JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

SEDIMENT YIELD MODELING IN AWASH MELKASA DAM WATERSHED, UPPER AWASH RIVER BASIN, ETHIOPIA

A THESIS SUBMITTED TO THE CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING, JIMMA INISTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

By
BAYISA ITANA DABA

FEBRARY, 2019

JIMMA, ETHIOPIA

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BAYISA ITANA DABA

Main advisor: Dr.-Ing. Tamene Adugna (PhD)
Co-advisor: Mr. Fayera Gudu (MSc)

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APPROVAL

The thesis entitled "**Sediment Yield Modeling in Awash Melkasa Dam Watershed, Upper Awash River Basin, Ethiopia**" submitted by Bayisa Itana Daba is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

	Name	Signature	Date
Advisor:	Dr.-Ing Tamene Adugna	___________	___________
Co-Advisor:	Mr. Fayera Gudu (MSc.)	___________	___________

As members of the examining board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by Bayisa Itana Daba. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

	Name	Signature	Date
External Examiner:	Dr. Zelalem Biru	___________	___________
Internal Examiner:	Mr. Berhan Tekuam (MSc.)	___________	___________
Chairman:	Mr. Megersa Kebede (MSc.)	___________	___________

DECLARATION PAGE

I, the undersigned, declare that this thesis: Sediment yield modeling in Awash Melkasa dam watershed, Upper Awash river basin, Ethiopia is my original work, and it has not been presented for a degree in Jimma University or any other university and that all source of materials used for the thesis have been fully acknowledged.

Submitted by:

Bayisa Itana (BSc) ____________ ________________

Signature Date

This thesis has been submitted for examination with my approval as University Supervisor.

Approved by:

Main advisor: Dr.-Ing. Tamene Adugna ___________ ____________

Signature Date

Co-Advisor: Mr. Fayera Gudu (MSc) _____________ ____________

Signature Date

ABSTRACT

Soil erosion is the major problem on the Ethiopian highlands. Upper Awash River Basin is one of the Ethiopian highlands which are affected with the high rate of surface erosion and sediment transport in the river system that contributes to increased sedimentation problems in the reservoirs. In order to develop alternative watershed management practices, sediment inflow rates of reservoir and spatial distribution of sediment yield are required at the sub basin level. Hence, this study aimed at estimating sediment yield in upper Awash River basin by using the soil and water assessment tool (SWAT). The main input data that was collected and for this study involves spatial (Digital Elevation Model, soil and land use land cover), weather (daily rainfall, minimum and maximum temperatures, precipitation, relative humidity, wind speed and Sunshine hour), hydrological (stream flow and sediment concentration), reservoir input (reservoir surface area when the reservoir is filled to the emergency and principal spill way, Volume of water needed to fill the reservoir to the emergency and principal spill way)and water abstraction (for irrigation and water supply) data. In order to address the objectives of the study, the collected data quality has been done by using double mass curve and Rainbow test. After the quality of each data checked, the input data was prepared as per the requirement of SWAT model. Then Arc SWAT 2012, with an interface in ArcGIS 10.1, was used to setup the model in this work. From the generated output of SWAT and observed hydrological data, sensitivity analysis, calibration and validation were followed using SWAT-CUP to evaluate the model performance. During sensitivity analysis, 24 parameters were tested for flow and 14 sediment parameters were analyzed. The first seventeen parameters showed a relatively high sensitivity from the flow parameters. In similar way, from sediment sensitivity analysis, the first seven were highly sensitive and given to high priority for calibration. The model was calibrated from 2004-2009 and validated from 2010-2013 for both flow and sediment at Wonji gauging station. Graphical comparisons and the statistical measures of coefficient of determination (R^2), Nash-Sutcliffe efficiency (ENS), Root mean Square Error Standard Deviation Ratio (RSR)) and percent bias (PBIAS) were used to evaluate the performance of the model. The results of the model calibration and validation showed reliable estimates of monthly stream flow (with R^2= 0.78, NSE = 0.75, PBIAS = 8.8 and RSR = 0.5) and (R^2= 0.83, NSE = 0.79, PBIAS = 0.1 and RSR = 0.45) respectively. Similarly, SWAT performed well (with R^2= 0.82, NSE = 0.82, PBIAS = 5 and RSR = 0.43) and (R^2= 0.78, NSE = 0.76, PBIAS = 4.9 and RSR = 0.49) during Sediment calibration and validation respectively. After calibration has performed the simulated average annual sediment yield estimated was 22,109.5ton/yr. at the outlet, with an average spatial distribution of 6.52 ton/ha/yr. The model prediction results indicated that about 26.16 % of the Awash Melkasa watershed is erosion potential area with an average annual sediment load ranging from 10 to 18.54 ton/ha/yr exceeding tolerable soil loss rates in the study area.

Key words: Calibration, sediment yield, spatial variability, SWAT model, validation

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ABBREVIATIONS

BMC	Billion meter cube
Cumecs	Meter cube per second
DEM	Digital Elevation Model
GIS	Geographical Information System
HBV	Hydrologiska Byrans Vattenbalansavdelning
HEC-HMS	Hydraulic Engineering Centre- Hydrologic Modeling System
HRU	Hydrologic Response Unit
LULC	Land use land cover
MoWIE	Ministry of Water, Irrigation and Electricity
MUSLE	Modified universal soli loss equation
NMSA	National Meteorological Service Agency
NSE	Nash Sutcliff Efficiency
PBIAS	Mean Relative Bias (Percent Bias)
RUSLE	Revised universal soli loss equation
SCS	Soil Conservation System
SUFI2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
USLE	Universal soil loss equation
UTM	Universal Transverse Mercator

CHAPTER ONE: INTRODUCTION

1.1 Background

Land and water resources degradation are the major problems on the Ethiopian highlands. 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 (Setegn et al., 2008). 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. Soils whose particles are strongly bound together, mainly soil textures with a higher clay percentage are less prone to the detachment processes. 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 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 (Geleta, 2011).

The Awash River which flows through a number of natural sediment sinks before entering the reservoir starts its journey from the highlands of Ethiopia (Asmelash, 2015). The high rate of surface erosion in the Awash River Basin and the rate of sediment transport in the river system contribute to increased sedimentation problems in the reservoirs, water conveyance channels, river morphology as well as the cropland areas (Halcrow, 1989; Wasu, 2017). The selected watershed, Awash Melkasa dam watershed, is one of the sub-watersheds of Awash Basin. As the result of rapid soil degradation and massive soil erosion from this watershed the middle part of this watershed is already taken out of cultivation due to an area is desiccated by gully (Gonfa and Kumar, 2016). Hence, proper utilization of the available soil and water resources are essential to reduce these problems. Proper utilization of soil and water resources requires knowledge, basic understanding of the hydrologic system and the processes influencing them both spatially and temporally. A comprehensive understanding of hydrological processes in the watersheds is a prerequisite for successful watershed management and environmental restoration. Due to the spatial and temporal heterogeneity in soils properties, vegetation and land use practices a hydrological cycle is a complex system. As a result, mathematical models and geospatial analyses tools are required for studying hydrological processes and hydrological responses to land use and climatic changes (Checkol et al., 2007).

Spatial analysis of sediment yield is useful for modeling of watershed erosion and sediment yield for identification of critical erosion prone areas and the source of sediment yield. Various erosion and sediment yield prediction methods are available, which can be supposed to apply various possible conditions, even though all methods have advantages and limitations. Each method infers runoff and water quality based on watershed characteristics, ecological considerations, site conditions, engineering requirements, availability of time, and data requirements and data availability. Empirical models like Universal Soil Loss Equation (USLE) or a modified version such as Modified Universal Soil Loss Equation (MUSLE) and Revised Universal Soli Loss Equation (RUSLE) has been widely used in most empirically based models (Wasu, 2017).

During recent decades, studies and simulation models have been developed around the world in order to estimate, analyze or predict runoff, soil erosion, sediment yield and to relate the spatial variability of land characteristics to runoff generation and erosion. Many attempts have been made to develop predictive erosion models; the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is one of them. The application of this model in several countries including Ethiopia has shown promising results in the assessment of erosion, runoff and sediment yield, under a wide range of soil types, land uses and climate conditions.

The Arc SWAT ArcGIS extension is a graphical user interface for the SWAT (Soil and Water Assessment Tool) model (Arnold et al., 1998). SWAT is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts (Winchell et al., 2013).

Physically based models are 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, the result can be taken as a representative value and can be used for further analysis. The reliability of the results of physically based models depends on the quality of the hydrological, climatic and spatial input data. The presence of erroneous 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.

Therefore, this study has initiated to estimate the sediment yields, identify the critical source area of soil erosion and map its spatial variability in the Awash Melkasa Dam watershed using Soil and Water Assessment Tool (SWAT) model with Geographic Information System (GIS) interface.

