined effect of factors such as land use, soil type and slope, etc.

Table 4. 10 Spatial variation of sediment at Gelana catchment

| No | Sub-catchment | Sediment distribution (ton/ha) | No | Sub-catchment | Sediment distribution (ton/ha) |
|---|---|---|---|---|---|
| 1 | 1 | 13.13 | 14 | 14 | 22.34 |
| 2 | 2 | 19.70 | 15 | 15 | 47.17 |
| 3 | 3 | 12.98 | 16 | 16 | 20.23 |
| 4 | 4 | 21.43 | 17 | 17 | 53.17 |
| 5 | 5 | 28.50 | 18 | 18 | 21.91 |
| 6 | 6 | 14.44 | 19 | 19 | 10.39 |
| 7 | 7 | 17.23 | 20 | 20 | 24.81 |
| 8 | 8 | 7.58 | 21 | 21 | 11.88 |
| 9 | 9 | 24.85 | 22 | 22 | 11.21 |
| 10 | 10 | 13.14 | 23 | 23 | 13.40 |
| 11 | 11 | 16.65 | 24 | 24 | 10.45 |
| 12 | 12 | 23.47 | 25 | 25 | 11.26 |
| 13 | 13 | 21.74 | | | |

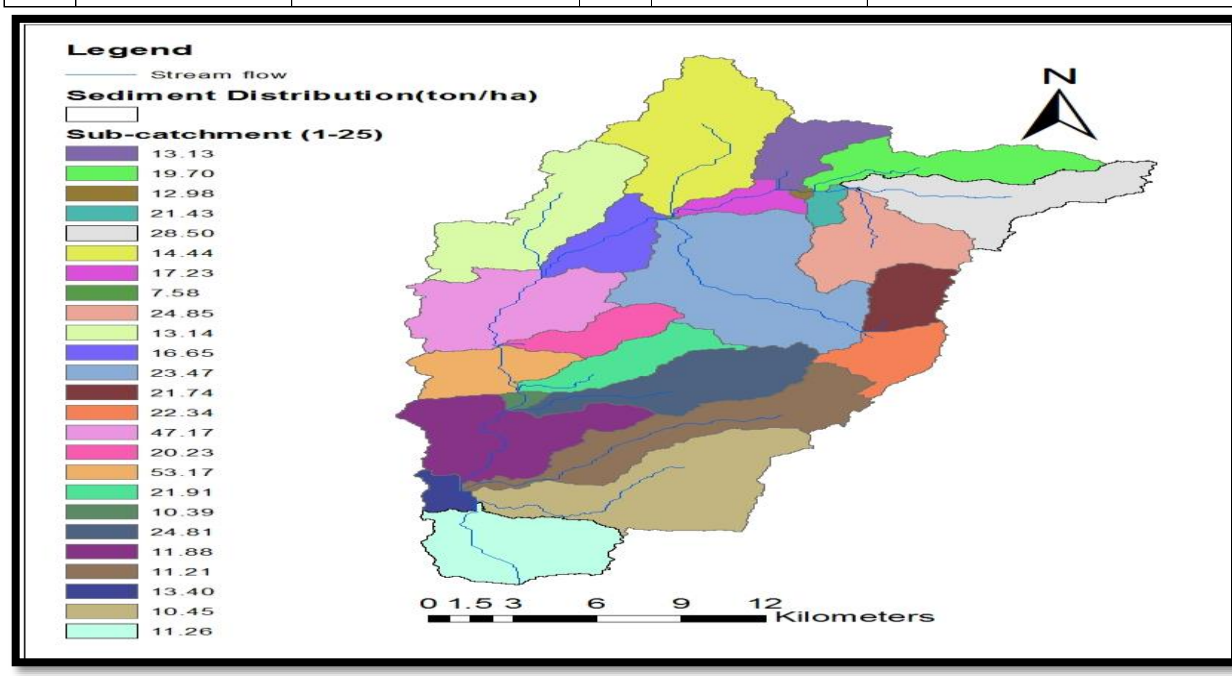

Figure 4. 11 Spatial variations of sediment yield in Gelana catchment

### 4.5 Scenario development for appropriate reduction measure

The important of SWAT model is the ability to build different scenarios. Scenarios are reasonable and often simplified description of how the future may develop based on coherent and internally consistent of assumption about key driving force and relationships. Scenario analysis is a process of evaluating possible future events through the consideration of alternative possible outcomes.

From model output HRU report 83.32% of Gelana catchment is agricultural land. It is the most vulnerable area that affected by soil erosion and source of sedimentation. Therefore, to minimize soil erosion and sediment deposing in the Gelana reservoir scenario development important for future plan. There are three alternative of agricultural change to forest-evergreen, forest-deciduous and forest mixed to minimize sediment loading in to the reservoir. From those alternative agricultural land changed to forest mixed land is high amount of sediment reduction when compare to others. Therefore, scenario development was made by agricultural land changed to forest mixed cover by 10%, 20%, 30%, 40% and 50%.

The scenario are:

So = Original land

Scenario1 ($S_1$) = 10% Agricultural land change to forest mixed land

Scenario2 ($S_2$) = 20% Agricultural land change to forest mixed land

Scenario3 ($S_3$) = 30% Agricultural land change to forest mixed land

Scenario4 ($S_4$) = 40% Agricultural land change to forest mixed land

Scenario5 ($S_5$) = 50% Agricultural land change to forest mixed land

Scenario5 is 51% reduction of sediment deposing in to the reservoir. The result of scenario development summarized in table (4.11).

Table 4. 11 The result of scenario development in Gelana catchment

| Scenarios | Average annual sediment yield (ton/year) | Sediment change (%) |
|---|---|---|
| $S_0$ | 96527.32 | 0 |
| $S_1$ | 79607.53 | -17.53 |
| $S_2$ | 71525.35 | -25.90 |
| $S_3$ | 63483.14 | -34.23 |
| $S_4$ | 55507.39 | -42.46 |
| $S_5$ | 47624.09 | -50.66 |

