



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

**ESTIMATION OF CATCHMENT SEDIMENT YIELD USING SWAT
MODEL**

A CASE OF GIDABO DAM, RIFT VALLEY BASIN, ETHIOPIA

Submitted in Partial Fulfillment for the Degree of Masters of Science in Civil
Engineering Major in Hydraulics Engineering.

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ABSTRACT

Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients in Gidabo sub basin. This serious problem can also play great role on the silting up of reservoirs and shortening their age for reservoirs found around the basin. The purpose of this study was to estimate sediment yield of Gidabo watershed to reservoir and recommend appropriate reduction measures. The soil and water assessment tool (SWAT) model was applied to simulate the sediment yield from the Gidabo watershed (area 2634 sq. Kilometer) located in Borena zone of Oromia region and Sidama zone of SNNPRS, Ethiopia. Model calibration and validation process was conducted by using multi gauge calibration approach in monthly base using SWAT-CUP. The time series data from 1997 to 2002 was used for model calibration and the time series data from 2003 to 2006 were used to validate the model using the input parameter set for both gauging stations Aposto, Bedassa and Maesso. Time series plots and the statistical measures of coefficient of determination and Nash-Sutcliffe efficiency were used to evaluate the performance of the model. Flow calibration at dam outlet (Maesso station) gives coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (ENS) 0.80 and 0.65 respectively. Flow validation gives 0.85 and 0.81 for R^2 and ENS values respectively. Sediment calibration gives R^2 and ENS 0.79 and 0.67 respectively and validation test gives R^2 and ENS 0.79 and 0.78 respectively. The two other stations, Aposto and Bedassa also shows good result of calibration and validation for both flow and sediment. This result indicates that the observed values show good agreement with simulated value for both flow and sediment yield. In this study, the SWAT model simulates average annual sediment yield of 95.32 ton/km²/year at dam outlet (Maesso station). Sub basin 4, 11,3,40 and 8 ranks first to fifth according to their Sediment yield respectively and found as erosion prone areas. For proper management of the watershed, from the scenarios developed, changing 30% of agricultural land to forest mixed reduces 27.2% of sediment volume and taken as best management method. Moreover, applying **terracing** and **filter strip** in low slope areas reduces 4.7% and 13% of sediment volume respectively and could give potential effect of best management practice.

Key words: Arc SWAT, SWAT CUP, sediment Yield, Gidabo Watershed.

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LIST OF ABBREVIATIONS

BMP	Best Management Practice
DEM	Digital Elevation Model
DMC	Double Mass Curve
ENMA	Ethiopia National Metrological Agency
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographical Information System
Ha	Hectare
HRU	Hydrologic Response Unit
HSELAM	Hagereselam Meteorological Station
MoWIE	Ministry of Water Irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
NSE	Nash Sutcliffe Simulation Efficiency
PCC	physical catchment characteristics
SUFI2	sequential uncertainty fittings
SWAT	Soil and Water Assessment Tool
YCHEFE	Yirgachefe Meteorological Station
SNNPRS	South Nation Nationality People Regional State

CHAPTER-ONE

1. INTRODUCTION

1.1. Background

Many reservoirs can no longer perform their design functions, because much of their original active storage volume has been filled by sediment. Erosion accelerates on-site and off-site problems. On-site effects mainly refer to agricultural and economic losses. The most significant off-site effect of soil erosion is loss of water storage capacity because of sediment deposition in a reservoir (B.K.Amegash, 2012). For irrigation projects and water supply schemes, any loss of storage increases the risk of failure to meet the design objectives in extreme dry periods. Number of studies on sediment measurements have been conducted to estimate the deposit of sedimentation in reservoirs (Duru, 2015). Reservoirs around the world have been filled with sediment at a rate of approximately 1% per year. This means that in 50 years most of the world's reservoirs will lose half of the current storage.

Ethiopia experiences persistent land, water and environmental degradation due to localized and global climatic changes. To tackle the problem of land degradation in Ethiopia, Government and Non-Governments (NGO's) 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's very little achievement had been recorded in terms of output, impact, and sustainability (Azene, 1997). Failures of previous attempts of Soil and Water Conservation (SWC), or land rehabilitation activities in general, were largely due to misguided nature of interventions; it disregarded local level biophysical and socio-economic realities.

Nile tributaries, originating from the Ethiopian plateau, carry large quantities of sediment. Reservoirs built on these tributaries are experiencing alarming loss in capacity due to sedimentation. In some reservoirs, the annual rate of capacity loss exceeds 1.0 %. Khashm El-Girba dam reservoir in Sudan for example has lost 50% of its original capacity in less than 40 years, which is about 1.25% annual loss (Tadesse, 2013). Reservoirs of Ethiopia, the existing and the new ones, are under similar threat of sedimentation problem (Haregeweyn, et al.,2012) The frequent power cuts and rationing based electric power distribution recently experienced in the country are partially attributed to storage loss due to sedimentation. A river does not only convey water, but it also transports erosion products

(boulders gravel, sand, silt and Clay) from its catchment. If the transport capacity of the river is affected by diversion of water from the river or by storing water in the reservoir, deposition of sediment can occur. Some depositions could be, harmful if they are not properly taken care. According to (Setegn et al, 2008), Many reservoirs are suffering from excessive sedimentation often because either the upstream sediment supply was never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data. Change in sediment yield due to changed land use in the upstream catchments causes detrimental sedimentation.

Comprehensive understanding of hydrological processes in the watershed is a pre-requisite for successful water management and environmental restoration. Due to the complexity of hydrologic cycle, mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes. Hence, to analyze the sediment yield of Gidabo dam watershed with respect to quantity and quality of runoff is essential for the proper and sustainable utilization of Gidabo dam Irrigation Project. A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource. If these are not investigated, the life of Gidabo dam reservoir can reduce by sedimentation (MOWIE, 2010).

This thesis is intended to provide a basis for future scenario analysis of water resource management of Gidabo dam catchment and to predict the sediment yield of Upper Gidabo River catchment to the Gidabo dam reservoir. Therefore, to address the above situation, watershed management strategies should be provided, to reduce land degradation and to increase the productivity of the watershed area as well as the life span of the Gidabo irrigation dam project.

1.2. Problem statement

All rivers contain sediments, when a river is stilled behind a dam, the sediments it contains sink to the bottom of the reservoir. The proportion of a river's total sediment load captured by a dam is known as its "trap efficiency". As the sediments accumulated in the reservoir, 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.

Watershed problems in Ethiopia in general, in the rift valley in particular, are characterized as land degradation, deforestation, over grazing and inappropriate farming practice (Bezuayehu ,2002). Observations at numerous points in the watershed indicate that physical and biological degradation are the common phenomena of Gidabo watershed. In fact, institutional and policy constraints are added factors for the deterioration of most sub watersheds.

The rift valley river watersheds suffer severe land degradation and soil erosion due to extended dry seasons in some parts of the Basin, torrential rain and geological nature, bringing large quantities of sediment in the drainage systems (Mengist, 2017). This leads to land degradation in the watershed and the upper lands. At the same time, the sediment deposition in the reservoir and water supply systems downstream leads to serious reduction in reservoirs storage capacities and hence leading to shortage of supply to the irrigable areas, banks flooding and ultimately negatively impact on the socio-economic lives of the users, environmental and ecosystem in general. Moreover, the sedimentation in the irrigation systems leads to water shortage and irrigation management difficulties. On the other hand, sediment deposition on the bed of the river course raise the bed level, hence leads to flood risks and loss of human lives and their properties.

Sedimentation of a reservoir created by a dam constructed on a natural water course is inevitable. The problem of concern is the rate of sedimentation & the period of time which will elapse before the usefulness of the storage works is seriously impaired or destroyed. The silting of dam reservoirs is the most challenging problem in Ethiopia (Tamene,2006). 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. In this study area it is clear that, Gidabo dam has problem of sedimentation due to the soil erosion and land degradation in the upstream. It is essential estimating and predicting of the sediment yield from

Gidabo dam watershed, and proposing alternative management plan to minimize erosion rate in the watershed.

1.3. Research Questions

To structure the research objective, the problem is divided into two major parts:

First, the sediment yield (ton) of the catchment will be assessed. To determine the sediment yield, it is necessary to define the upstream areas draining into the Gidabo dam reservoir. Moreover, it is necessary to look into the rainfall characteristics, soil properties and land cover of the catchment area. However, criteria like hill slopes and height characteristics will also have an impact on the sediment yield. The research question and sub-questions regarding the sediment yield are the following:

1. What is the sediment yield of the Gidabo dam watershed and what is the impact of different hydrological characteristics on the sediment yield?
2. What are the catchment areas of the rivers flowing into the reservoir?
3. What are the soil properties, land uses and rain characteristics in the catchment areas?

Second, identification of erosion prone areas and determination of the temporal and spatial changes in land cover as well as assessing mitigation methods by making different scenarios. Here also are the sub-questions: -

1. What is spatial distribution of sediment yield in Gidabo dam watershed?
2. What is the temporal variability of sediment yield in the catchment?
3. What are the most erosion prone areas?
4. What are the most sensitive sediment and flow parameters to the catchment?
5. What are best mitigation methods to the erosion exposed areas?

1.4. Thesis Layout

This thesis is sub divided in to five major chapters and it has a detail information of each sub chapter. Chapter-One: - Deals about the statement of the problem, research question, general and specific objectives of this study. This chapter also provides information on its background about the problem of sedimentation on reservoirs.

Chapter-Two: - Briefly reviews the theory of sediment transport and erosion in rivers and reservoirs that are related to this study.

Chapter-Three: - Outlines the research methodology employed in this study, and an overview of the selection of the erosion model (Arc SWAT) to Gidabo watershed.

Chapter-four: - widely deals the swat model simulation results and discussion and Sediment reduction methods in catchment are assessed and appropriate techniques that are remedy measures to the sediment problem of the catchment are specified here.

Chapter-five: -summarizes the entire study by outlining the main conclusions and recommendations.

1.5. OBJECTIVES

1.5.1.General objective

The general objective of this study is to estimate sediment yield from Gidabo watershed to reservoir using SWAT model and to take and recommended appropriate sediment reduction measures.

1.5.2. Specific objective

1. To estimate the amount of sediment yield of Gidabo watershed.
2. To assess the temporal and spatial variability of sediment yield in the catchment.
3. To assess appropriate mitigation measures to reduce sediment yield of the watershed.

CHAPTER-TWO

2. LITERATURE REVIEW

2.1. General

Land degradation is an increasing problem in many parts of the world. Success in fighting land degradation requires an improved understanding of its causes, impact, degree and acquaintance with climate, soil, water, land cover and socio-economic factors. (Kapalanga, 2008). Therefore, land degradation assessment is a primary goal in a decision support system for reversing degradation. Factors influencing soil erosion are climate, landscape relief, soil or bedrock properties, vegetation cover, and human activities. Therefore, spatial variability in sediment dynamics may reflect spatial variability in watershed characteristics and human activities. (M. Provansal, 2012).

Soil loss rate is defined as the amount of soil eroded from a specified area in a specified time period. It is expressed as the amount of soil detached and transported per unit area and per unit time. The detachment of the soil particles from their parent soil matrix is the preliminary start of the soil loss rate and the initiation of erosion. Soil erosion is a complex process that is related to the soil property, climate (rainfall depth and intensity), topography, land cover pattern and human influence. The rainfall drop and the surface runoff that is generated from the rainfall events are the main mechanisms of soil detachment and transport process respectively (Julian J, and Zemke, 2016). During the rainfall event, the splashes from raindrops detach individual soil particles and make them easily transportable. The rate and intensity of the detachment of the soil depends on the characteristics of the soil, the intensity and duration of the rainfall event.

Different Soils with different textures have different degree of detachment. mainly soil textures with a higher clay percentage are less prone to the detachment processes (Belasri et al. 2017). similarly, soil textures that are dominated by sand are less susceptible to detachment and transport processes because of their higher infiltration rate. In contrast, the presence of high silt content in soil texture facilitates soil detachment and transportability.

The dynamic nature of land use and land cover change due to anthropogenic effects is another factor for the occurrence of soil erosion. The pattern of agricultural practice and the change in land cover conditions play a fundamental role. Consequently, the temporal and spatial variability of land use and

land cover is one of the crucial aspects to be considered when analyzing the soil erosion and sediment yield (Melesse et al., 2005).

Undisturbed soils and soils that exist under a dense cover of vegetation are rich in organic content. Such soils have high infiltration rates and as a result of this, the rain drop that falls from the plant canopy after dissipating its potential energy has less capability to detach and transport the soil particles. Moreover, the presence of high organic matter in soils decreases soil erodibility factor because the organic content facilitates soil infiltration rate (USDA,1972).

The resulting water erosion due to either high rainfall intensity or the pre-saturated soil conditions is the main cause of the formation of rills and gullies. Rills are small ditches that are formed in agricultural fields and are the main causes for the initiation of land erosion. Gullies are relatively large ditches that can't be leveled by simple farm operations. Thus, the formation of gullies is an indication of the occurrence of severe erosion in the area (Alemu O, and Awdenegest M., 2014). Once a gully network is formed in a catchment area, the soil particles from the parent soil matrices can be easily transported to the adjoining river bodies. The soil that is eroded from the land surface is delivered to the nearby river section where it is defined as sediment yield.

The sediment yield from the watershed is the net sediment flux resulting from the upland erosion and in the lowland deposition and transport into the river networks. Soil eroded from the upland catchment causes depletion of fertile agricultural land and the resulting sediment delivered to the river networks creates river morphological change and reservoir sedimentation problems (Duru,2015).

The sediment delivery of a river network to a downstream section is influenced by the combined effect of geomorphologic and hydro-climatic parameters (J.Pietron,2017). As a result, there is a need to understand the interrelated natural processes and phenomena that play a fundamental role in erosion generation and sediment transportation for a given watershed. The quantity of sediment discharged at the outlet point of a river network or a basin is the sediment flux resulting from land surface erosion, river bank erosion and flood plain deposition. Erosion and deposition of sediment at different watershed sections depend on climatic factors and geomorphologic factors such as shed slope, watershed length, watershed area, flow velocity, drainage length etc.

2.1.1. Sediment Properties

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. Sediments are the products of disintegration and decomposition of rocks. The property of sediment is described based on different characteristics of sediment which will be discussed as follows.

2.1.1.1. Shape

Most of the sand particles on the face of the Earth are more or less rounded because their edges and corners are smoothed by abrasion as running water or wind moves the sand particles from their origin (source) to their final resting place. Roundness is a function of abrasion induced by transport and it increases slowly with distance. Thousands of kilometers if transports in a river are required to achieve even moderate rounding. Beaches where sand moves in and out with each wave are ideal places for rounding of sand particles if they stay there for any length of time.

2.1.1.2 Size

Sediments are referred to as gravel, sand, silt or clay. These terms refer to the size of the sediment particle. Various methods are available to determine the particle size. Cobbles can be measured directly with a ruler. Gravel, sand and silt are analyzed by wet or dry sieving methods yielding sieve diameters. Clay materials are analyzed hydraulically by using setting methods (Van Grensven et al, 2005) yielding the particle fall velocity from which the standard fall diameter is computed. Clay materials can also be analyzed with various electronic techniques such as the Coulter counter and the Laser Diffraction technique (Van Grensven et al, 2005).

2.1.1.3. Density and Porosity

The wet density or volume weight of deposited material (assuming total saturation) is the weight of water and sediment per unit volume (sometimes called the wet bulk density) and the porosity of sediment material is often related to the deposition history of the sediment bed. Loose packing occurs when sediments settle from suspension in still water. Basically, four packing arrangements are possible for spherical particles.

2.1.2. Physical factors controlling the amount of suspended sediment yield

Numerous previous studies (Williams, 1975) and (D. E. Walling, 1994) indicate that river sediment fluxes are sensitive to many factors including change in runoff, basin characteristics, lithology, topography, and land use. (Summerfield and Hilton, 1994) studied the variables controlling mechanical denudation rates in drainage basins exceeding 5×10^5 km² in area and concluded that physical factors (basin area, mean annual runoff, temperature, precipitation) have no significant influence on physical denudation processes, although channel gradient and basin relief can be considered as dominant controlling variables.

Understanding the order of significance of different geomorphologic and hydro climatic factors is helpful to adapt or formulate appropriate sediment yield modeling strategies. Studies have been conducted to analyze the combined effects of basin parameters and fluvial processes. To estimate sediment yield, different empirical models were developed based on basin hydrologic and geomorphologic parameter (Grauso et al., 2008). However, they are limited to certain boundary conditions and cannot be widely applied because they were developed based on data driven parameters of a specific area.

Physically based models are other helpful tools to analyze watershed sediment yield at different spatial scales. Model calibration and validation is a mandatory procedure when using physically based models for a watershed sediment yield analysis. Once the models are calibrated, simulation results can be taken as a representative values and can be used for further analysis. Similarly, for basin sediment yield modeling, different scenarios can be analyzed after extraction of the spatially variable basin parameters. The reliability of the results of physically based model depend on the quality of the hydro-climatic and hydraulic input data. The presence of incorrect values of any of the input data parameters may lead to a wrong conclusion on the model result. Besides that, the tiresome and lengthy calibration and validation work of physically based models needs a wide range of professional expertise and reliable data sources.

2.1.4. Sediment yield estimation on watershed

2.1.4.1. Sediment yield:

Refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which is also the amount, which will enter a reservoir located at the downstream limit of its

tributary watershed (Vanoni, 2006). The most common unit for sediment yield is tones/year. The specific sediment yield is the yield per unit of land area, which is most commonly given in tones/km²/year. Accurate estimation of sediment yield is very important in order to plan a reservoir and efficiently manage its sediment so that the reservoir can meet its requirements. Sediment yield is affected by geology, slope, climate, drainage density and patterns of human disturbance and therefore, no single parameter or simple combination of parameters explains the wide variability in sediment yields (Morris. et al, 2006).

Sediment yield from drier areas tends to be limited because of low runoff and yield in wetter areas is limited by the protective soil cover and reduced erodibility of humid zone soils (Vanoni, 2006). The process of soil erosion involves detachment, transport and subsequent deposition (Meyer & Wishmeier, 1969). Sediment is detached from soil surface both by the raindrop impact and by the shearing force of flowing water. The detached sediment is transported down slope primarily by flowing water, although there is a small amount of down slope transport by raindrop splash also (Walling, 1987). Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. However, if transport capacity is less than the amount of eroded soil material available, then the amount of sediment exceeding the transport capacity is deposited and estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. (Meyer & Wishmeier, 1969). The most important distribution principles of these sediments in the reservoir can be subdivided into the following groups:

Course sediment deltaic deposits: mainly the course sediment fractions are deposited in the head of the reservoir by backwater effects during high discharges, forming delta. The delta proceeds into the reservoir while the forest slope can be considered as an area of instability and slumping. Fine sediments in homogeneous flow: A large part of the fine sediments transported in suspension or as wash load are transported beyond the delta after which they settle out to form the bottom set bed. They are more evenly spread than coarse sediment, but the distribution is highly dependent on reservoir circulation and stratification, for instance generated by river inflow and wind shear, or precluded by an ice cover.

Sediment yield by a stream or the stream sediment load is the total sediment delivered past a point of interest or the watershed outlet during any given time (Singh, 2012). The stream sediment load can

be determined using either a short-term or a long-term analysis. The short-term analysis of sediment load is performed generally on a daily basis expressing often the magnitude and variability of sediment transport during rainstorm or snowmelt events (Julien 2010). On the other hand, the long-term sediment load analysis estimates the amount of sediment yielded by a stream. On an annual basis, it gives the mean annual sediment load of a stream (Julien 2010). The long-term sediment is utilized for reservoir sedimentation, sediment budget and degradation studies.

2.1.4.2. Daily sediment load or sediment rating curve

The sediment rating curve or daily total sediment discharge in tons per day is the product of the daily mean water discharge, the flux-averaged total sediment concentration, and a unit conversion factor, as expressed by equation 2.1 (Julien 2010) below.

$$Q_s(\text{metric tons/day}) = 0.0864 \text{ Cmg/l} * Q(\text{in m}^3/\text{s}) \dots\dots\dots 2.1$$

Where:- Q_s = the total sediment discharge in tons per day.

Cmg/l = the flux averaged total sediment concentration in mg/l;

Q = the daily mean water discharge in m^3/s .

2.1.4.3. Annual sediment Load

Two basic approaches can be used to determine the long-term average sediment load of a river, the summation approach and the flow duration curve approach. The summation approach utilizes the mass curves method to determine the cumulative sediment load as function of time in years. The second approach combines a sediment-rating curve between total sediment discharge or flux-averaged concentration, and water discharge; and a flow-duration curve (Julien 2010).

2.1.3. Spatial and temporal variability in sediment yields

The spatial and temporal variability of suspended sediment load have been studied at a variety of scales from all over the globe (Webb and Walling, 1984). A wide range of studies have been done on the impact of climate, topography, land use, lithology, and drainage characteristics across varying spatial (Langbein and Schumm, 1958; Dunne, 1975; Douglas, 1967; Hwang, 1980; 1969; Abernethy, 1990; Walling, 1994).

Studies focusing on temporal variation of suspended sediment yields mostly emphasize anthropogenic impacts and variation in macro and micro climate (Douglas, 1967) and (Walling,

1995). These studies suggest that soil erosion rates can be increased by the magnitude of agricultural activities, particularly given that the area of the world's surface given over to crop production and livestock grazing has increased by more than 5 fold over the past 200 years (Buringh and Dudal, 1987).

2.2. Hydrological models

2.2.1. Over view of hydrological models

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 are being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, K.J. 1989). 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 purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models, it is very important to understand how the catchment responds to rainfall under Many hydrological and soil erosion. Models are developed to describe the hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of sediments.

Hydrological models are a simplification of a real-world system (e.g., surface water, soil water, wetland, and groundwater) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models.

Researchers and practitioners currently use wide ranges of rainfall runoff models; however, the applications of these models are highly dependent on the purposes for which the modeling is made. Many Rainfall runoff models are used merely for research purposes in order to enhance the knowledge and understanding about the hydrological processes that govern a real-world system. Other types of models are developed and employed as tools for simulation and prediction aiming

ultimately to allow decision makers to take the most effective decision for planning and operation while considering the interactions of physical, ecological, economic, and social aspects of a real-world system. Examples of some of the implications of latter type of Rainfall runoff models are: real-time flood forecasting and warning, estimating flood frequencies, flood routing and inundation prediction, impact assessment of climate and land use change and integrated watershed management. The development of Rainfall runoff models could be recognized based on the importance of available data, which provides the learning data set for calibrating the nonlinear behavior of these models. These data are used as a priori knowledge in the model with the logic that gives the flexibility to the model to extrapolate the Rainfall runoff process for some future time. This line of thinking, known as batch model calibration (using batch of data for calibration), has been challenged by another philosophy that availability of observation continuously gives the opportunity to the model components (state variables and even parameters) to be updated (corrected) sequentially. This is thought to give more flexibility for taking advantage of the temporal organization and structure of information content for better compliance of the model output with observed system response.

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The first objective of the watershed hydrologic modelling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may affect these phenomena. The other objective is for hydrologic prediction. They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate. According to (E. Todini, 2007) based on process description, the hydrological models can be classified in to three main categories.

2.2.2. Lumped models

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models.

2.2.3. Distributed models

Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modelling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often-unavailable) data. However, the governing physical processes are modelled in detail, and if properly applied, they can provide the highest degree of accuracy.

2.2.4. Semi-distributed models

Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold et al., 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), are considered as semi-distributed models. Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003). Generally, for this study, semi-distributed models are selected because their structure is more physically based than the structure of lumped model, and they are less demanding on input data than fully distributed models.

2.3. Swat model

2.3.1. Introduction

SWAT (Soil & Water Assessment Tool) is semi distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch, et al, 2005). SWAT is a public domain software enabled model

actively supported by the USDA Agricultural Research Service (Arnold et al., 1998) at the Backland Research & Extension Center in Temple, Texas, USA. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, sediment loading, nutrient and pesticide loading, and water transfer. SWAT can be considered as a watershed hydrological transport model. This model is used worldwide and is continuously under development.

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

2.3.2. SWAT model application in Ethiopia

SWAT model was calibrated and validated in many parts of Ethiopia, especially in Blue Nile basin. Through modelling of Gumara watershed (in Lake Tana basin),(Awulachew et al. 2008) indicated that stream flow and sediment yield simulated with SWAT were reasonably accurate. A study conducted on modelling of the Lake Tana basin with SWAT model also showed that the SWAT model was successfully calibrated and validated (Setegn et al., 2008). This study reported that the model can produce reliable estimates of stream flow and sediment yield from complex watersheds. (Gessese, 2008) used the SWAT model to predict the Legedadi reservoir sedimentation. According to this study, the SWAT model performed well in predicting sediment yield to the Legedadi reservoir. The study further put that the model proved to be worthwhile in capturing the process of stream flow and transport of the watersheds of the Legedadi reservoir. In addition to the above, the SWAT model was tested for prediction of sediment yield in Anjeni gauged watershed by (Setegn et al., 2008). The

study found that the observed values showed a good agreement at Nash-Sutcliff efficiency (ENS) of 80 %. In light of this, the study suggested that the SWAT model can be used for further analysis of different management scenarios that could help different stakeholders to plan and implement appropriate soil and water conservation strategies.

2.3.3. Swat model operation

SWAT is a continuous time model that operates on a daily time step at basin scale. The objective of such a model is to predict the long-term impacts in large basins of management and timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies. SWAT uses a two-level disaggregation scheme; a preliminary sub basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change. The literature reviewed and presented above showed that SWAT is capable of simulating hydrological and soil erosion process with reasonable accuracy and can be applied to large and complex watersheds.

2.4. Hydrologic parameters

Hydrologic parameters are the main driving forces 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 2012 and other hydrologic models can help to simulate the surface runoff, peak flow and stream discharges, which can then be used as primary input data for sediment modeling.

2.5. Soil erosion and sedimentation

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster and Meyer, 1977), (Wischmeier and Smith, 1978; Julien, 1998). The major forces originate from raindrop impact and flowing water. Figure 2.1 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills and the rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join to form progressively larger channels, with the flow eventually proceeding to some established streambed or constructed reservoirs. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems. Figure 2.1 shows the processes from erosion to sediment ending up in the reservoir.

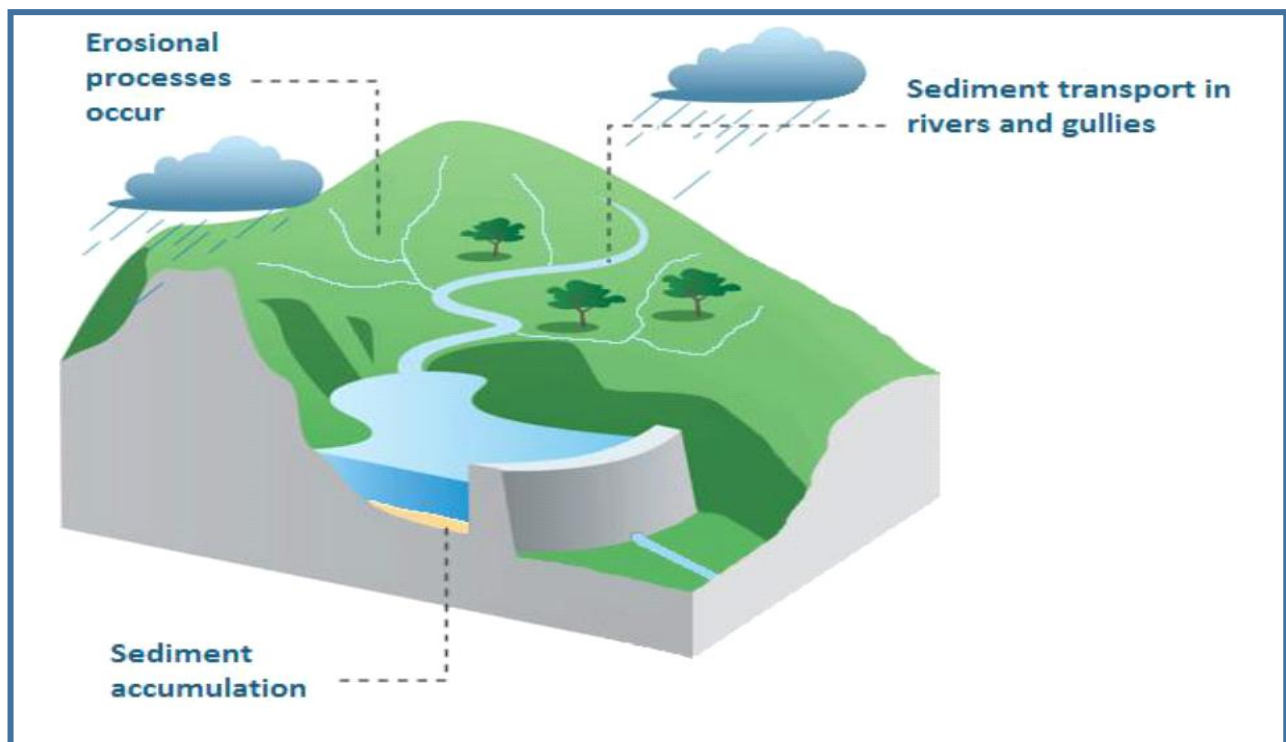


Figure 2. 1.The processes from erosion to sedimentation

2.6. Uncertainty analysis

Most important issue with calibration of watershed models is that of uncertainty in the predictions. Watershed models suffer from large model uncertainties. These can be divided into conceptual model uncertainty, input uncertainty, and parameter uncertainty.

1. Conceptual model uncertainty (or structural uncertainty)
2. Input uncertainty is because of errors in input data such as rainfall, and more importantly, extension of point data to large areas in distributed models.
3. Parameter uncertainty

The packages like SWAT-CUP can help decrease model uncertainty by removing some probable sources of modeling and calibration errors. On a final note, it is highly desirable to separate quantitatively the effect of different uncertainties on model outputs, but this is very difficult to do. The combined effect, however, should always be quantified on model outputs (Abbaspour, 2013).

2.6.1. SWAT-CUP (swat calibration and uncertainty procedures)

SWAT-CUP is a program designed to integrate various calibration/uncertainty or sensitivity programs for SWAT (Soil & Water Assessment Tool) using the same interface. To create a project, the program guides the user through the input files necessary for running a calibration program. Each SWAT-CUP project contains one calibration method and allows user to run the procedure many times.

Until convergence is reached, user can save calibration iterations in the iteration history for later use. Many computer programs have been developed by hydrologists for parameters uncertainty analysis in river basin model, such as, generalized likelihood uncertainty estimation (GLUE; Beven & Binley 1992), sequential uncertainty fitting (SUFI-2), (Abbaspour et al. 2014), parameter solution (ParaSol; Van Griensven & Meixner, 2006) and Markov chain Monte Carlo (MCMC; Kuczera & Parent 1998; Vrugt et al., 2008).

The generalized likelihood uncertainty estimation (GLUE) (Beven and Binley, 1992) was introduced partly to allow for the possible non-uniqueness of parameter sets during the estimation of model parameters in over parameterized models. The procedure is simple and requires few assumptions when used in practical applications. GLUE assumes that in the case of large over parameterized models; there is no unique set of parameters, which optimizes goodness of fit criteria. The technique

is based on the estimation of the weights (probabilities) associated with different parameter sets, based on the use of a subjective likelihood measure to derive a posterior Probability function, which is subsequently used to derive the predictive probability of the output variables.

The ParaSol method aggregates objective functions (OF's) into a global optimization criterion (GOC), minimizes these OF's or GOC using the shuffle complex evolution (SCE-UA) algorithm and performs uncertainty analysis with a choice two statistical concepts.

The MCMC (Markov Chain Monte Carlo) generates samples from a random walk, which adapts to the posterior distribution (Kuczera and Parent, 1998). In this particular study, it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an Interface is to provide a link between the input/output of a calibration program and model. A schematic of the linkage between SWAT and five optimization programs is illustrated in Figure-2.2.