1.2 Statement of problem

Soil erosion is a serious problem affecting the quality of soil, land and water resources upon which man depends for his sustenance. Today, soil erosion is universally recognized as a major environmental and agricultural problem. Because, as the top soil is eroded by erosion agents such as water, wind, avalanches, its fertility and nutrient content decreases. This eventually results in the loss of productivity. Loss of the organic matter rich surface soil (topsoil) is known to decrease soil quality, which in turn reduces productivity (Verity and Anderson, 1990; Lemma, 2015). Another major problem caused by erosion is sedimentation of reservoirs. Reservoirs are the main destination of the sediment eroded from upland area. Since the velocity of water in the reservoir is very low, sediments get deposited in the reservoir unless there is a facility to avoid the settlement. The sedimentation of reservoirs causes another serious problem by decreasing the capacity of reservoirs. The loss in capacity of reservoirs increases the risk of supply failure (which cannot perform as designed) and this is often undesirable.

In Awash River Basin, reservoir sedimentation is considered as a critical problem. According to Katherine (2017) sedimentation was noted as a basin-wide problem by experts at the Awash Basin Authorities. Specifically, Koka reservoir which is located upstream of Melkasa dam faces a sedimentation challenge which has resulted in a 40 % loss of storage capacity (Geleta, 2011). Moreover, accelerated wearing of hydropower equipment due to siltation and removal of siltation from the irrigation channel increases operation cost every year. It is believed that if it continues with the present rate of sedimentation the reservoir will not be able to function effectively after some decades in the future. Other impact of siltation is the reduction of the active storage volume resulting in loss of reservoir capacity to regulate water supply for irrigation and flood control service at the downstream. This in turn resulted in breakage of dikes and flooding of Wonji sugar plants and downstream villages that have become common phenomena every year in the downstream of Awash basin (Gonfa and Kumar, 2016). In addition, the current capacity of Melkasa reservoir, located on the main river, but below Koka reservoir, has reduced to the level that it can no longer store the required amount due to heavy siltation (Tsegaye, 2009, cited in Wasu, 2017).

In order to develop alternative watershed management practices, to alleviate the recognized problem, quantitative data (sediment inflow rates of reservoir) and spatial distribution of sediment yield were required at the sub basin level. Because there was no reliable prediction of sediment yield available at Melkasa reservoir that can help in the sustainable development of land and water resource of the area.

Generally, reduction in the soil production capacity, reservoir siltation, change in river bank and flooding due to sediment deposition were problems calling for sediment yield estimation and identification of critical source areas in upper Awash River Basin.

1.3 Objectives

1.3.1 General objectives

The general objective of the study is to model sediment yield in upper Awash River Basin using a semi distributed soil and water assessment tool (SWAT) for the case of Awash Melkasa dam watershed.

1.3.2 Specific objectives

- To evaluate the performance of SWAT model in sediment yield estimation in the Awash Melkasa watershed
- To determine the rate of sediment inflow to the reservoir per year
- To identify the most erodible sub basin and to map the spatial variability based on their sediment delivery to the reservoir

1.4 Research questions

1. Is SWAT model well perform in sediment yield estimation in Awash Melkasa watershed?

2. What is the rate of sediment inflow to Melkasa reservoir?

3. Which sub basins of Awash Melkasa watershed is most erodible?

1.5 Significance of the study

This study can provide the following significances. Firstly, this study will be useful as an input for the designers and policy makers to take appropriate measures or conduct effective land and water management intervention for sediment yield reduction at Awash Melkasa reservoir, by giving priority to the severely eroded sub basins of the watershed. Secondly, the results of the study can also be used by researchers and development practitioners as baseline information for further studies that could be conducted in the study area or related problems.

1.6 Scope of the study

The study mainly focuses on the application of SWAT model for the Melkasa reservoir watershed for characterization and quantification of sediment yield. In addition to this, identifying and mapping of sediment prone areas according to their relative severity is the scope of the study. However, this study does not include soil and water resources management scenarios, land use/cover dynamics in relation to sediment yield, but it will be a great in light to develop management scenarios, especially on the erosion hot spot areas or sub basins.

CHAPTER TWO: LITTRATURE REVIEW

2.1 Soil erosion and sedimentation

Soil erosion is the detachment and transportation of soil particles from their original place to further downstream by erosion agents such as water and wind. It is one of the normal aspects of landscape development. The severity of erosion increases with the decrease in cover material most likely vegetation. The vegetation cover decreases the soil erosion by decreasing the impact of raindrops that cause the detachment of the soil particles. Therefore, bare soil is more likely to be eroded by different soil erosion agents than soil with vegetation cover.

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; Julien, 1998). Spatial and temporal information on runoff, soil erosion, and sediment yield of a catchment can provide a useful perspective on the availability of water, rate of soil erosion, and soil loss in the catchment. The dynamics of the processes of soil erosion and sediment yield are influenced by the spatial and temporal characteristics of the input variables affecting them and by controls exerted by the land surface (Wischmeier and Smith, 1978; Wubetu, 2014). The major forces originate from raindrop impact and flowing water. The mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. 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 (Wubetu, 2014).

Soil erosion is influenced by several factors; which include rainfall erosivity, soil erodibility, topography, land cover and management factors (Wischmeier and Smith, 1978). The soil particles of major interest are in the silt and clay ranges. Rainfall characteristics play a major role in determining sediment yield in the upland phase. Major factors affecting the yield in this phase are: soil characteristics, climate, vegetation, topography and human activities.

2.2 Spatial variability in sediment yield

The process of erosion and the delivery of sediment to the exit of a basin is never a spatially uniform process. When virtually any landscape unit is examined, at any scale, there may be large variations in the specific sediment yields. The large variability in specific sediment yield worldwide was summarized by (Jansson, 1988; Asmelash, 2015) in an analysis of suspended sediment data from 1358 gaging stations with tributary watersheds between 350 and 10,000 km^2, and totaling 16 × 10^6 km^2 of land area. Stations were divided in six yield classes. The highest yield class, with specific sediment yields exceeding 1000 t/km^2/yr., represented only 8.8 percent of the total land area in the global dataset but contributed 69 percent of the total sediment load. In contrast, basins with specific yields less than 50 t/km^2/yr. constitutes nearly half the total land area but contributed only 2.1 percent of the total sediment yield.

2.3 Overview of Hydrological Models

According to Sharma et al. (2008), a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behavior and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model.

Hydrological models are tools that describe the physical processes controlling the trans-formation of precipitation to stream flows. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. The focus of these models is to establish a relationship between various hydrological components such as precipitation, evapotranspiration, surface runoff, ground water flow and soil water movement (infiltration). Many of these hydrological models describe the canopy interception, evaporation, transpiration, snow-melt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated subsurface flow. These models range from simple unit hydrograph based models to more complex models that are based on the dynamic flow equations (Setegn et al., 2008).

The current review followed the classification system outlined in Wheater *et al*. (1993) and classifies hydrological models based on their structure (metric, conceptual, physics based, and hybrid), spatial representation (lumped, semi-distributed and distributed), process (deterministic and stochastic), time-scale and space-scale. Classifications of hydrological model based on spatial representation are discussed as below.

a) **Lumped models** treat the catchment as a single unit, with state variables that represent averages over the catchment area (Beven, 2001; Pechlivanidis, 2011). In general a lumped model is expressed by differential or empirical algebraic equations, taking no account of spatial variability of processes, inputs, boundary conditions and system (catchment) geometric characteristics (Singh, 1995).

The Hydrologic Simulation Program FORTRAN (HSPF) (Johanson et al., 1984), is an example of the lumped models. HSPF is the modification of the Stanford Watershed model (SWM), probably the first physically based model capable of simulating the entire hydrological cycle at the watershed scale. In HSPF, the watershed is subdivided into land segments, based on land use. These non-spatially explicit segments have uniform characteristics and are either pervious or impervious. The tool requires an extensive calibration and is not user-friendly (Pandey et al., 2016; Naomi, 2017).

b) Distributed models make predictions that are distributed in space, with state variables that represent local averages, by discretizing the catchment into a number of elements (or grid squares) and solving the equations for the state variables associated with every element (Singh and Frevert, 2006). Distributed models hence are capable to some extent of taking into account spatial variability in processes, inputs, boundary conditions, and catchment characteristics. However, all distributed models use average variables and parameters at element or grid scales, and often parameters are averaged over many grid squares, mainly due to data availability (Beven, 2001; Pechlivanidis, 2011). Some examples of distributed models are The Annualized Agricultural NonPoint Source model (AnnAGNPS) and The European Hydrological System (MIKE SHE).