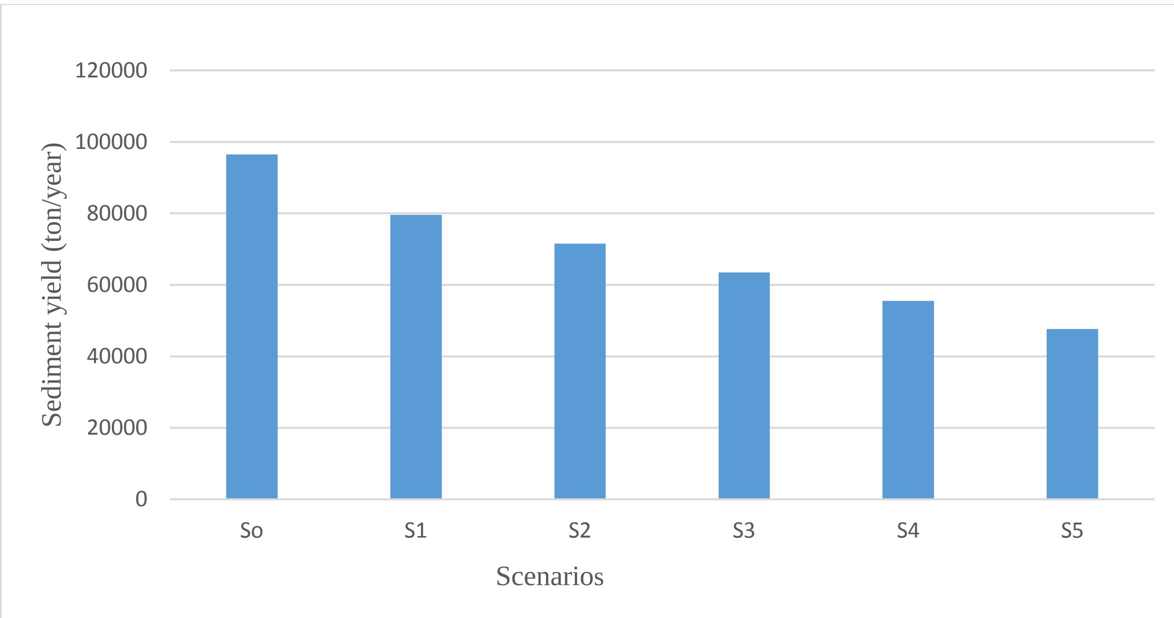


Figure 4. 12 Graphical comparison for sediment yield in the five scenarios

Simulation of sediment yield using SWAT model, five scenarios ($S_1$-$S_5$) developed which is 40% of sediment reduce by agricultural land change to forest (Lemma, 2015). Fasil (2012), prediction of sediment inflow to Gefersa reservoir using SWAT model and assessing sediment reduction measure indicated that: change of 53 % of forest land to agricultural land, change of 35 % of rangeland grass land to agricultural land, change of 16 % of forest changes to agricultural land and change of 18 % of rangeland grass changes to agricultural land result in 74.5 %, 40.47 %, 52.89 % and 29.51% of sediment increased respectively.

Soil conservation measure focuses on reducing sediment inflow into reservoir. In the upstream watershed of a reservoir, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering the reservoir those are: structural measures, vegetative measures, and tillage practice. Structural measures include terraced farmlands, flood interception and diversion works, gully head protection works, bank protection works, check dams, and silt trapping dams. Vegetative measures include growing soil and water conservation forests, closing off hillsides, and reforestation. Tillage practice includes contour farming, ridge and furrow farming, pit planting, rotation cropping of grain and grass, deep ploughing, intercropping and inter planting.

Applying filter strip and terracing (stone bunds) in low slope areas of the catchment could give potential effect of best management practices (Betrie et al., 2011).

Filter Strips: A filter strip is a strip of dense vegetation located to intercept runoff from upslope pollutant sources and filter it. Filter strips increase sediment deposition by reducing overland flow velocity before it joins the tributary and main channel. Filter strips reduce sediment, nutrients, bacteria, and pesticides, but do not affect surface runoff in SWAT (Arnold et al., 2012). Filter strip was applied to the land slope between 0 and 25%.

Terracing: a terrace is an embankment within a field designed to intercept runoff and prevent erosion. It is constructed across slope on a contour. Terracing in SWAT is simulated by adjusting both erosion and runoff parameters (Arnold et al., 2012). Like filter strip, terracing was also applied the land slope between 0 and 25%.

# 5. CONCULUSION AND RECOMANDETION

## 5.1 Conclusion

SWAT model has been successfully used to estimate the sediment yield in the Gelana catchment. Calibration and validation of the SWAT model is a key factor in reducing uncertainty and increasing user confidence in its predicative abilities, which makes the application of the model for decision making.

The study area covers 644.28km$^2$ which is subdivided into 25 sub basins, sub basins were further divided into 212 HRU based on 5% land use, 10% soil and 10% slop classification. The important parameters were identified for calibration based on the sensitivity analysis using the SWAT model. The most stream flow sensitive parameters are base flow alpha factor for bank of storage (ALPHA-BNK), Effective Hydraulic conductivity (CH-N$_2$), Ground water revap coefficient (GW-REVAP), saturated hydraulic conductivity (SOL-K), Soil evaporation compensation factor (ESCO) and the most sediment sensitive parameters are average slop steepness (HRU_SLP), sediment concentration in the lateral flow and ground water flow (LAT_SED), soil conservation service run off curve number (CN2), average slop length (SLSUBBSN), exponent parameter for calculating sediment reentrained in channel sediment routing (SPEXP) and threshold depth of water in the shallow aquifer fore return flow to occur (GWQMN).

Automatic model calibration was performed for stream flow and sediment yield at Tore gauged station. The steam flow calibration period 1989-2006 and validation period 2007-2015. The model performance evolution during monthly stream flow calibration and validation period indicated that $R^2$=0.76, NS=0.70 and $R^2$=0.70, NS=0.64 respectively.

Sediment data taken from the rating curve equation for the period 2003-2011. The model calibration period is 2003-2008 and the validation period is 2009-2011. The model performance evaluation during monthly sediment yield calibration and validation period indicated that $R^2$=0.71, NS=0.66 and $R^2$=0.80, NS=0.64 respectively. The total annual sediment yield into the reservoir is 57,429.59 ton/year. The annual specific sediment yield into the reservoir is 89.14 ton/km$^2$ /year. Spatial and temporal variation of sediment yield is performed. Sub-catchment 15 and sub-catchment 17 are high sediment generated area and sub-catchment 8, 19 and 24 are low sediment generate area. The sediment inflow into the reservoir vary from time to time. Sub-catchment, 15 and 17 are 43.17 ton/ha and 53.17 ton/ha sediment generate respectively. Agricultural lands will change to mixed forest lands are high amount of sediment reduction into the reservoir.

### 5.2 Recommendation

- Model prediction output depends on the quality of input data .One of the constraint in conducting this research work was lack of continuous measured suspended sediment data. The sediment data used for this study were generated from sediment rating curves developed from limited sediment measurement data. Therefore, possible discrepancy of actual sediment and sediment data derived based on rating curves. However, superior results can be obtained if detail suspended sediment data are used. Hence, responsible bodies should give due attention to the time and frequency of sampling, method of sampling and recording of reliable sediment data together with flow measurement.
- This study depends on the secondary data collected from different organizations and agencies as its input and simulation of the final model result. But the primary and representativeness of these data will be used for better result.
- The sub-catchment that produce the highest sediment are 15, 17 and the like their order of importance contributing sediment yield, this can be reduced by using sediment yield more emphasis and intervention strategies such as land slope stabilization, construction terraces, changing the land use of steep area and afforestation.