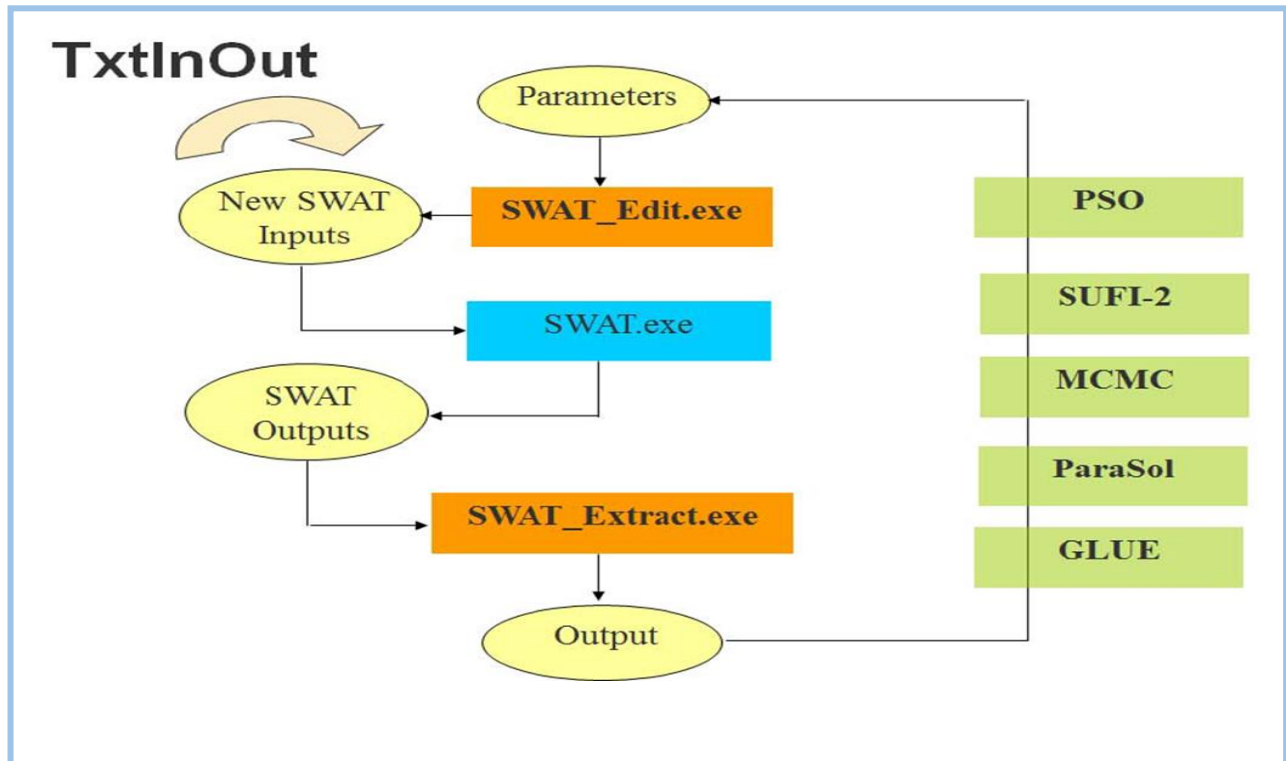


Figure 2. 2. A schematic linkage of the five optimization programs and Arc Swat

2.6.2. Calibration and uncertainty analysis procedure of SUFI-2

The program SUFI-2 was used for calibration and uncertainty analysis. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g. rainfall), conceptual model, parameters, and measured data.

The percentage of measured data is bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. As all forms of uncertainties are reflected in the measurements (e.g., discharge), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is of some interest, but quite difficult to do. Another measure quantifying the strength of a calibration/uncertainty analysis is called R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data (large P-factor, maximum 100%). The calibrated parameter ranges can be generated with an acceptable value of the R-factor and P-factor.

CHAPTER-THREE

3. MATERIALS AND METHODS

3.1. Location and description of the study area

3.1.1. Location of the study area

The Gidabo dam is located in Oromia Regional State, 377 Km from capital city of Ethiopia. The study area is accessible by 360 Km asphalt road from Addis Ababa to Dilla town and the rest 17 km by gravel road. The dam is constructed on Gidabo River, which originates in the highland area of Aletawendo Escarpment, joining numerous large streams, draining an extensive catchment and flowing into the Lake Abaya as the Eastern tributary. The Gidabo catchment is found in Borena zone in Oromia Region, Sidama Zone, and Gedeo Zone in SNNP Region (Birhanu Debisso, 2009). Gidabo irrigation project is found in Abaya district, Borena zone of Oromia region and Dale district, Sidama zone of SNNPRS near Dilla to east of Lake Abaya, located in Dibicha Launchpad Kebele of Gelana Abaya district, which is situated in Borena zone. The project area lies in the low land, very close to the Dure and Gola marsh. The command area is situated in the northern part of Lake Abaya. The northern Lake Abaya area, which is located in the southern part of the Main Ethiopian Rift (MER), encloses irrigable lands at different places. The absolute geographical location of the area is between $6^{\circ}15'0''$ and $7^{\circ}0'0''$ N latitude and $38^{\circ}15'0''$ to $38^{\circ}45'0''$ E longitudes See Fig.3.1 and the area coverage of the Gidabo River Catchment is also 2634 square kilometers.

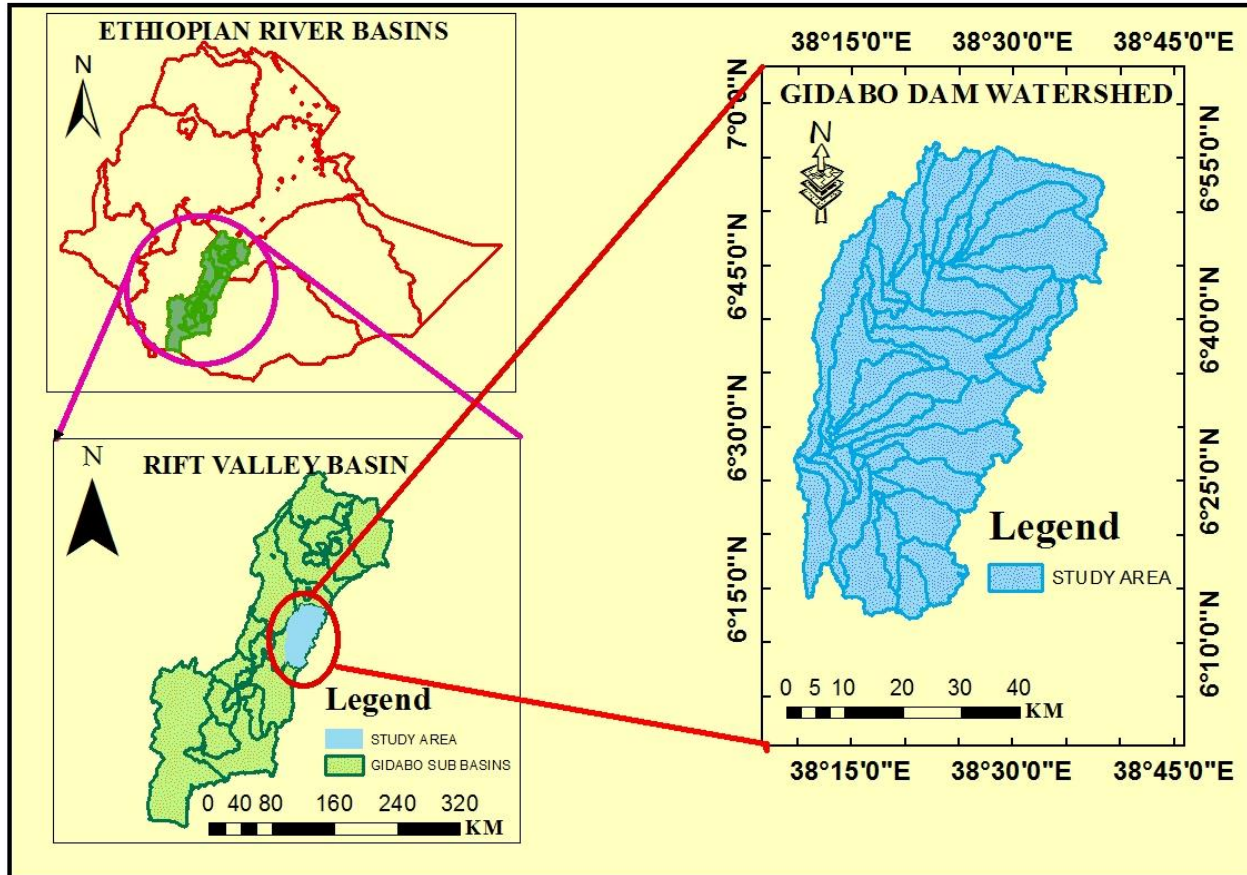


Figure 3. 1.Gidabo Dam Watershed.

3.1.2. Description of the study area

3.1.2.1. Climate

The main rainy season in the Gidabo River Basin is between April and May with a second peak in September to October. These two peaks are separated by a relatively small rainy season in July to August. The main dry season is between November and February (Raunet, 1977 as cited in Birhanu Debisso, 2009). The mean annual rainfall in the north tip of Lake of Abaya is 818 mm and 745.1 mm at Mirab Abaya (WWDSE, 2008).

The areas adjacent to the Abaya Lake are characterized by arid Kolla climatic zones (Ataklti Hagos, 2017). The annual monthly temperature at Gidabo dam is in the range 15 C⁰ to 30 C⁰. The command area is relatively hotter as it is the lowest part of the catchment, daily temperature may reach 36 to 40 o C. Maximum average temperature is attained during the month of February and March, in July the minimum temperature is observed (WWDSE, 2008)

3.1.2.2. Topography

The altitude of the catchment area ranges from 1184 to 3184 m-a.s.l. The major physiographic units in this area are undulating plains, valleys, steep stream banks, and major escarpment at the eastern part of the watershed. The Gidabo watershed elevation varies from 1184 m.a.s.l catchment at the dam site to 3148 m.a.s.l at the peak of the watershed, which is located at the western part of the watershed.

3.1.2.3. Hydrogeology

Gidabo dam is located in Gidabo River Catchment, which is part of Abaya sub-Basin and found within Rift Valley Basin. Major river system is Gidabo River it collects small streams in the direction of NS and Eastern direction near the Lake Abaya. Gidabo River Catchment covers the whole of the hydrographical system of the Gidabo River, which rises in the highland area of the Aletawondo Escarpment, joining numerous large streams, draining an extensive catchment and flowing into the Lake Abaya as the Eastern tributary.



Figure 3. 2. Base Map of the Delineated Gidabo Watershed

3.2. Data collection and analysis

3.2.1. Spatial data

To get a better result, it is critical to use all relevant and good quality data required. The outcome depends on the quality and quantity of data used because the spatial and temporal resolution of data used in modelling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of digital elevation model (DEM), Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The length of period of weather and climatic data also affect the SWAT model performance. The output from the SWAT model can be affected by the DEM data resolution, mesh size, soil data resolution and soil map scale, watershed subdivision which on the other hand is affected by DEM data resolution etc. (Bosch et al., 2004) found that SWAT stream flow estimates were more accurate when using high-resolution topographic data, land use/land cover data, and soil data. The required DEM data, soil data, land use/land cover data, flow data, climatic and sediment data was collected from different sources. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the next sections.

3.2.1.1. Digital elevation model (DEM) data

The DEM (Digital Elevation Model) data with (30x30) resolution was collected from ministry of water irrigation and electricity (MoWIE), GIS Department. 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 (HRUs). 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 HRUs. 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, the decrease in the DEM resolution results in large Error in the predicted output. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and sub basin classification (Chaubey et al., 2005). In this research paper digital elevation model (DEM),

30mX30m resolution was used to delineate the watershed. Fig.3.3 shows the digital elevation model (DEM) of the Gidabo watershed.

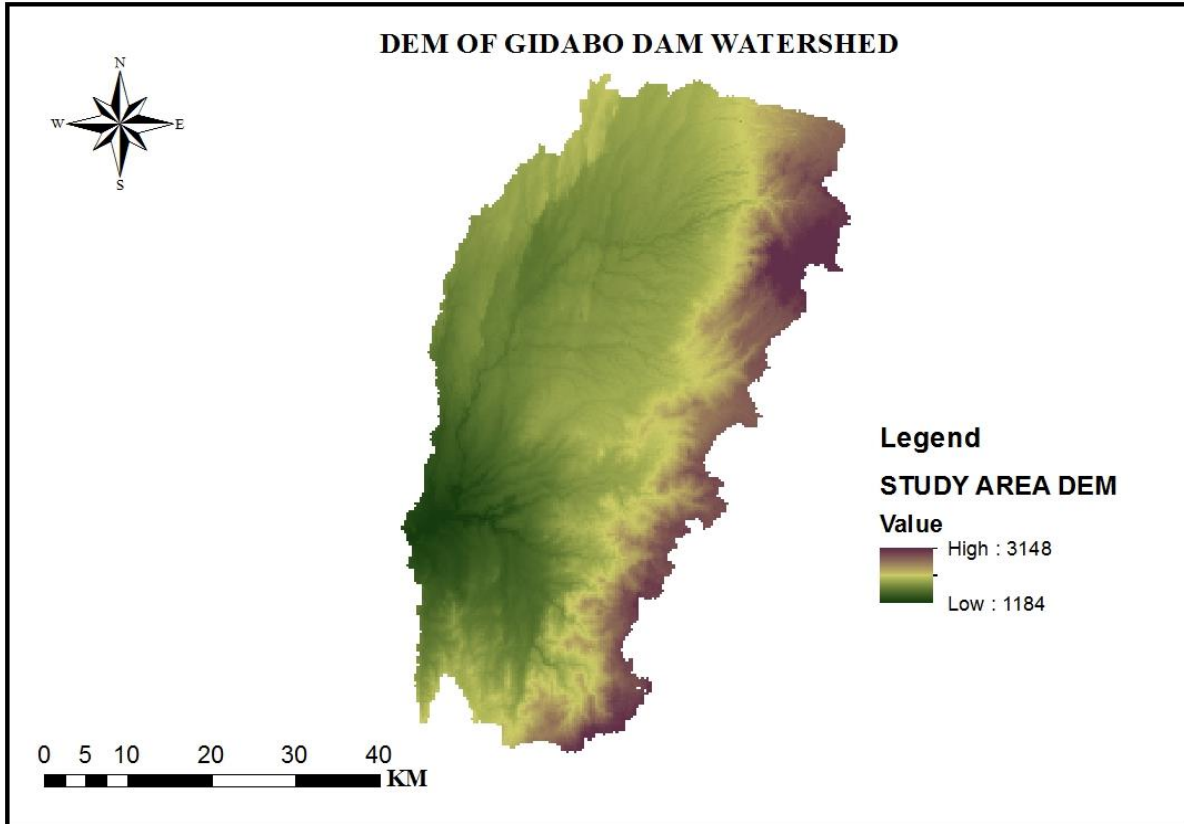


Figure 3. 3.DEM of the Gidabo watershed

3.2.1.2. Soil data

Soils in the Gidabo River Catchment mainly range between the sandy alluvial deposits (transported soils) of the river flood plains and the in-situ clayey loam soils, which have developed on their parental bedrocks (i.e. on volcanic terrain) According to their texture, (Birhanu, 2009). The Eastern high plateau and the escarpment area have mainly reddish-brown silty loam soil derived from weathering of trap-series basalts and post-rift ignimbrites. The foot part of the escarpment is mainly covered with red to reddish sandy loam soil. This soil is developed from weathering of underlying ignimbrites. The Rift floor is mainly occupied by grayish gravelly to sandy loam soils.

SWAT model requires different soil Textural and physicochemical properties such as soil texture, available water content, hydraulic Conductivity, bulk density and organic carbon content for

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

different layers of each soil type. The major aim of soil classification is to convert user's soils into SWAT database (or grid properties). Since swat soil data base is developed in U.S database SWAT does not recognize the soils of the catchment. To reclassify the soils, new FAO soils and their properties were added to the soil database with the soil Database Editor. The soil characteristics were entered manually and to facilitate their manipulation, they were rearranged in an excel table.

Soils in the study watershed are classified based on the FAO/Globe soil (FAO/UNESCO,) classification system. According to FAO, four major soils types are identified for the study area as shown in figure 3.4 below. Eutric Cambisols (clay), Ferric Acrisols (clay loam), Eutric Nitosols (clay), Haplic Xerosols (silt) are found in the study area.

Table 3. 1. Soil types of Gidabo dam watershed

Soil Group Name	SNAME	Soil Group	Area (km2)	Percent area coverage
Ferric Acrisols	Af14-3c-1	C	10.19	0.39
Eutric Cambisols	Be49-3c-20	C	462.62	17.56
Eutric Nitosols	Ne10-3b-154	C	2054.43	77.99
Haplic Xerosols	Xh17-2a-310	D	106.91	4.06
TOTAL			2634.12	100

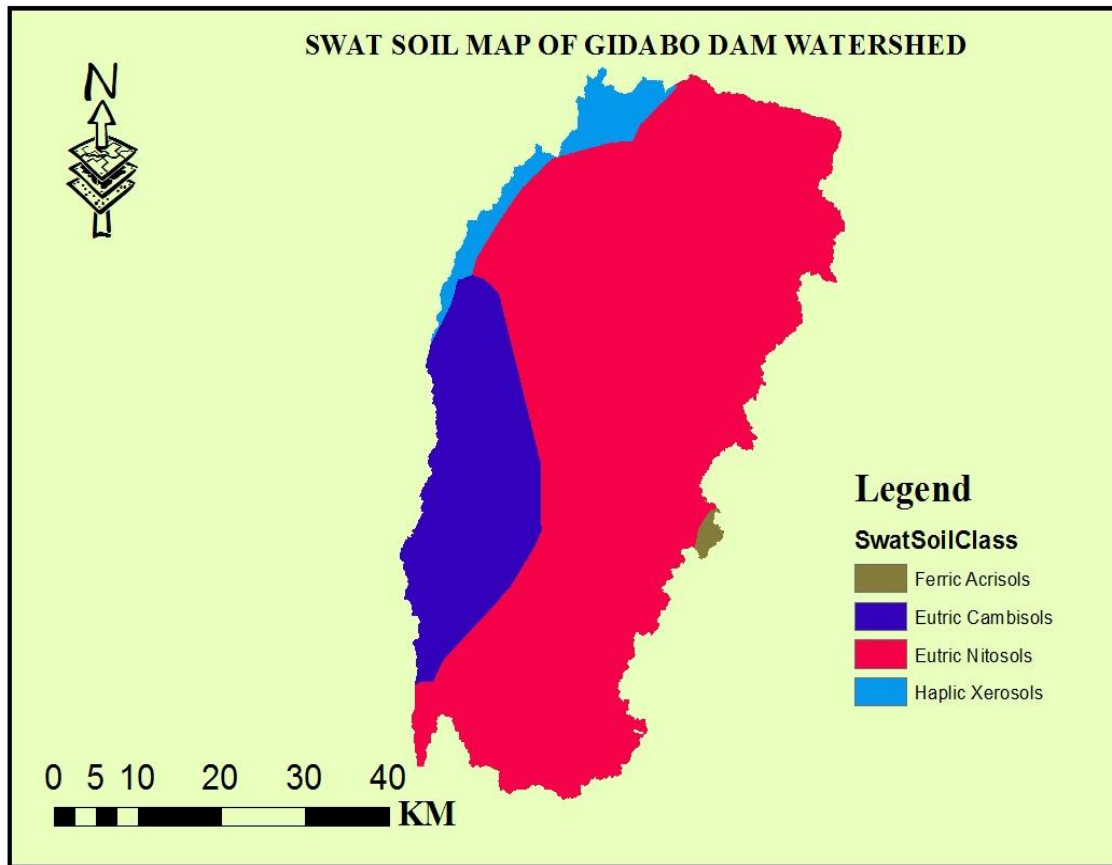


Figure 3. 4. Soil map of Gidabo dam watershed

3.2.1.3. Land use/cover data

Land use land cover in a catchment can often be correlated with the amount of interception storage/loss and actual evapotranspiration in a catchment. The Land Use, Soil and Slope Definition option in the HRU Analysis menu allows specifying the land use, soil and sloping themes that will be used for modeling using SWAT. These themes are then used to determine the hydrologic response unit (HRU) distribution in each sub watershed. SWAT require land use data to determine the area of each land category to be simulated within each sub basin. In addition to land use information, SWAT relies on soil data to determine the range of hydrologic characteristics found within each sub basin. Land Use, Soil and Slope Definition option guides the process of specifying the data to be used in the simulation and of ensuring that those data are in the appropriate format. In particular, the option allows the user to select land use or soil data that are in either shape or grid format. Shape files are automatically converted to grid, the format required by ArcGIS to

calculate land use and soil distributions within the sub basins of interest. When we select the Land Use / Soil / Slope definition option from the HRU Analysis menu. The Land Use / Soil / Slope Definition dialog box will open.

The LULC map and all datasets were obtained from the Ministry of Water Irrigation and Electric (MoWIE) as shape file format. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database. A lookup table that identifies the SWAT land use code for the different categories of LULC was prepared to relate the grid values to SWAT LULC classes. The land use/cover of the study area is shown in the figure.3.5 below.

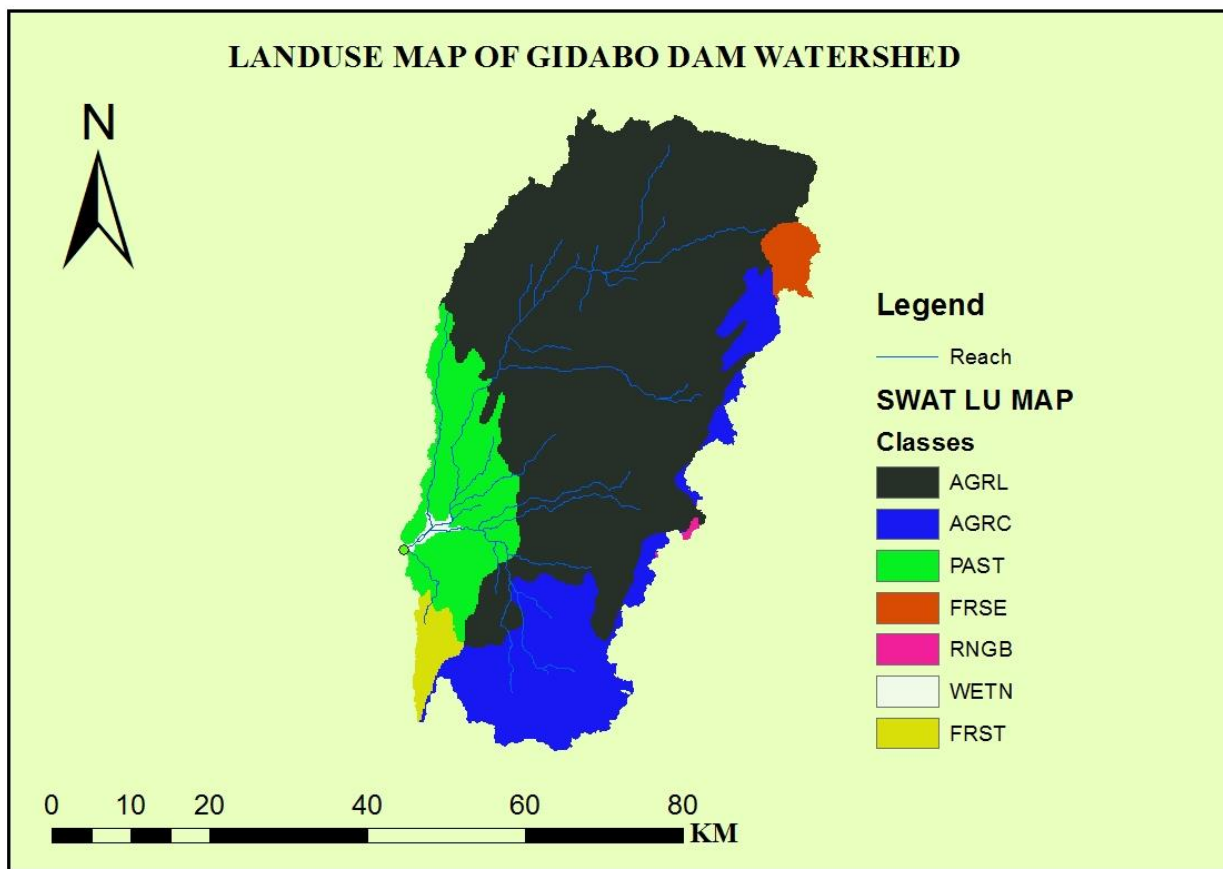


Figure 3. 5. LULC of Gidabo dam watershed

The main land use types are agricultural land generic, Forest-Evergreen, Agricultural Land-Close-grown, Pasture, Forest Mixed, Range-Brush and wetland.

Agricultural land generic occupies about 51.42% of the watershed area, Forest-Evergreen is about 15.72% of the watershed, and Pasture, Forest Mixed, Agricultural land close growing and wetland also covers, 1.85%, 3.11%, 28.76%,1.84 of the total area of the watershed respectively. The summary of the land use of Gidabo dam watershed is given in the Table 3.2 below. These percentages are based on the total area of the catchment delineated by Arc SWAT.

Table 3. 2 Summary of land use proportion of Gidabo dam watershed.

No.	Descriptions	SWAT-code	% Area coverage
1	Forest-mixed	FRST	3.11
2	Agricultural land generic	AGRL	51.42
3	Forest-Evergreen	FRSE	15.72
4	Agricultural land close growing	AGRC	28.76
5	Range-Brush	RNGB	0.01
6	Pasture	PAST	1.85
7	Wetlands-Mixed	WETL	1.84
		TOTAL	100

3.2.1.4. Slope

The slope is derived from DEM input so that the model uses this slope for the development of Hydrological Response Unit in addition to land use and soil input parameters. Arc SWAT allows the integration of land slope classes (up to five classes) when defining hydrologic response units. There are possibilities to choose simply a single slope class, or choose multiple classes. This study considers five slope classes for Gidabo watershed. Table 3.3 below shows the slope distribution of Gidabo watershed.

Table 3. 3. Slope distribution of Gidabo watershed.

No	Slope (%)	Area [ha]	% Area of coverage
1	0-5	39252.13	14.90
2	5-10	84471.26	32.07
3	10-15	41656.44	15.81
4	15-20	937.27	0.36
5	>20	97098.83	36.86
	Total	263415.93	100%

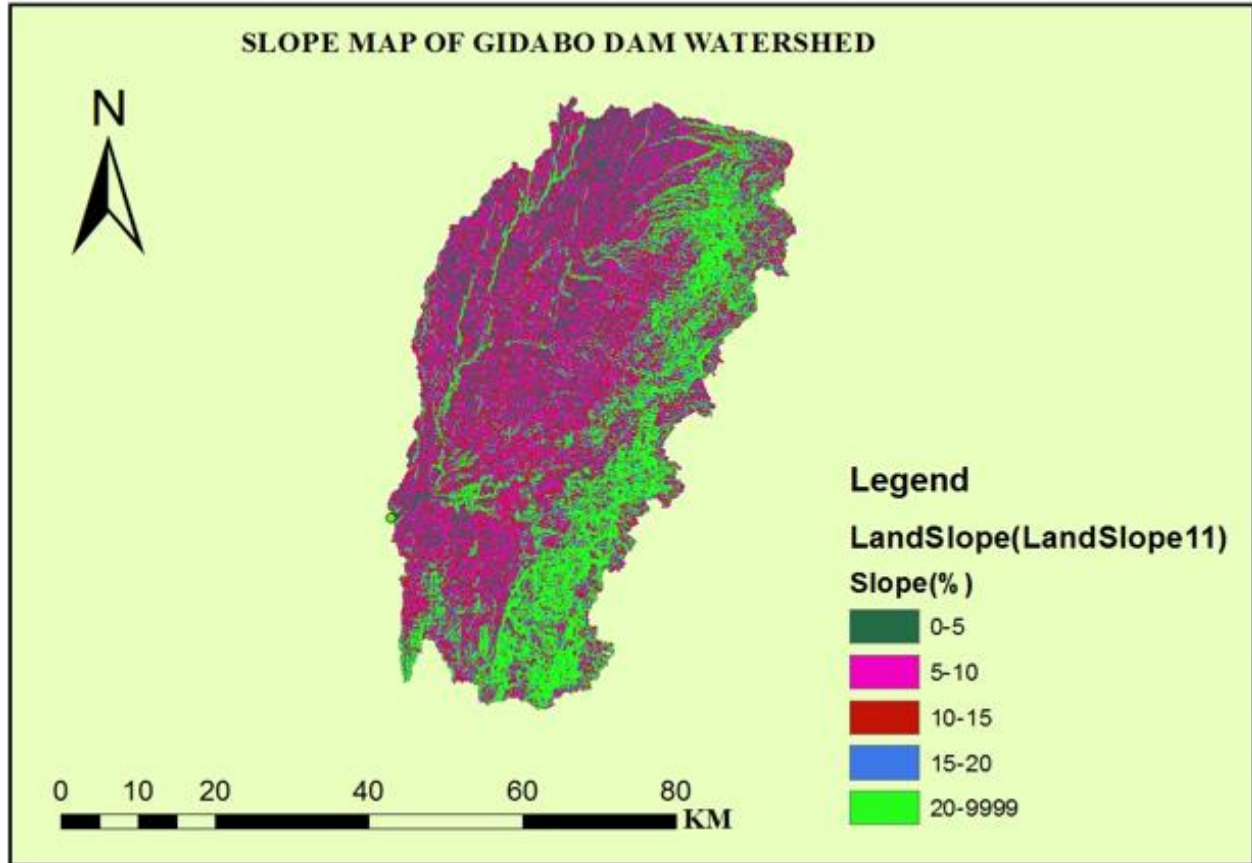


Figure 3. 6. Slope map of Gidabo watershed

3.2.2. Meteorological data

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, and relative humidity and wind speed. The weather data definition dialog is divided in five sections: weather generator data, rainfall data, temperature data, solar radiation data, wind speed data, and relative humidity data. The first one listed must be set prior to proceed with the next input data. To generate the values, SWAT includes the WXGEN weather generator model (Neitsch, et al, 2001) that generates the climatic data and fill in gaps in measured records. This weather generator was developed only for the contiguous US and cannot be use for Gidabo catchment. Therefore, the only option was to collect the weather data available for the weather stations. The data were obtained from Ethiopian National Meteorological Agency (NMA) for stations located within and around the watershed. Once collected, the daily values were rearranged,

using excel, and converted to text format. The daily values are used in the weather station into the SWAT input menu.

The meteorological stations in the watershed are first class, third class and fourth classes. The first-class gauging stations (Bilate and Dilla) contains all meteorological data i.e. precipitation, maximum and minimum temperature, relative humidity and sunshine hours. Third class stations (Hagereslam, Yergalem and Telamo Kentiso) has rainfall data and maximum and minimum temperature. The fourth-class gauging station contains the precipitation data only.in the study we select five meteorological stations which have good data quality and with fair missing data. All the meteorological stations in the study area and the other neighbor stations nearest to the study area are shown in the figure 3.7 below.