The Annualized Agricultural NonPoint Source model or AnnAGNPS, to begin with, was developed based on the single event Agricultural NonPoint Source model (AGNPS) (Young et al., 1987). This was done with the philosophy of maintaining AGNPS' simplicity while adapting it to continuous long-term simulations. The study area is represented by homogeneous drainage areas or cells. Because of this distributed representation, the study area is said to be limited to 3,000 km^2 (Bingner et al., 2015; Naomi, 2017).

The European Hydrological System or MIKE SHE uses a distributed structure by dividing the watersheds into rectangular or square grids, each consisting of several horizontal layers. This structure, combined with detailed process descriptions and multi-dimensional flow equations, makes the developed model computationally and data intensive (El-Nasr et al., 2005; Naomi, 2017).

c) Semi-distributed models have been suggested to combine the advantages of both types of spatial representation. This type of model does not pretend to represent a spatially continuous distribution of state variables; rather it discretizes the catchment to a degree thought to be useful by the modeler using a set of lumped models. A semi-distributed model can therefore represent the important features of catchment, while at the same time requiring less data and lower computational costs than distributed models (Orellana *et al*., 2008). SWAT, HEC-HMS and HBV are considered as semi-distributed models.

According to Cunderlik et al. (2003) semi-distributed models are mainly differentiated based on model type, the model objectives, the spatial scale they represent and cost. SWAT and HEC-HMS are physical based models types, because it tries to simulate the internal mechanisms of the system using a theoretical approach without using major simplifications. But HBV is conceptual based model types, because they simulate physical processing using major simplifications. Each physical component of the system or process is modelled in a simplified manner. And also the other characteristics of the above semi-distributed models are compared in table 2.1.

Table2.1 Comparison of three selected semi-distributed models

Description	SWAT	HEC-HMS	HBV
Model type	Semi-distributed Physically-based	Semi-distributed Physically-based	Semi-distributed Conceptual model
Model Objective	Predict the impact of land management practices on water and sediment	Simulate the rainfall runoff process of watershed	Simulate rainfall runoff process and floods
Spatial scale	Medium +	Flexible	Flexible
Cost	Public domain	Public domain	Public domain

(Source: Cunderlik et al., 2003)

2.4 Soil and water assessment tool (SWAT) model

2.4.1 Overview of the model

SWAT is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods (Gassman et al., 2007).Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. The model is based on a command structure that distributes runoff, sediment and agrochemicals across the basin (Duraes et al., 2011).

In SWAT, a watershed is divided into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub watershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub watersheds that are characterized by dominant land use, soil type, and management (Gassman et al., 2007).

Daily rainfall data, maximum and minimum air temperature, solar radiation, relative air humidity and wind speed are the inputs used by this model and are able to describe water and sediment circulation, vegetation growth and nutrients circulation. Based on amount of precipitation and mean daily air temperature rate of snowfall can be determined. Penman Monteith, Priestly-Taylor and Hargreaves methods are used for the estimation of evapotranspiration.

2.4.2 Hydrological component of SWAT

Simulation of hydrology of a watershed is done in two separate components. These are land phase of hydrologic cycle and routing phase of the hydrological cycle. The land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapo-transpiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow.

In order to obtain accurate forecasting of water, nutrient and sediment circulation, it is necessary to simulate hydrologic cycle which integrates overall water circulation in the catchment area and hence the model uses the following water balance equation in the catchment (Gayathri, 2015).In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$\mathrm{SWt} = \mathrm{SWo} + \sum_{i=1}^{t}(\mathrm{Rday} - \mathrm{Qsurt} - \mathrm{Ea} - \mathrm{Wsweep} - \mathrm{Qgw}) \qquad 2.1$$

Where; SWt is the final soil water content (mm H2O), SW0 is the initial soil water content on day i (mm H2O), t is the time (days), Rday is the amount of precipitation on day i (mm H2O), Qsurf is the amount of surface runoff on day i (mm H2O), Ea is the amount of evapotranspiration on day i (mm H2O), wseep is the amount of water entering the vadose zone from the soil profile on day i (mm H2O), and Qgw is the amount of return flow on day i (mm H2O).

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number method (USDA Soil Conservation Service, 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911). Even though the latter method is better in estimating runoff volume accurately, its sub-daily time step data requirement makes it difficult to be used for this study. Hence, the SCS curve number method was adopted; and the model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981). SCS curve number method calculates the runoff as follow:

$$Q_{surf} = \frac{\left(R_{day-I_a}\right)^2}{\left(R-I_{a-S}\right)} \qquad 2.2$$

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

SCS defines three antecedent moisture conditions: I – dry (wilting point), II – average moisture and III – wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the Equations (2.3) and (2.4), respectively.

$$CN_1 = CN_2 - \frac{20\ x\ (100-CN_2)}{(100-CN_2+exp[2.533-0.0636\ x\ (100-CN_2)])} \qquad 2.3$$

$$CN_3 = CN_2\ x\ exp(0.00673(100-CN_2) \qquad 2.4$$

Where CN1 is the moisture condition I curve number, CN2 is the moisture condition II curve number, and CN3 is the moisture condition III curve number. The retention parameter is defined by Equation (2.5).

$$S = 25.4 * (\frac{1000}{CN} - 10) \qquad 2.5$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition. And Commonly I_a is approximated by 0.2S and equation (2.6) rewrite as follow:

$$Q_{surf} = \frac{\left(R_{day-0.25}\right)^2}{(R+0.85)} \qquad 2.6$$

The maximum runoff flow rate that occurs with a given rainfall event is called the peak runoff rate. It 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 for each HRU as follow (Neitch et al., 2011)

$$Q_{Peak} = \frac{a_{tc} * Q_{sur} * A}{3.6 * t_{conc}} \qquad 2.7$$

Where Q_{peak} is peak runoff rate (m^3/s), a_{tc} the fraction of daily rainfall that occurs during the time of concentration, $Q_{sur}f$ is the surface runoff (mm); A is the sub-basin area (km^2),t_{conc} time of concentration (hr) and 3.6 is conversion factor.

SWAT estimates the value *atc* by using:

$$a_{tc} = 1 - \exp(2 * t_{conc} * \ln(1 - a_{0.5}) \qquad 2.8$$

Where a_{tc} is the fraction of daily rain falling in the half-hour highest intensity rainfall and t_{conc} is the time of concentration for the sub basin (hr).

The time of concentration, t*conc* is a time within which the entire sub basin area is discharging at the outlet point. It is calculated by summing up both the overland flow time of the furthest point in the sub basin to reach a stream channel (*tov*) and the upstream channel flow time needed to reach the outlet point (*tch*) and calculated by the following equation.

$$t_{conc} = t_{ov} + t_{ch} \qquad 2.9$$

To compute t_{ov} and t_{ch} SWAT model uses equations 2.9 and 2.10 as follows:

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \qquad 2.10$$

$$t_{ch} = \frac{L_c}{3.6 * V_c} \qquad 2.11$$

Where L_{slp} is the average sub-basin slope length (m); V_{ov} is the overland flow velocity (m/s), L_c is the average flow channel length (km); V_c is the average flow velocity (m/s) and 3600 and 3.6 are a unit conversion factors.

The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. The change in channel dimensions with time due to down cutting and widening is also included. Similar to the case for the overland flow, the rate and velocity of flow is calculated by using the manning's equation. The channel cross section and longitudinal slope are computed from the digital elevation model (DEM). The main channels or reaches are assumed to have a trapezoidal shape by the model.

Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model. The method was recommended by Williams and Hann (1973) and Arnold et al. (1995). The Storage routing is based on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \qquad 2.12$$

Where: V_{in} is volume of inflow during the time step (m^3), Vout is volume of outflow during the time step (m^3), and ΔV_{stored} is change in volume of storage during the time step (m^3). The above equation can be re-written as flows:

$$V_{Stored2} - V_{Stored1} = \Delta t * \left(\frac{q_{in.1}+q_{in.2}}{2}\right) - \Delta t * \left(\frac{q_{out.1}+q_{out.2}}{2}\right) \qquad 2.13$$

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

SWAT model is capable of doing channel water balance for watersheds which are subjected for water abstraction from the river or addition of water from sources outside the watershed to the river. Water storage in the reach at the end of the time step is calculated:

$$V_{Stored2} = V_{Stored1} + V_{in} - V_{out} - t_{loss} - E_{ch} + div + V_{bnk} \qquad 2.14$$

where $V_{stored,2}$ is the volume of water in the reach at the end of the time step (m^3), $V_{stored,1}$ is the volume of water in the reach at the beginning of the time step (m^3), V_{in} is the volume of water flowing into the reach during the time step (m^3), V_{out} is the volume of water flowing out of the reach during the time step (m^3), t_{loss} is the volume of water lost from the reach via transmission through the bed (m^3), evaporation from the reach for the day (m^3) the volume of water added or removed from the reach for the day (m^3), and V_{bnk} is the volume of water added to the reach via return flow from the bank storage.