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# APPENDEX

SWAT model simulation Date: 9/16/2017 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 2 / 10 / 10 [%]
Number of HRUs: 212
Number of Subbasins: 25

| | Area [ha] | Area[acres] |
|---|---|---|
| Watershed | 64427.6348 | 159203.9070 |

| | | Area [ha] | Area[acres] | %Wat.Area |
|---|---|---|---|---|
| LANDUSE: | | | | |
| | Agricultural Land-Generic --> AGRL | 53677.8909 | 132640.7523 | 83.32 |
| | Forest-Evergreen --> FRSE | 10203.1070 | 25212.3874 | 15.84 |
| | Residential-Low Density --> URLD | 257.7736 | 636.9714 | 0.40 |
| | Forest-Mixed --> FRST | 151.8542 | 375.2394 | 0.24 |
| | Forest-Deciduous --> FRSD | 137.0091 | 338.5564 | 0.21 |
| SOILS: | | | | |
| | Ne10-3b-154 | 56011.7250 | 138407.7729 | 86.94 |
| | Be49-3c-20 | 8415.9098 | 20796.1340 | 13.06 |
| SLOPE: | | | | |
| | 20-9999 | 23748.8408 | 58684.5731 | 36.86 |
| | 15-20 | 11967.5522 | 29572.4198 | 18.58 |
| | 10-15 | 13473.8988 | 33294.6777 | 20.91 |
| | 5-10 | 11401.0202 | 28172.4909 | 17.70 |
| | 0-5 | 3836.3228 | 9479.7454 | 5.95 |

Appendex1 HRU report in Gelana catchment

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Dec | Nov | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 7.35 | 9.77 | 9.81 | 13.05 | 12.19 | 12.00 | 11.18 | 11.68 | 11.70 | 10.68 | 8.56 | 7.25 | 10.43 |
| 1987 | 5.01 | 10.14 | 10.92 | 13.18 | 12.22 | 11.21 | 11.72 | 10.44 | 11.68 | 10.04 | 8.82 | 11.00 | 10.53 |
| 1988 | 6.37 | 8.90 | 13.11 | 11.61 | 13.19 | 12.42 | 12.44 | 12.50 | 11.65 | 12.23 | 9.80 | 7.39 | 10.97 |
| 1989 | 8.00 | 10.21 | 10.27 | 13.58 | 12.50 | 12.77 | 12.61 | 12.37 | 11.99 | 12.32 | 8.17 | 6.50 | 10.94 |
| 1990 | 6.82 | 7.38 | 9.76 | 12.50 | 11.34 | 12.42 | 12.81 | 11.98 | 12.17 | 11.74 | 9.77 | 10.58 | 10.79 |
| 1991 | 7.70 | 10.09 | 11.27 | 11.73 | 11.98 | 11.30 | 11.21 | 11.27 | 10.83 | 10.19 | 9.08 | 7.87 | 10.38 |
| 1992 | 7.61 | 9.69 | 10.00 | 9.87 | 11.18 | 12.35 | 12.02 | 11.79 | 11.45 | 9.89 | 8.97 | 7.06 | 10.15 |
| 1993 | 7.74 | 11.09 | 10.53 | 11.35 | 11.37 | 12.32 | 12.95 | 11.76 | 11.97 | 10.94 | 9.07 | 8.45 | 10.79 |
| 1994 | 9.02 | 9.46 | 9.03 | 11.23 | 12.50 | 11.78 | 11.24 | 11.66 | 11.58 | 11.66 | 9.21 | 7.18 | 10.47 |
| 1995 | 5.70 | 7.73 | 9.52 | 10.95 | 11.39 | 11.93 | 12.49 | 12.11 | 11.40 | 10.58 | 9.23 | 6.37 | 9.96 |
| 1996 | 5.43 | 10.13 | 11.17 | 11.53 | 12.29 | 11.61 | 11.94 | 11.76 | 11.30 | 11.03 | 8.38 | 5.56 | 10.17 |
| 1997 | 6.15 | 7.89 | 7.84 | 9.45 | 11.16 | 12.11 | 11.32 | 12.84 | 11.13 | 10.27 | 7.28 | 5.68 | 9.43 |
| 1998 | 6.32 | 4.43 | 5.53 | 10.72 | 10.77 | 10.67 | 10.73 | 8.33 | 9.85 | 10.19 | 10.52 | 7.52 | 8.82 |
| 1999 | 6.76 | 7.55 | 8.79 | 9.33 | 10.45 | 9.25 | 11.53 | 11.50 | 10.88 | 10.97 | 9.37 | 7.58 | 9.51 |
| 2000 | 9.02 | 7.52 | 10.84 | 10.77 | 10.58 | 10.70 | 12.13 | 11.34 | 11.82 | 12.16 | 8.40 | 8.13 | 10.30 |
| 2001 | 6.42 | 7.20 | 11.42 | 12.38 | 12.79 | 12.85 | 12.90 | 13.15 | 12.55 | 12.85 | 10.20 | 9.06 | 11.17 |
| 2002 | 10.03 | 10.13 | 12.45 | 12.88 | 13.24 | 12.72 | 12.68 | 12.17 | 12.18 | 11.77 | 9.95 | 9.52 | 11.65 |
| 2003 | 9.97 | 8.79 | 12.45 | 12.62 | 12.66 | 12.92 | 12.79 | 13.03 | 12.55 | 12.39 | 10.22 | 11.77 | 11.87 |
| 2004 | 9.95 | 10.26 | 11.79 | 13.60 | 12.94 | 13.00 | 12.92 | 12.84 | 12.40 | 11.52 | 10.43 | 8.65 | 11.69 |
| 2005 | 10.95 | 9.70 | 11.29 | 12.78 | 12.08 | 12.40 | 11.77 | 11.82 | 11.72 | 10.79 | 11.07 | 9.74 | 11.35 |
| 2006 | 8.68 | 9.11 | 12.34 | 12.25 | 12.90 | 11.78 | 10.69 | 10.77 | 11.43 | 11.18 | 10.80 | 9.37 | 10.95 |
| 2007 | 13.08 | 13.52 | 11.65 | 11.73 | 12.08 | 10.80 | 9.71 | 9.97 | 10.77 | 10.42 | 10.78 | 11.39 | 11.31 |
| 2008 | 10.92 | 10.50 | 9.24 | 7.55 | 12.79 | 11.58 | 11.63 | 12.33 | 12.50 | 10.44 | 9.72 | 8.03 | 10.61 |
| 2009 | 8.67 | 7.20 | 10.74 | 11.41 | 12.19 | 11.72 | 12.42 | 12.76 | 13.22 | 13.35 | 11.49 | 6.77 | 11.02 |
| 2010 | 8.29 | 9.14 | 11.15 | 12.12 | 12.37 | 11.32 | 11.42 | 11.85 | 12.18 | 12.04 | 9.27 | 11.39 | 11.06 |
| 2011 | 9.08 | 11.59 | 11.56 | 12.58 | 12.48 | 12.08 | 11.81 | 12.02 | 12.14 | 12.29 | 10.35 | 9.94 | 11.49 |
| 2012 | 8.96 | 8.31 | 10.71 | 11.70 | 12.96 | 12.82 | 12.60 | 12.35 | 12.83 | 11.12 | 11.35 | 8.12 | 11.16 |
| 2013 | 9.11 | 9.68 | 11.26 | 11.88 | 12.02 | 11.30 | 12.15 | 11.31 | 11.13 | 10.63 | 10.57 | 9.40 | 10.88 |
| 2014 | 9.82 | 9.70 | 12.24 | 11.68 | 11.47 | 12.38 | 11.73 | 11.44 | 11.60 | 11.25 | 8.93 | 7.51 | 10.82 |
| 2015 | 9.00 | 10.32 | 10.92 | 11.35 | 8.99 | 10.19 | 10.23 | 12.16 | 11.70 | 11.71 | 9.88 | 7.73 | 10.34 |
| 2016 | 8.05 | 11.19 | 12.03 | 11.75 | 10.24 | 9.03 | 11.29 | 11.61 | 9.87 | 11.97 | 10.13 | 10.48 | 10.64 |
| **Mean** | **8.26** | **9.30** | **10.70** | **11.65** | **11.91** | **11.73** | **11.84** | **11.77** | **11.68** | **11.31** | **9.67** | **8.48** | **10.70** |