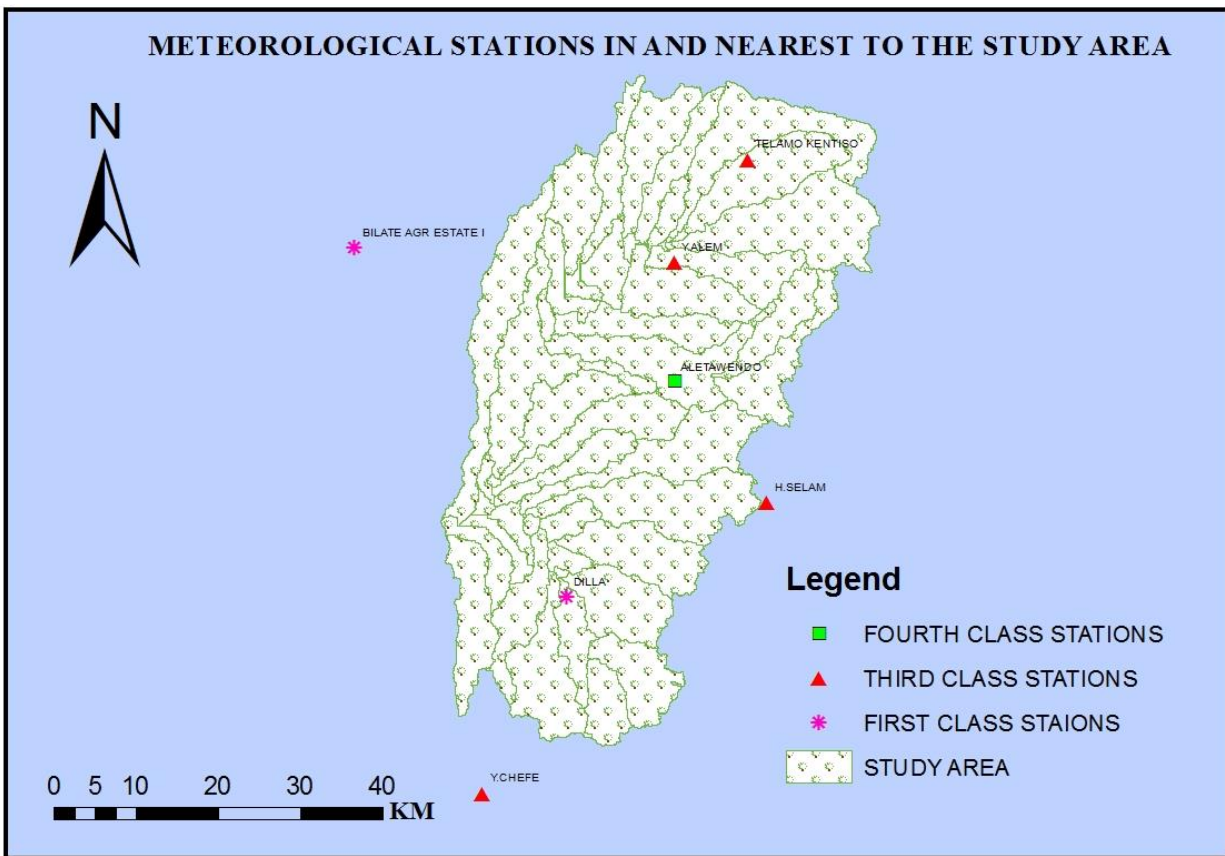


Figure 3. 7. Meteorological stations at the vicinity of Gidabo dam watershed

Table 3. 4. Meteorological station locations and length of data series.

No.	Name of station	Latitude	Longitude	Elevation(m)	Data series
1	Dilla	6.36670	38.30000	1579	1990-2017
2	Bilate	6.81667	38.08333	1361	1990-2017
3	Hagereselim	6. 6.470	38.5200	2841	1990-2017
4	Yirgalem	6.816830	38.39267	1786	1990-2017
5	Yirgachefe	6.150667	38.20200	1856	1990-2017
6	Aletawendo*	6.603889	38.41806	1947	1990-2017

*Aletawendo*__ precipitation data only.

3.2.2.1. Precipitation data

The precipitation data for both selected stations has the same duration i.e.1990-2017 with different degree of missing values. The gauging stations Dilla and Bilate has relatively small missing precipitation data values. This small missing value and equal duration of time of these two synoptic stations are important to the next arc SWAT analysis of preparing weather generator data because the weather generator stations generate missing data of other stations.

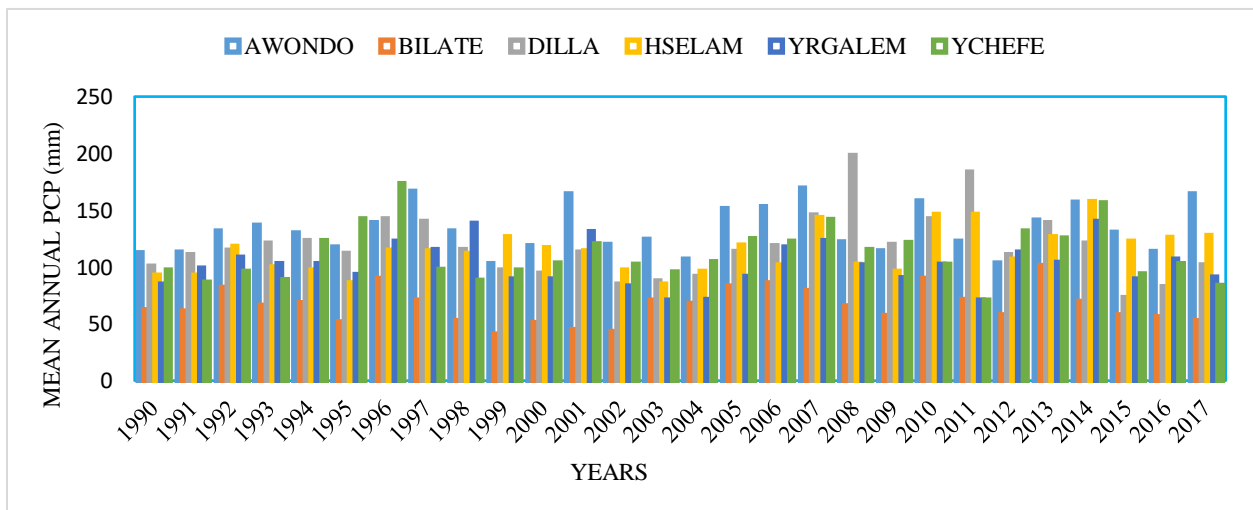


Figure 3. 8. Average Annual Precipitation of the Six Meteorological Stations (1990-2017).

Where, *Awendo --Aletawendo meteorological station (Not used for model input)

Hselam --Hagereselim Meteorological Station

Ychefe --Yrgachefe Meteorological Station

The metrological data collection covers from 1990 to 2017 years. Metrological station also referenced using latitude, longitude and elevation data. The precipitation of Gidabo catchment is characterized by a bimodal pattern maximum precipitation during April, May and October and minimum January, February and December.

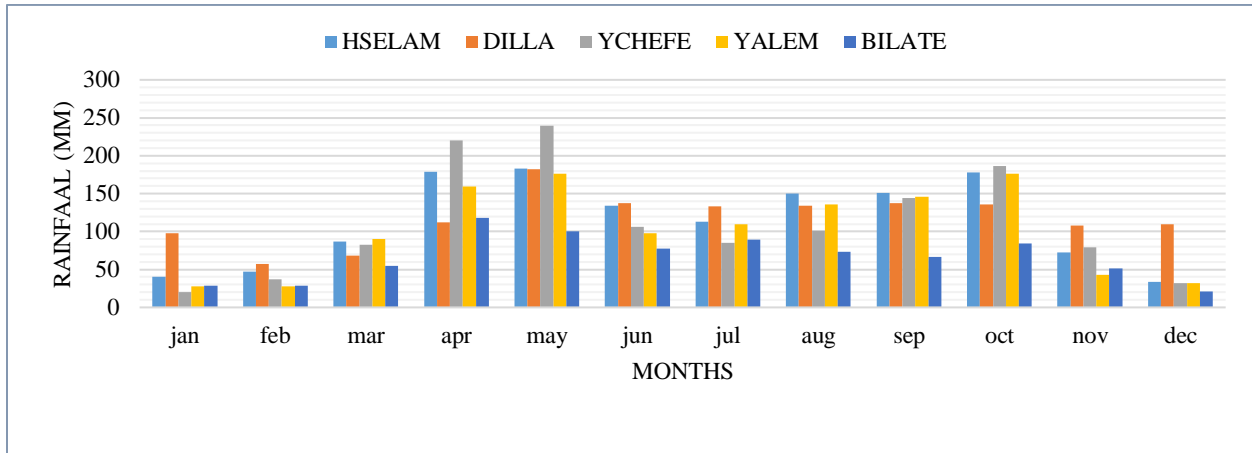


Figure 3. 9. Mean monthly rainfall graph selected meteorological stations in and around Gidabo river catchment (1990-2017)

3.2.3 Temperature

According to (Birhanu, 2009), the diurnal variation of temperature in the Gidabo River Catchment is more visible than its seasonal variation. Average monthly temperature varies from 20°C to 25°C in the rift floor as seen for Billate and 10 °C to 15°C in the high-altitude plateau of Hagere Selam (see Fig.3.10). The maximum and minimum temperature represented the basin was also collected for five stations the average monthly maximum and minimum temperature each station shown in the Figure 3.10 below.

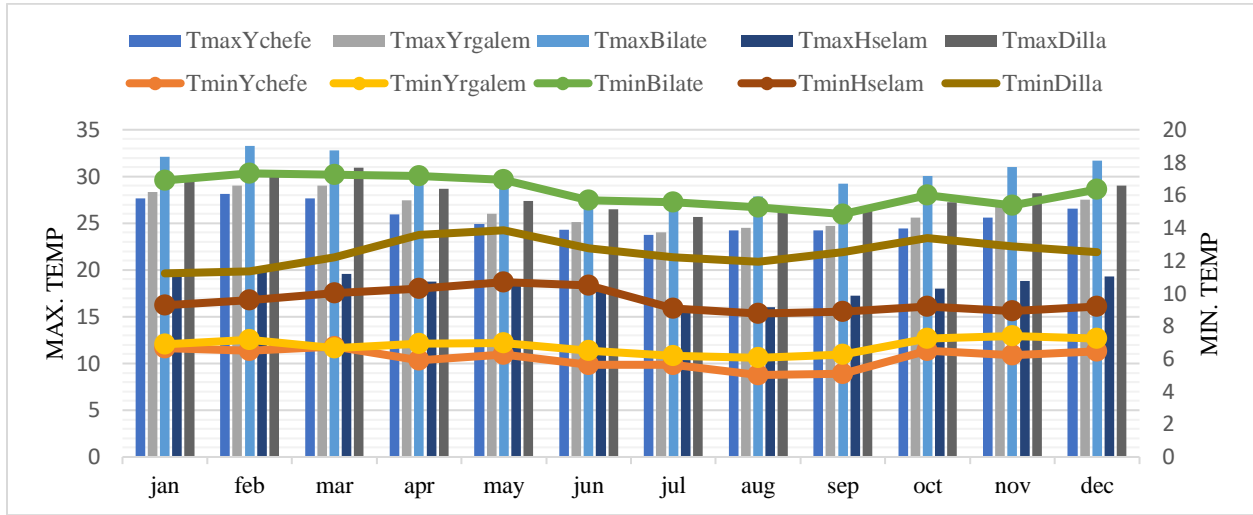


Figure 3. 10. Graph of mean monthly temperature of selected meteorological stations

3.2.4. Other climatic data

Relative humidity, solar radiation and wind speed was needed to the two weather generator stations Dilla and Bilate. Data for two Class-I stations are available in the catchment. The mean annual relative humidity, wind speed and solar radiation of Dilla and Bilate stations were estimated about 69.8%, 1.464 m/s and 22.8 MJ m⁻²day⁻¹ and 62.8%, 0.79 m/s and 21.34 MJ m⁻²day⁻¹, respectively from collected records.

3.2.2.1. Data Quality analysis

The precipitation data was checked for inconsistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any, accumulated plot and double mass curve. This will help to identify if there are any gaps or unphysical peaks in data series and correct them before the data is used as input to the model. Otherwise, using the incorrect data as input to the model will give incorrect output from the model. The series data Stream flow of Gidabo catchment were checked the unrealistic data record or the outlier. An outlier is an observation that appears to deviate markedly from other observations in the sample. The monthly flow data of the Gidabo River was checked by through the steps calculating the quartiles, calculating the upper and lower boundaries and evaluating the results in excel spread sheet and there was no outlier identified.

3.2.2.2. Visual inspection

The first Step in data quality control is by visual inspection. This can be done by checking if date and time record is complete, unphysical values (spikes and negatives), flat regions (sensor or transfer system fall out) and unphysical variation patterns (sensor malfunctioning). The visual inspection was done by plotting the time series data against time. The percentage of missing data points for five precipitation stations from 1990 to 2017 is shown in Table 3.5 below. From the table, Yergachefe station has 1238 missing data, which accounts about 12% of the total data available. The next station, which has higher missing data compared to the other stations, is Hagereselam with 1053 missing data points, about 10.38% of the total data points.

Table 3. 5. Percent of missing data points for all PCP stations.

Stations	Data points	Missing pt. Data	Data without missing	% of missing
Hagereselam	10227	1053	9174	10.38
Dilla	10227	998	9229	9.76
Bilate	10227	961	9266	9.40
Yrgalem	10227	1222	9005	11.95
Yrgachefe	10227	1238	8989	12.00

3.2.2.3. Filling of missing data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. Here, the station whose data was missing is called interpolation station and gauging stations whose data are used to calculate the missing station data are called index stations.

There are methods to fill in missing data. These are arithmetic mean method, normal ratio method and inverse distance weighing method. Arithmetic mean method can be used to fill in missing data when normal annual precipitation is within 10% of the gauge/station for which data are being reconstructed. The normal ratio method is used when the normal annual precipitation at any of the index station differs from that of the precipitation station by more than 10%. In the absence of Normal annual rainfall for the stations inverse distance weighing method can be used to fill the

missing data. For this study, arithmetic mean and normal ratio method were used. According to Richard H. (1998), the two formulas are described below.

Arithmetic mean method

$$P_x = \frac{1}{n} \sum_{i=1}^{i=n} P_i \dots\dots\dots [3.1]$$

Where, n is the number of nearby stations, Pi is precipitation at *ith* station and Px is the missing precipitation.

Normal ratio method

$$P_x = \frac{1}{N} \sum_{i=1}^{i=n} \frac{N_x}{N_i} P_i \dots\dots\dots [3.2]$$

Where

P_x = the missing precipitation for any storm at the interpolation station *x*,

P_i = the precipitation for the same period for the same storm at the *ith* station of a group of index stations,

N_x = the normal annual precipitation for station *x*,

N_i = the normal annual precipitation value for the *ith* station.

3.2.2.4. Checking consistency of gauging stations

3.2.2.4.1. Double mass curve

Sometimes a significant change may occur in and around a particular rain gauge station. Such a change occurring in particular year will start affecting the rain gauge data, being protected from that particular station. After a number of years, it may be felt that, the data of that station is not giving a consistent rainfall value. In order to detect such inconsistency, to correct and adjust the reported rainfall values a technique called Double Mass Curve method was adopted. In this method, groups of neighboring stations were chosen nearby the doubtful station. The yearly rainfall values reported from this group of stations was taken, and their mean yearly values are worked out for each consecutive year’s available records. The mean yearly rainfall values of the selected stations are arranged in a revers chronological order (i.e. the latest year getting the first entry). To check for inconsistency of the recorded precipitation data, the cumulative of Dilla,

Bilate, Hagereselam, Yirgalem and Yrgachefe was plotted against the average cumulative of the base stations. Dilla and Bilate were selected as base stations because these two stations with full of all meteorological data with small missing data points. The accumulated plots have almost the same gradient for all the stations, which shows no significant error exists.

Double mass curve is based on the principle that when each recorded data comes from the same parent population they are consistent (Subramanya, 2008). If the cumulative plot of DMC shows different, gradient it should be corrected as:

$$P_{CX} = P_X \left(\frac{M_C}{M_a} \right) \dots \dots \dots [3.3]$$

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

M_C = correct slope of the double mass curve

M_a = original slope of double mass curve

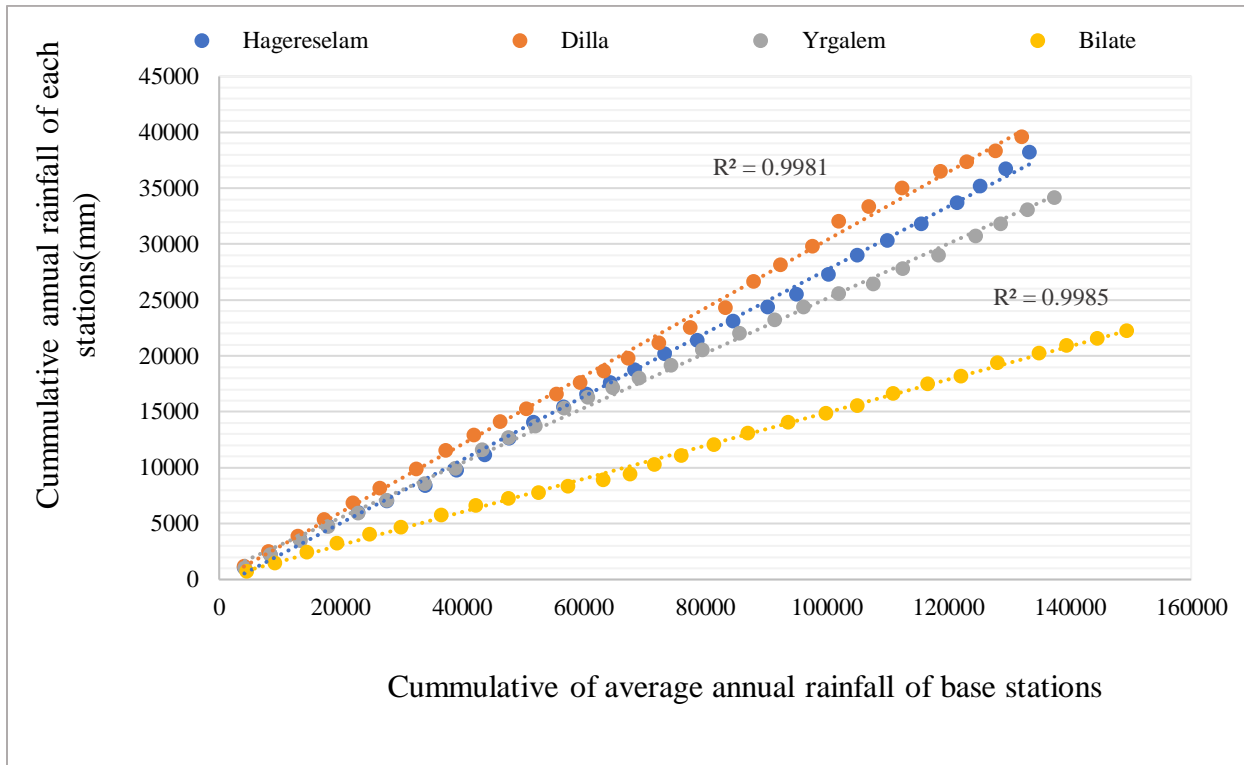


Figure 3. 11. Double mass curve of meteorological station.

3.2.2.5. Checking homogeneity of selected stations 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.

$$P_i = \frac{\bar{P}_i}{\bar{P}} * 100 \dots\dots\dots [3.4]$$

Where:

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

\bar{P}_i - is over year's average monthly precipitation for the station i

\bar{P} -is over year average yearly precipitation for station i

The selected stations was plotted for comparison and the stations have the same trend of the hence the group of station selected are homogeneous.

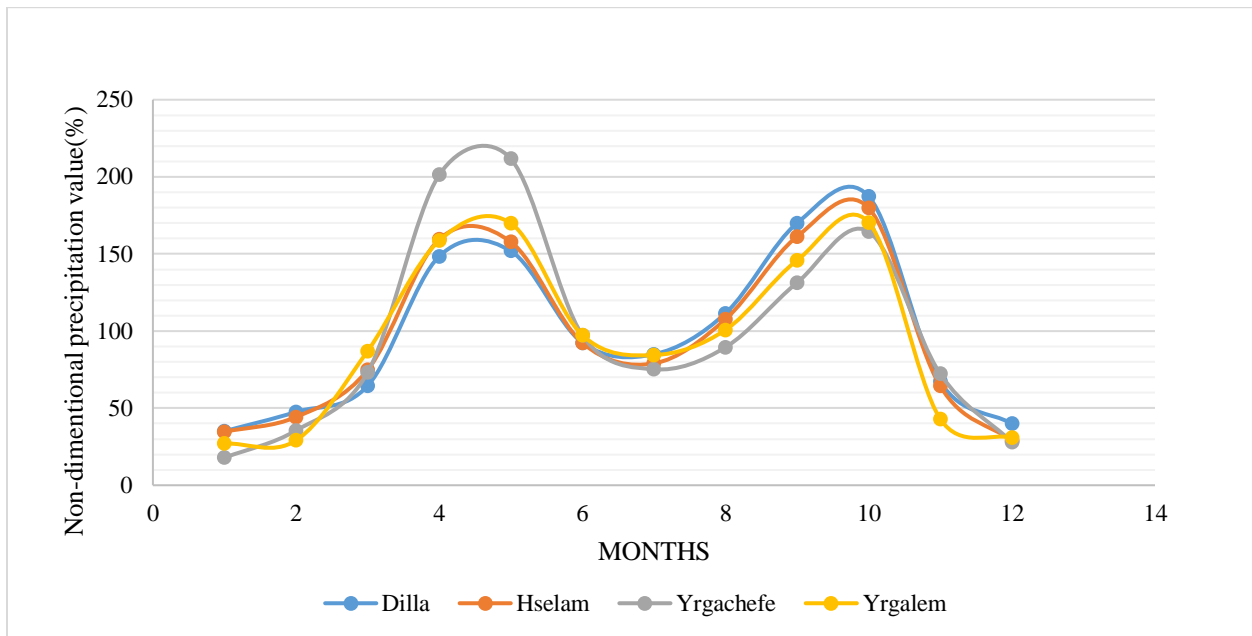


Figure 3. 12. Homogeneity tests for selected weather station at Gidabo catchment

3.2.3. Temperature data

The temperature data record was available from five weather stations: Dilla, Yirgalem, Hagereselam, Yirgachefe, and Bilate. The five-gauge stations have a temperature record from 1990 to 2017 the same length of years as the precipitation data recorded at all stations. This is very important to use as input to the SWAT model as it requires the same length of year for both precipitation and temperature data. The daily maximum and minimum air temperature were available with some missing data. When this data is used as input to the SWAT model, the filling of the missing data was performed.

Figure 3.8 shows the daily maximum, minimum and mean temperature values of Dilla station.

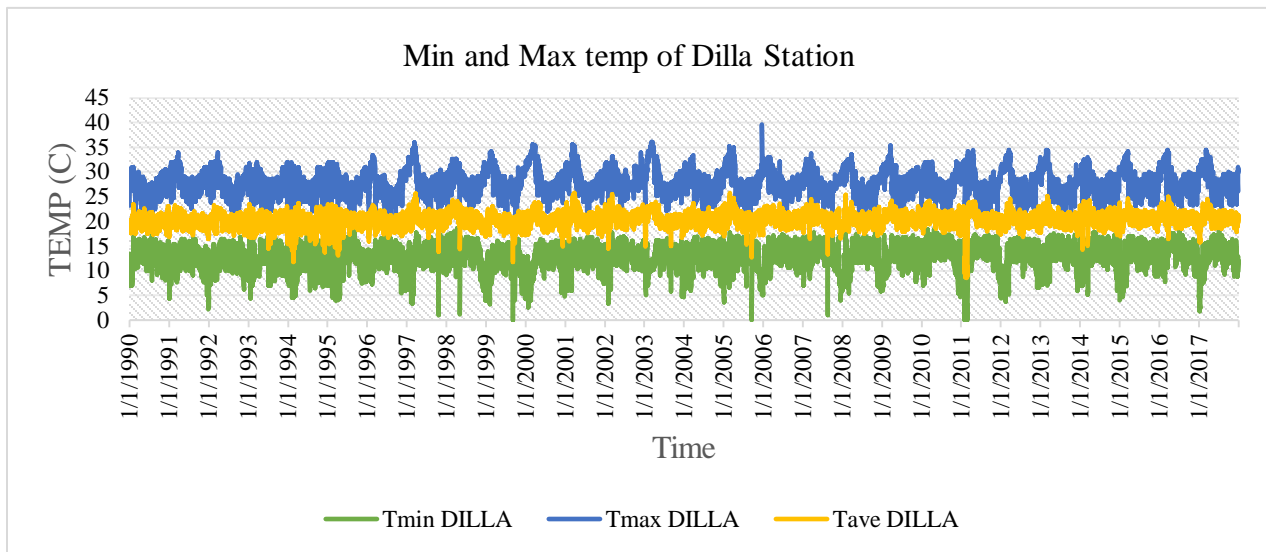


Figure 3. 13. Daily max and min air temperature at Dilla meteorological stations

3.2.4. Weather generator data preparation

If there are no daily values for weather, SWAT generates from average monthly values. The model generates a set of weather data for each sub basin. SWAT requires daily precipitation (mm), maximum/minimum air temperature ($^{\circ}\text{C}$), solar radiation ($\text{MJ}/\text{m}^2/\text{day}$), wind speed (m/s) and relative humidity (percentage).

In order to generate data, weather parameters were developed by using the weather parameter calculators pcpSTAT.exe And DEW02, which were downloaded from the SWAT website (http://www.brc.tamus.edu/swat/soft_links.html). The statistical parameters for precipitation were calculated using the programme pcpSTAT.exe. This programme calculates the statistical

parameters of daily precipitation data used by the weather generator of the SWAT model (Liersch, 2003). The result is shown in Table 3.6. On the other hand, the statistical calculator Dew02 software calculated statistical parameters calculation for temperature data. This software calculates the temperature data to use in weather generator by taking the average of daily maximum and minimum temperature. In addition, the results of the Dew02 calculator for the weather generator station Dilla are shown in the table 3.7 below. In this study weather, generator parameters were calculated for Dilla and Bilate observation stations. The reason they are selected as weather generator stations were because they are first class meteorological stations i.e. Full off all the meteorological data (precipitation data, maximum and minimum temperature, relative humidity, wind speed and sunshine hours) with different degree of missing data.

Statistical Analysis of Daily Precipitation Data (1990 - 2017)

Input Filename = Rdilla.txt

Number of Years = 28

Number of Records = 10227

Number of Leap Years = 7

Number of No Data values =2

Table 3. 6. PcpSTAT output of weather generator station (Dilla gauging station)

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	97.91	6.8717	3.1562	0.1939	0.6715	12.39
Feb.	57.68	5.858	4.4298	0.1685	0.5878	8.75
Mar.	68.66	5.3393	3.7057	0.2379	0.5372	11.04
Apr.	112.47	7.3706	2.8634	0.2706	0.6481	13.5
May.	182.28	10.0332	2.1095	0.2998	0.7028	16.46
Jun.	137.34	8.5879	2.7261	0.3447	0.6381	15.39
Jul.	132.99	8.1676	3.1361	0.4066	0.6186	16.86
Aug.	133.89	7.7061	2.7605	0.4474	0.623	17.43
Sep.	137.28	8.0642	3.1086	0.4663	0.6693	18.36
Oct.	135.73	6.9939	2.6195	0.4711	0.6865	19.25
Nov.	105.63	6.7697	2.8492	0.3104	0.6555	14.93
Dec.	107.53	7.1284	3.0512	0.2554	0.6823	14.5

Where:-

- PCP_MM = Average monthly precipitation[mm]
- PCPSTD = standard deviation.
- PCPSKW = skew coefficient.
- PR_W1 = Probability of wet day following a dry day.
- PR_W2 = Probability of wet day following a wet day.
- PCPD = average number of precipitation days in a month.

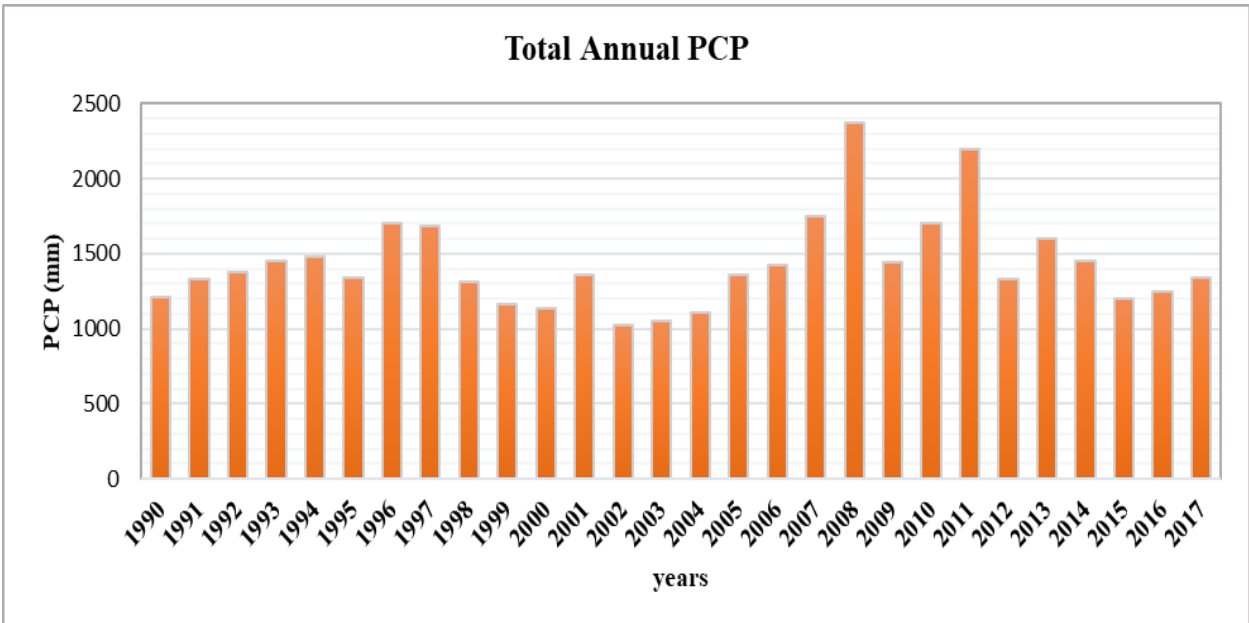


Figure 3. 14. Total Annual Precipitation at Dilla Station (1990-2017)

From figure 3.14 above the years 2008 and 2011 are the wettest years and the years 2002,2003, 2004, are the driest years in the period from 1990-2017.this diagram is constructed from the pcp STAT software result of the synoptic station of Dilla.

The Dilla and Bilate stations have a temperature records from 1990 to 2017, which is the same length of years as their precipitation data recorded. This is very important to use as input to the SWAT model as it requires the same length of year for both precipitation and temperature data.

Table-3.7. Dew 02 output weather generator station (Dilla gauging station)

This file has been generated by the program 'dew02.exe'

Input Filename = dewdilla.txt

Number of Years = 28

Number of Records = 10227

Number of No Data Values:

Tmp _ max = 16

Tmp _ min = 6

Hmd = 21

Table 3. 7. Average daily dew point temperature for period (1990 - 2017)

Month	tmp_max	tmp_min	hmd	dewpt
Jan	30.28	10.22	66.97	16.35
Feb	30.36	10.17	66.15	16.2
Mar	31.57	12.5	66.69	17.74
Apr	28.94	13.99	67.8	16.65
May	27.5	14.01	67.03	15.51
Jun	26.56	13.85	67.3	14.93
Jul	25.81	14.43	67.7	14.77
Aug	26.49	14.05	68.05	15.14
Sep	26.68	13.65	68.15	15.16
Oct	27.31	13.61	68.11	15.55
Nov	28.1	12.18	68.29	15.69
Dec	28.9	10.54	67.57	15.67

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]

dewpt = average daily dew point temperature in month [°C]

3.2.4. Solar Radiation

Once water is introduced to the system as precipitation, the available energy solar radiation exerts a major control on the movement of water in the land phase of the hydrologic cycle. Arc SWAT takes the daily solar radiation but the data acquired from the National Meteorological Agency (NMA) is sunshine hour, hence a conversion of variable were made using (Angstrom, 1994) empirical equation.

$$R_s = (a_s + b_s \frac{n}{N})R_a \dots \dots \dots [3.5]$$

Where R_s is solar or shortwave radiation [$\text{MJm}^{-2}\text{day}^{-1}$]

n - Actual duration of sunshine [hour]

N - Maximum possible duration of sunshine or daylight hour [hour]

R_s - Extraterrestrial radiation [$\text{MJm}^{-2}\text{day}^{-1}$]

a_s - Regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days ($n=0$)

$a_s + b_s$ - Fraction of extraterrestrial radiation reaching the earth on clear days ($n=N$).

3.2.3. Hydrological data

3.2.3.1. Flow data

Observed flow data was required for the Soil and Water Assessment Tool (Arc SWAT) calibration and Validation. The observed stream flow data 1997-2006, for Aposto and Bedassa and Maesso (the outlet of the watershed) is taken from Ministry of water resources, Irrigation and energy, Hydrology department. This flow data was formatted as to the requirement of the Arc SWAT model and used for model calibration and validation. The stream flow data from 1997 to 2006 was available for model calibration and validation at the outlet of Gidabo dam (Maesso gauge station). From 1997 to 2002, flow data was used for model calibration and 2003-2006. Here, it should be noted that the efficiency of the model during calibration and validation depends on the accuracy of the calculation. Any error during calculation may cause significant problem in model calibration and validation.