2.4.3 Sediment Component of SWAT

Erosion and sediment yield for each HRU are estimated with the modified universal soil loss equation, MUSLE, (Williams and Berndt, 1977) and the general equation is:

$$Sed=1.18*(Q_{Sur}*Q_{Peak}*A_{HRU})^{0.56}*K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG \qquad 2.15$$

Where: Sed is the sediment yield on a given day in metric tons, Q_{sur} is the surface runoff from the watershed in mm/ha, Q_{peak} is the peak runoff rate (m^3/sec), A_{HRU} is the area of HRU, K_{USLE} is the USLE soil erodability factor, C_{USLE} is the USLE land 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.

2.4.2 Advantage and disadvantage of the SWAT

SWAT is an open source tool and detailed online documentation, user groups, video tutorials, international conferences and a unique literature database are available. This all makes the tool user-friendly, which can explain, the fact that it is one of the best known and most widely used tools to develop water quality models at the watershed scale. According to Naomi (2017) the advantage and disadvantage of SWAT is reviewed as below:

i. SWAT was developed to predict the effects of various management scenarios on water quality, sediment yields and pollutant loadings from rural watersheds
ii. SWAT models can be built fairly easily using GIS interfaces

iii. Extensively used around the world with 700 peer review articles
iv. Training provided from courses through universities
v. Calibration, uncertainty and sensitivity analysis available through a separate program (SWAT CUP)
vi. User manual and technical manuals are available

Every tool has its shortcomings and these are often linked with its advantages. The constant improvements, for example, have led to a difficult code and a high number of parameters, requiring expertise to run the model and complicating the calibration process (Arnold et al., 2012).

i. Sub-basins lack interior routing routines (i.e. All HRUs are "connected")
ii. Cannot explicitly place a best management practice (BMP) into the model (except filter strips)
iii. Cannot account for transient nutrient loads
iv. Model formulas are empirical
v. Not applicable for 2D or 3D hydraulics applications
vi. Limited snowmelt model

2.5 Previous Studies in Ethiopia Using Hydrological Models

In Ethiopian River Basin many researches are found using hydrological model. These are mainly focused on hydrologic, sediment yield and sediment management scenario analysis.

Ayana et al. (2012) conducts, Simulation of Sediment yield using SWAT Model in Fincha Watershed, Ethiopia. The average monthly simulated flows and sediment yields were compared with the average monthly observed values using graphical and statistical methods. The results showed reliable estimates of average monthly flow and sediment yields with a high coefficient of determination (R^2) and Nash-Sutcliffe model efficiencies (ENS) during both the calibration and validation periods. This indicates SWAT model performed well in predicting both the flow and sediment yields from the Fincha watershed and the results were acceptable.

Setegn et al. (2008) entitled hydrological model for Lake Tana basin. SWAT 2005 model was used to examine the effect of land use, soil, topography and climatic conditions on stream flow. The sensitivity analysis of the model to sub-basin delineation and HRU definition thresholds showed that the flow is more sensitive to the HRU definition thresholds than sub-basin discretization effect. The authors concluded, despite data uncertainty, the SWAT model produced good simulation results for daily and monthly time steps. The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flow and of soil erosion.

Checkol et al. (2007) under takes application of SWAT for assessment of spatial distribution of water resources and analyzing impact of different land management practices on soil erosion on the upper part of the Awash River Basin in Ethiopia, which lies upstream of Koka dam. After simulating the available data they compared the output of the SWAT model with Hurny (1985) soil loss tolerability level. According to Hurny (1985) the range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to 18t/ha/y. The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y. This fact shows how far soil erosion is a serious threat to the study area. They concluded as successful tackling of soil erosion and sedimentation problems depends, understanding of the sources and evaluating the outcome(s) of a certain management action. And also they showed that SWAT is a useful tool for evaluating the outcome (s) of a certain management action on water quality of the system.

Wasu (2017) Assessed, effectiveness of watershed management options for sediment yield reduction of the Proposed Middle Awash Dam Watershed using SWAT model. The model successfully calibrated the flow and sediment parameter. In addition to this, the study also simulated sediment reduction best management options (filter strip, grassed waterway, and terracing) for that specific watershed by selecting the critically eroding sub basins and the result indicated the proposed reduction options can satisfactorily reduce the sediment yield from the existing baseline for affected sub basins, in turn, reduce the sediment yield inflow to the reservoir. The model evaluation on the coefficient of determination (R^2) and Nash-Sutcliffe (ENS) model efficiency 0.77 to 0.81 and 0.77 to 0.8 respectively during validation which is within the appreciable range.

Asmelash (2015) estimates sediment inflow and its spatial variability at sub basin scale for the case study of Tendaho dam which is located in Afar region. Even though, sediment data was scarce and of few days, the researcher prepared some 11 years monthly sediment data for model calibration and validation on the selected stations. A stream flow and sediment load relation developed using sediment rating curve. By simulating the model the sediment yield result is not as such far from the accepted results, since soil erosion has a direct relation with stream flow which is calibrated well. Therefore, to deal with sediment yield, taking SWAT as a helping model is a good option, because the model considers the factors affecting soil erosion and sediment transport.

CHAPTER THREE: METHODS AND MATERIALS

3.1 Description of the study area

3.1.1 Location

Awash River basin has a catchment area of 112,696 km^2. The Awash River originates from Central West part of Ethiopia, flowing 1200 Km long, and provides a number of benefits to Ethiopia. Relatively, the most utilized river basin and the only river entirely in the country, Awash covers parts of the Amhara, Oromia, Afar, Somali regional states, and Dire Dawa, and Addis Ababa City administrative states of the country (Awulachew et al., 2007).

The basin is bordered on its western side by the Abbay river (Blue Nile) basin, to the south west by the Omo-Gibe and rift valley lakes river basins and to the south east by the Wabi-Shebele river basin. The basin lies between longitude 7°52′12″N and 12°08′24″N and latitude 37°56′24″E and 43°17′2″E.

Based on physical and socio-economic factors the Awash basin has been divided into Upland (all lands above 1500m a.m.sl), Upper Valley, Middle (between 1500m and 1000m a.m.sl), Lower Valley (between 1000m and 500m a.m.sl) and Eastern Catchment (closed sub basin between 2500m and 1000m a.m.s.l), and the Upper, Middle and Lower Valley are part of the Great Rift Valleys systems (Asmelash, 2015).

According to the above classification Awash Melkasa dam watershed is one of the upland areas which are located between 8.11°N and 9.30°N and latitude 37.96°E and 39.35°E. The watershed of the Melkasa dam is delineated as figure 3.1.