Appendex1 Hagermariam minimum temperature

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 12.66 | 12.75 | 13.39 | 12.28 | 12.19 | 11.67 | 11.71 | 10.60 | 10.37 | 11.92 | 12.20 | 12.32 | 12.00 |
| 1987 | 11.63 | 11.18 | 11.02 | 10.63 | 10.39 | 10.30 | 10.21 | 10.32 | 10.27 | 10.45 | 10.28 | 10.31 | 10.58 |
| 1988 | 10.29 | 10.45 | 10.50 | 11.03 | 10.56 | 10.65 | 10.53 | 10.44 | 10.82 | 10.37 | 10.62 | 10.81 | 10.59 |
| 1989 | 10.22 | 9.84 | 10.47 | 10.26 | 39.03 | 9.85 | 9.51 | 10.35 | 10.79 | 10.55 | 10.38 | 10.42 | 12.69 |
| 1990 | 12.06 | 10.82 | 10.50 | 11.19 | 12.79 | 11.27 | 11.60 | 11.80 | 11.80 | 11.35 | 10.73 | 10.28 | 11.35 |
| 1991 | 10.21 | 10.23 | 10.19 | 9.85 | 12.68 | 12.36 | 12.35 | 12.29 | 12.21 | 13.03 | 12.99 | 13.65 | 11.85 |
| 1992 | 12.91 | 13.05 | 13.05 | 12.42 | 14.19 | 13.83 | 14.80 | 14.81 | 14.23 | 14.32 | 14.70 | 14.06 | 13.87 |
| 1993 | 14.25 | 14.12 | 14.02 | 13.67 | 14.19 | 13.95 | 12.56 | 12.10 | 12.00 | 12.67 | 12.44 | 13.04 | 13.25 |
| 1994 | 12.79 | 12.72 | 12.50 | 12.45 | 12.41 | 12.08 | 12.38 | 11.42 | 12.30 | 12.15 | 12.77 | 9.43 | 12.11 |
| 1995 | 11.80 | 12.30 | 12.32 | 12.18 | 11.82 | 11.15 | 10.56 | 10.52 | 10.66 | 11.10 | 10.68 | 11.16 | 11.35 |
| 1996 | 11.46 | 12.59 | 12.32 | 12.19 | 11.72 | 10.93 | 11.58 | 11.54 | 11.48 | 11.54 | 11.66 | 11.83 | 11.73 |
| 1997 | 13.04 | 13.15 | 13.76 | 13.02 | 12.34 | 11.81 | 11.42 | 11.26 | 11.69 | 11.76 | 11.65 | 11.20 | 12.17 |
| 1998 | 12.13 | 13.27 | 13.90 | 13.71 | 12.75 | 11.63 | 11.45 | 11.97 | 12.04 | 12.64 | 11.49 | 11.83 | 12.40 |
| 1999 | 12.75 | 13.64 | 13.07 | 13.08 | 12.41 | 11.73 | 11.33 | 11.33 | 11.71 | 12.04 | 11.64 | 11.74 | 12.20 |
| 2000 | 12.61 | 13.33 | 14.34 | 13.24 | 12.65 | 11.80 | 11.58 | 11.51 | 11.70 | 12.16 | 11.60 | 11.81 | 12.36 |
| 2001 | 11.98 | 12.55 | 12.96 | 12.85 | 12.47 | 11.88 | 11.85 | 11.73 | 12.10 | 12.00 | 11.83 | 12.69 | 12.24 |
| 2002 | 12.99 | 13.76 | 13.72 | 13.14 | 11.90 | 12.16 | 11.83 | 12.01 | 12.02 | 12.67 | 12.65 | 13.11 | 12.66 |
| 2003 | 13.14 | 14.26 | 14.35 | 13.37 | 12.72 | 12.56 | 11.77 | 11.34 | 11.91 | 12.84 | 12.59 | 12.08 | 12.73 |
| 2004 | 13.15 | 13.25 | 13.82 | 12.78 | 12.68 | 11.85 | 11.29 | 11.55 | 11.79 | 12.28 | 12.37 | 12.71 | 12.46 |
| 2005 | 12.82 | 14.14 | 13.87 | 14.17 | 12.83 | 12.20 | 11.47 | 11.78 | 12.13 | 12.41 | 12.33 | 12.25 | 12.69 |
| 2006 | 13.47 | 13.96 | 13.77 | 13.01 | 13.06 | 12.06 | 11.81 | 11.72 | 11.76 | 12.70 | 12.37 | 12.60 | 12.69 |
| 2007 | 12.96 | 14.00 | 14.20 | 13.99 | 13.22 | 12.64 | 12.02 | 12.01 | 12.65 | 12.51 | 12.37 | 12.17 | 12.88 |
| 2008 | 13.86 | 13.59 | 14.34 | 13.68 | 12.66 | 11.68 | 11.67 | 11.85 | 12.58 | 12.83 | 11.94 | 12.88 | 12.80 |
| 2009 | 13.35 | 14.35 | 14.85 | 13.88 | 13.56 | 12.38 | 11.50 | 13.21 | 14.40 | 14.76 | 14.76 | 14.85 | 13.82 |
| 2010 | 14.35 | 13.79 | 13.40 | 13.70 | 13.58 | 12.78 | 11.99 | 12.24 | 12.45 | 13.05 | 13.11 | 12.82 | 13.10 |
| 2011 | 13.46 | 13.70 | 14.23 | 14.68 | 13.23 | 12.77 | 12.23 | 12.05 | 12.54 | 13.11 | 12.90 | 11.65 | 13.04 |
| 2012 | 12.88 | 13.92 | 14.63 | 13.50 | 13.25 | 12.81 | 12.17 | 12.04 | 12.34 | 12.88 | 12.90 | 13.07 | 13.03 |
| 2013 | 13.15 | 14.01 | 14.10 | 13.37 | 12.66 | 11.99 | 11.82 | 11.47 | 12.23 | 12.32 | 12.83 | 12.34 | 12.68 |
| 2014 | 13.34 | 14.00 | 13.99 | 13.70 | 13.32 | 12.23 | 12.05 | 11.88 | 12.01 | 12.67 | 12.71 | 12.38 | 12.85 |
| 2015 | 12.69 | 14.11 | 14.23 | 13.69 | 13.54 | 12.94 | 12.48 | 11.84 | 12.73 | 13.34 | 13.11 | 12.80 | 13.12 |
| 2016 | 14.18 | 14.53 | 14.97 | 14.46 | 13.02 | 12.14 | 12.05 | 13.10 | 11.87 | 12.66 | 12.86 | 12.41 | 13.18 |
| Mean | 12.66 | 13.08 | 13.25 | 12.88 | 13.54 | 12.00 | 11.73 | 11.74 | 11.99 | 12.36 | 12.24 | 12.15 | 12.47 |