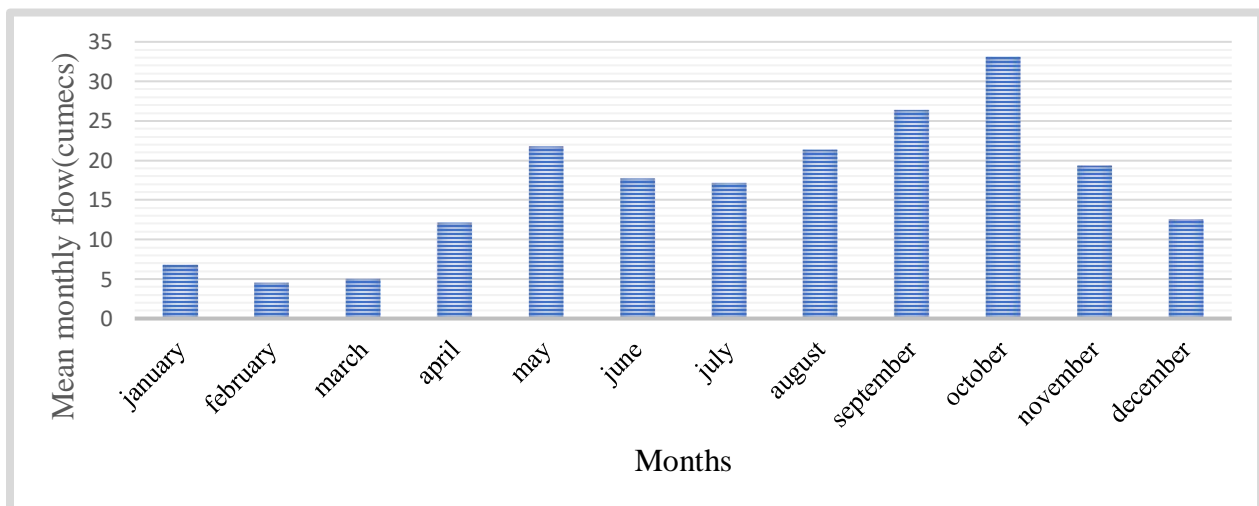


Figure 3. 15. Mean monthly flow at the outlet of Gidabo dam watershed (Maesso gauge station).

3.2.3.2. Sediment data

The sediment gauging stations were established at different stations within the watershed. The two major Gauging stations for which flow measurement and sediment sampling was made at Gidabo near Aposto and Bedassa near Dilla. And these sub-watershed covers 585 km² and 152KM² respectively. The sediment data for the dam outlet was estimated using area ratio method because the study area has similar catchment characteristics. The sediment data collected from Ministry of water, Irrigation and Energy (MoWIE) is not data of all monthly days rather it is sample taken in different seasons within different years. Therefore, it was important to develop relationship between river discharge and sediment concentration for the existing data to get the daily sediment loads (sediment rating curve). Suspended sediment flux estimation was calculated using a relation of discharge to suspended sediment discharge known as a sediment-rating curve (SRC) (Khassaf and Hassan, 2014).

$$Q_s = aQ^b \dots\dots\dots [3.6]$$

Where *a* and *b* are coefficient usually obtained by regression analysis. To work on the above formula, the first task was conversion of the measured suspended sediment concentration (mg/l unit) to sediment load (ton/day unit) by using the conversion formula of the second chapter of this paper equation 2.1. (In the review part) and also the graph shows degree of quality of sediment data.

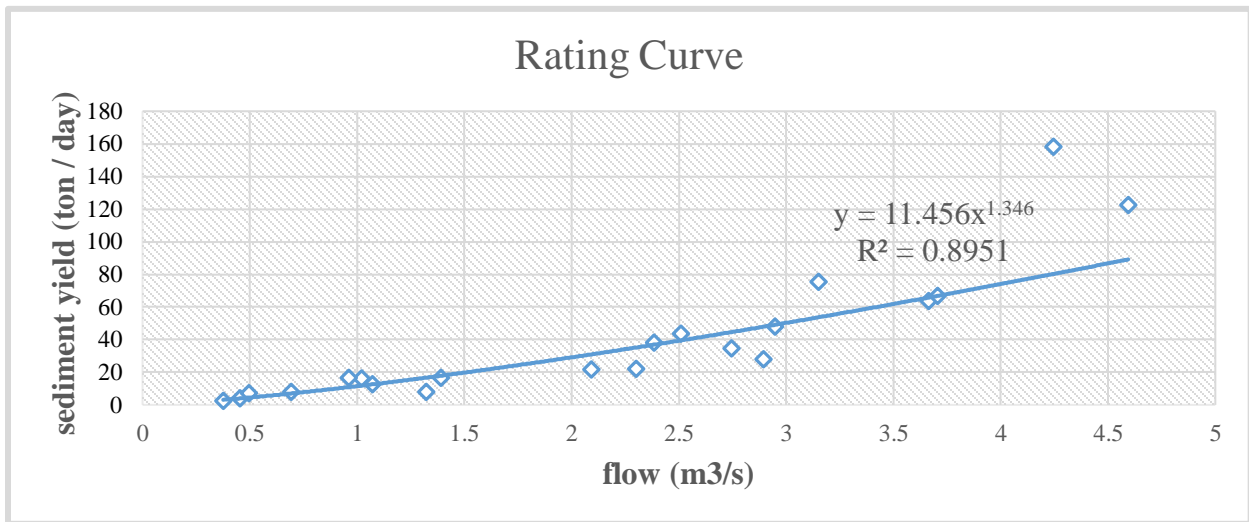


Figure 3. 16. Sediment rating curve at Gidabo watershed gauging station (Bedassa Nr. Dilla)

The relation of sediment load and discharge at the gauging station with R^2 value of 0.8951 was derived as: -

$$Q_S = 11.456 * Q^{1.346} \dots\dots\dots [3.7]$$

Where Q_S is suspended sediment load (ton/day) and Q is stream flow (m³/s).

3.4. Methodology

3.4.1. General

The general methodology of this study is depending on the data, which are collected from different organization. In this methodology, the first part is the prediction of sediment yield in the watershed by using SWAT model for determination of sediment yield at the Reservoir site and to characterize the sub basins in terms of sediment yield. The conceptual framework followed to accomplish this work can be described as follows. This is the driving force and the target to be accomplished during the course of the project work. For this specific project, the SWAT (Soil and Water Assessment) model was selected. The reason for the selection of the SWAT model was that SWAT model is physically semi distributed and continuous time developed to predict the impact of land management practices on water, sediment and agricultural chemical yields from a watershed. After the objective is set and the suitable model is selected, the necessary data required to run the model was collected and prepared as to the requirement of the SWAT model format. The geospatial data including the digital elevation map, land use/land cover map, soil map and the hydro-meteorological data including the daily stream flow data (1997-2017), daily rainfall data (1990-2017), maximum and minimum daily air temperature data and sediment load/concentration data are all collected and processed as per the input requirement format of the model. The conceptual framework of the steps followed during the course of this study is shown below.

❖ Set objective

- Clearly specify the aim of the research
- List all tasks to be done to reach the aim of the research

❖ Data collection and preparation

- Collect all necessary data required for the model to run.
- Prepare the collected data as per the requirement of the model (model input)

❖ Import prepared data in to the model

❖ **Model set up and run**

- Delineate the watershed
- Create HRUs
- Model Setup
- Run the Model

❖ **Sensitivity analysis**

- Identify Sensitive parameters prior to calibration to save time during calibration

❖ **Calibration and validation**

- Calibrate the model for better prediction of the observed value
- Validate the model outside the calibration period to see if the model is applicable

❖ Model output interpretation and development of scenarios. Diagrammatically the methodology is shown in the figure-3.17 below.

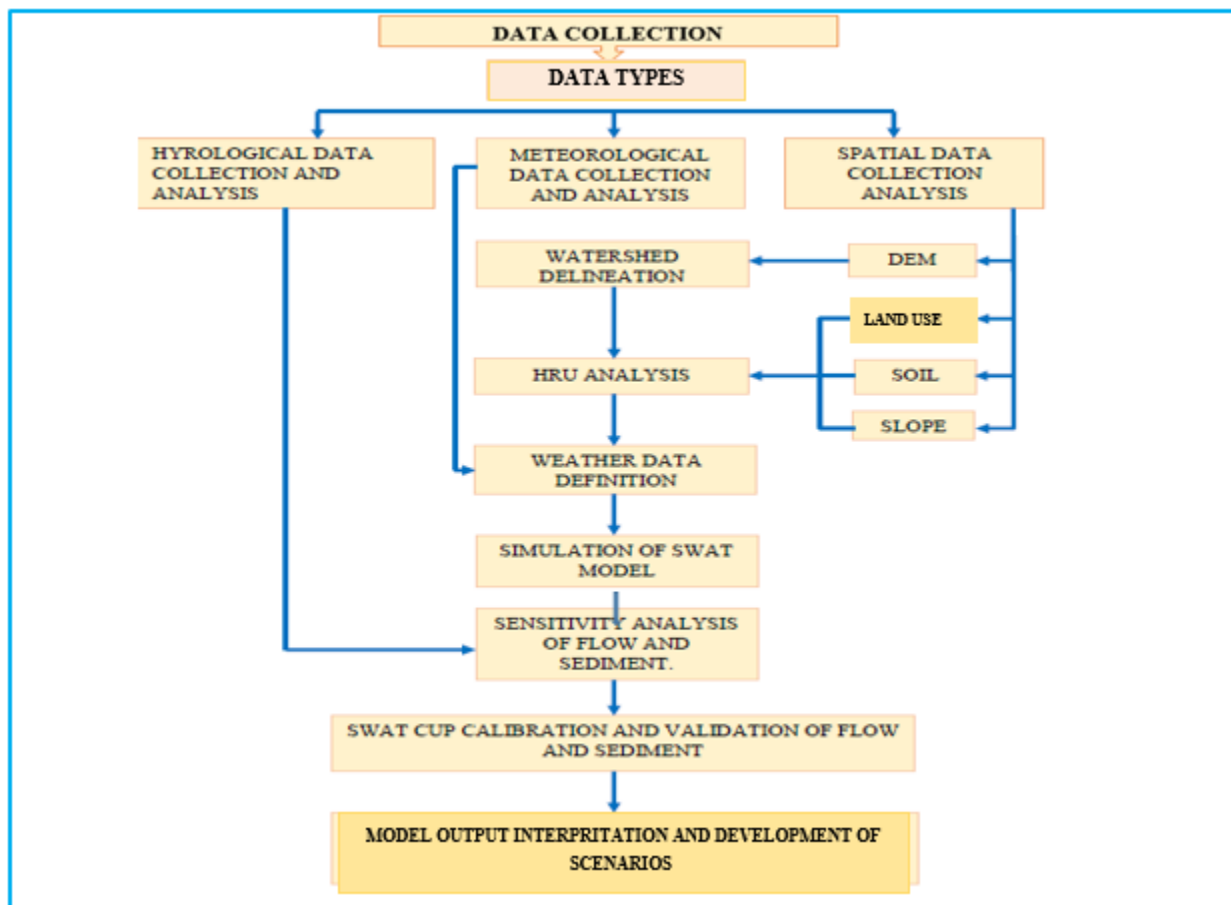


Figure 3. 17. Conceptual frame work of Methodology

3.4.2. Sediment modeling

It is important to identify the source of erosion and what causes it for a watershed in which erosion and sedimentation process is significant. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied. Degree of erosion in a given area ranges from low to severe, but if an erosion type which includes land sliding is dominant in a given area SWAT model is not applicable. Gidabo watershed has no dominant land sliding so, semi-distributed, physical based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study.

SWAT uses a Modified Universal Soil Loss Equation (MUSLE) developed by (Williams, 1975) to simulate sediment yield from the upland watersheds. MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and (Smith, 1978) (Neitsch et al., 2011).

$$S_{ed} = 1.292EI_{USLE}K_{USLE}C_{USLE}P_{USLE}LS_{USLE}CFRG..... [3.8]$$

Where, S_{ed} is the sediment yield on a given day (metric tons/ha), EI_{USLE} is the rainfall erosion index (0.017 m-metric ton cm/ (m²hr)), K_{USLE} is the $USLE$ soil erodibility factor (0.013 metric ton m² hr/ (m³-metric ton cm)), C_{USLE} is the $USLE$ cover and management factor, P_{USLE} is the $USLE$ support practice factor, LS_{USLE} is the $USLE$ topographic factor and $CFRG$ is the coarse fragment factor. The value of EI_{USLE} for a given rainstorm is the product, total storm energy (storm E) times the maximum 30 minutes intensity (30 I). The storm energy indicates the volume of rainfall and runoff, while the 30 minutes' intensity indicates the prolonged peak rates of detachment and runoff (Neitsch et al., 2011).

$$S_{ed} = 11.8(Q_{surf}q_{peak}Area_{hru})^{0.56}K_{USLE}C_{USLE}P_{USLE}LS_{USLE}CFRG..... [3.9]$$

Where, Q_{surf} is the surface runoff volume (mm), q_{peak} is the peak runoff rate m³/s, $Area_{hru}$ is the area of the HRU (ha), and the other variables in the equation carries the same meaning as described in USLE equation.

USLE predicts the average annual gross erosion as a function of rainfall energy. Whereas in MUSLE the rainfall energy is replaced with a runoff factor, which improves the sediment yield

prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events (Neitsch et al., 2011). Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy (Neitsch et al., 2011). Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor used by USLE represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment (Neitsch et al., 2011).

3.4.3. Arc SWAT model description

3.4.3.1. Overview of SWAT model

The Soil and Water Assessment Tool (SWAT) model is developed by the USDA Agricultural Research Service, which simulates the land phase of the hydrologic cycle in daily basis. SWAT predicts surface runoff using the Soil Conservation Service (SCS) curve number (CN) method and it used daily rainfall data as an input. The modified universal soil-loss equation is used to predict the sediment loss. The SWAT model is designed to route water and sediments from individual watersheds through the river systems. It can incorporate the tanks and the reservoirs/check dam off-stream as well as on-stream. The agricultural areas can also be integrated with respect to its management practices.

The Arc SWAT, ArcGIS extension evolved from AVSWAT2000 an ArcView extension developed for an earlier version of SWAT. The interface requires the designation of land use, soil, weather, groundwater, water use, management, soil chemistry, pond, and stream water quality data, as well as the simulation period, in order to ensure a successful simulation.

3.4.3.2. Hydrological component of SWAT model

The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snowmelt, transmission losses and ponds. The percolation and return flow or base flow considered in SWAT for hydrological modelling is only the percolation to shallow aquifer from vadose zone and base flow to the channel from the shallow aquifer. The groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream

flow somewhere outside the watershed. According to (Arnold, 1993), the water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer. The water percolated to the deep aquifer is assumed lost from the watershed system and is not included in the water balance (Neitsch et al., 2011). Equation 3.10 is used to determine the soil water content of the watershed.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \dots \dots \dots [3.10]$$

Where SW_t is the final soil water content (mm), SW_0 is the initial soil water content (mm), t is time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff 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 level zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

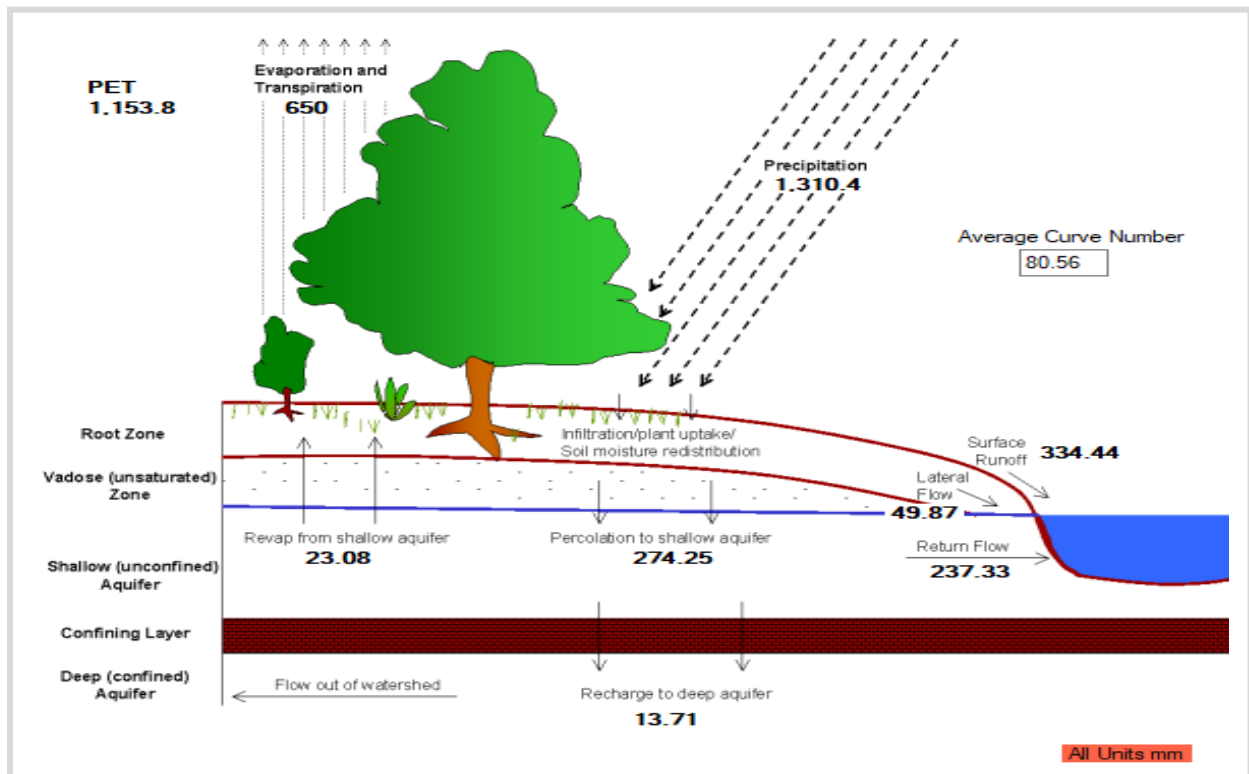


Figure 3. 18. Hydrological cycle of Swat Model from swat check.

3.4.3.2.1. Surface runoff

Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. SWAT provides two methods for estimating surface runoff volume the SCS

curve number method and Green & Ampt infiltration method. The later method is better in estimating runoff volume precisely; its sub daily time step data requirement makes it difficult to be used for the case of our country. Therefore, the SCS curve number method was adopted. The general equation for the SCS curve number method is expressed by equation 3.11.

$$Q_{surf} = \frac{(R_{day}-I_a)^2}{(R_{day}-I_a+S)} \dots\dots\dots [3.11]$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm water), I_a is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water), and S is retention parameter (mm water). The retention parameter S can be calculated by using equation 3.12.

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \dots\dots\dots [3.12]$$

Where, CN is the curve number for the day and its value is the function of land use practice, soil permeability and soil hydrologic group. The initial abstraction, I_a , is commonly approximated as $0.2S$ and equation 3.11 becomes: -

$$Q_{surf} = \frac{(R_{day}-0.2s)^2}{(R_{day}+0.8s)} \dots\dots\dots [3.13]$$

3.4.3.2.2. Peak discharge

The peak discharge or the peak surface runoff rate is the maximum volume flow rate passing a particular location during a storm event. The peak run off rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method see equation 3.14 (Neitsch *et al.* 2011).

$$Q_{peak} = \frac{c*i*Area}{3.6} \dots\dots\dots [3.14]$$

Where: Q_{peak} is peak runoff rate (m³/s), C is the runoff coefficient, i is the rainfall intensity (mm/hr.), sub-basin area (km²) and 3.6 is conversion factor.

3.4.3.2.3. Sediment component of SWAT model

Erosion and sediment yield in SWAT are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE). It uses the amount of runoff to simulate erosion and sediment yield.

The hydrology module/component supplies estimate of runoff volume and peak runoff rate, which, with the sub basin area, are used to calculate the runoff erosive energy variable. The crop management factor is recalculated every day that runoff occurs.

3.4.3.2.4. Routing phase of the hydrologic model

The studies by (Setegn et.al, 2008) show that sediment transport in the channel network consists of two components operating simultaneously, which are deposition and degradation. To determine the deposition and degradation process the maximum concentration of sediment is calculated using Equation 3.15 below.

$$conc_{sed,ch,mx} = C_{sp} * V_{ch,pk}^{spexp} \dots\dots\dots [3.15]$$

Where $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (ton/m³ or kg/L), C_{sp} is the coefficient defined by the user, $V_{ch,pk}$ is the peak channel velocity (m/s), and $spexp$ is an exponent parameter for calculating sediment re-entrained in channel sediment routing that is defined by the user and set at 1.5 for this particular study. It normally varies between 1 and 2. The peak channel velocity, $V_{ch,pk}$ is calculated by using equation 3.16.

$$V_{ch,pk} = \frac{prf * q_{ch}}{A_{ch}} \dots\dots\dots [3.16]$$

Where prf , is the peak rate adjustment factor (a user specified parameter), q_{ch} is the average rate of flow (m³/ s), and A_{ch} , is the cross-sectional area of flow (m²).

The maximum concentration of sediment ($Conc_{sed, ch, mx}$) that is calculated from the previous equation is compared to the concentration of sediment in the reach at the beginning of the time step $Conc_{sed, ch, i}$. If $Conc_{sed, ch, i} > Conc_{sed, ch, mx}$, deposition is the dominant process in the reach segment, Equation 3.17 below is used to calculate the net amount of sediment deposited in the reach.

$$Sed_{dep} = (Conc_{sed,ch,i} - Conc_{sed,ch,mx}) * V_{ch} \dots\dots\dots [3.17]$$

Where Sed_{dep} is the amount of sediment deposited in the reach segment (metric tons) and V_{ch} is the volume of water in the reach segment (m³). If $Conc_{sed, ch, i} < Conc_{sed, ch, mx}$ degradation is

the dominant process in the reach segment and the net amount of sediment re-entrained is calculated by Equation 3.18 below.

$$Sed_{deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \dots \dots \dots [3.18]$$

In which, Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), K_{ch} is the channel erodibility factor (cm/hr/pa), and C_{ch} is the channel cover factor.

The channel erodibility factor (K_{ch}) is conceptually similar to the soil erodibility factor in the Universal Soil Loss Equation. Channel erodibility is a function of properties of the bed or bank materials. In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility. The channel cover can be defined as a ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface.

After the amount of deposition and degradation is calculated, equation 3.19 is used to determine the final amount of sediment in a reach.

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \dots \dots \dots [3.19]$$

where, Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons), Sed_{dep} is the amount of sediment deposited in the reach segment (metric tons), and Sed_{deg} is the amount of Sediment re-entrained in the reach segment (metric tons).

Finally, Equation 3.20. Below is used to calculate the amount of sediment transported out of the reach.

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V_{ch}} \dots \dots \dots [3.20]$$

where, Sed_{out} is the amount of sediment transported out of the reach (t), Sed_{ch} is the amount of suspended sediment in the reach (t), V_{out} is the volume of out flow during the time step (m³), and V_{ch} is the volume of water in the reach segment (m³).

3.5. Arc SWAT Model Setup

3.5.1. Watershed delineation

The concept of a watershed is basic to all hydrologic designs. Since large watersheds are made up of many smaller watersheds, it is necessary to define the watershed in terms of a point; this point is usually the location at which the design is being made and is referred to as the watershed "outlet." With respect to the outlet, the watershed consists of all land area that sheds water to the outlet during a rainstorm. Using the concept that "water runs downhill," a watershed is defined by all points enclosed within an area from which rain falling at these points will contribute water to the outlet.

The first step in creating Arc SWAT model input is delineation of the watershed from a DEM. Inputs entered into the Arc SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, Land use / land cover map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameter for Ethiopia. A watershed was divided into a number of sub-basins, for modeling purposes. The Watershed delineation process includes five major steps, DEM setup, stream definition, outlet and definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition, the threshold-based stream definition option was used to define the minimum size of the sub-basins.

3.5.2. Hydrological response units (HRUs)

Before executing SWAT, the distribution of hydrologic response units (HRUs) within the watershed must be determined based on the land use, soil and slope layers specified in the previous step. The interface allows specifying criteria to be used in determining the HRU distribution. One or more unique land use/soil/slope combination(s) (hydrologic response units (HRUs) can be created for each sub basin.

Subdividing the watershed into areas having unique land use, soil and slope combinations enables the model to reflect differences in sediment yield and other hydrologic conditions for different land covers and soils. Hydrologic response units (HRUs) are lumped land areas within the sub-basin that are comprised of unique land cover, soil and management combinations. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. The land area in a sub-basin was divided into HRUs. The HRU analysis tool in Arc SWAT helped 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 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option that considers different slope classes for HRU definition) was selected. The LULC, soil and slope map were 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 were made to be overlaid for HRU definition. For this specific study a 5% threshold value for land use, 10% for soil and 10% for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub basin. 49-sub basin and 379 HRUs were created by integrating land use, soil and slope maps. The full hydraulic response unit of Gidabo Dam watershed is shown in the figure 3.19 below.

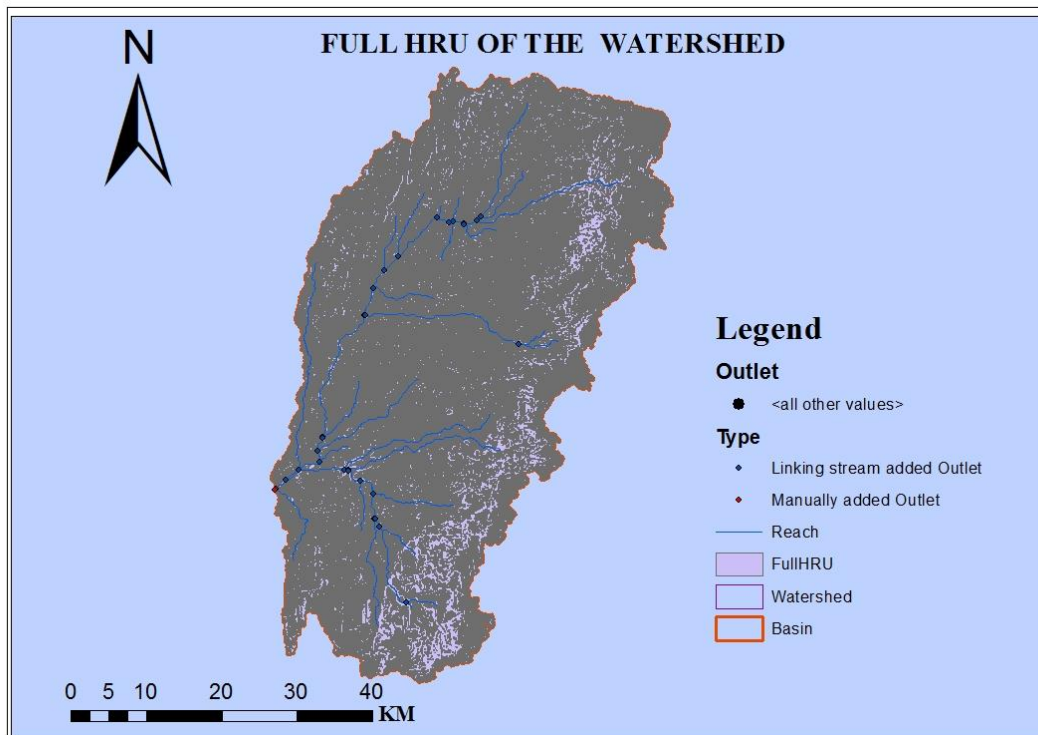


Figure 3. 19. Hydraulic response unit of Gidabo watershed

3.5.3. Importing climate data

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle. The climatic

variables required by SWAT consist of daily precipitation, maximum/minimum temperature, solar radiation, wind speed and relative humidity. These climate data were loaded on the Arc SWAT model at the stage of write input table after HRU analysis is completed.

3.5.4. Sensitivity analysis

Sensitivity analysis is a technique of identifying the responsiveness of different parameter involving in the simulation of hydrological process. Sensitivity analysis was performed to choose the most sensitive flow parameters that influence the catchment represented by SWAT to be used for calibration. This was achieved using the global sensitivity approach in semi-automated Sequential Uncertainty Fitting (SUFI2) algorithm. The global sensitivity analysis method takes into consideration, the sensitivity of one parameter relative to the other in order to give their statistical significances. The t-statistics and p-values of the parameters were used to rank to the different parameters considered to influence flow and the final selection done based on the significance of the ranked values.

3.5.5. Calibration and validation of model

An important part of any modeling exercise is the model calibration and validation. Calibration is a process where in certain parameters of the model are altered in a systematic fashion and the model is repeatedly run until the simulated results match field observed values within an acceptable level of accuracy. The process of model calibration is quite complex and limited by the model itself, input, and output data. Imperfect knowledge of watershed characteristics, mathematical structures of the hydrological processes and model limitations can cause error in calibration process. Before starting model calibration, field conditions at the site should be properly characterized. Lack of proper site characterization may lead to a wrong representation of the simulated system. Model calibration can be performed either by trial and error or by automated techniques. Automated calibration can be performed by means of specifying an objective or a set of objective functions. Uncertainty in models and data leads to uncertainty in model parameters and model predictions. Automated parameter estimation techniques for model calibration are accurate and rapid. Validation of hydrologic models is a process of matching the simulated results with observed values without altering the calibrated parameters.

Calibration was accomplished by comparing the output of the SWAT model with the observed data at the same conditions. For calibration and validation, the Sequential Uncertainty Fitting

(SUF2) calibration method within the SWAT Calibration and Uncertainty Procedures (SWAT-CUP) was used. Figure 3.20 below shows the procedure of calibration using the Sequential Uncertainty Fitting (SUF2).

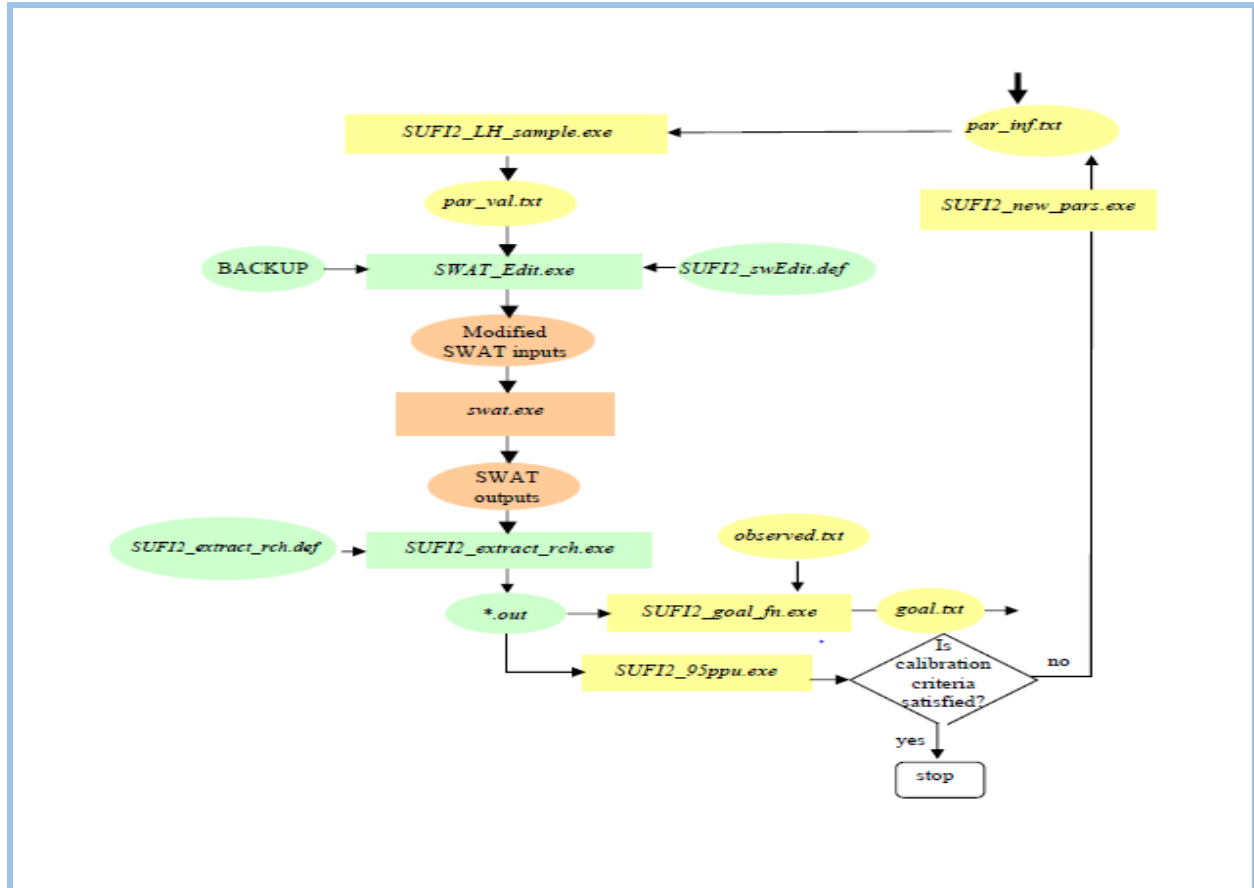


Figure 3. 20. Systematically creating of SWAT-SUF2 input files

In this study, the model was calibrated with observed Monthly discharge data for the period of 1997 to 2002 and validated for the period of 2003 to 2006. The model was also calibrated for sediment for the period of 1997 to 2002 and validated for 2003 to 2006 for monthly time step. The graphical and statistical approaches were used to evaluate the Arc SWAT model performance a number of times until the acceptable values were obtained for flow and sediment independently.