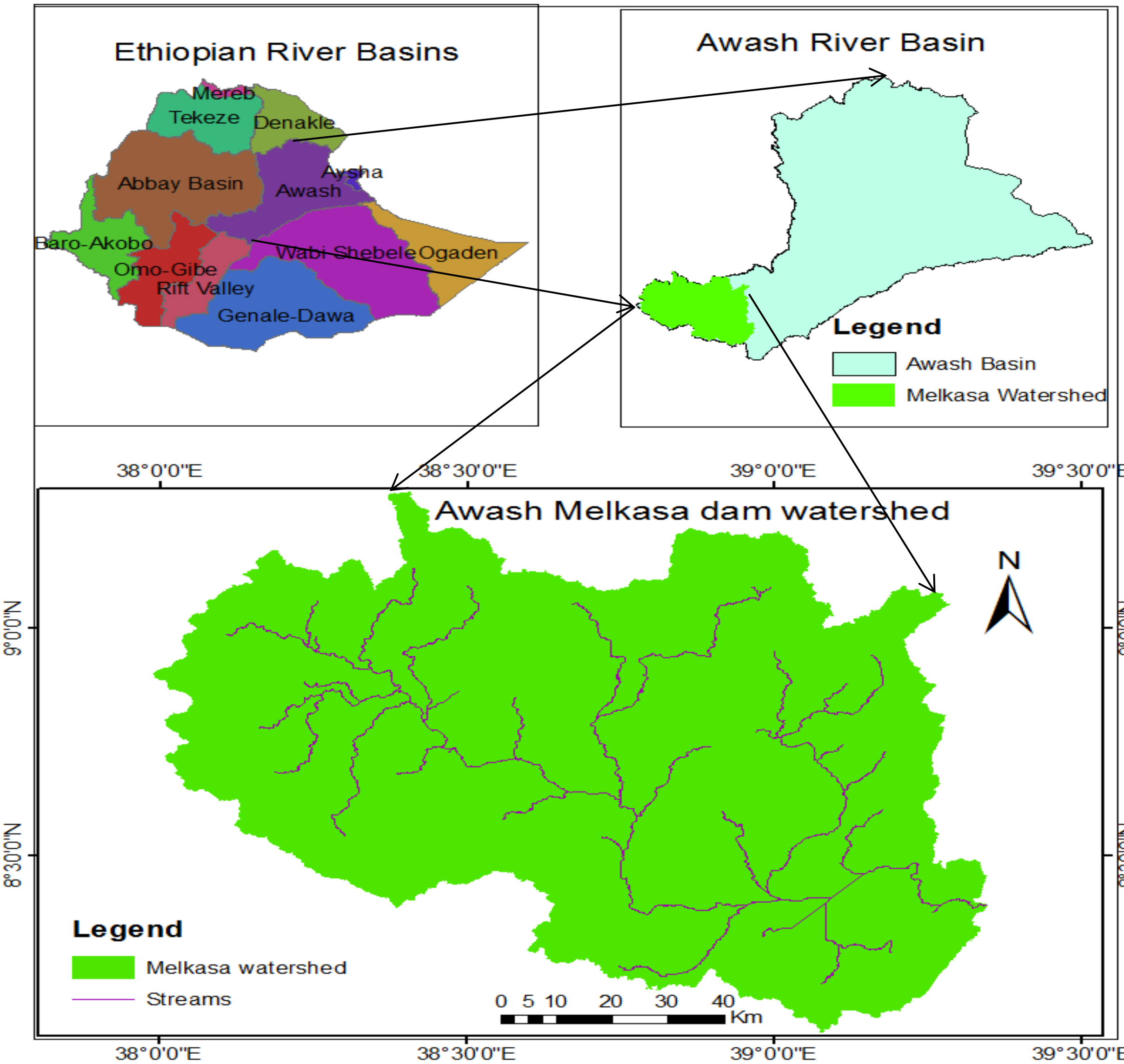


Figure3. 1: Awash Melkasa dam watershed and its location with respect to Ethiopian river basins

3.1.2 Topography and Geology

The altitude of the watershed area ranges from 1474m to 3575m. The major physiographic units in this area are undulating plains, valleys, steep stream banks, hills and mountains. Around 26% of the area is approximately below 2150 m. Elevation above 2150m – 2700m covers approximately 36% of the watershed and the rest of the area is between 2700 and 3575m which covers below 8% of the total area.

The geological feature of the watershed is the upper part of the basin rift embayment and part of central-western highlands that form most part of Upper Awash River Basin and some part of the

Middle Valley. A variety of basalts associated with locally occurring phonolites, trachytes, and rare rhyolites are dominant in the southeastern highlands of the Upper Awash valley (Tsegaye, 2009; Wasu, 2017).

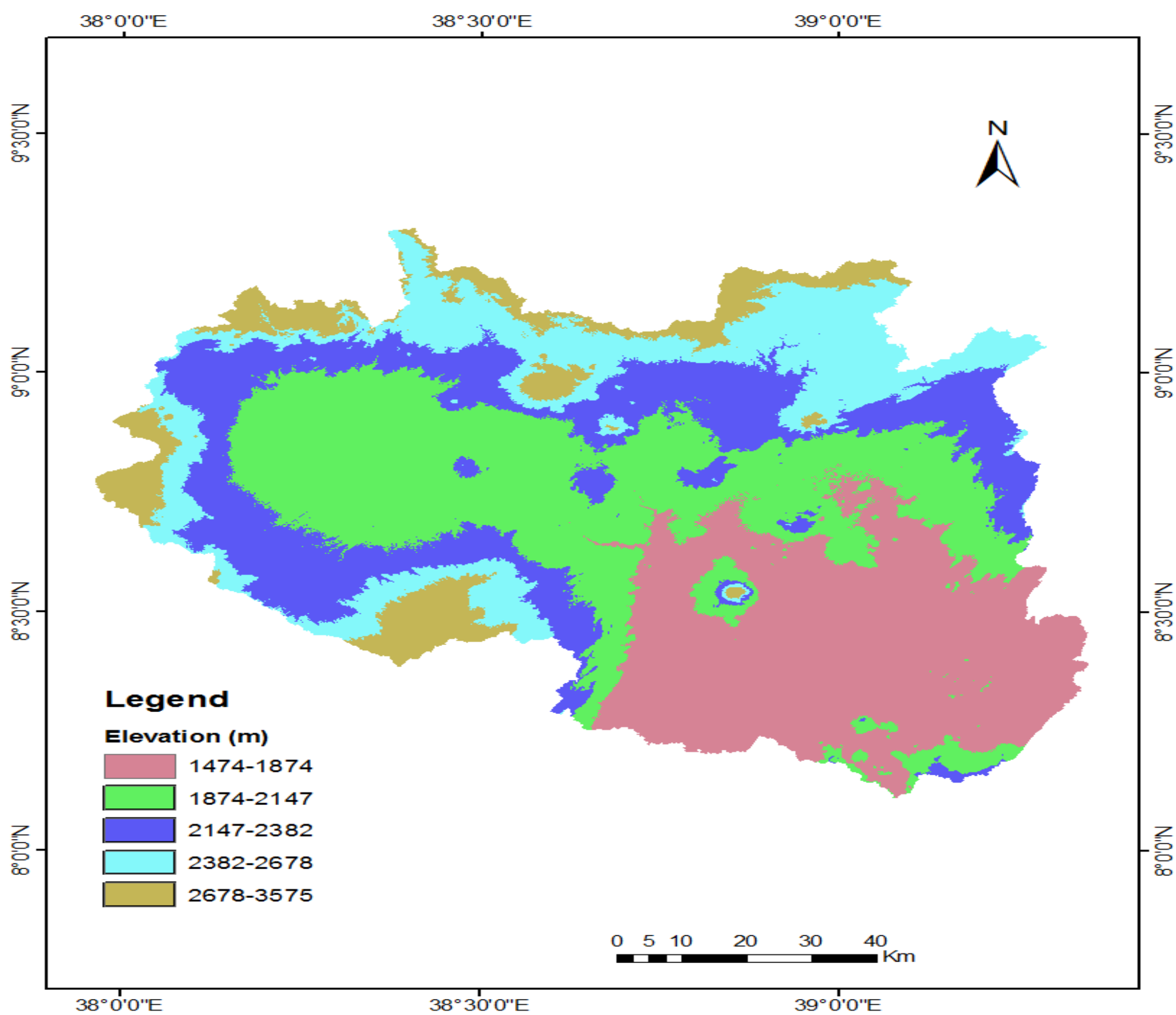


Figure3. 2: Elevation map of Awash Melkasa Dam watershed

3.1.3 Climate

The climate of the upper Awash River basin varies from sub-humid zone (at the upper of the watershed) to semi-arid zone (at the lower of the watershed). The monthly average maximum temperature of the watershed varies between 23.45°C and 27.75°C. Similarly, the average monthly minimum temperature of the watershed varies between 9.43°C and 13.240°C. The average maximum temperature lowers during the rainy season (form July-september).

The rainfall distribution of the basin is bimodal with a short rainy season in March to May and the main rains from July to September. The mean monthly rainfall of the watershed varies from 8.22 mm to 245 mm (figure3.5). Similarly, the mean annual rainfall distribution of Melkasa dam watershed varies from 842mm to 1217mm.

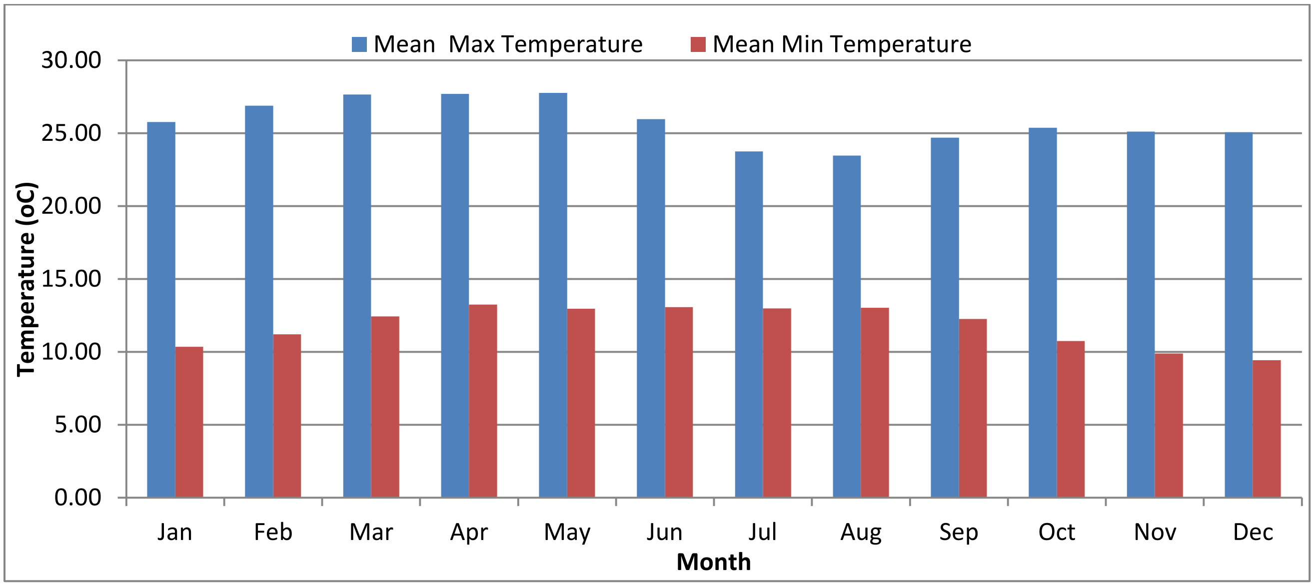


Figure3. 3: long term mean monthly minimum and maximum temperature of the Awash Melkasa Dam watershed (1992-2015), Data source: NMSA