Appendex2 Yirgachefe minimum temperature

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 25.73 | 25.89 | 26.65 | 24.01 | 23.53 | 21.87 | 19.85 | 21.66 | 23.27 | 23.26 | 24.32 | 25.55 | 23.79 |
| 1987 | 26.39 | 26.15 | 25.84 | 23.70 | 21.95 | 22.31 | 21.77 | 22.35 | 23.14 | 23.26 | 24.10 | 25.19 | 23.83 |
| 1988 | 26.49 | 28.21 | 26.61 | 25.26 | 23.54 | 21.71 | 22.63 | 23.48 | 25.04 | 24.50 | 23.87 | 25.98 | 24.77 |
| 1989 | 27.03 | 27.47 | 28.15 | 25.35 | 21.80 | 21.11 | 20.48 | 21.08 | 22.72 | 22.54 | 24.11 | 24.78 | 23.86 |
| 1990 | 25.85 | 26.43 | 25.82 | 22.91 | 22.42 | 21.54 | 20.15 | 22.02 | 22.77 | 22.24 | 23.22 | 23.92 | 23.26 |
| 1991 | 25.45 | 25.93 | 24.59 | 23.43 | 22.55 | 21.60 | 21.56 | 21.40 | 24.63 | 24.04 | 23.58 | 25.00 | 23.63 |
| 1992 | 26.39 | 27.43 | 27.28 | 24.89 | 23.33 | 22.76 | 20.31 | 22.86 | 24.59 | 25.08 | 24.62 | 26.35 | 24.65 |
| 1993 | 26.79 | 27.69 | 28.49 | 25.34 | 23.75 | 23.20 | 22.59 | 21.27 | 23.71 | 22.64 | 24.12 | 26.26 | 24.64 |
| 1994 | 25.37 | 24.49 | 27.42 | 26.67 | 22.35 | 22.38 | 22.65 | 23.35 | 23.13 | 23.95 | 26.31 | 27.09 | 24.60 |
| 1995 | 27.99 | 27.59 | 25.87 | 24.98 | 22.63 | 22.13 | 21.90 | 21.98 | 23.65 | 24.14 | 24.08 | 25.43 | 24.34 |
| 1996 | 27.46 | 26.59 | 26.79 | 24.17 | 23.26 | 22.32 | 20.92 | 21.69 | 22.88 | 22.33 | 23.96 | 25.06 | 23.95 |
| 1997 | 26.60 | 27.29 | 26.21 | 24.56 | 22.73 | 20.20 | 21.71 | 22.67 | 23.35 | 22.87 | 23.63 | 25.43 | 23.92 |
| 1998 | 26.48 | 29.54 | 29.93 | 23.87 | 23.93 | 23.13 | 22.70 | 26.10 | 25.60 | 23.72 | 23.66 | 24.03 | 25.20 |
| 1999 | 24.41 | 26.11 | 26.37 | 24.12 | 24.92 | 23.54 | 21.17 | 22.67 | 23.77 | 24.04 | 24.41 | 26.59 | 24.33 |
| 2000 | 27.45 | 29.06 | 25.45 | 24.95 | 23.32 | 22.94 | 21.39 | 23.45 | 24.59 | 23.44 | 24.90 | 26.02 | 24.73 |
| 2001 | 28.01 | 29.55 | 29.55 | 26.31 | 23.25 | 22.37 | 22.79 | 21.80 | 24.11 | 23.45 | 23.94 | 25.20 | 25.00 |
| 2002 | 26.46 | 27.68 | 26.71 | 24.26 | 23.52 | 22.49 | 21.62 | 23.02 | 23.28 | 23.18 | 24.23 | 26.17 | 24.37 |
| 2003 | 26.00 | 28.19 | 26.45 | 24.86 | 22.82 | 21.78 | 22.53 | 22.46 | 24.53 | 22.91 | 24.52 | 24.67 | 24.28 |
| 2004 | 25.80 | 28.96 | 28.45 | 24.36 | 22.15 | 21.58 | 22.01 | 22.50 | 24.18 | 24.56 | 25.30 | 25.26 | 24.58 |
| 2005 | 26.27 | 27.77 | 28.42 | 24.16 | 22.95 | 22.01 | 22.77 | 23.72 | 24.67 | 23.83 | 23.32 | 25.00 | 24.56 |
| 2006 | 26.84 | 28.54 | 26.66 | 25.85 | 23.12 | 21.36 | 20.65 | 22.23 | 23.22 | 22.39 | 23.47 | 25.42 | 24.12 |
| 2007 | 26.99 | 27.47 | 27.55 | 24.07 | 23.96 | 23.05 | 22.25 | 22.57 | 23.33 | 23.35 | 23.77 | 24.09 | 24.35 |
| 2008 | 26.26 | 28.38 | 27.93 | 24.92 | 23.14 | 22.65 | 21.73 | 21.92 | 22.75 | 23.21 | 24.17 | 26.18 | 24.42 |
| 2009 | 27.96 | 28.43 | 27.91 | 23.96 | 22.87 | 21.64 | 21.65 | 23.03 | 25.14 | 23.66 | 24.24 | 26.00 | 24.69 |
| 2010 | 26.60 | 27.89 | 28.59 | 23.93 | 23.41 | 23.18 | 22.67 | 23.65 | 25.28 | 24.35 | 25.68 | 25.39 | 25.04 |
| 2011 | 27.22 | 27.29 | 25.78 | 25.02 | 23.95 | 22.76 | 21.14 | 22.14 | 23.78 | 24.43 | 25.57 | 26.78 | 24.64 |
| 2012 | 28.39 | 29.18 | 29.33 | 27.98 | 23.73 | 23.32 | 23.63 | 23.18 | 23.95 | 23.91 | 24.89 | 25.03 | 25.53 |
| 2013 | 27.32 | 29.24 | 28.32 | 24.23 | 22.96 | 22.79 | 22.55 | 24.27 | 24.11 | 24.10 | 24.02 | 28.07 | 25.15 |
| 2014 | 28.07 | 29.73 | 27.54 | 24.43 | 23.37 | 22.10 | 22.68 | 21.91 | 24.66 | 23.94 | 24.34 | 25.41 | 24.82 |
| 2015 | 27.75 | 27.20 | 27.24 | 24.81 | 23.67 | 23.59 | 22.71 | 23.78 | 24.23 | 23.97 | 25.60 | 25.95 | 25.03 |
| 2016 | 28.32 | 29.48 | 28.75 | 25.35 | 24.14 | 23.73 | 23.51 | 24.82 | 26.88 | 25.05 | 25.99 | 24.70 | 25.88 |
| Mean | 26.78 | 27.78 | 27.31 | 24.73 | 23.20 | 22.36 | 21.89 | 22.74 | 24.03 | 23.62 | 24.38 | 25.55 | 24.51 |