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 (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation.

Validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Two statistical model performance measures used in calibration and validation procedure of stream flow and sediment.

3.5.6. Evaluation of model performance

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these two numerical model performance measures are coefficient of determination (R^2 coefficient) and Nash-Sutcliffe simulation efficiency (ENS). The R^2 and ENS measures how well trends in the measured data are reproduced by the simulated results over a specified period and for a specified time step. In this study, these measures were computed of a monthly time step for both flow and sediment calibration and validation.

The R^2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results and it is calculated for n time steps using Equation 3.21 below. The model could be evaluated in order to determine the performance that how the model, simulated value fitted with the observed value. Statistical techniques like the coefficient of determination is one of the methods to assess the model performance and also estimate that at which level simulate value fitted with the observed value. It shows the best fitness and efficiency of the model. R square describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0. High values indicating better agreement. The Nash and Sutcliffe simulation efficiency indicates the degree of fitness of the observed and simulated plots with the 1:1 line (Santhi et al., 2002).

$$R^2 = \frac{\left[\sum_{i=1}^n \left(q_{si} - \bar{q}_s \right) \left(q_{oi} - \bar{q}_o \right) \right]^2}{\sum_{i=1}^n \left(q_{si} - \bar{q}_s \right)^2 \sum_{i=1}^n \left(q_{oi} - \bar{q}_o \right)^2} \dots\dots\dots [3.21]$$

Where q_{si} is the simulated values of the quantity in each model time step, \bar{q}_s is the average simulated value of the quantity in each model time step, q_{oi} is the measured values of the quantity in each model time step and \bar{q}_o is the average measured value of the quantity in each model time step.

The range of values for R^2 is between 1.0 (best) to 0.0 (bad). A value of 0.0 for R^2 means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

E_{NS} is computed for n time steps using Equation 3.22. It measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison.

$$E_{NS} = 1 - \frac{\sum_{i=1}^n (q_{oi} - q_{si})^2}{\sum_{i=1}^n (q_{oi} - \bar{q}_o)^2} \dots\dots\dots [3.22]$$

where q_{oi} is the measured values of the quantity in each model time step, q_{si} is the simulated values of the quantity in each model time step and \bar{q}_o is the average measured value of the quantity in each model time step.

The Nash-Sutcliffe simulation efficiency (ENS) values range from 1.0 (best) to negative infinity. A value of 0.0 for ENS means that the model predictions are just as accurate as using the measured data average to predict the measured data. ENS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average.

3.5.7. Catchment characteristics

Physical catchment characteristics has dominant influence on the dynamic property of flow and sediment. Therefore, it is important to analyze the correlation of physical characteristics and their correlation integration (Heuvelmans et al., 2006). As (Tamene et al., 2006) the physical catchment characteristics that can influence the erosion processes are listed in table 3.8 below.

Table-3. 1. Physical characteristics and influence on erosion.

Watershed Attributes	Description and Relation with Erosion
Catchment Area [KM2]	Represents flow
Height difference [HD]	Runoff potential erosive power HD = maxEle - minEle
Slope	Flow velocity and momentum of runoff
Hypsometric integral [HI]	Distribution of elevation within catchment $HI = \frac{meanEle - minEle}{maxEle - minEle}$
Relief ration [RR]	intensity of erosion process $RR = \frac{maxEle - minEle}{L}$
Drainage length (DL)	sediment transport potential DL=sum of length of all stream
Drainage density (DD)	balance between erosive forces and surface resistance $DD = \frac{DL}{A}$
Catchment shape indices Circularity index (CI) Elongation ratio (ER)	speed of sediment delivery $CI = \frac{A}{AC_P}$ $ER = \frac{DC}{L}$

A= basin planimetric area (m²); mean Ele, maxEle, min Ele= mean, maximum, and minimum elevation of catchment (m); L= horizontal distance between the outlet of a catchment and the most remote point on the water divide (m); HD=height difference or basin relief (m), DL= drainage length (m); AC_p=area of a circle having a perimeter equal to the perimeter of a catchment (m²); DC=diameter of a circle with the same area as the catchment area(m), L=maximum length of a watershed(m).

The brief description of each group of physical characteristics are listed below-

1- Geography And Physiography

Catchment Area:

Area of the catchment is easily derived from each of the catchments. The amount of water and sediment reaching the outlet mainly depends on its area.

Length flow path:

Length of flow path is one of the out puts in the map of catchment delineation. This indirectly is indication of water to reach the gauging station.

Hypsometric integral:

This indicates the distribution of elevation across the catchment and simply calculated as:

$$HI = \frac{H_{mean} - H_{min}}{H_{max} - H_{min}} \dots\dots\dots [3.23]$$

Where H_{mean} – average altitude of the basin above sea level [m].

H_{max} – Maximum attitude of the basin above sea level [m].

H_{min} – Minimum attitude of the basin above sea level [m].

Average slope:

Slope is one dominant factor that controls the water flow velocity where a high slope results in high velocities that reduce the travel time of water to reach the catchment outlet. A percentage slope calculation was calculated during the HRU analysis of Arc SWAT and the catchment was classified in to five slope classes.

Catchment shape:

The physical catchment shape affects the hydrological process at catchment scale (Deckers, 2006). It is determined by the formula 3.24 below.

$$SHAPE = \frac{H_{max} - H_{min}}{\sqrt{AREA}} \dots\dots\dots [3.24]$$

Circularity Index:

The circularity is calculated as the ratio of perimeter square to the catchment area.

$$CI = \frac{P^2}{A} \dots\dots\dots [3.24]$$

Where P and A are perimeter and area in [KM] and [KM²] respectively.

2- LAND USE:

The characteristic land cover is one of the most used physical catchment characteristics when establishing the model. This includes the land cover type such as forest, grass crop etc. it is a

general concept deforestation increases the soil erosion, since it changes the soil properties and infiltration rates.

3.6. Summary of methods

3.6.1. Creation of database

In this study, digital elevation model (DEM) 30mx30m resolution was found from ministry of water resource irrigation and electricity (MoWIE) and used to delineate the Gidabo dam watershed.

The LULC map and all datasets were obtained from the ministry of water irrigation and electric (MoWIE) as shape file format. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database. A lookup table that identifies the SWAT land use code for the different categories of LULC was prepared to relate the grid values to SWAT LULC classes. The land use classes in this study area was Agricultural Land: Generic (AGRL), Agricultural Land-Close-grown (AGRC), Forest-Evergreen (FRSE), Forest Mixed (FRST), Range-Brush (RNGB), Pasture (PAST) and Wetlands-Non-Forested (WETN). From this land use types major area is covered by Agricultural Land: Generic.

Soils in the study watershed are classified based on the FAO/Globe soil (FAO/UNESCO,) classification system. The soil of Gidabo dam watershed According to FAO, four major soils types were identified for the study area. Eutric Cambisols (clay), Ferric Acrisols (clay loam), Eutric Nitisols (clay), Haplic Xerosols (load) are found in the study area. The major soil in the study area was Eutric Nitisols, which has 77.99 % area of the watershed.

3.6.2. Model setup

The first step in model set up was creating the new SWAT project in Arc SWAT, then the DEM map was imported in to Arc SWAT next, the area of interest was delineated by selecting a point at the outlet of the watershed and found to be 2634.16 km². The drainage network, flow accumulation and flow direction all were automatically processed in Arc SWAT. A total 49-sub basin were delineated by SWAT for Gidabo watershed.

Land use and soil map in Arc shape format were imported in to the Arc SWAT model for HRU analysis. Both the maps were reclassified in Arc SWAT. The land slope of the study area was also classified in to five slope classes and made to overlay with land use and soil maps to subdivide the

study watershed into hydrologic response units (HRUs). Subdividing areas into hydrologic response units enables the model to reflect the evapotranspiration and other hydrologic conditions for different land use, soils and slopes. The HRUs are the elementary units with unique land cover, soil and slope angle lumped together. A total of 379 HRUs and 49 sub catchments were defined for the whole catchment.

After HRUs are defined, the next step in model set up is importing the climate data. Climate data is one of the main sets of input for simulating the hydrological processes in SWAT. These available climate data were prepared in text (.txt) format and imported into the SWAT model. Then the SWAT input tables were written into the model. Some SWAT input files were edited before the model was run for simulation. Soil parameters were also edited. The statistical parameters of daily precipitation and minimum and maximum daily temperature were also edited.

Hargreaves method was selected for calculating the potential evapotranspiration since it needs only daily minimum and maximum air temperature, SCS curve number was chosen to calculate surface runoff, initial curve number was estimated using soil moisture method, and Muskingum method was selected for channel routing.

Finally, the model was run for 28 years (1990 to 2017) by fixing the warm up period of two years. The warm up period of (2-5) years is generally recommended for SWAT model to reach at hydrological equilibrium.

CHAPTER-FOUR

RESULTS AND DISCUSSION

4.1. Sensitive parameters

4.1.1. Parameters sensitive to flow

A sensitivity analysis was implemented for nine years to identify sensitive parameters for model calibration. Nineteen hydrological parameters related to stream flow were tested. The sensitivity analysis resulted in a list of parameters ranked from the most to the least sensitive. Based on this ranking, the seven most sensitive parameters for this area were chosen for calibration. The post calibration fitted values of these parameters by means of SUFI-2 are listed in Table 4.1 below.

Table 4. 1. List of parameters and their initial ranges used for Sensitive analysis.

Parameter	Definition	Range Value	
		Min	Max
CN2	SCS runoff curve number (dimensionless)	-0.2	0.2
ALPHA_BF	Base-flow alpha factor (days)	0	1
GW_DELAY	Groundwater delay (days)	30	450
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	2
GW_REVAP	Groundwater “revap” coefficient (dimensionless)	0.02	0.2
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	0	500
RCHRG_DP	Deep aquifer percolation fraction (dimensionless)	0	1
SOL_AWC	Available water capacity of the soil layer (mm H ₂ O/mm soil)	-0.25	0.25
SOL_ALB	Moist soil albedo	-0.25	0.25
CH_N2	Manning’s “n” value for the main channel	-0.01	0.3
CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/h)	-0.01	500
ALPHA_BNK	Base-flow alpha factor for bank storage	0	1
TLAPS	Temperature laps rate (0C/km)	-10	10

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

SLSUBBSN	Average slope length (m)	10	150
HRU_SLP	Average slope steepness	0	1
CANMX	Maximum canopy storage (mm)	0	100
ESCO	Soil evaporation compensation factor (dimensionless)	0	1
EPCO	Plant uptake compensation factor	0	1
SURLAG	Surface runoff lag time (days)	0.05	24

After a thorough preprocessing of the required input for SWAT model, flow simulation was performed for ten years of recording periods starting from 1997 through 2006. The simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. From the parameter used to sensitivity, eight of them are the most sensitive parameters. The sensitive parameters are identified based on the value of P-value and t-stat. The P-value having less than 0.05 is the more sensitive model parameter. The analysis was performed at all the three gauging stations but the final parameters for the whole catchment are taken at the outlet of the catchment for calibration and validation. The following sensitivity analysis in the table 4.2 was taken at bedassa outlet and the same procedure was used at the catchment outlet.

Table 4. 2. Sensitivity rankings of stream flow parameters in the Gidabo catchment.

Parameter Name	t-Stat	P-Value	rank
CN2	-9.61	0.00	1
GW_REVAP	6.72	0.00	2
ESCO	-5.04	0.00	3
SOL_AWC	4.05	0.00	4
HRU_SLP	-3.03	0.00	5
GW_DELAY	2.70	0.01	6
GWQMN	2.40	0.02	7
REVAPMN	2.09	0.04	8
EPCO	1.35	0.18	9
CH_N2	1.32	0.19	10
CH_K2	-1.14	0.26	11
RCHRG_DP	-1.01	0.32	12
SLSUBBSN	0.91	0.37	13
TLAPS	0.89	0.38	14
SOL_K	0.57	0.57	15
OV_N.	-0.51	0.61	16

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

SURLAG	0.30	0.77	17
CANMX	-0.23	0.82	18
ALPHA_BF	0.18	0.86	19
ALPHA_BNK	0.13	0.90	20
SOL_ALB	-0.06	0.95	21

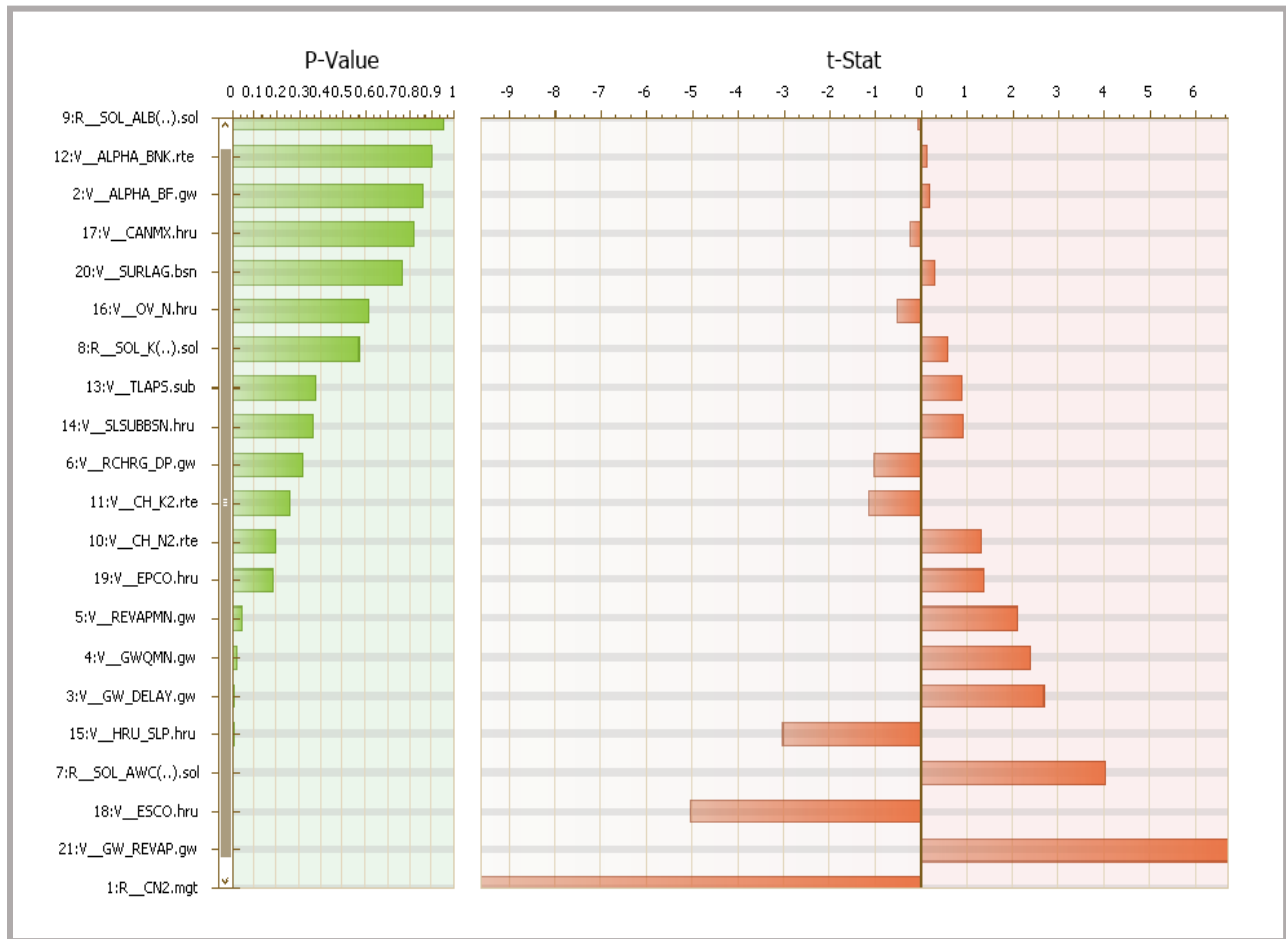


Figure 4. 1.Global sensitive parameter (p-value) and (t-stat) of the study area

The global sensitivity analysis of twenty-one flow parameters at Bedassa gauging station showed that, only eight parameters were very sensitive to flow. The rankings of the flow parameters are presented in table 4.2 while the fitted values for the most sensitive parameters are indicated in the above Table 4.3 bellow. The most sensitive parameter was the SCS runoff curve number (CN2). The curve number estimates runoff based on the relationship between precipitation, hydrologic soil group and land uses. The other sensitive parameters included the Groundwater “revap”

coefficient (GW_REVAP), soil evaporation compensation factor (ESCO), available water capacity of the soil layer (SOL_AWC), slope steepness (HRU_SLP), Groundwater delay (GW_DELAY) and Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN). The more sensitive parameters were found not to be sensitive to flow in the catchment as their p-values were greater than 5%.

Table 4. 3. List of flow sensitive parameters, their calibrated and fitted values of the whole catchment.

No.	Parameter_Name	Fitted_Value	Min_value	Max_value
1	CN2	-0.12	-0.135	0.2
2	ALPHA_BNK	0.96	0.12	1.0
3	CH_K2	76.5	74.2	77.9
4	SOL_AWC	0.73	0.02	1.0
5	HRU_SLP	0.68	0.0	1.0
6	ESCO	0.66	0.51	0.9
7	GW_REVAP	0.16	0.127	0.17

4.1.2. Parameters sensitive to sediment

The most sensitive parameters for erosion simulations were Average slope steepness (HRU_SLP), Average slope length (SLSUBBSN), Initial residue cover (RSDIN), Channel cover factor (CH_COV2), USLE equation soil erodibility (K) factor (USLE_K), SCS runoff curve number f (CN2), Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) and Exponent parameter for calculating sediment re-entrained in channel sediment routing Other parameters included in the table below were also affecting the soil erosion simulation to some extent. These sediment parameters are used to compute the amount of sediment from a catchment (from upland) and from the channel (instream sediment). The parameters that were used to evaluate the sensitivity to sediment are shown in Table 4.4 below.

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table 4. 4. List of parameters used in sensitivity analysis to sediment

No.	Parameter Name	Fitted Value	Min_value	Max_value
1	CN2	33.45	32.921516	33.828484
2	SPEXP	1.10	0.936893	1.110319
3	SPCON	0.0045	0.004444	0.00485
4	LAT_SED	333.60	333.16925	335.192688
5	HRU_SLP	0.00658	0.000000	0.033749
6	CH_COV1	0.573728	0.55038	0.577186
7	CH_COV2	0.57368	0.542573	0.587853
8	CH_BED_BD	1.851668	1.754378	1.85478
9	CH_N2.rte	0.037558	0.012721	0.042537
10	CH_ERODMO	1.015876	0.956235	1.032018
11	USLE_K	0.047967	0.047238	0.151382
12	SOL_AWC	0.67497	0.675312	0.674898
13	BIOMIX	0.041988	0.017492	0.058116
14	RSDIN	356.482941	353.89093	357.708313
15	USLE_P	0.017788	0	0.036829
16	SLSUBBSN	16.855671	16.63526	18.398542
17	SOL_ALB	0.001292	0	0.008673

To see which parameter is highly sensitive to sediment from the list of parameters in Table 4.4. Global sensitivity analysis was applied. Seventeen parameters that directly affect the sediment yield and sediment transport in the watershed were analyzed and the result is tabulated in Table 4.5 below.

Table 4. 5. List of parameters sensitive to sediment.

No	Parameter_Name	Fitted_Value	Min_value	Max_value
1	SPEXP	1.08301	1.081077	1.08564
2	SPCON	0.0041	0.004084	0.00410
3	RSDIN	881.025	881.0000	882.000
4	HRU_SLP	0.00298	0.000000	0.01085
5	CH_COV2	0.61331	0.612381	0.61575
6	CN2	69.4926	66.950371	69.5578
7	SLSUBBSN	17.0401	17.036945	17.0406
8	USLE_K	0.04251	0.029215	0.04285

As the sediment transport consists of landscape and channel components, each transport component is affected by different factors. The parameters used in the sensitivity analysis are related to the corresponding transport component. Therefore, the parameters can be categorized in to upland factors, which affect the landscape component of the sediment transport and channel factors, which affect the channel component of the sediment transport. Parameters such as USLE _ K, RSDIN, HRU _ SLP, and SLSUBBSN are included in upland factors whereas SPCON, SPEXP and CH _ COV 2 are categorized under channel factors. From the global sensitivity analysis, the upland factors occupy higher rank that shows upland parameters are very sensitive in this case. The sensitivity of the parameter decreases with increasing rank number value and therefore, parameters that have low p_value and t_value in the global sensitivity are less sensitive.

4.2. Physical catchment characteristics

Generally runoff and sediment yield in the watershed are affected by the physical catchment characteristics (PCC). The physical catchment characteristics of the Gidabo River Catchment outlet were determined from DEM30m. The climatic characteristics, geography and physiographic, land use and cover conditions affects the physical characteristics of the catchment. The climatic characteristic of Gidabo River Catchment is similar, because the circularity index and elongation ratio, which shows speed of sediment delivery, are similar in both the three gauging stations. The slope of the Gidabo River Catchment also showed similarity. The drainage density of the Gidabo River Catchment also shows similarity with a low drainage density for both gauged catchment and the Gidabo River Catchment. The land use and land cover conditions in the Gidabo River Catchment are mainly dominated by agricultural land followed by forestland for Gidabo River Catchment. The results are shown in the table 4.6 below.

Table 4. 6. Physical catchment characteristics.

Catchment characteristics	Maesso	Aposto	Bedassa
Min ele. (m)	1181	1650	1469
Max ele. (m)	3173	3173	3021
Mean ele. (m)	1952.23	2157	2267
Standard deviation	403.2	398.94	423
Length(m)	71000	31240	21520
Area (Km2)	2634.16	543.54	151.99
perimeter(KM)	410.75	154.64	96.287
Hypsometric integral (HI)	0.39	0.33	0.514

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Height difference (HD)	1992	1523	1552
Relief ratio(RR)	0.028	0.049	0.072
Drainage density (DD)	0.095	0.147	0.058
Elongation Ratio(ER)	1.12	0.98	1.08
Circularity index (CI)	0.20	0.29	0.21
Ruggedness number((RG)	38.81	65.33	125.89
Slope (%)			
0_5	0.5	14.37	1.58
5_10	15.8	25.88	7.70
10_15	18.27	18.94	14.94
15_20	13.33	11.83	16.97
20_9999	52.1	28.98	58.81
Land use (%)			
AGRL	51.28	85.00	97.38
AGRC	32.12	6.01	2.62
FRSE	12.69	8.99	0.00

4.3. Model calibration and validation

4.3.1. Model calibration and validation for runoff

4.3.1.1. Model calibration for flow

The calibration of SWAT model for runoff was done by using the monthly-observed runoff data at Gidabo near Aposto, Gidabo near Dilla and at Maesso (outlet of the watershed) for the years 1997 to 2002. In this study, we have stream flow data of ten years. Out of the total stream flow data two-third of the data were used for calibration and one-third of the data were used for validation. The calibration period was carried out for six years that is from January 1997 to December 2002. In addition, the validation period were carried out for four years from January 2003 to December 2006.

The model was calibrated by using the values of parameters that were identified as highly sensitive to runoff as it was described under sensitivity analysis section. The simulation was done and parameters were calibrated using auto calibration tool (SUFI2 in SWAT_CUP) and the calibrated parameters were updated in the model and the final simulation was run.

For model performance evaluation NSE, and R^2 were used as criteria and the objective function was specified as $NSE > 0.5$ in SUFI-2 in observed.txt file before starting calibration. The simulated

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

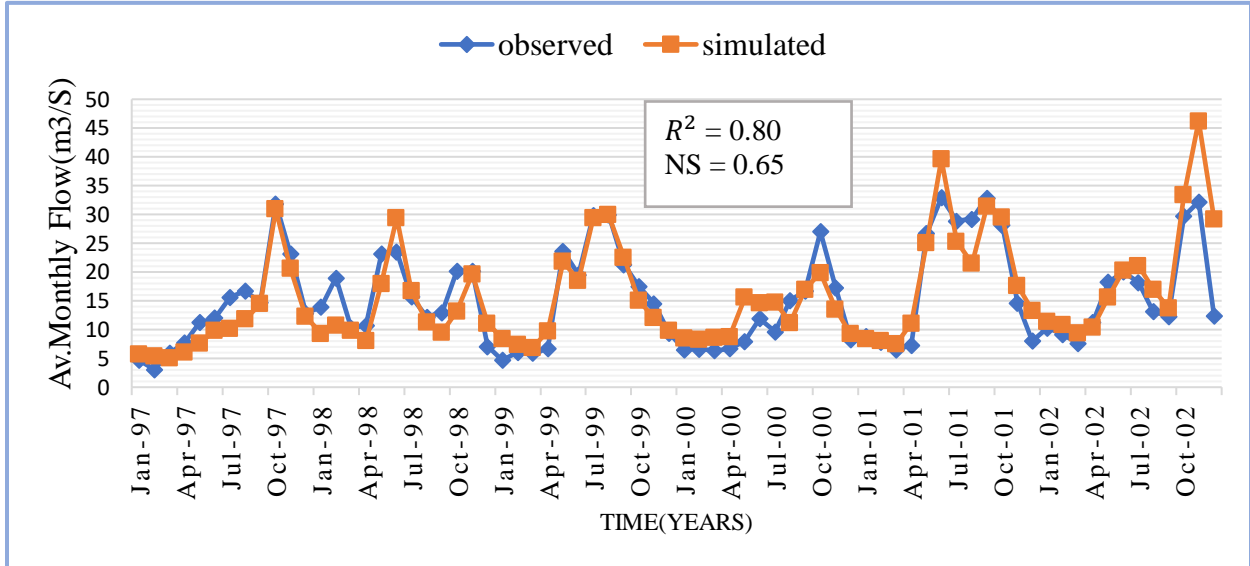
and observed monthly discharge at both of the gauging were plotted for visual comparison in figure 4.2 below.

The observed and simulated runoff for the calibration period were also plotted against each other in order to determine the goodness of fit (figure 4.3) by using the coefficient of determination (R^2) and the Nash-Sutcliffe coefficient of efficiency (NS). The coefficient of determination (R^2) value for monthly stream flow for the calibration period of Aposto, Bedassa and Maesso was 0.86, 0.88, 0.77 respectively. In addition, the Nash- Sutcliffe coefficient of efficiency (NS) for the same period was found to be 81, 79, and 65 respectively. In general, the model performs well in predicting the stream flow from Gidabo catchment by responding to each rainfall events.

Table 4. 7. Observed and simulated flow of gauging stations

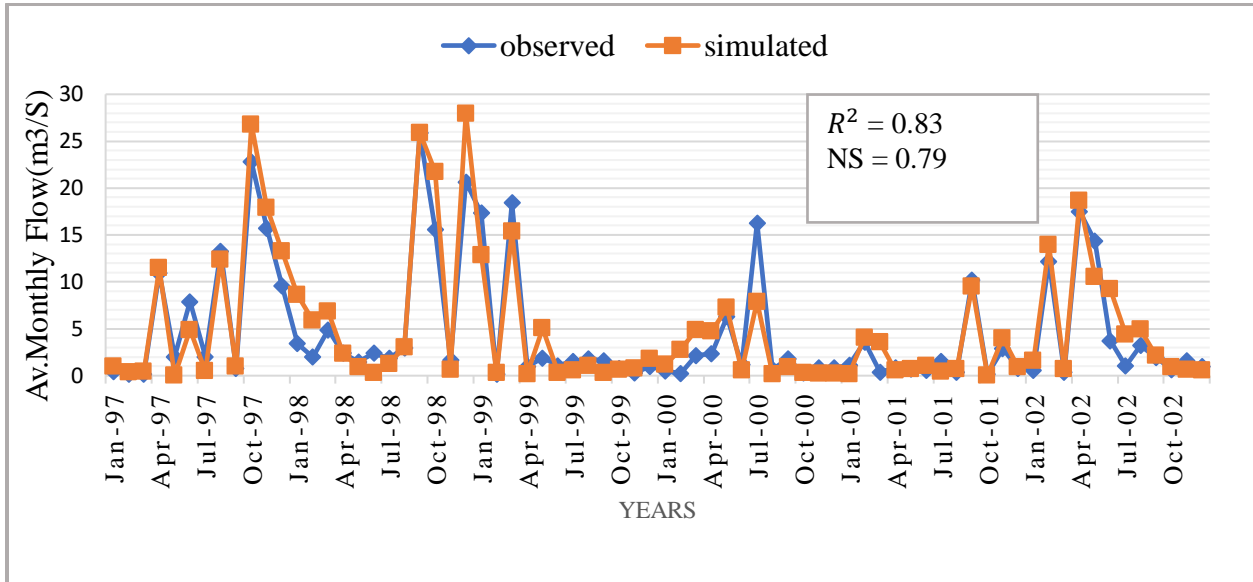
Average observed and simulated flow (m ³ /s)				Model efficiency	
Stations	Year	Observed flow	Simulated flow	R ²	NS
Aposto	1997-2002	7.14	7.12	0.85	0.81
Bedassa	1997-2002	5.84	6.61	0.83	0.79
Maesso	1997-2002	19.27	21.63	0.80	0.65

A) Maesso



Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

B) Bedassa



C) Aposto

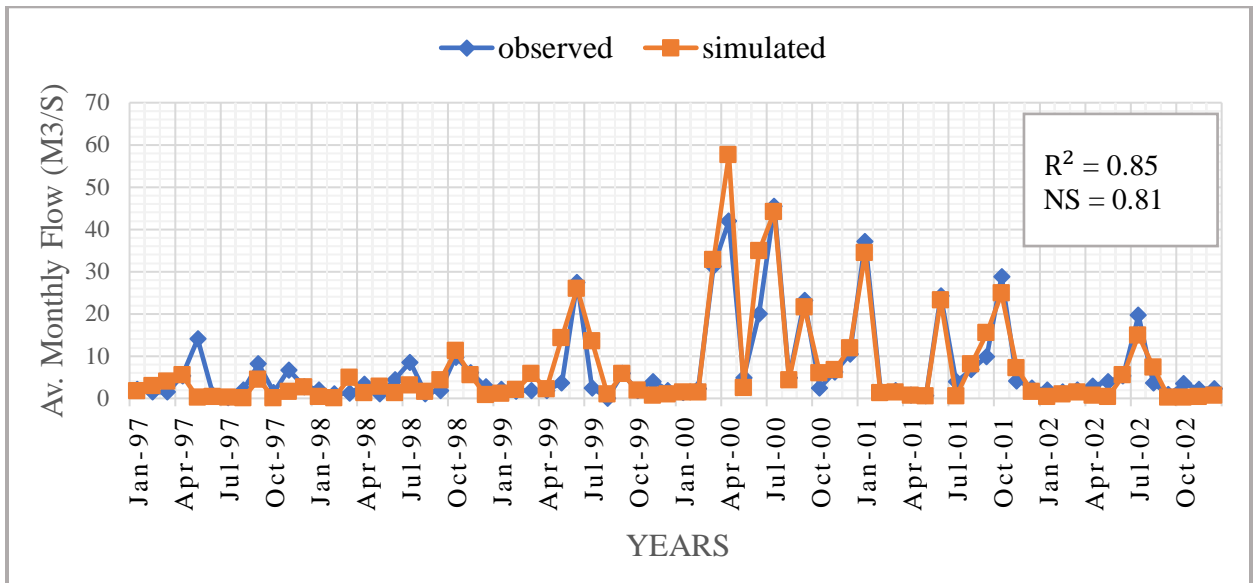


Figure 4. 2. Observed and simulated flow for calibration

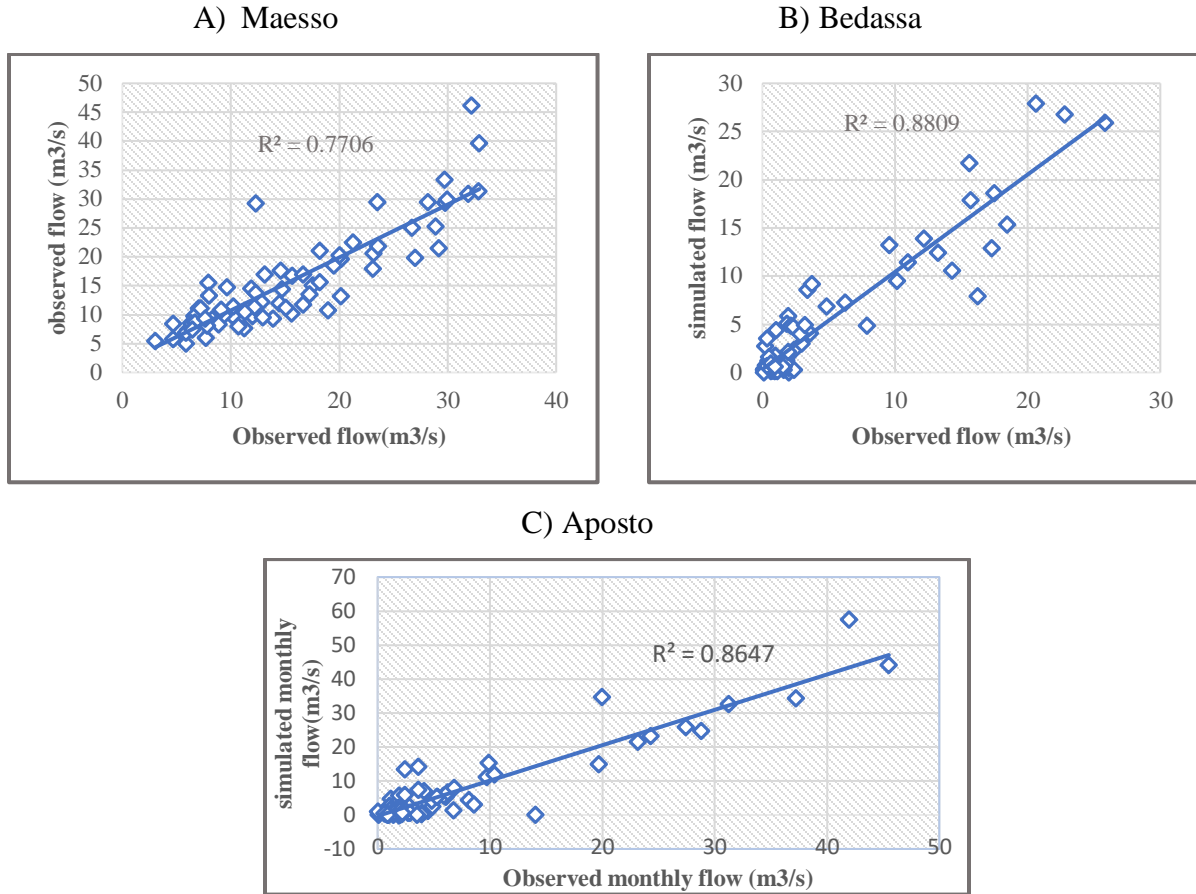


Figure 4. 3. Fit line observed and simulated flow for calibration period

4.2.1.2. Model validation for flow

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions. This implies the application of the calibrated model without changing the parameter values that were set during the calibration, when simulating the response for a period other than the calibration period (Refsgaard, 1997).