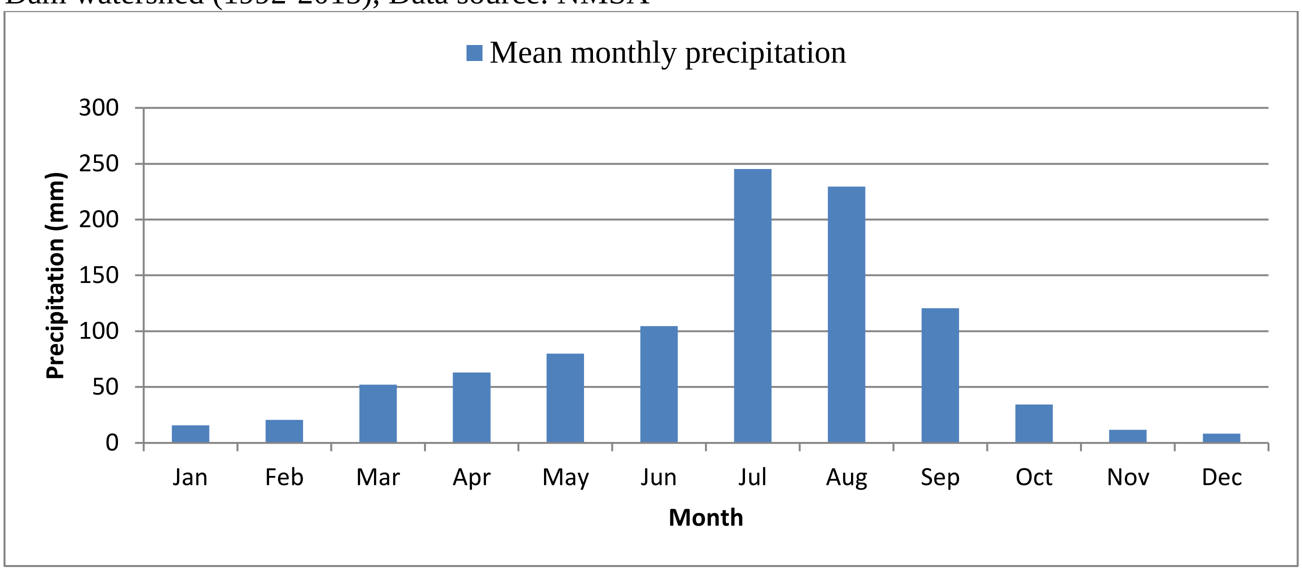


Figure3. 4: Long term mean monthly precipitation of the Awash Melkasa Dam watershed (1992-2015), Data source: NMSA

3.1.4 Surface Water Resources

Awash River rises on the high plateau to the West of Addis Ababa, at an altitude of about 3,000m. It then flows Eastwards, through the Becho Plains and is joined by several small tributaries before entering Koka reservoir, created by a dam, commissioned in 1960 (Asmelash, 2015). The tributaries upstream of Koka Dam and those flowing directly into the Koka Lake contribute a total of 1650.9 million m^3/annum. Seepage and evaporation losses from the Koka reservoir account for over 400 million m^3/annum and the mean annual runoff reduces to 1248.3 million m^3/annum immediately downstream of the Dam (Azazh, 2008). In addition to this, due to presence of water abstraction and diversion below koka dam, stream flow that reaches Melkasa dam decreases significantly.

3.1.5 Soil of the Study Area

The soil types that were found in the watershed area are: fluvisols, xerosols, cambisols, luvisols, vertisols, nitisols, cambisols, fluvisoils, nitisols, regosols, leptosols, phaeozems, andosols, orthic, luvisols, slonchacks, vertisols, cambisols, andosols and acrisols. The dominant soil types found in the catchment was vertisols which covers about 44% of the total area (see table3.2for details).

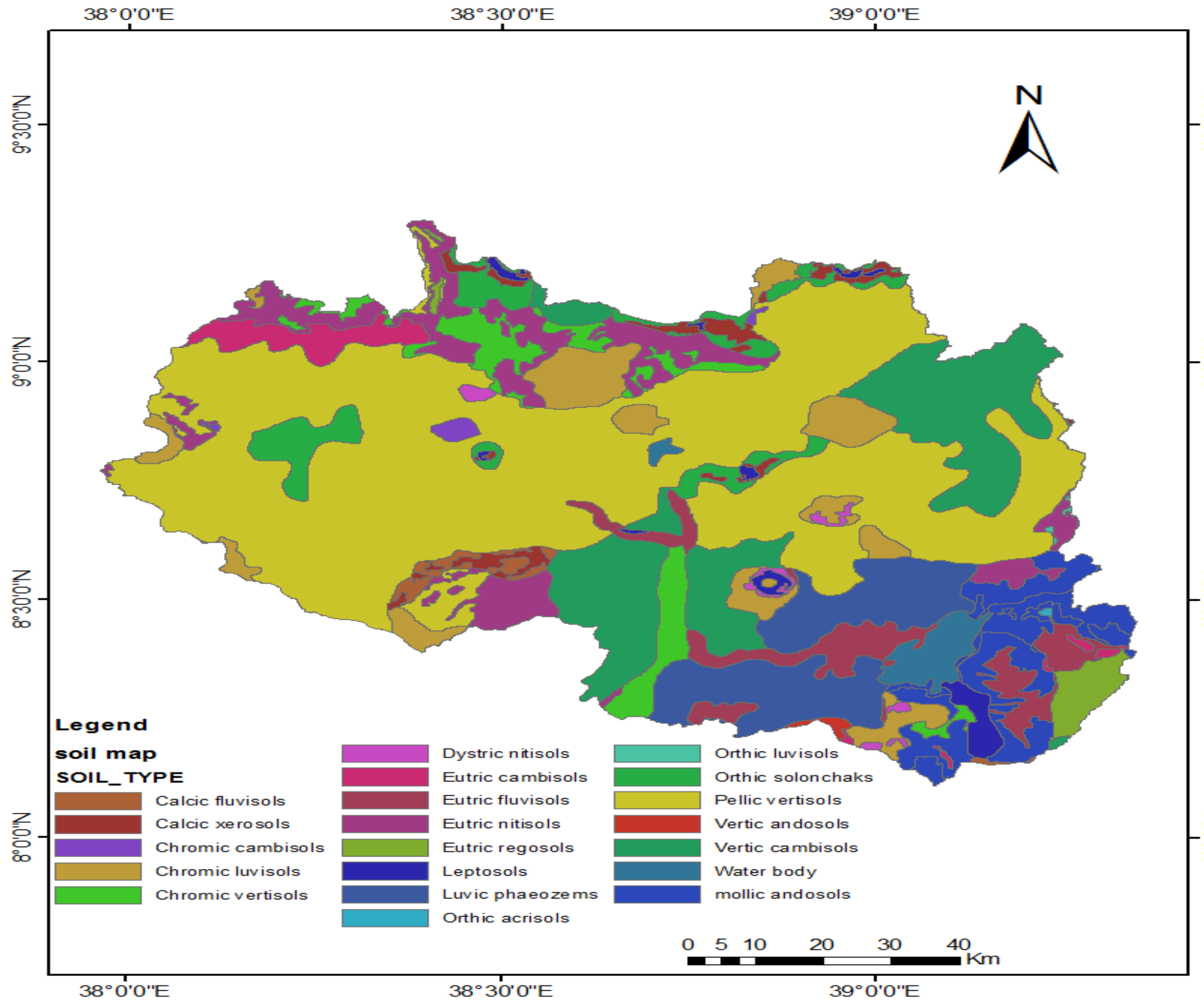


Figure3. 5: soil map of the study area

3.1.6 Land use land cover

The land use and land cover types that were found in the watershed area are: Dense Forest Moderate Forest, Sparse Forest, Wood Land, Closed Grass Land, Closed Shrub Land, Open Shrub Land, Perennial Crop, Annual Crop, Wet Land, Water Body, Salt pan, bare soil, lava field, built-up areas (settlements) and a water body. The dominant land cover types found in the catchment was Annual Crop Land which covers about 62.8% of the total watershed (table3.1).