Appendex4 Hageremariam maximum temperature

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 27.74 | 27.29 | 27.37 | 23.28 | 23.16 | 22.90 | 22.16 | 22.52 | 23.52 | 24.18 | 25.30 | 26.95 | 24.69 |
| 1987 | 27.31 | 27.52 | 27.08 | 25.20 | 23.67 | 22.67 | 22.69 | 23.58 | 23.32 | 24.68 | 26.15 | 26.02 | 24.98 |
| 1988 | 27.66 | 27.76 | 26.27 | 25.57 | 23.95 | 23.42 | 23.34 | 24.32 | 24.45 | 24.44 | 25.78 | 27.47 | 25.36 |
| 1989 | 28.24 | 28.64 | 29.13 | 25.78 | 24.23 | 23.32 | 22.00 | 22.44 | 23.22 | 24.13 | 25.34 | 27.40 | 25.30 |
| 1990 | 27.08 | 27.45 | 27.48 | 25.72 | 25.32 | 23.78 | 23.82 | 23.55 | 23.48 | 24.02 | 25.43 | 25.68 | 25.22 |
| 1991 | 27.44 | 26.66 | 25.41 | 25.61 | 25.32 | 23.97 | 24.05 | 23.77 | 23.55 | 25.06 | 25.97 | 26.58 | 25.28 |
| 1992 | 28.18 | 27.55 | 27.40 | 26.68 | 26.23 | 25.10 | 23.46 | 24.15 | 25.43 | 25.23 | 27.67 | 28.45 | 26.29 |
| 1993 | 27.79 | 26.64 | 27.58 | 27.38 | 26.98 | 26.07 | 25.58 | 24.74 | 24.70 | 24.98 | 28.03 | 27.60 | 26.51 |
| 1994 | 27.98 | 26.68 | 28.63 | 27.98 | 25.27 | 23.65 | 23.55 | 23.95 | 23.95 | 24.69 | 27.93 | 29.32 | 26.13 |
| 1995 | 30.24 | 29.31 | 26.32 | 26.23 | 23.56 | 23.23 | 22.10 | 23.47 | 24.58 | 25.34 | 24.57 | 27.55 | 25.52 |
| 1996 | 28.65 | 27.07 | 27.19 | 25.84 | 24.56 | 24.11 | 23.60 | 24.02 | 23.83 | 23.87 | 26.28 | 28.37 | 25.62 |
| 1997 | 28.77 | 25.98 | 25.69 | 24.95 | 23.95 | 23.65 | 23.90 | 23.05 | 23.65 | 24.34 | 26.67 | 28.16 | 25.23 |
| 1998 | 28.11 | 29.68 | 30.46 | 25.17 | 23.89 | 24.23 | 24.03 | 27.24 | 26.25 | 25.44 | 24.78 | 24.97 | 26.17 |
| 1999 | 27.61 | 27.96 | 27.53 | 26.92 | 26.26 | 26.68 | 24.37 | 23.79 | 24.22 | 24.69 | 26.58 | 27.34 | 26.15 |
| 2000 | 26.62 | 27.47 | 24.60 | 24.38 | 24.11 | 25.05 | 21.90 | 23.06 | 22.32 | 22.82 | 24.73 | 26.92 | 24.49 |
| 2001 | 28.19 | 30.00 | 30.31 | 26.20 | 23.21 | 23.20 | 22.97 | 22.90 | 24.37 | 22.60 | 24.82 | 26.42 | 25.40 |
| 2002 | 26.84 | 28.23 | 27.10 | 24.60 | 23.94 | 23.55 | 23.02 | 24.87 | 23.83 | 22.39 | 25.78 | 28.56 | 25.21 |
| 2003 | 26.16 | 28.66 | 25.52 | 25.33 | 23.91 | 23.40 | 23.77 | 23.87 | 23.83 | 23.06 | 24.90 | 24.05 | 24.68 |
| 2004 | 24.97 | 28.05 | 27.48 | 25.38 | 24.16 | 23.35 | 22.02 | 22.23 | 23.87 | 24.74 | 24.52 | 23.98 | 24.55 |
| 2005 | 25.18 | 26.73 | 27.44 | 24.48 | 24.73 | 23.60 | 23.31 | 23.98 | 24.08 | 24.29 | 24.65 | 26.05 | 24.87 |
| 2006 | 26.89 | 29.20 | 27.79 | 28.57 | 25.52 | 23.57 | 23.48 | 24.02 | 23.88 | 24.00 | 25.28 | 26.77 | 25.72 |
| 2007 | 27.87 | 27.89 | 26.77 | 24.63 | 24.50 | 23.93 | 22.77 | 23.55 | 23.68 | 24.24 | 24.12 | 25.06 | 24.90 |
| 2008 | 26.66 | 27.76 | 28.61 | 26.07 | 25.05 | 24.52 | 23.94 | 22.87 | 24.10 | 24.13 | 25.12 | 26.65 | 25.45 |
| 2009 | 28.39 | 28.39 | 28.99 | 26.12 | 24.97 | 24.00 | 22.40 | 23.32 | 24.05 | 24.23 | 25.43 | 26.92 | 25.59 |
| 2010 | 26.81 | 27.96 | 29.19 | 25.35 | 24.39 | 24.35 | 23.92 | 24.76 | 24.50 | 24.92 | 26.43 | 25.40 | 25.65 |
| 2011 | 27.35 | 27.60 | 25.76 | 24.75 | 24.26 | 24.15 | 23.55 | 24.13 | 24.47 | 24.44 | 25.12 | 27.19 | 25.22 |
| 2012 | 28.75 | 30.14 | 29.85 | 29.03 | 25.92 | 24.61 | 24.38 | 23.74 | 24.61 | 26.07 | 26.72 | 26.56 | 26.68 |
| 2013 | 28.15 | 28.48 | 28.63 | 25.57 | 24.66 | 23.58 | 23.58 | 24.52 | 22.98 | 23.34 | 25.17 | 26.58 | 25.42 |
| 2014 | 28.05 | 28.96 | 27.24 | 24.62 | 24.82 | 24.60 | 25.10 | 25.44 | 24.73 | 26.03 | 26.45 | 27.26 | 26.10 |
| 2015 | 28.85 | 28.31 | 28.35 | 27.62 | 26.48 | 26.08 | 24.15 | 24.45 | 24.95 | 25.15 | 26.85 | 27.48 | 26.55 |
| 2016 | 28.23 | 30.71 | 28.39 | 25.85 | 26.86 | 25.20 | 25.12 | 25.66 | 26.68 | 27.68 | 27.87 | 27.68 | 27.15 |
| Mean | 27.64 | 28.09 | 27.60 | 25.83 | 24.77 | 24.11 | 23.48 | 23.93 | 24.16 | 24.49 | 25.82 | 26.82 | 25.55 |