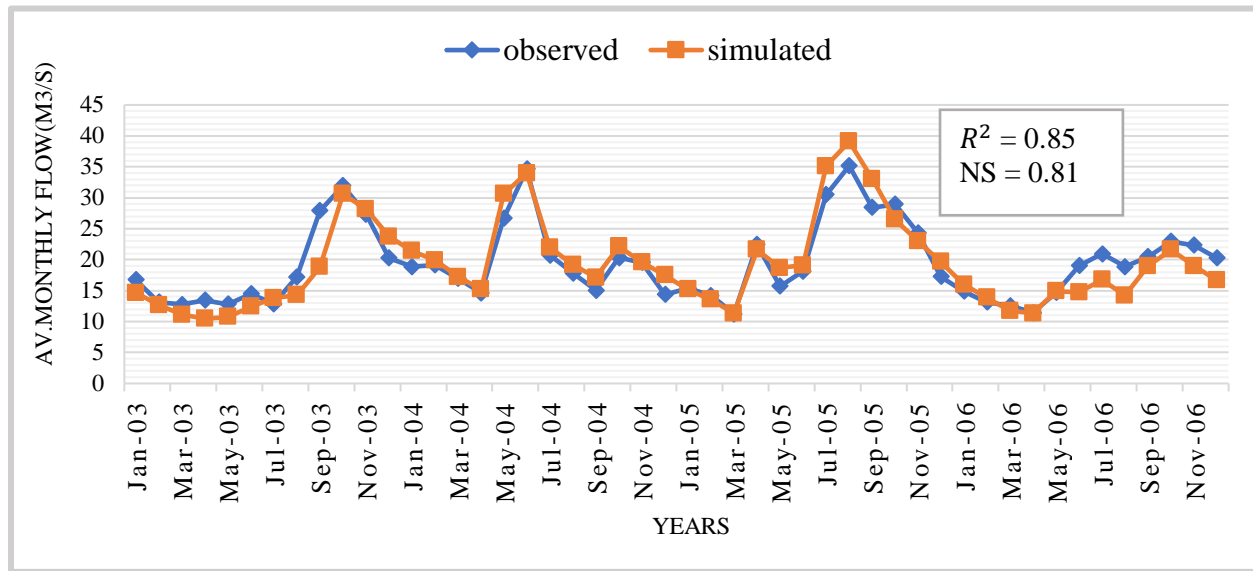
The model validation was carried out for monthly stream flow of the years 2003-2006. Model validation involves re-running the model using the input data, which are not used in calibration period and without any adjustment of calibration parameters at different period. The value of coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) for monthly streamflow of the period 2003-2006 both the three gauging station (Aposto, Bedassa and Maesso) were 0.88, 0.82, 0.85 and 0.67, 0.75, 0.81 respectively. The observed and simulated daily stream flow for validation of the three stations is shown in the table 4.8. Below

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

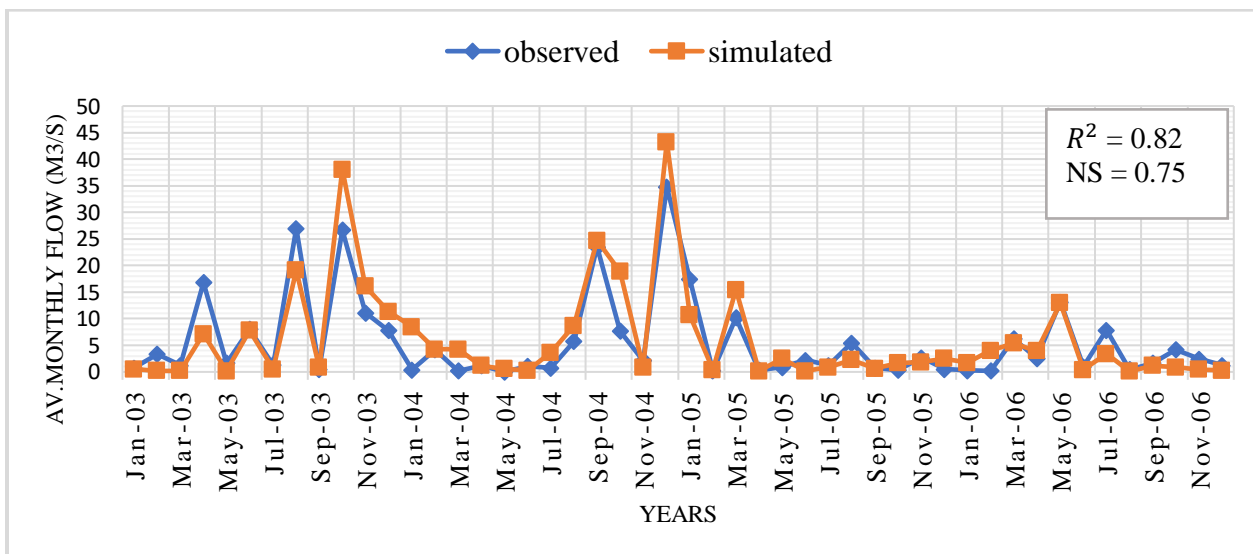
Table 4. 8. Observed and simulated flow for Validation

Average observed and simulated for flow (m3/sec)				Model efficiency	
Station	Year	Observed flow	Simulated flow	R ²	NS
Aposto	2003-2006	6.41	6.61	0.88	0.67
Bedassa	2003-2006	5.65	6.15	0.82	0.75
Maesso	2003-2006	18.44	19.22	0.85	0.81

A) Maesso



A) Bedassa



Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

A) Aposto

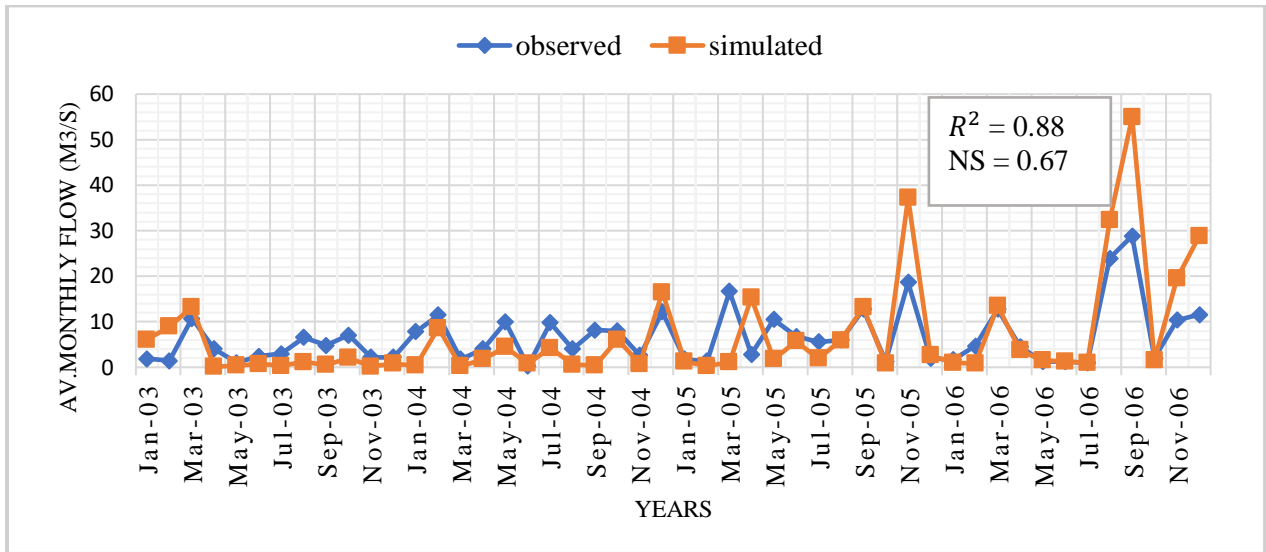
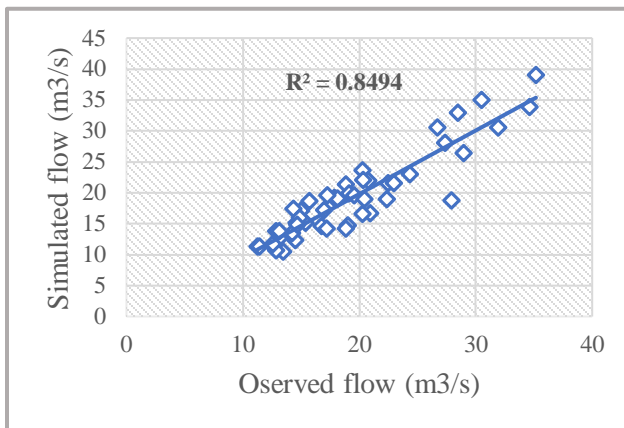
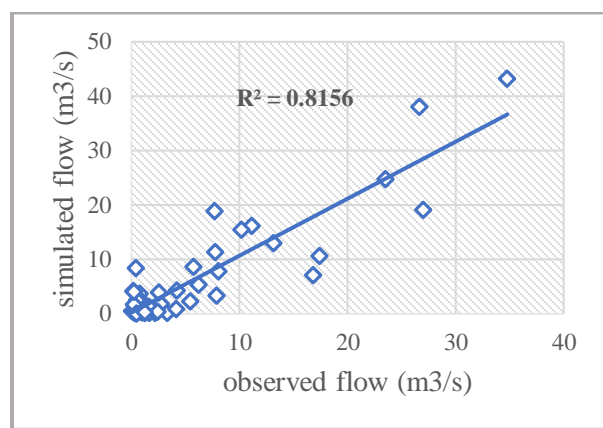


Figure 4. 4. Observed and simulated flow for validation

A) Maesso



B) Bedassa



C) Aposto

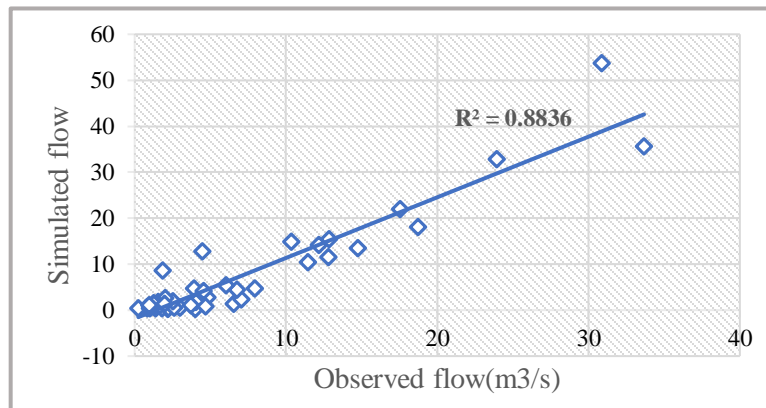


Figure 4. 5. Fit Line Observed and Simulated Flow for Validation Period.

The spatially and temporally distributed data should be used in the development of SWAT project to get a good result. The SWAT model looks for rain gauges or precipitation station close to the center of each sub basin to generate runoff. Therefore, having precipitation station distributed throughout the watershed helps the model to better predict the runoff from each sub basin. In this study there was only three precipitation measurement station located close to the center of the watershed the rest other two stations are nearest stations, off course swat understands these nearest stations but for better result more precipitation stations are needed. It is obvious that rainfall distribution may not be uniform throughout the watershed and as the sub basin gets far from the precipitation station, it is likely to have higher or lower rainfall intensity than the precipitation recording station and this could affect the runoff generated by the model. Therefore, rain gauge density is also very important input requirement.

4.3.2. Model calibration and validation for sediment

4.3.2.1. Model calibration for sediment

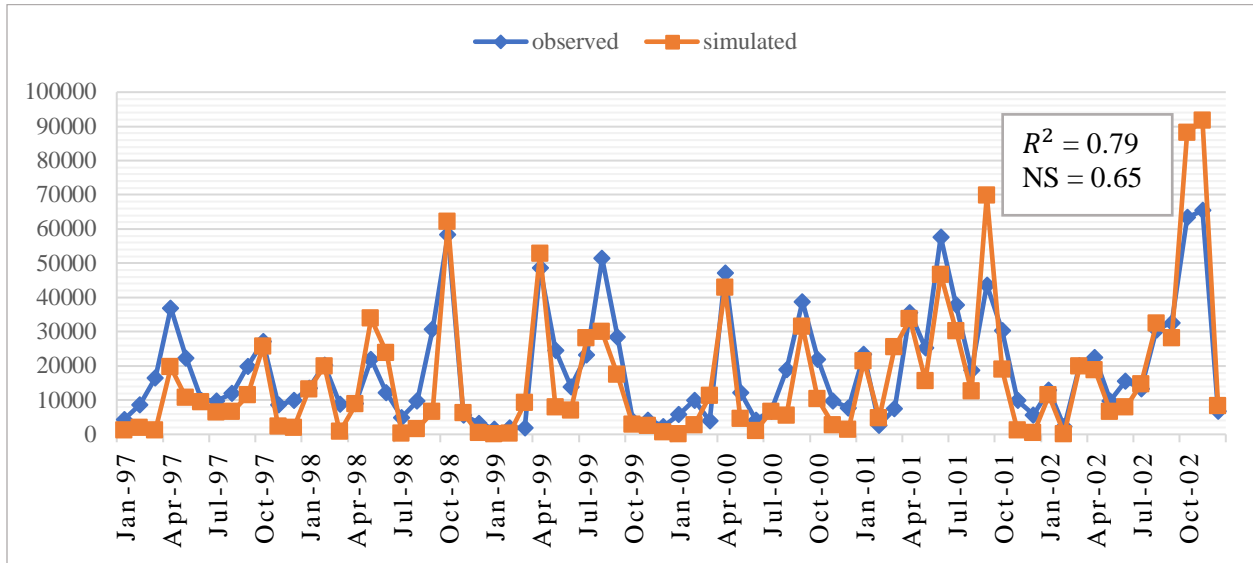
Model calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold et al., 2012). The model was calibrated for sediment for the year 1997-2002.

Table 4. 9. Observed and simulated sediment calibration.

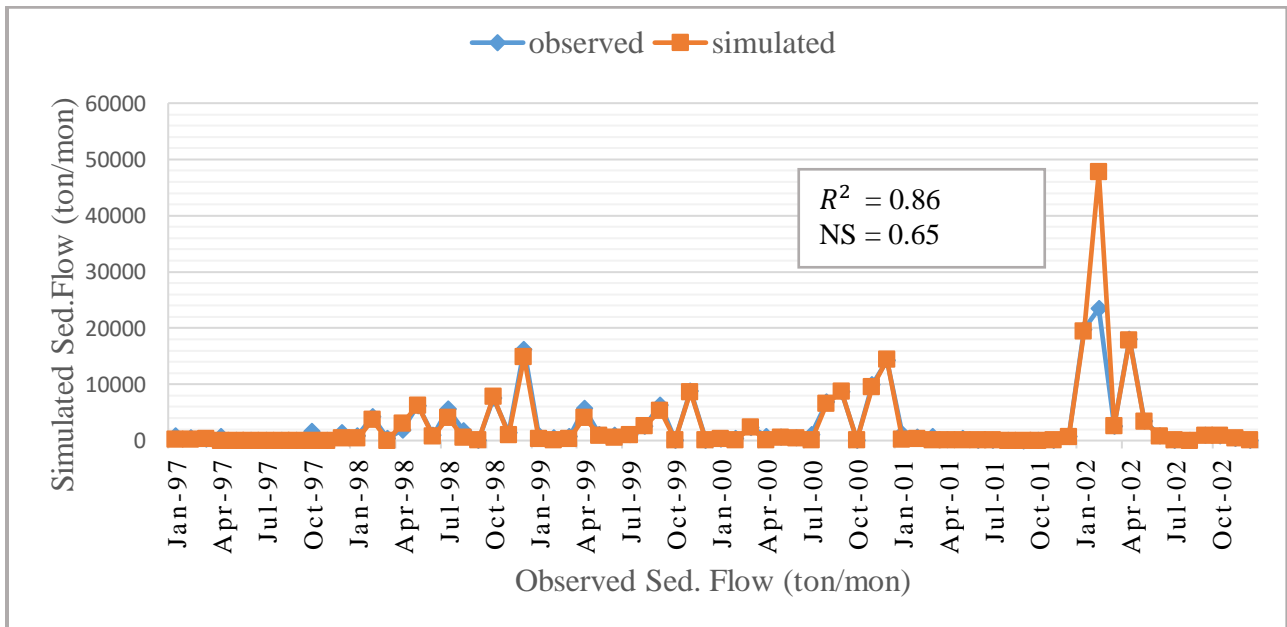
Average Observed and Simulated for Sediment (ton/month)				Model efficiency	
Station	Year	Observed	Simulated	R ²	NS
Aposto	1997-2002	2821.72	2859.17	0.86	0.65
Bedassa	1997-2002	603.81	583.95	0.87	0.80
Maesso	1997-2002	10996.78	10173.16	0.79	0.65

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

A) Maesso (Dam outlet)



B) Aposto



C) Bedassa

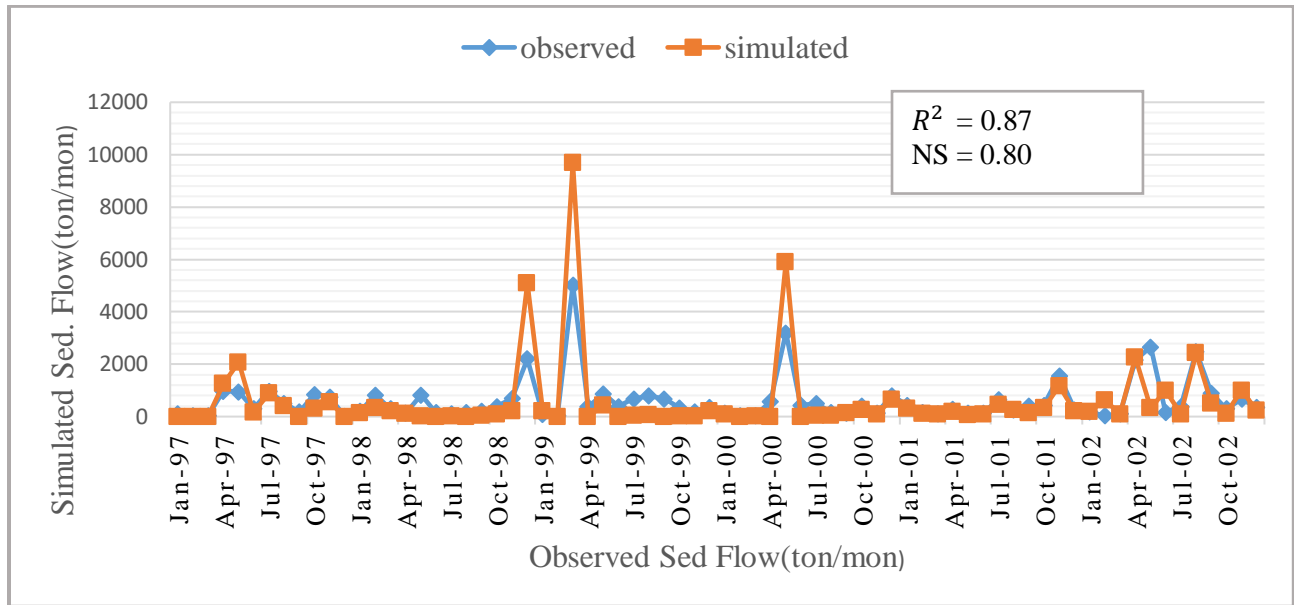


Figure 4. 6.Observed and simulated sediment for calibration

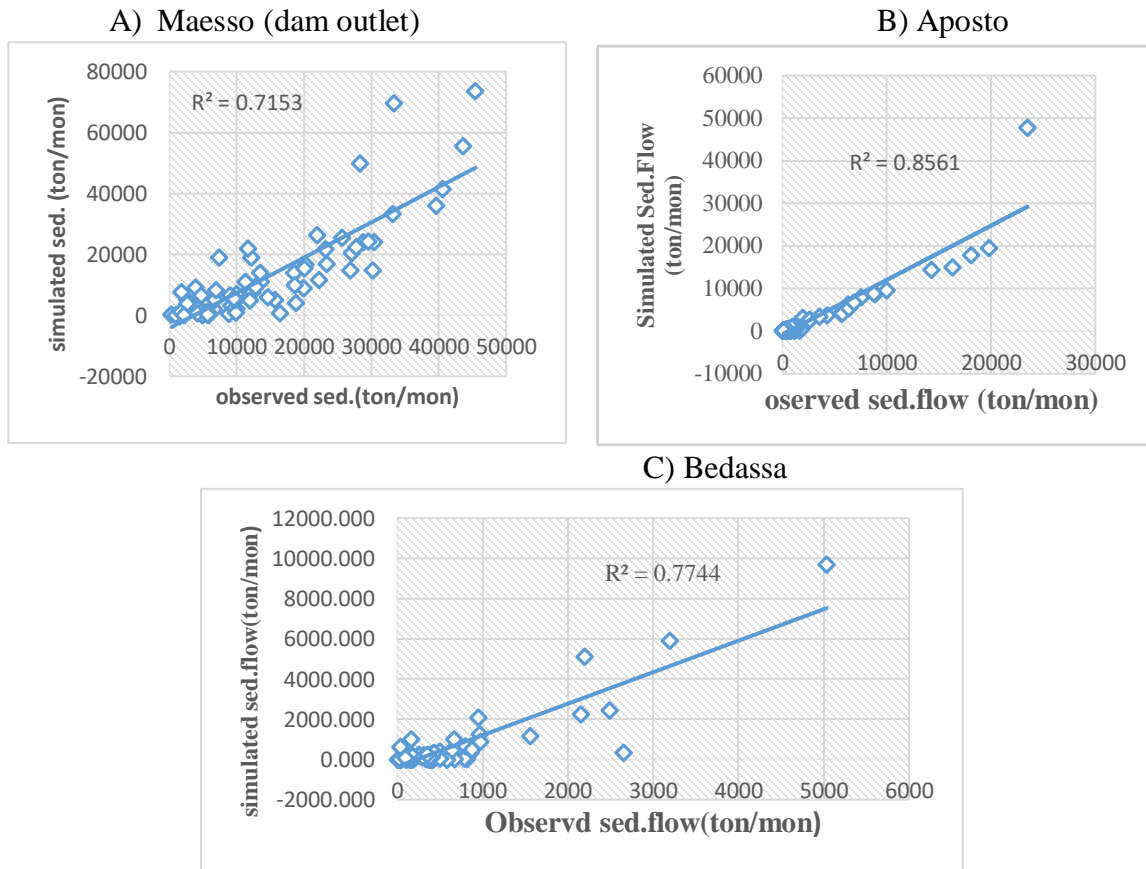


Figure 4. 7. Fit line observed and simulated sediment for calibration period

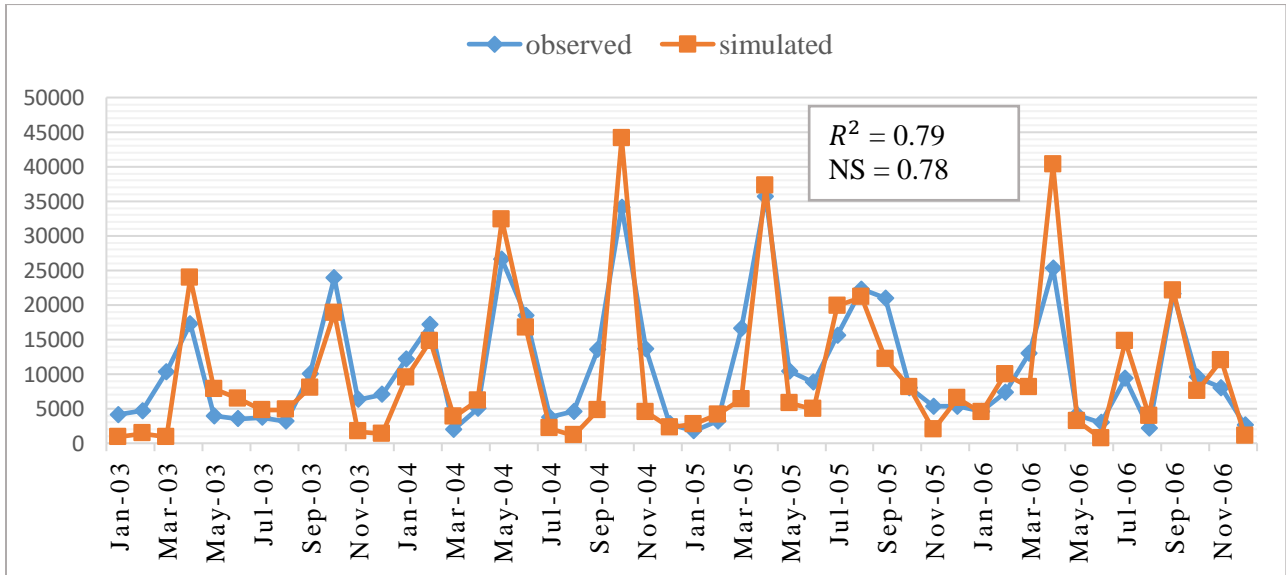
4.3.2.2. Model validation for sediment

In order to utilize the calibrated model for estimating the effectiveness of future potential management practice, the model was tested against an independent set of measured data. as the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases. The model was used for future predictions under different management scenarios. In this study, the model was validated with independent validation period of 2002-2006.