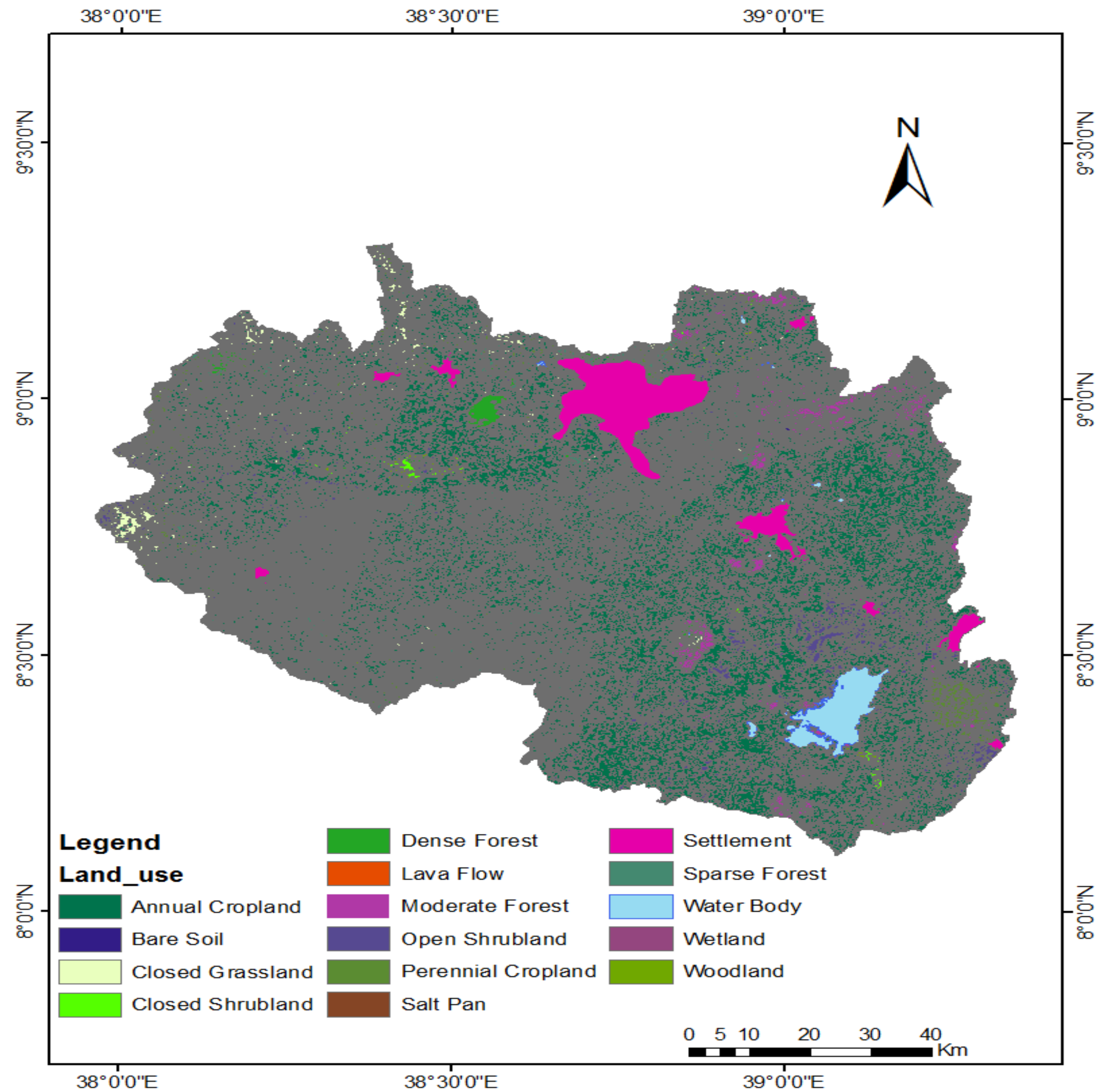


Figure3. 6: land use/ land cover map of the study area

3.2 Materials used

To achieve the objectives of the study, different tools were used for data processing and analyzing. These tools that have been used in this study include: Arc GIS, SWAT, SWAT-CUP, PCPSTAT and Dew02. These tools were described as below.

Arc-GIS: The geographical information system, GIS is a system capable of capturing, storing, analyzing and displaying geographically referenced information (Goodchild, 2000). Hence, in this context, this model with its SWAT extension shall be used to map and obtain physical parameters and spatial variability of sediment yield of the catchments of the study area.

Dew02: designed to calculate the average daily dew point temperature per month using daily air temperature and humidity data (Leirsch, 2003b).

PCPSTAT: Calculates the daily statical parameters of daily precipitation data used by weather generator of SWAT model (Leirsch, 2013a).

SWAT_CUP: SWAT CUP is an interface that was developed for SWAT (Abbaspour, 2015). Using this generic interface, any calibration or sensitivity program can easily linked to SWAT.

3.2.1 SWAT Model Description

The SWAT model is a comprehensive, time-continuous, semi-distributed, process-based model (Arnold et al., 2012). It was developed by the Agricultural Research Service of the United States Department of Agriculture (Arnold et al., 1998). SWAT can be used to model changes in hydrological processes, erosion, vegetation growth, and water quality in large river basins and evaluate the effects of climate change and water resources management (Abbaspour, 2015; Dile et al., 2016; Yang et al., 2016; Tuo et al., 2016). It divides the river basin into sub basins and subsequently into Hydrologic Response Units (HRUs), characterized by different combinations of land use, soil characteristic, topography, and management schemes. The hydrological cycle is calculated based on water balance, which is controlled by climate inputs such as daily precipitation and maximum /minimum air temperature. Using daily input time series, SWAT simulates the daily, monthly and yearly fluxes of water and solutes in river basins. Simulations start by calculating the quantity of water, sediment and contaminants loading from land of each sub basin to the main river. Then, these loads are transported and routed through the streams and reservoirs within the basin.

3.2.2 Model Choice Justification

Hydrological models are important for water resources planning, development and management. Their selection is usually based on data availability, spatial representation, computational cost, and model robustness. Sediment yield estimation is required in a wide spectrum of practical studies for the operation and maintenance of water resources structures. But, the measurement and sampling of sediment transportation is too lengthy and costly. Hence, it is better to go through other options to minimize the sediment yield estimation problems in water resources development. Hydrological models, most of the time the physically based models for sediment yield modelling, could one option. SWAT model was selected for this study, due to: it's physically based, spatially distributed, based readily observed and measured information, public domain with for free and online access, compatibility with ArcGIS interface for ease of data base management, smart and coordinated user groups belongs to the public domain and tested its applicability in different watersheds of Ethiopia.

3.3 Data collection and Analysis

The main input data needed for this study involves spatial data, temporal data and reservoir input data. The spatial data mainly consists of digital elevation model (DEM), land use/cover, Soil map of the study area. The temporal data consists of Metrological (precipitation, maximum and minimum temperature, relative humidity, wind speed, Sunshine hour) and hydrological data (daily river discharge and sediment concentration or sediment load data).

3.3.1 Spatial data

a) Digital elevation model (DEM)

The DEM is one of the main inputs of the SWAT model. Topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. A 30 m x 30 m resolution DEM was collected from Ethiopian Mapping Agency. The DEM is used to delineate the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient and slope length, and stream network characteristics such as channel slope, length and width is derived from the DEM.