Appendix 5 Yirgachefe maximum temperature

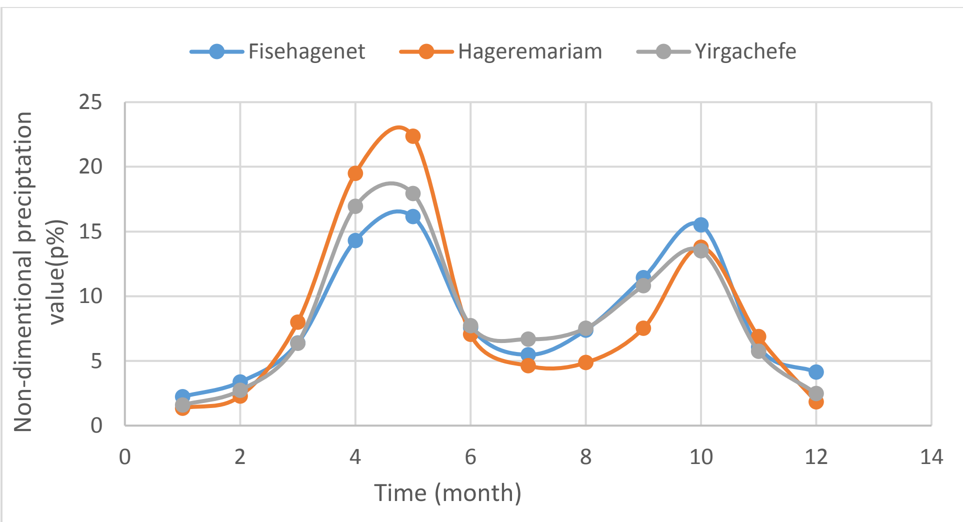
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 23.94 | 24.30 | 24.29 | 21.17 | 19.77 | 18.35 | 20.19 | 20.11 | 19.03 | 20.92 | 22.23 | 22.37 | 21.38 |
| 1987 | 23.69 | 24.07 | 23.27 | 20.78 | 20.35 | 19.30 | 19.39 | 20.39 | 20.90 | 20.19 | 21.07 | 23.53 | 21.40 |
| 1988 | 23.89 | 23.95 | 25.24 | 22.23 | 19.98 | 19.35 | 17.92 | 18.76 | 20.34 | 20.15 | 21.65 | 22.23 | 21.30 |
| 1989 | 22.21 | 23.09 | 22.55 | 21.13 | 20.34 | 19.97 | 18.97 | 20.13 | 20.41 | 19.87 | 21.12 | 21.95 | 20.96 |
| 1990 | 25.36 | 22.71 | 22.24 | 21.74 | 21.31 | 20.05 | 20.23 | 19.74 | 21.35 | 21.40 | 22.17 | 20.38 | 21.55 |
| 1991 | 20.41 | 20.66 | 20.34 | 20.27 | 23.28 | 22.22 | 22.05 | 22.27 | 22.76 | 23.43 | 24.61 | 25.87 | 22.36 |
| 1992 | 25.22 | 24.62 | 24.93 | 21.81 | 20.19 | 18.77 | 18.11 | 18.39 | 17.13 | 17.45 | 18.23 | 17.99 | 20.23 |
| 1993 | 18.43 | 17.60 | 19.08 | 18.14 | 17.34 | 18.11 | 21.77 | 22.18 | 22.15 | 22.69 | 24.29 | 25.23 | 20.61 |
| 1994 | 25.39 | 24.90 | 25.67 | 24.49 | 23.36 | 22.33 | 21.82 | 20.61 | 22.08 | 21.88 | 21.60 | 23.07 | 23.09 |
| 1995 | 25.84 | 24.78 | 23.27 | 21.93 | 21.88 | 21.10 | 20.35 | 20.74 | 21.01 | 21.34 | 22.13 | 23.27 | 22.29 |
| 1996 | 23.68 | 25.22 | 24.37 | 21.93 | 21.25 | 20.27 | 19.83 | 20.44 | 21.33 | 21.87 | 22.19 | 22.71 | 22.08 |
| 1997 | 24.18 | 26.35 | 26.34 | 23.23 | 21.45 | 21.41 | 20.23 | 22.13 | 23.56 | 22.02 | 21.53 | 22.16 | 22.86 |
| 1998 | 22.81 | 24.50 | 25.32 | 24.95 | 22.28 | 21.11 | 20.12 | 20.74 | 21.21 | 20.72 | 22.41 | 24.38 | 22.53 |
| 1999 | 25.59 | 26.74 | 23.44 | 22.63 | 21.70 | 21.78 | 19.75 | 21.18 | 21.81 | 21.43 | 23.20 | 24.13 | 22.75 |
| 2000 | 25.99 | 27.26 | 27.53 | 24.57 | 21.85 | 21.26 | 21.06 | 21.53 | 22.68 | 21.22 | 22.43 | 23.96 | 23.43 |
| 2001 | 24.04 | 25.86 | 25.65 | 23.30 | 21.87 | 21.04 | 21.33 | 21.84 | 21.73 | 21.35 | 22.11 | 24.00 | 22.83 |
| 2002 | 24.23 | 26.10 | 24.78 | 23.66 | 21.44 | 21.39 | 21.09 | 22.28 | 23.37 | 21.55 | 24.28 | 23.30 | 23.10 |
| 2003 | 24.38 | 27.33 | 27.36 | 25.36 | 22.56 | 22.24 | 21.32 | 21.71 | 22.96 | 23.73 | 24.53 | 23.86 | 23.92 |
| 2004 | 25.11 | 24.79 | 26.59 | 23.67 | 22.85 | 21.91 | 21.63 | 22.69 | 22.64 | 22.82 | 22.93 | 24.94 | 23.55 |
| 2005 | 24.94 | 27.21 | 25.41 | 25.05 | 22.05 | 20.90 | 21.15 | 21.81 | 22.35 | 21.82 | 23.09 | 25.04 | 23.38 |
| 2006 | 26.19 | 26.06 | 25.31 | 23.44 | 22.46 | 21.85 | 22.11 | 21.78 | 22.81 | 23.42 | 23.26 | 23.50 | 23.50 |
| 2007 | 25.64 | 26.14 | 27.95 | 26.31 | 23.22 | 22.10 | 22.40 | 21.45 | 23.15 | 23.17 | 24.03 | 24.98 | 24.20 |
| 2008 | 26.69 | 27.19 | 28.36 | 26.02 | 23.62 | 22.07 | 21.73 | 21.71 | 22.63 | 22.53 | 23.15 | 25.01 | 24.22 |
| 2009 | 25.71 | 26.16 | 27.52 | 24.29 | 23.34 | 22.52 | 22.67 | 23.31 | 23.18 | 23.21 | 24.84 | 24.65 | 24.28 |
| 2010 | 25.35 | 25.49 | 26.38 | 25.07 | 23.95 | 22.74 | 21.83 | 22.18 | 22.43 | 23.38 | 24.49 | 25.33 | 24.05 |
| 2011 | 26.71 | 27.65 | 27.45 | 27.08 | 23.79 | 21.43 | 21.62 | 22.14 | 22.73 | 22.79 | 22.17 | 23.78 | 24.09 |
| 2012 | 26.28 | 27.64 | 28.35 | 24.02 | 22.40 | 22.44 | 20.92 | 21.13 | 22.06 | 21.90 | 23.37 | 24.57 | 23.74 |
| 2013 | 26.23 | 27.69 | 25.86 | 24.24 | 22.36 | 21.14 | 21.15 | 21.15 | 21.84 | 22.24 | 22.40 | 24.84 | 23.40 |
| 2014 | 25.94 | 24.94 | 25.08 | 23.93 | 22.86 | 21.98 | 21.27 | 21.53 | 21.79 | 21.26 | 22.77 | 23.68 | 23.08 |
| 2015 | 25.56 | 27.17 | 27.32 | 24.72 | 23.32 | 22.07 | 22.03 | 22.73 | 24.12 | 24.10 | 24.12 | 23.49 | 24.21 |
| 2016 | 24.87 | 26.51 | 27.03 | 24.18 | 22.78 | 22.58 | 22.05 | 23.53 | 22.37 | 24.20 | 23.48 | 22.90 | 23.87 |
| Mean | 24.66 | 25.32 | 25.30 | 23.40 | 21.97 | 21.16 | 20.91 | 21.36 | 21.93 | 21.94 | 22.77 | 23.58 | 22.85 |