Table 4. 10. Observed and simulated for sediment validation

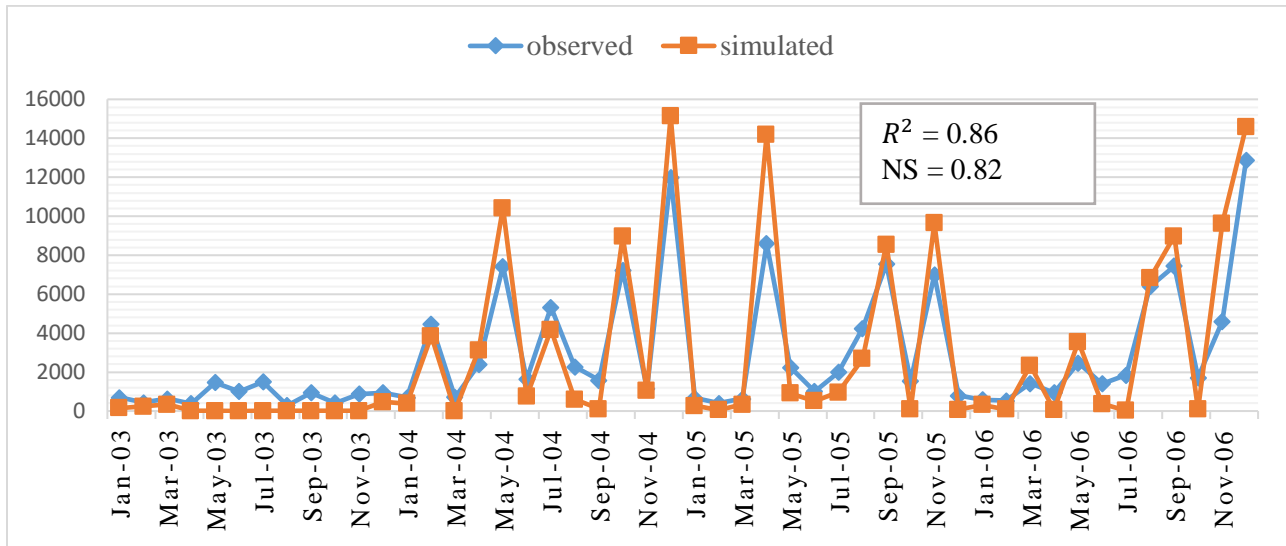
Average observed and simulated sediment for calibration (ton/month)				Model efficiency	
Station	Year	Observed	Simulated	R ²	NS
Aposto	2003-2006	2820.35	2810.58	0.86	0.82
Bedassa	2003-2006	438.96	408.68	0.88	0.77
Maesso	2003-2006	10759.42	10044.49	0.79	0.78

A) Maesso (Dam outlet)



Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

B) Aposto



C) Bedassa

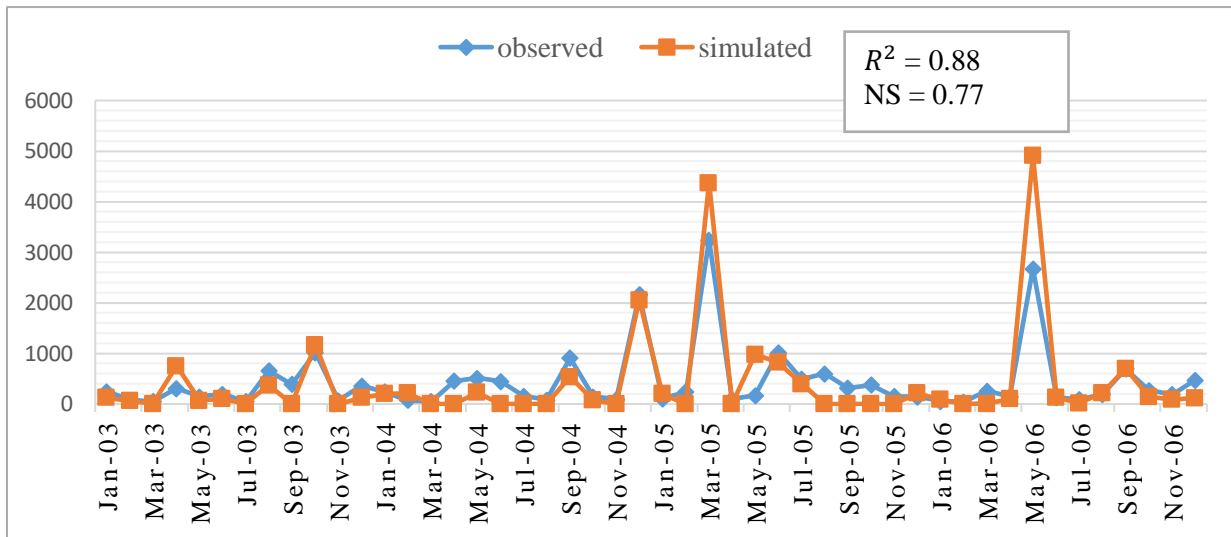
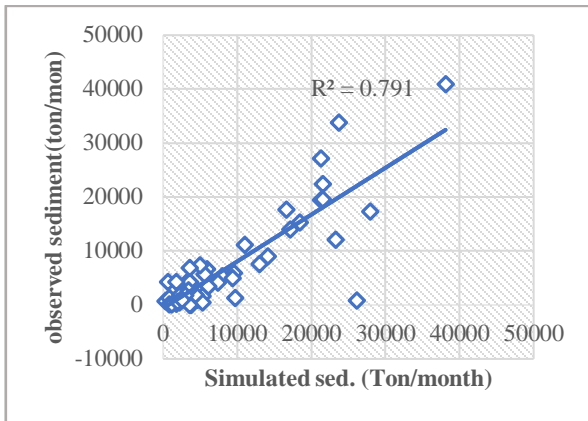
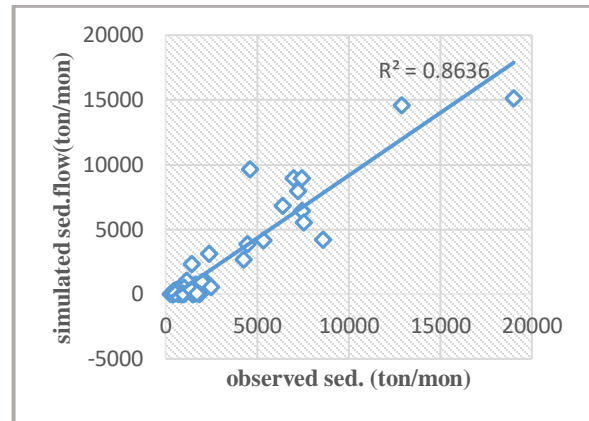


Figure 4. 8. Observed and simulated sediment for validation

A) Maesso



B) Aposto



B) Bedassa

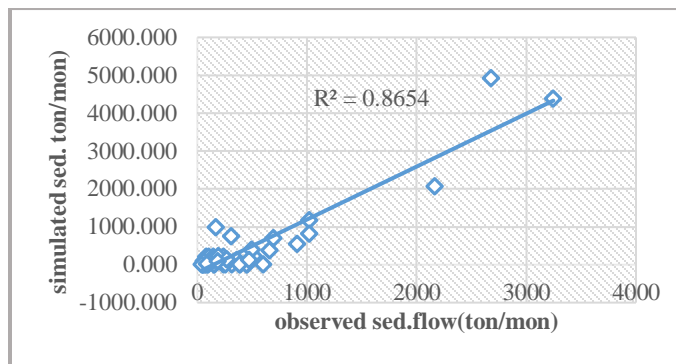


Figure 4. 9. Fit line observed and simulated sediment for validation period

After calibration and validation of the model the total observed and simulated of sediment yield in the Gidabo catchment at the dam site and at the two upstream gauging stations (Aposto and Bedassa) during calibration and validation period, the results show good relationship. Therefore, we can say it is good to use SWAT estimation of catchment sediment yield in the study area. The result indicated that the model simulation is 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 the model is 2,512,090 ton/year. Based on this result 2,512,090 ton/year sediment enter into the reservoir. The total catchment area of this study is 2634 km². 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 95.37 ton/km²/year. Sedimentation modeling for Ribb dam (catchment area 844km²), estimation of the average annual sediment yield is 72.79 ton/km²/year (Tensay, 2011). Sediment management in Gibe I reservoir

(catchment area 3602km²), estimation of average annual sediment yield was estimated 106.178 ton/km²/year (Tufa, 2016) and estimation of Catchment Sediment yield Gelana Reservoir (catchment area, 644.28 km²) is 89.14 ton/km² /year (Mengist, 2017). The amount of specific sediment yield of Gelana is almost similar with the amount of specific sediment yield of Gidabo catchment because Gidabo and Gelana catchments are found in rift valley basin which are nearest each.

4.4. Temporal variation of sediment yield

Catchment sediment yield is a function of catchment size, land use, soil type, slope and climate. The temporal variation of sediment yield characteristics of the entire sub-catchments has been computed with SWAT model. After calibration and validation of flow and sediment at both gauging stations the comparison between sediment yield catchment discharge and rainfall have direct relationship which is the higher rainfalls will have the higher runoff and sediment yield.

Table 4. 11. Yearly temporal variation of sediment.

No	Year	Sediment in tons (sed. load)	No	Year	Sediment in tons (sed. load)
1	1992	21909.854	14	2005	36961.092
2	1993	24813.841	15	2006	48850.688
3	1994	28172.616	16	2007	72203.588
4	1995	23017.709	17	2008	69866.025
5	1996	55698.785	18	2009	48631.760
6	1997	56710.687	19	2010	62201.372
7	1998	65221.990	20	2011	60934.515
8	1999	37077.284	21	2012	52907.505
9	2000	43866.746	22	2013	54342.505
10	2001	61935.645	23	2014	63862.567
11	2002	33024.071	24	2015	40259.520
12	2003	26308.390	25	2016	57889.248
13	2004	22726.483	26	2017	65490.031

The trend or moving average of the graph 4.10 below generally shows that the variation of sediment increases from time to time. According to (Mengistu, 2017), the cultivated area in the rift valley basin wide spread for the last two decades. Therefore, sediment yield varies from season to season due to wide spread of cultivated area and uneven distribution rainfall in the basin. Graph 4.10 below shows the temporal variation of sediment in the Gidabo catchment.

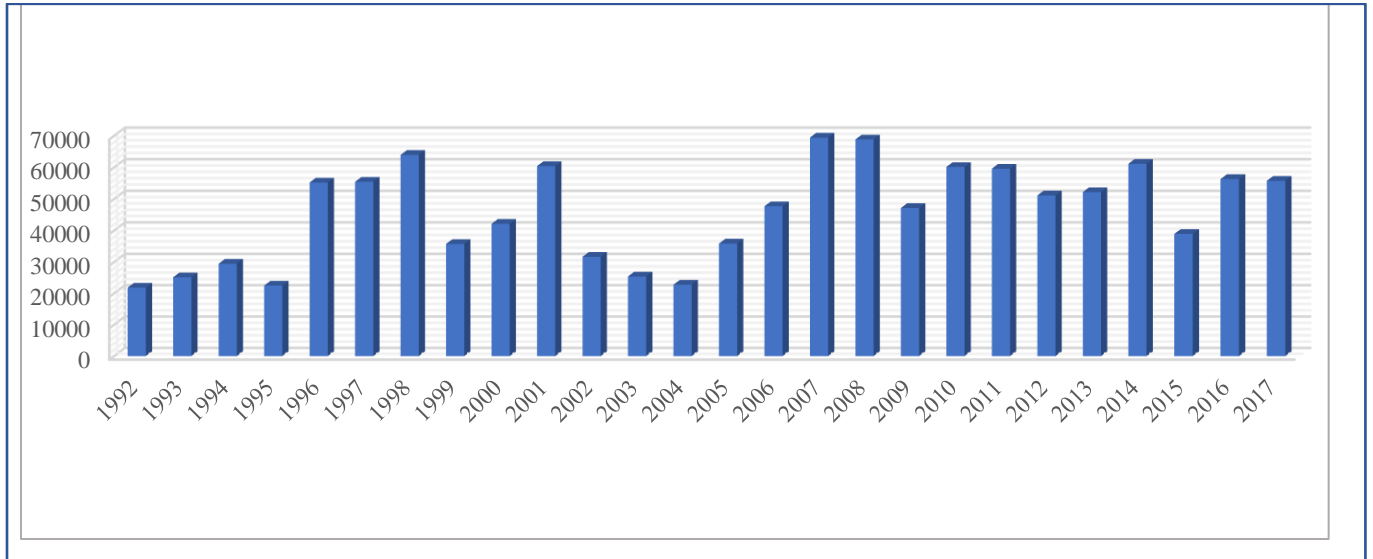


Figure 4. 10. Temporal variation of sediment

4.5. Spatial distribution of sediment in Gidabo watershed

The spatial variability of sedimentation rate were identified and shown in base on which the potential area of intervention can be identified. Erosion prone areas identification in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield. Spatial analysis of sediment prone areas is one of the many tasks SWAT can do while modelling sediment. SWAT is powerful in spatial visualization of sub basin or HRU level detail so that one can see which area produces high sediment and which area produces less. The spatial visualization of sub basin wide sediment yield in tons/ha is, given in the figure the 4.12 below. Assessment of the spatial variability of soil erosion is useful for catchment management planning.

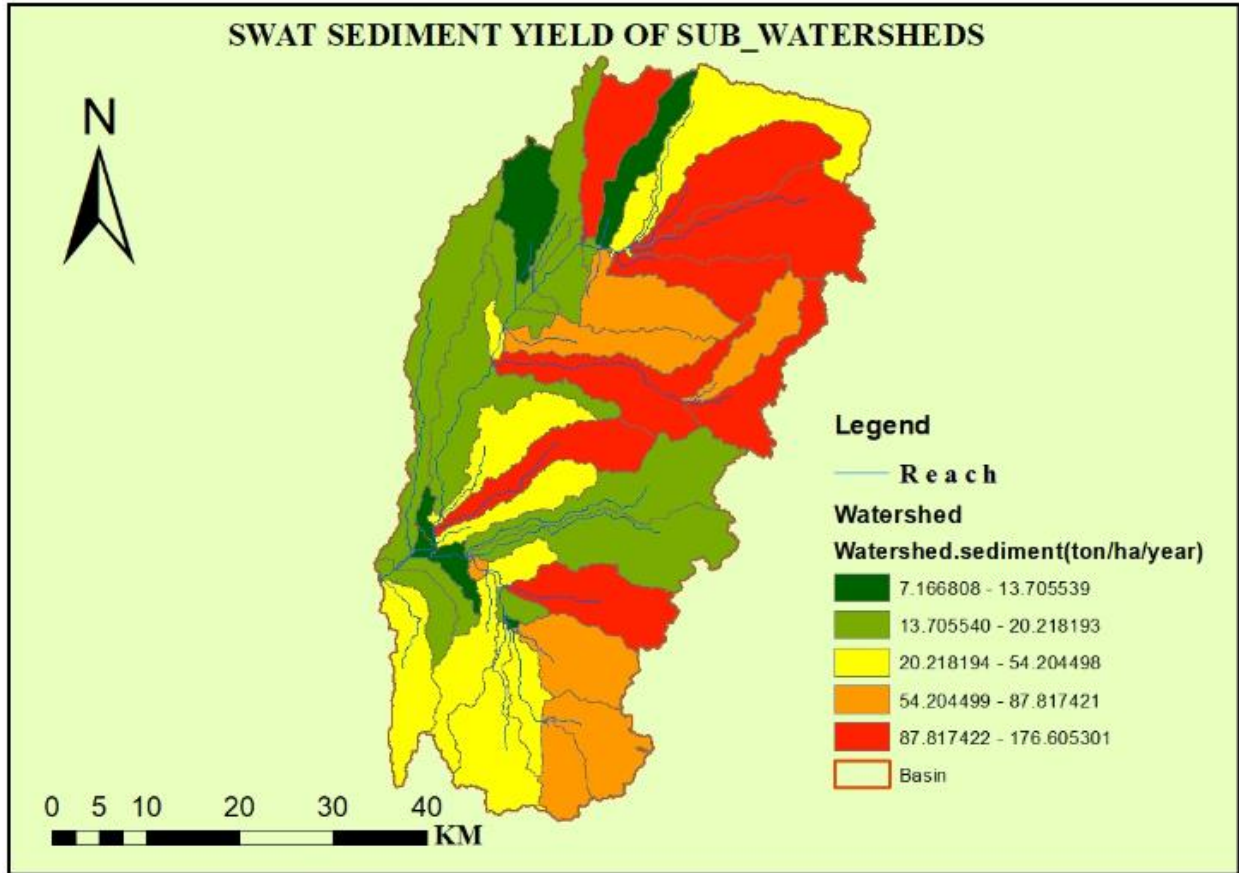


Figure 4. 11. Spatial distribution of sediment yield in Gidabo catchment

After the model calibration and validation of sediment, we identify the model simulation of the spatial sediment distribution on the Gidabo catchment. Table 4.13 below shows the spatial distribution of sediment in the Gidabo catchment. The most sensitive sub-catchments for erosion which have the maximum annual sediment generation in the sub-catchments are sub-catchments 4, 11,3,40 and 8, both these sub catchments have annual sediment above 100 to/ha moreover, the sub catchments with the minimum annual sediment generation in the study area are sub-catchment 29, 5, 15, 33, 27 and 42 which have annual sediment generation less than 15 ton/ha. Therefore, sub-catchment 4, 11,3,40 and 8, are more erodible areas. The average annual sediment distribution ranges from 7.167 ton/ha to 176.605 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 distribution.

Table 4. 12. Spatial variation of sediment at Gidabo catchment.

Sub-catchment	Sediment distribution ton/ha/year.	Sub-catchment	Sediment distribution ton/ha/yr.
1	44.619	26	105.680
2	104.800	27	13.482
3	119.612	28	32.956
4	176.605	29	7.167
5	9.754	30	20.218
6	15.900	31	86.682
7	74.217	32	15.624
8	112.560	33	12.816
9	45.094	34	17.777
10	38.754	35	19.082
11	134.643	36	70.757
12	17.612	37	19.161
13	17.928	38	18.672
14	87.817	39	36.343
15	12.188	40	114.078
16	16.051	41	19.377
17	17.099	42	13.706
18	62.990	43	39.596
19	31.587	44	76.764
20	82.508	45	38.478
21	105.653	46	54.205
22	105.185	47	70.135
23	17.312	48	67.060
24	36.278	49	39.689
25	40.361		

4.6. Scenarios development for mitigation measure

Analyzing the effect of land use/land cover change on the hydrology and sediment transport is one of the essential parts of this study. To do this it is necessary to develop scenarios that reflect the changes made to the watershed land use.

Scenario analysis is the process of evaluating possible future events through the consideration of alternative possible outcomes. Therefore, when scenario is developed it should be able to present several alternative future developments. The scenarios may be developed based on future land use master plan in the watershed if there is any. But, in the absence of future master plan, the scenarios

can be developed by changing the land use by a specified percentage and quantify the changes caused by the conversion of one land use type to the other.

The main advantage of scenario analysis in the watershed is that it enables us to apply improved management practices and decision-making.

Depending on the watershed area delineated by Arc SWAT and the land use adopted in this study, Gidabo watershed consists of about 83.25% of agricultural land (AGRL and AGRC), 12.52% of forest cover, 1.86 Pasture (grass land), 1.97% forest mixed and 0.39% wetland. The valuable scenario development was made by changing the agricultural land to forest cover by 10%, 20%, 30%, 40%, 50% and e.i. AGRL(40%), AGRC(20%), FRST(10%), PAST(12%), RANG(8%), FRSE(10%) and AGRL(50%), AGRC(5%), FRST(15%), PAST(10%), RANG(5%), FRSE(15%) which reduces low amount of sediment which is 16% and 12% respectively and difficult for application. Moreover, two other operational best Management Practices (OBMP): applying filter strip and terracing were also applied. These scenarios were developed to evaluate the sediment yield change from the watershed. Applying filter strip and terracing (stone bunds) in low slope areas of the catchment could give potential effect of BMPs (Betrie et al., 2011).

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). The USLE practice (TERR_P) factor, the slope length (TERR_SL) factor and curve number (TERR_CN) were adjusted to simulate the effects of terracing. Like filter strip, terracing was also applied the land slope between 0 and 20%.

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 20%. Generally, seven scenarios were selected compared to the baseline i.e. the original land use to evaluate the sediment yield change from the watershed, the reason they selected were they showed more sediment reduction than that of combination of scenarios. In fig. 5.0. The SWAT model simulation shows that the scenarios are: -
So = Original land

Scenario -1_ 10% Agricultural land change to forest mixed land.

Scenario -2 _ 20% Agricultural land change to forest mixed land.

Scenario -3_ 30% Agricultural land change to forest mixed land.

Scenario -4_ 40% Agricultural land change to forest mixed land.

Scenario -5_50% Agricultural land change to forest mixed land.

Scenario -6_ Applying filter strip to agricultural land, forest area and grass land between a slopes of 0 to 20 %.

7. Scenario -7_ applying terracing to agricultural land, forest area and grass land between a slopes of 0 to 20 %.

The results from the simulation was summarized in table 4.14 below.

Table 4. 14. Summary of scenario development result

Scenarios	Average sediment yield (ton/year)	Sediment change (%)
Base-Scenario	47495.558	0
Scenario-1	40443.412	-14.84801268
Scenario-2	37527.487	-20.9873767
Scenario-3	34567.111	-27.22032862
Scenario-4	31565.930	-33.53919588
Scenario-5	28535.568	-39.91950247
Scenario-6	43695.914	-13.000
Scenario-7	45263.267	-4.700

The scenario developed in table 4.14 above shows the percentage of reduction of sediment volume increases when the percentage of agricultural land to forest mixed increases. 50% Agricultural land change to forest mixed land results 40% reduction of sediment volume. The life of community around this study area is depended on agriculture especially irrigation using the natural river and using traditional dams. Therefore applying scenario five which is changing 50% Agricultural land change to forest mixed land as best management strategy is not simply applicable management type because it reduces highly the functional agricultural land. To make balance of the functionality of the agricultural land and reduction of sediment yield, scenario three (30% Agricultural land changed to forest mixed land) preferable best management method. Moreover, applying filter strip and terracing in low slope areas is also taken as operational management method because we can easily apply it without additional complicated technology.

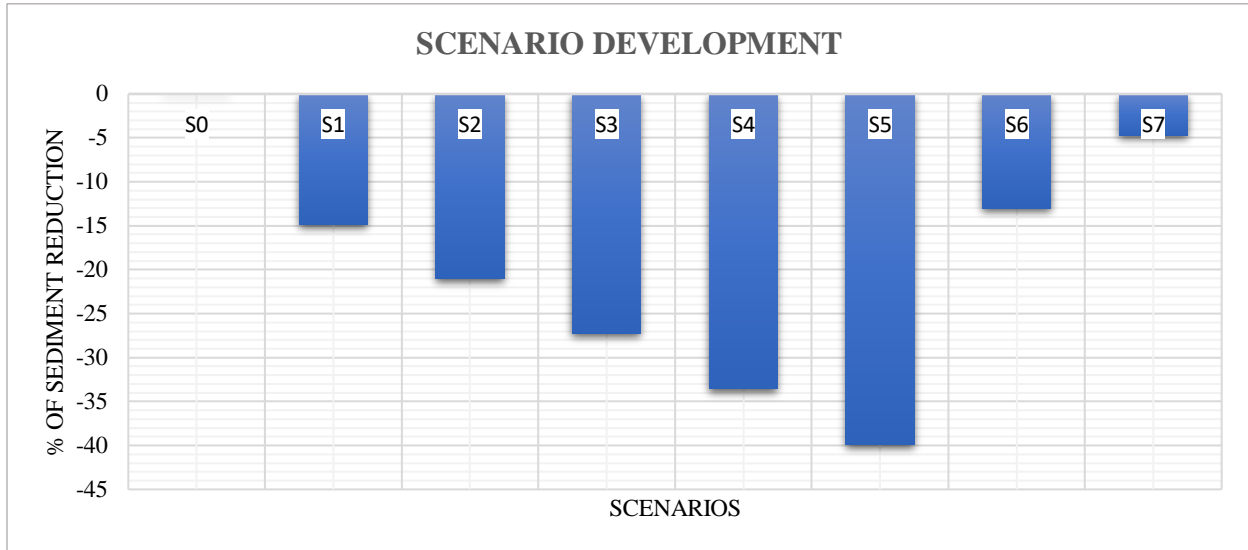


Figure 4. 12. Comparison of change of sediment load.

From simulation of sediment yield using SWAT model, (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 and according to (Tufa 2016) Sediment Management in Reservoir (Gilgel Gibe-I), applying **filter strip** and **terracing** (stone bunds) in low slope areas of the catchment could give potential effect of best management practice.

CHAPTER-FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

In this study, a conceptual, distributed parameter, continuous time, river basin model, SWAT2012 was used to simulate runoff and sediment from Gidabo watershed of rift valley basin Ethiopia. The model operates on a monthly time step and allows a basin to be subdivided into natural sub-watersheds. The objective of this study was to estimate sediment yield from watershed to reservoir using SWAT model and to take and recommend appropriate sediment reduction measures around high sediment producing areas. Arc GIS interface was used to prepare and process a geospatial data required running the model. Automatic calibration of SWAT model using Sequential Uncertainty Fitting version two was used for calibration and validation.

The meteorological data was collected from Ethiopian meteorological agency (EMA) for the years (1990-2017) and the daily stream flow and sediment data was collected from Ministry of Water Irrigation and Electricity (MoWIE) hydrology department for three gauging stations, (Aposto, Bedassa and Maesso). The available stream flow and sediment data for calibration and validation were ten years (1997 to 2006) data. Here multiguage calibration and validation method was used to evaluate the representativeness of the sediment data and stream flow of the whole catchment.

The model calibration for sediment and flow data was carried out for monthly sediment and flow data for both the three gauging stations for the years 1997-2002 and validated for the years 2003-2006 at the three outlets. The flow and sediment data were collected at the outlets of the Aposto, Bedassa and Maesso (flow data only) of sub-watersheds. The average simulated monthly flow and monthly sediment yield by SWAT were compared with the corresponding average values of the observation using graphical and statistical methods. The model performance evolution during monthly stream flow calibration and validation period at the outlet indicated that, $R_2=0.80$, $NS=0.65$ and $R_2=0.85$, $NS=0.81$ respectively. At the same time the model performance evaluation during monthly sediment yield calibration and validation period indicated that $R_2=0.79$, $NS=0.67$ and $R_2=0.79$, $NS=0.67$ respectively. The other two gauging stations found at the upstream the catchment, Aposto and Bedassa also shows good reasonable agreement with measured simulated values. This shows that SWAT has the capability of simulating runoff and sediment for Gidabo watershed.

The study area covers 2634 km² which is subdivided into 49 sub basins, sub basins were further divided into 379 HRU based on 5% land use, 10% soil and 10% slop classification. The Global sensitivity analysis of the SWAT parameters of all the catchment calibrated at the outlet (Maesso) showed that flow is most sensitive to SCS runoff curve number (CN2), Base flow alpha factor for bank (ALPHA_BNK), Average slope steepness (HRU_SLP), Soil evaporation compensation factor (ESCO), Available water capacity of the soil layer (SOL_AWC) and Ground water trap coefficient (GW_REVAP). The sensitivity analysis of the SWAT parameters showed that sediment yield is most sensitive to upland factors such as Average slope steepness (HRU_SLP), Average slope length (SLSUBBSN), Initial residue cover (RSDIN), Channel cover factor (CH_COV2), USLE equation soil erodibility (K) factor (USLE_K), SCS runoff curve number (CN2), Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) and Exponent parameter for calculating sediment re-entrained in channel sediment routing (SPEXP).

Total annual sediment load into the reservoir is 2,512,090 ton/year and annual specific sediment yield into the reservoir is 95.37 ton/km² /year. Spatial and temporal variation of sediment yield is analyzed and the sediment inflow into the reservoir varies from time to time. Sub-catchment, 4,11,3 and 40 respectively generates more sediment when compared to the other sub catchments, this is due to the reason they are agricultural areas and additionally the soil around these areas contain silt materials and the catchments are relatively having steeper slopes from the low slopes. On the other hand, sub catchment 29,5,15 and 33 generates the least sediment from the whole 49 sub catchments. The reason is even if they are agricultural areas they are medium slope as well as small has lower silt content as compared to the more erosive areas.

The sediment mitigation measures are selected according to applicability of the measures, which depends on the life of the society around the catchment and changing agricultural lands to mixed forest lands reduces high amount of sediment inflow to the reservoir more ever, constructing filter strip and terracing have good potential for sediment reduction.

5.2. Recommendations

- ❖ Sediment reduces the lifetime of the reservoirs. Therefore, sediment trap means should be exercised in upstream of the watershed. Stakeholders can achieve this through soil and water conservation program at critical sub basins with vegetation screen upstream of reservoir with continuous follow up.
- ❖ Short period of sediment yield and flow record of observation data was used in this study. Using longer period of runoff and sediment data will improve the calibration result.
- ❖ Sediment has socio-economic, environmental and geomorphological impacts, therefore; changes in sediment quantity and quality can have significant implications and impacts on a range of social, economic and environmental systems. It is, therefore important to study the socio-economic and environmental impacts that will be involved before monitoring sediment measure is applied
- ❖ It is important to incorporate more hydrological gauging stations to improve the quality of sediment and rainfall data around critical sub-catchments.
- ❖ Stakeholders should take decision on the sub-catchments that produce the highest sediment (sub catchments, 4,11,3 and 40) by intervention strategies such as land slope stabilization, construction of terraces, filter strip in low slopes, changing the land use of steep area to forest mixed and afforestation.
- ❖ 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 data is better for representativeness of these data and for better result.

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Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

APPENDIXES

A - TABLES

Table-A-1-Total Monthly PCP of Dilla

A-1-Total Monthly PCP of Dilla													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	13.20	199.10	169.00	151.70	159.40	53.70	41.60	108.90	136.30	90.60	59.30	25.30	1208.10
1991	72.30	71.20	117.70	181.60	201.50	138.70	133.00	123.80	134.60	102.20	8.60	45.30	1330.50
1992	14.10	46.20	54.50	202.60	175.70	148.00	101.00	99.90	213.00	220.60	54.10	49.70	1379.40
1993	103.10	146.60	87.50	166.80	358.80	127.80	33.60	80.50	119.10	157.10	50.50	17.60	1449.00
1994	1.30	10.20	137.90	385.10	141.60	107.50	255.40	173.40	133.20	92.70	37.80	0.80	1476.90
1995	0.10	55.40	76.20	272.50	179.70	66.00	151.50	124.20	181.50	173.70	42.40	18.40	1341.60
1996	87.60	41.20	158.10	281.70	253.10	230.90	128.50	172.80	226.70	85.20	34.40	5.90	1706.10
1997	98.40	5.30	16.30	231.40	299.30	133.50	143.00	84.20	146.70	215.80	241.60	69.70	1685.20
1998	90.10	44.70	109.90	180.50	253.60	74.60	70.00	162.60	82.50	165.10	142.80	5.40	1381.80
1999	12.70	19.20	80.40	112.30	262.20	145.50	85.90	42.10	51.90	183.70	127.20	42.50	1165.60
2000	3.30	0.00	1.20	34.20	306.00	195.10	12.60	116.30	95.70	157.10	151.60	63.30	1136.40
2001	13.10	15.70	28.90	105.60	228.00	148.10	191.10	70.50	130.60	164.40	202.80	56.30	1355.10
2002	27.50	38.40	15.50	131.40	146.10	135.90	134.60	36.10	125.90	94.40	58.10	76.70	1020.60
2003	100.50	42.60	45.80	47.30	89.20	152.30	126.10	48.20	72.40	124.20	128.40	77.70	1054.70
2004	67.60	10.80	109.60	44.40	196.30	206.00	60.20	40.80	84.50	115.20	105.70	62.50	1103.60
2005	87.20	43.20	44.60	36.10	59.40	301.70	219.00	70.20	69.10	98.90	152.80	179.20	1361.40
2006	57.30	4.00	15.50	51.40	145.00	186.10	201.20	155.80	52.40	146.50	125.60	282.00	1422.80
2007	113.80	36.00	27.30	62.60	91.80	97.80	289.30	264.70	59.80	252.20	189.50	263.10	1747.90
2008	121.40	0.00	10.50	2.90	480.80	589.10	277.00	138.70	105.30	99.70	100.70	451.70	2377.80
2009	575.80	5.30	0.30	75.30	18.10	90.40	160.00	176.80	58.60	34.20	68.20	176.10	1439.10
2010	130.90	30.70	138.20	18.60	146.60	203.90	227.00	313.70	139.80	92.90	135.50	128.40	1706.20
2011	253.30	6.70	14.30	5.00	799.10	141.40	66.20	304.40	117.50	76.40	159.00	256.60	2199.90
2012	219.40	146.90	80.40	0.00	14.80	30.30	80.70	180.80	186.80	105.10	161.30	123.70	1330.20
2013	226.70	85.20	77.70	117.00	17.00	79.60	195.50	213.20	146.00	117.20	118.20	275.90	1669.20
2014	229.40	187.80	77.00	3.40	8.10	41.40	155.40	108.20	365.30	77.30	96.90	104.70	1454.90
2015	3.70	3.60	63.00	101.40	6.30	0.30	68.00	149.40	109.20	208.60	71.90	90.70	876.10
2016	17.60	0.00	111.90	54.60	18.00	13.50	76.90	85.70	345.20	96.80	124.70	50.60	995.50
2017	0.00	319.00	53.40	91.70	48.20	6.50	39.30	103.00	154.20	252.60	75.30	78.60	1221.80
Total	2741	1615	1923	3149	5104	3846	3724	3749	3844	3800	3025	3078	39597.4

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table-A-2-Average Monthly Precipitation Data of Dilla

Average monthly precipitation data of Dilla												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.43	7.11	5.45	5.06	5.14	1.79	1.34	3.51	4.54	2.92	1.98	0.82
1991	2.33	2.54	3.80	6.05	6.50	4.62	4.29	3.99	4.49	3.30	0.29	1.46
1992	0.45	1.59	1.76	6.75	5.67	4.93	3.26	3.22	7.10	7.12	1.80	1.60
1993	3.33	5.24	2.82	5.56	11.57	4.26	1.08	2.60	3.97	5.07	1.68	0.57
1994	0.04	0.36	4.45	12.84	4.57	3.58	8.24	5.59	4.44	2.99	1.26	0.03
1995	0.00	1.98	2.46	9.08	5.80	2.20	4.89	4.01	6.05	5.60	1.41	0.59
1996	2.83	1.42	5.10	9.39	8.16	7.70	4.15	5.57	7.56	2.75	1.15	0.19
1997	3.17	0.19	0.53	7.71	9.65	4.45	4.61	2.72	4.89	6.96	8.05	2.25
1998	2.91	1.60	3.55	6.02	8.18	2.49	2.26	5.25	2.75	5.33	4.76	0.17
1999	0.41	0.69	2.59	3.74	8.46	4.85	2.77	1.36	1.73	5.93	4.24	1.37
2000	0.11	0.00	0.04	1.14	9.87	6.50	0.41	3.75	3.19	5.07	5.05	2.04
2001	0.42	0.56	0.93	3.52	7.35	4.94	6.16	2.27	4.35	5.30	6.76	1.82
2002	0.89	1.37	0.50	4.38	4.71	4.53	4.34	1.16	4.20	3.05	1.94	2.47
2003	3.24	1.52	1.48	1.58	2.88	5.08	4.07	1.55	2.41	4.01	4.28	2.51
2004	2.18	0.37	3.54	1.48	6.33	6.87	1.94	1.32	2.82	3.72	3.52	2.02
2005	2.81	1.54	1.44	1.20	1.92	10.06	7.06	2.26	2.30	3.19	5.09	5.78
2006	1.85	0.14	0.50	1.71	4.68	6.20	6.49	5.03	1.75	4.73	4.19	9.10
2007	3.67	1.29	0.88	2.09	2.96	3.26	9.33	8.54	1.99	8.14	6.32	8.49
2008	3.92	0.00	0.34	0.10	15.51	19.64	8.94	4.47	3.51	3.22	3.36	14.57
2009	18.57	0.19	0.01	2.51	0.58	3.01	5.16	5.70	1.95	1.10	2.27	5.68
2010	4.22	1.10	4.46	0.62	4.73	6.80	7.32	10.12	4.66	3.00	4.52	4.14
2011	8.17	0.24	0.46	0.17	25.78	4.71	2.14	9.82	3.92	2.46	5.30	8.28
2012	7.08	5.07	2.59	0.00	0.48	1.01	2.60	5.83	6.23	3.39	5.38	3.99
2013	7.31	3.04	2.51	3.90	0.55	2.65	6.31	6.88	4.87	3.78	3.94	8.90
2014	7.40	6.71	2.48	0.11	0.26	1.38	5.01	3.49	12.18	2.49	3.23	3.38
2015	0.12	0.13	2.03	3.38	0.20	0.01	2.19	4.82	3.64	6.73	2.40	2.93
2016	0.57	0.00	3.61	1.82	0.58	0.45	2.48	2.76	11.51	3.12	4.16	1.63
2017	0.00	11.39	1.72	3.06	1.55	0.22	1.27	3.32	5.14	8.15	2.51	2.54

Table-A-3-Dilla monthly average maximum temperature.

Dilla Monthly Average Maximum temperature													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1990	28.40	27.68	27.84	26.84	26.60	25.92	25.22	25.11	26.44	27.44	28.40	28.91	27.06
1991	30.02	30.18	30.58	29.49	27.56	26.48	25.83	26.26	27.18	27.81	29.56	29.52	28.36
1992	30.02	30.05	30.59	29.49	27.56	26.48	25.83	25.34	26.31	26.07	28.15	28.83	27.88
1993	28.97	28.00	29.73	28.72	27.12	25.87	25.26	25.81	26.97	26.25	29.06	29.22	27.58
1994	26.88	26.16	26.85	27.35	26.45	25.79	25.83	25.08	26.69	27.95	27.89	29.01	26.83
1995	29.33	29.19	28.90	27.12	27.14	27.38	25.26	25.39	26.07	26.59	28.62	29.96	27.57
1996	28.04	31.72	28.06	27.20	26.90	25.54	24.39	24.80	25.34	26.48	28.56	29.52	27.19
1997	30.86	32.88	33.32	28.17	27.27	27.41	25.97	26.96	27.63	26.94	27.00	27.73	28.49
1998	28.05	29.85	30.80	30.27	28.31	27.58	26.85	26.48	26.16	25.97	28.28	29.89	28.19
1999	30.87	32.99	29.34	28.82	27.08	26.78	25.32	26.88	26.53	26.24	29.04	30.06	28.30
2000	31.69	33.00	34.01	30.07	28.86	26.78	25.66	26.35	26.83	27.91	28.51	28.34	28.99
2001	29.95	29.94	33.95	30.07	28.86	26.78	25.66	26.35	26.83	27.91	28.51	28.34	28.59
2002	29.93	29.49	30.33	29.47	27.85	26.97	27.43	27.23	27.23	29.99	28.98	29.62	28.71
2003	29.89	33.81	34.65	30.07	28.86	26.78	25.66	26.35	26.83	27.91	28.51	28.34	28.94
2004	29.33	30.00	31.41	26.99	28.22	25.93	26.17	26.79	26.70	27.37	28.20	29.25	28.03
2005	30.75	32.79	31.15	30.13	25.98	26.17	25.49	26.51	26.46	26.46	27.99	29.89	28.28
2006	31.19	30.75	29.61	27.42	27.60	27.26	25.40	25.99	26.66	27.19	27.50	28.06	27.87
2007	29.46	31.04	30.37	28.31	28.26	27.10	26.15	25.74	25.55	27.28	28.20	29.08	28.03
2008	30.68	30.93	31.72	28.46	26.09	25.88	24.64	25.20	26.30	26.31	27.29	29.20	27.72
2009	29.64	30.94	32.34	28.13	27.78	27.27	26.88	27.59	27.18	27.38	29.46	28.17	28.55
2010	29.20	29.45	28.46	27.95	26.84	26.44	25.06	25.59	25.91	27.49	29.45	29.93	27.64
2011	31.04	18.90	32.03	31.74	27.02	25.96	25.94	25.49	25.52	27.29	26.48	28.06	27.19
2012	30.70	31.88	32.38	28.28	27.50	24.79	25.00	26.01	25.43	27.30	28.01	30.12	28.11
2013	30.58	32.30	30.82	27.55	26.35	25.96	24.91	24.99	26.23	26.09	27.19	28.58	27.60
2014	30.17	30.28	30.66	28.57	27.01	26.69	25.96	25.84	27.83	27.65	27.78	28.55	28.05
2015	30.38	31.92	32.01	28.75	27.52	26.58	26.70	28.02	27.53	28.75	29.88	26.95	28.61
2016	30.55	31.93	31.98	28.40	27.20	26.23	25.56	28.32	26.67	27.65	27.98	27.55	28.45
2017	30.79	31.19	32.18	30.05	27.11	26.43	25.64	29.05	29.53	27.75	27.58	28.45	28.55
Mean	29.91	30.34	30.93	28.71	27.39	26.47	25.70	26.22	26.61	27.22	28.23	28.99	28.05

Table-A-4-Dilla average monthly minimum temperature

Dilla Average Monthly Minimum Temperature													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1990	9.77	12.83	13.02	14.36	13.70	12.76	14.36	14.48	12.97	11.92	11.61	12.40	12.85
1991	8.84	11.72	10.12	13.45	12.91	13.25	13.52	13.03	13.03	11.03	9.96	8.51	11.60
1992	8.84	11.54	10.45	13.45	12.91	13.25	13.52	14.57	13.30	13.76	10.98	11.44	12.33
1993	12.13	11.26	10.54	11.96	13.20	13.52	12.38	12.48	12.97	13.78	10.66	11.34	12.19
1994	11.70	9.62	10.56	12.23	13.11	12.70	13.26	11.79	11.78	12.51	11.57	10.95	11.83
1995	10.06	11.42	12.08	7.33	14.57	13.97	14.37	14.58	13.89	12.95	11.02	10.75	12.27
1996	10.97	10.26	12.27	13.49	13.45	14.49	14.06	14.32	13.57	12.63	10.52	9.06	12.43
1997	11.27	7.04	12.91	13.89	12.42	13.17	14.17	13.92	12.75	14.29	14.37	12.86	12.79
1998	13.90	14.02	13.50	14.79	13.64	13.35	15.36	15.32	14.26	14.53	10.01	7.10	13.31
1999	8.37	8.13	12.84	12.23	12.38	12.40	13.79	12.22	12.04	13.66	10.02	8.85	11.43
2000	6.92	7.23	10.44	13.23	13.17	12.65	13.57	13.94	13.33	14.54	11.64	9.60	11.70
2001	11.19	10.17	13.29	13.58	13.55	13.69	14.34	14.85	13.35	13.85	11.34	10.43	12.82
2002	10.67	9.50	13.75	13.49	14.03	14.00	13.49	13.98	13.12	12.96	12.27	13.42	12.91
2003	10.72	9.72	11.15	13.66	13.23	13.12	13.49	13.17	12.75	12.41	11.39	9.36	12.02
2004	11.29	11.32	11.33	14.44	12.86	13.05	13.58	14.46	13.29	12.33	12.72	11.61	12.69
2005	10.13	10.47	13.82	14.06	14.94	13.80	13.90	14.16	13.56	13.64	11.40	7.20	12.60
2006	9.85	12.31	13.32	14.12	13.58	13.91	14.85	14.09	13.98	14.44	13.15	12.68	13.36
2007	12.27	12.29	12.11	13.98	14.34	15.11	14.85	14.11	14.55	12.16	11.94	7.66	12.94
2008	9.30	10.21	11.07	13.73	14.06	13.92	14.95	14.43	14.37	13.80	11.48	9.23	12.55
2009	10.41	11.24	12.47	14.32	14.17	13.19	13.57	13.78	14.20	14.06	11.35	13.51	13.04
2010	11.32	14.81	14.45	15.03	15.70	14.74	15.07	15.39	14.72	13.94	11.09	9.60	13.81
2011	10.03	0.83	12.94	13.76	15.43	15.24	14.73	14.76	14.66	12.95	13.82	9.97	12.50
2012	8.16	8.28	10.80	14.17	13.87	14.55	14.04	14.73	14.35	13.25	12.76	10.45	12.46
2013	10.43	10.61	13.29	14.85	14.13	14.94	15.11	14.56	14.10	14.03	12.91	9.79	13.24
2014	10.52	12.92	10.80	13.13	14.30	13.57	14.45	13.90	14.10	14.03	12.91	9.82	12.86
2015	8.05	9.93	12.26	13.50	14.36	14.49	13.96	13.06	13.05	13.69	13.05	12.21	12.65
2016	13.32	11.61	13.55	16.13	15.02	13.97	15.62	13.06	13.05	13.69	13.05	12.21	13.70
2017	5.76	11.05	12.96	13.70	14.94	13.97	15.65	13.06	13.05	13.69	13.05	12.21	12.76
Mean	10.22	10.44	12.22	13.57	13.86	13.74	14.22	13.94	13.50	13.37	11.86	10.51	12.63

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table-A-5- Pcp stat and dew point results of weather generator meteorological stations.

a) Dilla gauging station

Month												
Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
PCP_MM	97.91	57.68	68.66	112.47	182.28	137.34	132.99	133.89	137.28	135.73	105.63	107.53
PCPSTD	6.87	5.86	5.34	7.37	10.03	8.59	8.17	7.71	8.06	6.99	6.77	7.13
PCPSKW	3.16	4.43	3.71	2.86	2.11	2.73	3.14	2.76	3.11	2.62	2.85	3.05
PR_W1	0.19	0.17	0.24	0.27	0.30	0.34	0.41	0.45	0.47	0.47	0.31	0.26
PR_W2	0.67	0.59	0.54	0.65	0.70	0.64	0.62	0.62	0.67	0.69	0.66	0.68
PCPD	12.39	8.75	11.04	13.50	16.46	15.39	16.86	17.43	18.36	19.25	14.93	14.50
tmp_max	29.91	30.34	30.93	28.71	27.39	26.47	25.70	26.22	26.61	27.22	28.23	28.99
tmp_min	10.22	10.44	12.22	13.57	13.86	13.74	14.22	13.94	13.50	13.37	11.86	10.51
hmd	60.05	60.43	64.96	69.56	70.08	69.57	70.91	70.86	69.64	69.25	65.23	61.26
dewpt	14.31	14.71	16.74	16.73	16.07	15.33	15.32	15.54	15.38	15.65	14.91	14.08

b) Bilate gauging station

MONTH												
Item	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
tmp_max	32.08	33.27	32.81	31.10	29.50	28.44	27.51	27.84	29.20	30.02	31.00	31.66
tmp_min	16.89	17.34	17.27	17.17	16.94	16.71	16.77	16.76	16.35	15.99	15.37	16.35
hmd	51.61	47.92	50.23	57.82	64.14	66.97	70.68	68.34	63.97	60.73	55.74	52.82
dewpt	14.97	14.66	15.03	16.22	16.91	16.87	17.19	16.83	16.49	16.04	15.15	15.02
PCP_MM	28.97	28.38	54.66	115.69	100.68	77.80	89.51	73.15	66.36	83.91	48.80	21.23
PCPSTD	4.03	3.82	4.19	8.15	6.84	6.75	7.51	6.13	5.39	5.85	5.41	2.97
PCPSKW	8.83	5.89	3.57	3.55	3.15	4.13	4.58	4.55	4.39	3.81	5.63	7.69
PR_W1	0.12	0.12	0.25	0.40	0.36	0.24	0.34	0.32	0.42	0.30	0.13	0.08
PR_W2	0.41	0.39	0.52	0.58	0.55	0.42	0.43	0.48	0.47	0.62	0.51	0.41
PCPD	5.18	4.75	10.96	15.21	14.46	9.25	12.04	12.18	13.64	14.50	6.50	4.00

tmp_max = Average dailly maximum temperature in month [°C]

tmp_min=Average dailly minimum temperature in month [°C]

hmd = Average dailly humidity in month [%]

dewpt = average dailly dew point temperature in month [°C]

PCP_MM = Average monthly precipitation[mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = Probability of wet day following a dry day

PR_W2 = Probability of wet day following a wet day

PCPD = average number of precipitation days in a month

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table-A-6-Annual rainfall for selected stations (mm).

Year	Hgereslam	Bilate	Yrgalem	Dilla	Ychefe
1990	1115.40	746.10	1022.90	1208.10	1170.40
1991	1117.40	732.60	1186.50	1330.50	1037.40
1992	1415.20	986.00	1300.60	1379.40	1152.30
1993	1200.10	796.20	1233.90	1449.00	1066.30
1994	1169.90	821.60	1234.00	1476.90	1477.30
1995	1035.60	621.00	1120.70	1341.60	1710.30
1996	1378.20	1082.00	1472.20	1706.10	2080.30
1997	1372.70	849.30	1386.70	1685.20	1175.90
1998	1343.60	632.40	1658.80	1381.80	1057.70
1999	1517.40	493.60	1075.70	1165.60	1170.10
2000	1407.30	616.40	1071.70	1136.40	1245.70
2001	1370.40	536.90	1573.90	1355.10	1444.60
2002	1169.20	520.60	1000.90	1020.60	1229.80
2003	1017.60	851.00	852.50	1054.70	1146.30
2004	1156.00	813.80	858.40	1103.60	1253.50
2005	1428.60	1000.70	1100.80	1361.40	1498.20
2006	1220.70	1032.40	1412.90	1422.80	1471.60
2007	1720.90	953.30	1482.20	1747.90	1704.10
2008	1231.60	787.00	1224.10	2377.80	1386.70
2009	1153.30	685.70	1090.50	1439.10	1461.00
2010	1756.60	1082.30	1227.40	1706.20	1232.10
2011	1755.90	857.90	853.50	2199.90	853.50
2012	1286.00	692.90	1360.80	1330.20	1577.40
2013	1517.40	1215.40	1250.10	1669.20	1506.60
2014	1890.10	833.80	1679.60	1454.90	1880.20
2015	1475.40	692.20	1075.50	876.10	1129.40
2016	1513.20	677.20	1281.80	995.50	1233.10
2017	1533.20	634.60	1096.70	1221.80	1003.70
Total	38268.90	22244.90	34185.30	39597.40	37355.50

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table-A-7-Simulated average annual basin values

Basin average annual values							
Year	PRECIP-mm	WYLD-mm	SURQ-mm	SYLDt_ha	ET-mm	PET-mm	SW-mm
1992	111.97	45.41	25.49	2.58	63.06	103.26	139.96
1993	109.78	48.08	30.25	3.39	61.34	102.44	142.76
1994	110.57	52.82	33.84	3.52	56.41	100.57	137.40
1995	99.94	41.91	26.47	2.85	53.47	102.07	137.76
1996	129.81	70.30	41.90	6.71	58.32	100.19	152.87
1997	125.67	63.51	38.42	7.60	53.69	93.83	143.59
1998	122.91	68.24	39.20	8.32	58.05	99.13	150.33
1999	96.52	40.73	19.97	4.58	53.74	100.81	140.50
2000	94.38	41.65	22.46	5.38	49.60	102.65	134.12
2001	119.13	59.81	32.34	7.53	56.70	101.10	143.29
2002	85.05	29.08	16.52	4.20	54.51	104.06	139.21
2003	80.29	22.96	13.77	3.55	55.57	103.77	131.39
2004	83.67	26.89	17.00	3.43	56.83	101.01	136.25
2005	104.66	43.82	25.35	5.19	55.43	100.19	139.78
2006	115.50	53.78	30.89	7.19	56.88	100.04	146.96
2007	134.99	75.05	41.84	11.00	59.17	97.60	150.07
2008	144.51	86.91	57.48	10.85	53.60	99.40	147.88
2009	103.87	51.50	29.56	8.82	54.01	102.71	139.29
2010	125.35	68.71	38.52	8.97	55.01	91.10	153.24
2011	130.72	76.51	49.33	9.92	50.94	97.82	143.75
2012	110.36	60.30	28.76	10.48	49.09	91.01	137.92
2013	122.52	65.33	37.25	9.10	53.07	89.53	150.72
2014	132.27	77.84	36.57	10.26	55.37	90.05	147.36
2015	85.59	37.48	18.43	5.26	46.92	91.62	135.09
2016	97.44	49.21	27.25	7.41	46.78	90.03	135.13
2017	107.27	55.34	35.17	9.16	49.26	98.87	139.69
Mean	110.95	54.35	31.31	6.82	54.49	98.26	142.17

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

Table-A-8-Simulated average monthly basin values

Average monthly basin values							
Month	PRECIPmm	SYLDt_ha	SURQmm	SNOW fall mm	PETmm	WYLDmm	ETmm
Jan	63.39	6.92	20.26	0.00	106.43	35.21	35.95
Feb	39.05	3.96	9.88	0.00	104.04	18.70	31.44
Mar	77.62	3.50	12.17	0.00	113.88	19.25	63.98
Apr	139.62	7.03	31.81	0.00	105.09	41.68	74.05
May	179.93	9.37	54.88	0.00	100.24	76.29	69.80
Jun	121.75	5.33	35.69	0.00	90.95	64.48	55.92
Jul	122.65	5.07	34.02	0.00	88.25	62.12	55.58
Aug	136.63	7.61	37.73	0.00	89.26	66.84	59.06
Sep	138.99	8.41	39.04	0.00	89.94	69.74	58.81
Oct	161.09	11.84	49.39	0.00	94.24	86.96	60.55
Nov	78.52	5.93	24.89	0.00	95.47	59.97	46.53
Dec	72.15	6.83	25.95	0.00	101.38	51.00	42.24
Mean	110.95	6.82	31.31	0.00	98.26	54.35	54.49

Table-A-9- HRU analysis report

SWAT model simulation Date: 10/4/2018 12:00:00 AM Time: 00:00:00			
MULTIPLE HRUs LandUse/Soil/Slope OPTION		THRESHOLDS : 5 / 10 / 10 [%]	
Number of HRUs: 379			
Number of Subbasins: 49			
		Area [ha]	Area[acres]
Watershed		263415.9484	650913.9793
LANDUSE:		Area [ha]	Area[acres] %Wat.Area
	Agricultural Land-Generic --> AGRL	135080.6582	333791.0605 51.28
	Agricultural Land-Close-grown --> AGRC	84608.0224	209070.6539 32.12
	Pasture --> PAST	4886.1464	12073.9122 1.85
	Forest-Evergreen --> FRSE	33437.2912	82625.2184 12.69
	Wetlands-Non-Forested --> WETN	574.4422	1419.4753 0.22
	Forest-Mixed --> FRST	4829.3879	11933.6590 1.83
SOILS:			
	Ne10-3b-154	206703.2497	510774.0653 78.47
	Xh17-2a-310	10616.5899	26234.1245 4.03
	Be49-3c-20	45785.1873	113137.4872 17.38
	Af14-3c-1	310.9214	768.3024 0.12
SLOPE:			
	10-15	55758.1435	137781.1606 21.17
	5-10	75808.5514	187326.7210 28.78
	0-5	41045.8205	101426.2747 15.58
	20-9999	63059.0588	155822.0873 23.94
	15-20	27744.3741	68557.7356 10.53

B – FIGURES

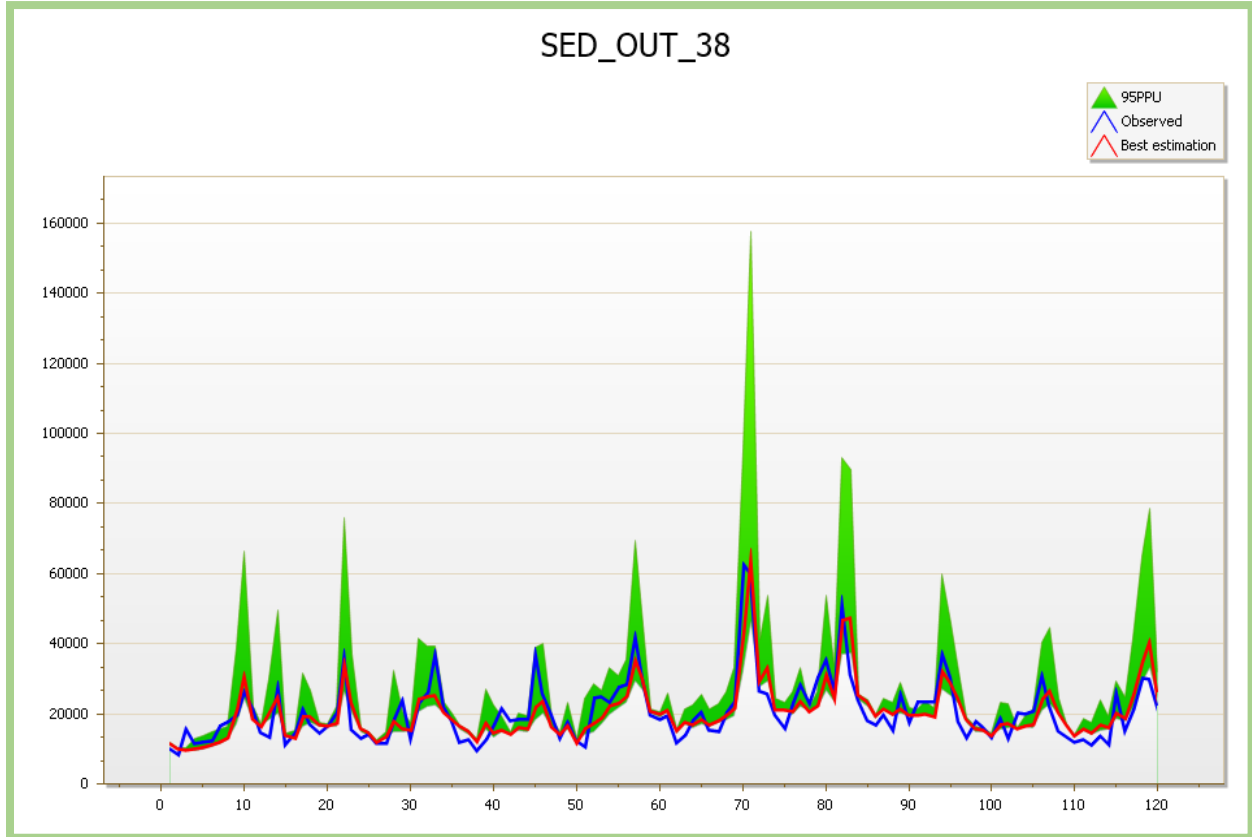


Figure-B-1-Sensitivity Analysis Result at Dam Outlet (Maesso Gauging Station).

Estimation of Catchment Sediment Yield using SWAT Model (Case Study Gidabo Dam, Rift Valley Basin, Ethiopia)

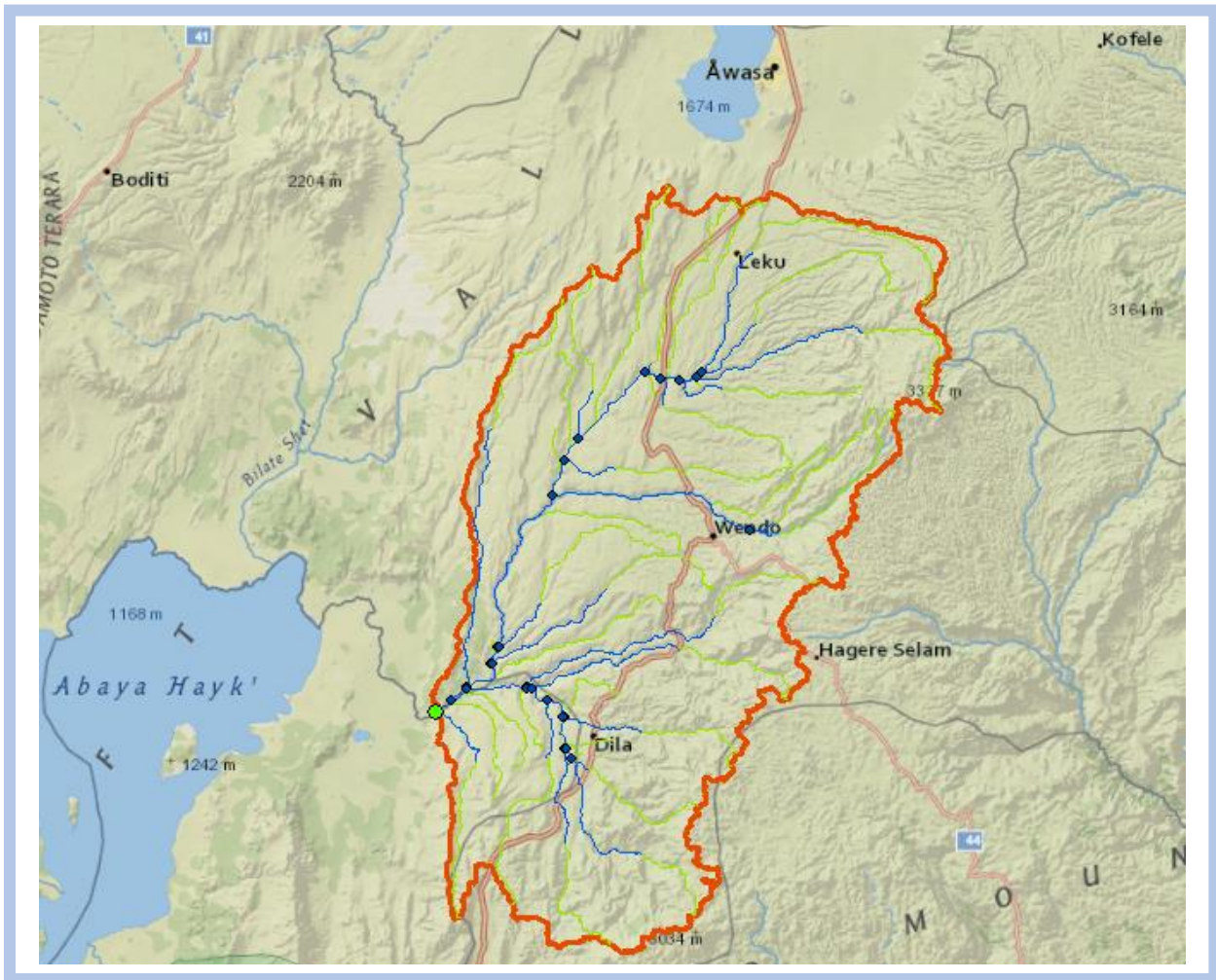


Figure-B-2-Base map of the delineated Gidabo catchment and nearby.

Figure-B-3-Maximum and minimum temperature of selected meteorological stations.

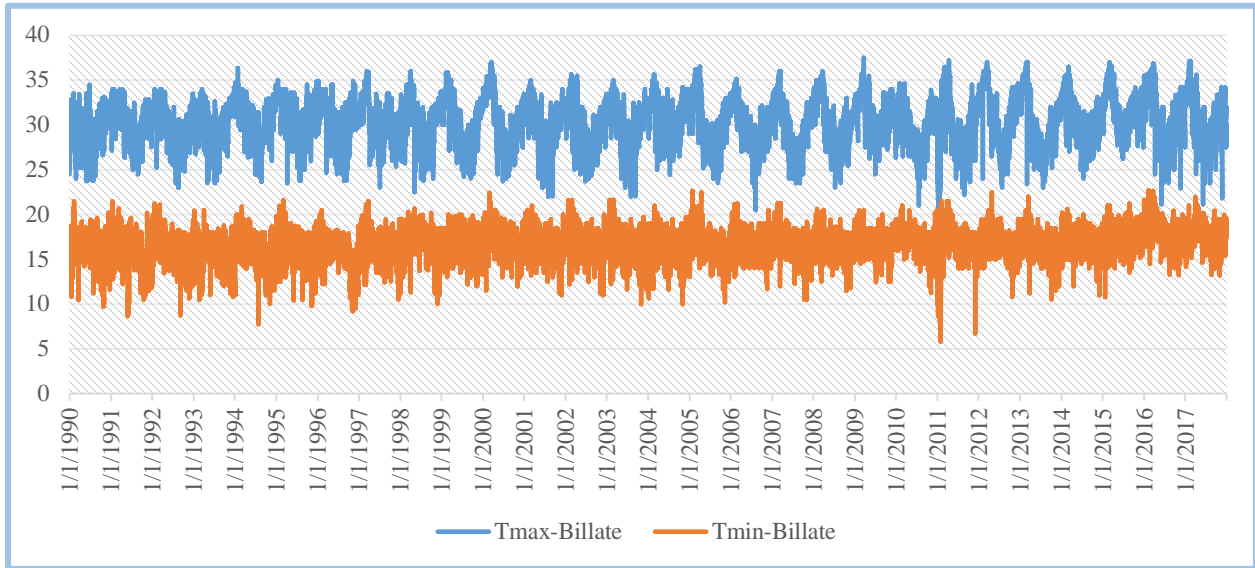


Figure-B-3.1- Maximum and Minimum Temperature of Bilate M. Station.

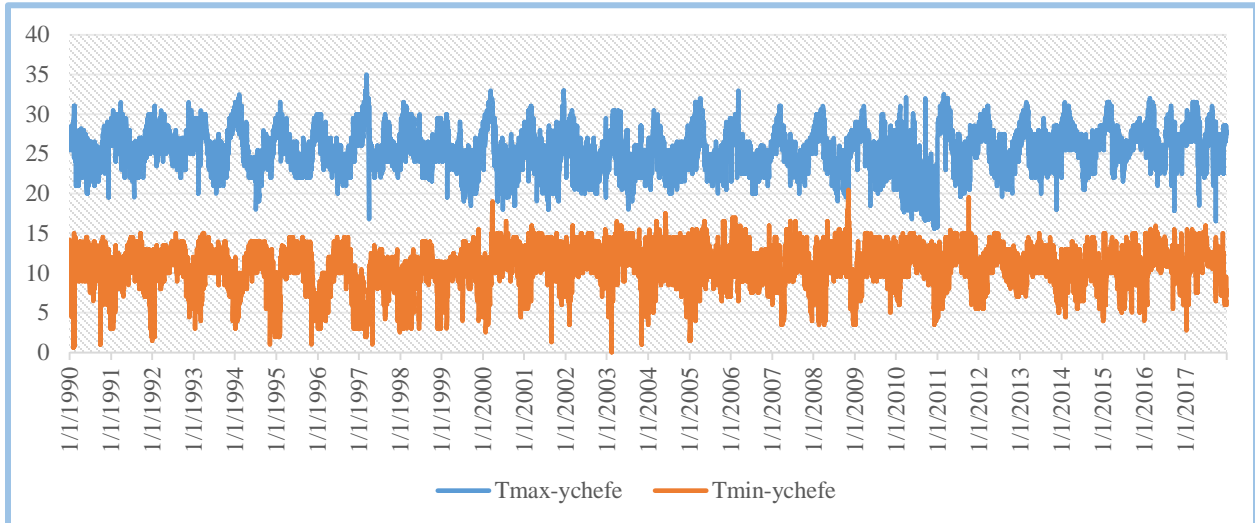


Figure-B-3.2- Maximum and Minimum Temperature of Y.chefe M. Station.