Appendex6 Fishagenet maximum temperature

| No | year | Hageremariam | Yirgachefe | Fishagenet |
|---|---|---|---|---|
| 1 | 1986 | 955.200 | 1360.900 | 1154.700 |
| 2 | 1987 | 1289.100 | 1546.800 | 1462.400 |
| 3 | 1988 | 1476.000 | 1460.400 | 1258.000 |
| 4 | 1989 | 979.300 | 1364.000 | 1467.300 |
| 5 | 1990 | 914.300 | 2083.100 | 1129.400 |
| 6 | 1991 | 833.900 | 1170.400 | 900.900 |
| 7 | 1992 | 585.000 | 1037.400 | 2649.100 |
| 8 | 1993 | 991.800 | 1150.900 | 1346.000 |
| 9 | 1994 | 882.000 | 1066.300 | 1354.600 |
| 10 | 1995 | 979.000 | 1477.300 | 1252.600 |
| 11 | 1996 | 515.600 | 1710.300 | 1584.300 |
| 12 | 1997 | 1138.000 | 2080.300 | 1247.600 |
| 13 | 1998 | 982.300 | 1175.900 | 1163.100 |
| 14 | 1999 | 570.600 | 1056.400 | 1210.000 |
| 15 | 2000 | 615.800 | 1159.700 | 1259.400 |
| 16 | 2001 | 845.600 | 1245.700 | 1504.100 |
| 17 | 2002 | 768.100 | 1444.600 | 1181.200 |
| 18 | 2003 | 734.300 | 1229.800 | 1174.000 |
| 19 | 2004 | 707.400 | 1148.200 | 1084.000 |
| 20 | 2005 | 709.600 | 1251.600 | 1213.000 |
| 21 | 2006 | 1129.900 | 1498.200 | 1360.400 |
| 22 | 2007 | 860.300 | 1503.200 | 1508.700 |
| 23 | 2008 | 995.700 | 1704.100 | 1192.500 |
| 24 | 2009 | 888.500 | 1386.700 | 1131.000 |
| 25 | 2010 | 612.300 | 1461.000 | 1660.800 |
| 26 | 2011 | 1046.300 | 1232.900 | 1406.400 |
| 27 | 2012 | 1015.600 | 853.500 | 1316.200 |
| 28 | 2013 | 812.900 | 1439.300 | 2326.500 |
| 29 | 2014 | 898.000 | 1506.600 | 1515.400 |
| 30 | 2015 | 780.800 | 1847.900 | 1256.500 |
| 31 | 2016 | 889.500 | 1141.300 | 1090.800 |

Appendex7 Annual rainfall for selection station

| Month | Fisehagenet | Hageremariam | Yirgachefe |
|---|---|---|---|
| January | 2.236260325 | 1.339284085 | 1.596693048 |
| February | 3.367964326 | 2.284446423 | 2.729076264 |
| March | 6.388910528 | 7.997022191 | 6.368545638 |
| April | 14.302340130 | 19.487860685 | 16.937377759 |
| May | 16.141772248 | 22.357650888 | 17.926752612 |
| Jun | 7.579631217 | 7.052589708 | 7.719413853 |
| July | 5.474151871 | 4.625456616 | 6.679331786 |
| August | 7.386292548 | 4.864484157 | 7.521959495 |
| September | 11.426338912 | 7.511668558 | 10.805777351 |
| October | 15.506516623 | 13.774555062 | 13.512420931 |
| November | 6.064554814 | 6.868301299 | 5.732485565 |
| December | 4.125266460 | 1.836680327 | 2.470165698 |




Appendex8 Homogeneity test by non-dimensional