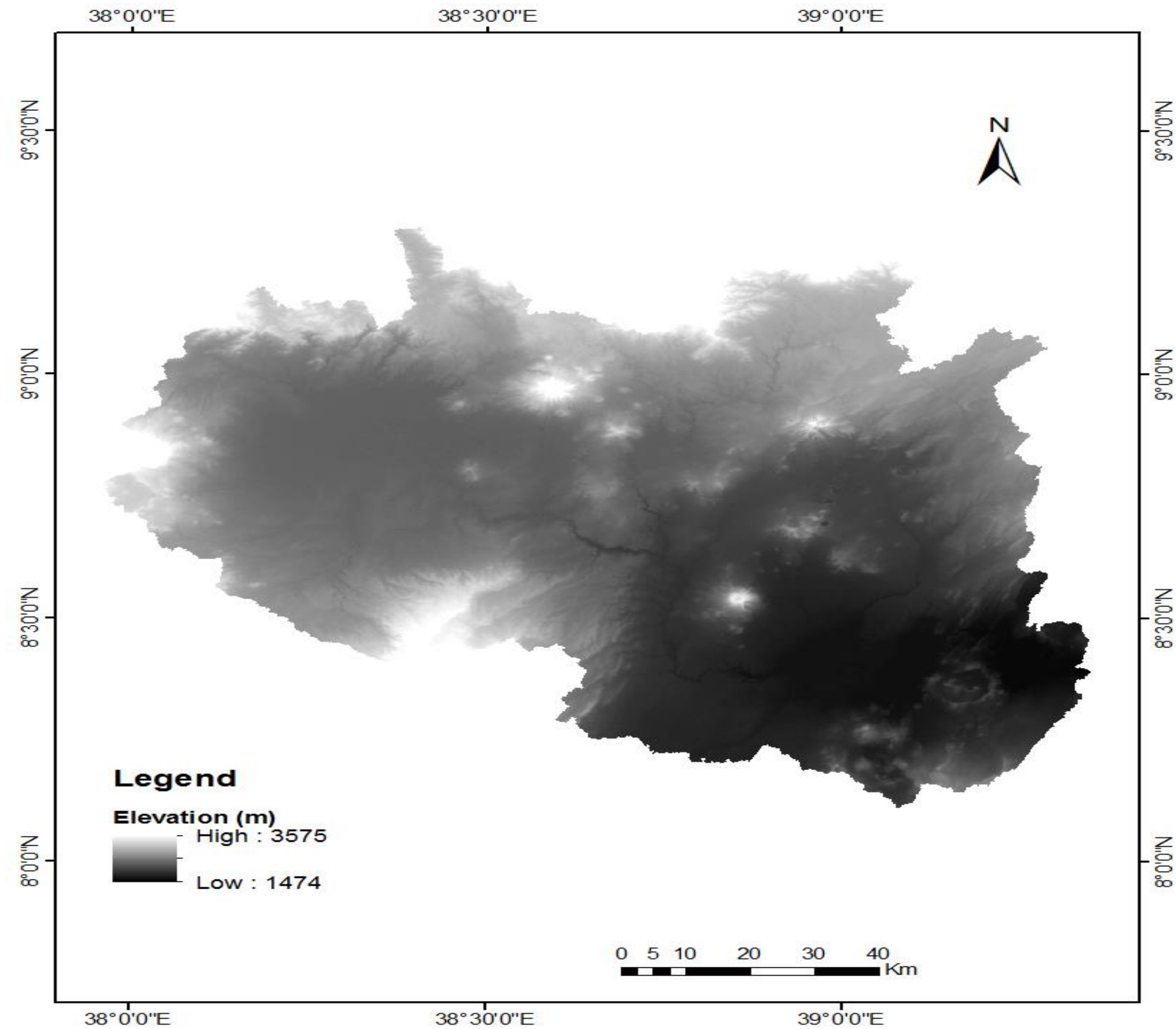


Figure3. 7: DEM of the study area

b) Land use/cover data

The land use of an area is one of the most important factors that affect surface erosion, runoff, and evapotranspiration in a watershed (Neitsch *et al*., 2005; Ayana et al., 2012). The land use/land cover map gives the spatial extent and classification of the various land use/land cover classes of the study area. The 2013 land use map of the study area with spatial resolution of 30m x 30m was collected from Ethiopian Mapping Agency.

Table3.1: Original and redefined LULC types of Awash Melkasa dam watershed

S/No	Original Land cover	Redefined land cover	SWAT Code	Area(Km^2)	% Covering
1	Dense Forest	Forest-Evergreen	FRSE	106.3869	0.88
2	Moderate Forest	Forest-Mixed	FRST	187.3685	1.55
3	Sparse Forest	Forest-Mixed	FRST	468.9892	3.88
4	Wood Land	Forest-Deciduous	FRSD	157.0559	1.30
5	Closed Grass Land	Range-Grass	RNGE	559.3771	4.62
6	Closed Shrub Land	Range-Brush	RNGB	165.899	1.37
7	Open Shrub Land	Range-Brush	RNGB	1120.124	9.26
8	Perennial Crop Land	Sugarcane	SUGC	1130.037	9.34
9	Annual Crop Land	Agri. Land-Close Grown	AGRC	7601.25	62.82
10	Wet Land	Wetlands-mixed	WETL	9.456601	0.08
11	Water Body	Water	WATR	157.9581	1.31
12	Settlement	Residential-High Density	URHD	416.7223	3.44
13	Bare soil/ lava field	Barren	BARR	19.00092	0.16
14	Salt Pan	Mixed Dry Land /Irrigated Crop	MIXC	0.94871	0.01

c) Soil data

The soil textural and physicochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. The shape file format of soil type distribution through the catchment was collected from Ministry of Water, Irrigation and Electricity. The physical and chemical properties of the soils were collected from the study undertaken in the middle Awash watershed by Wasu (2017).

Table3.2: Soil types and their area coverage of Awash Melkasa dam watershed

S/no	soil type	Area km^2	% Coverage	S/no	soil type	Area km^2	% of area coverage
1	Calsic Fluvisols	76.57	0.65	11	Leptosols	126.61	1.07
2	Calsic Xerosols	173.16	1.46	12	Luvic Phaeozems	824.70	6.96
3	Chromic Cambisols	34.92	0.29	13	Mollic Andosols	585.48	4.94
4	Chromic Luvisols	698.31	5.89	14	Orthic Luvisols	5.50	0.05
5	Chromic Vertisols	429.35	3.62	15	Orthic Slonchacks	427.90	3.61
6	Distric Nitisols	55.94	0.47	16	Pellic Vertisols	5226.68	44.12
7	Eutric cambisols	210.37	1.78	17	Vertic Cambisols	1418.93	11.98
8	Eutric fluvisoils	468.92	3.96	18	vertic Andosols	14.40	0.12
9	Eutric Nitisols	762.93	6.44	19	Water Body	170.71	1.44
10	Eutric Regosols	131.72	1.11	20	Orthic Acrisols	3.10	0.03

3.3.2 Weather data

The weather variables required by the SWAT model for driving the hydrological balance are daily rainfall, minimum and maximum temperatures, relative humidity, wind speed and Sunshine hour. These data were collected from National Meteorological Service Agency (NMSA).

Table3.3: List and location of the Meteorological stations with in and around the watershed

S/no	Station name	Latitude (degree)	Longitude (degree)	Elevation (m)	Meteorological variables
1	Addis Ababa Obs	9.01891	38.7475	2386	PCP, Tmax, Tmin, RH, S and W
2	Asgori	8.79	38.3342	2072	PCP, Tmax and Tmin
3	Chefe Donsa	8.97	39.1232	2392	PCP, Tmax and Tmin
4	Debrezeit	8.733333	38.95	1900	PCP, Tmax and Tmin
5	Melkasa	8.4	39.31667	1540	PCP, Tmax, Tmin, RH, S and W
6	Nazreth	8.55	39.28333	1622	PCP, Tmax and Tmin
7	Woliso Giyon	8.55	37.98333	2058	PCP, Tmax and Tmin

Note: PCP = Precipitation, Tmin =minimum Temperature, Tmax = maximum temperature, RH= Relative humidity, S=Sunshine hour and W=wind speed

3.3.2.1 Filling Missing Weather Data

There are number of methods for estimating missing data such as, Arithmetic average method, normal ratio method, quadrant method, and inverse distance, weighting method and regression methods. The method used to estimate missing rainfall data can be selected based on its percentage of missing data.

Normal ratio method can be used when the mean annual precipitation at any of the index station differs from that of the considered precipitation station (station x) by more than 10%. Normal ratio methods are expressed by the following relationship

$$\mathrm{Px} = \frac{\mathrm{Nx}}{\mathrm{N}}\left(\frac{\mathrm{P1}}{\mathrm{N1}} + \frac{\mathrm{P2}}{\mathrm{N2}} + \frac{\mathrm{P3}}{\mathrm{N3}} \ldots + \frac{\mathrm{Pn}}{\mathrm{Nn}}\right) \quad (3.1)$$

Where, Px =Missing value of precipitation to be computed, Nx = Average Annual value of rainfall for the station, N1, N2………Nn= Average Annual value of rainfall for the neighboring station, P1, P2...............Pn= Rainfall of neighboring station during missing period, N= Number of stations used in the computation, Normal ratio method was used in this study to fill the missing data. Because, the mean annual precipitation of each station differs from that of each considered precipitation stations by more than 10%.

3.3.2.2 Homogeneity Test

Homogeneity is an important issue to detect the variability of the data. One of the methods to check homogeneity of the selected stations in the watershed is the RAINBOW Test. For this study RAINBOW method was used to check the homogeneity of data which is based on the cumulative deviation from the mean. The figure 3.8 show the homogeneity test of Addis Ababa rain fall data. The homogeneity tests of the other stations were shown in appendix A.

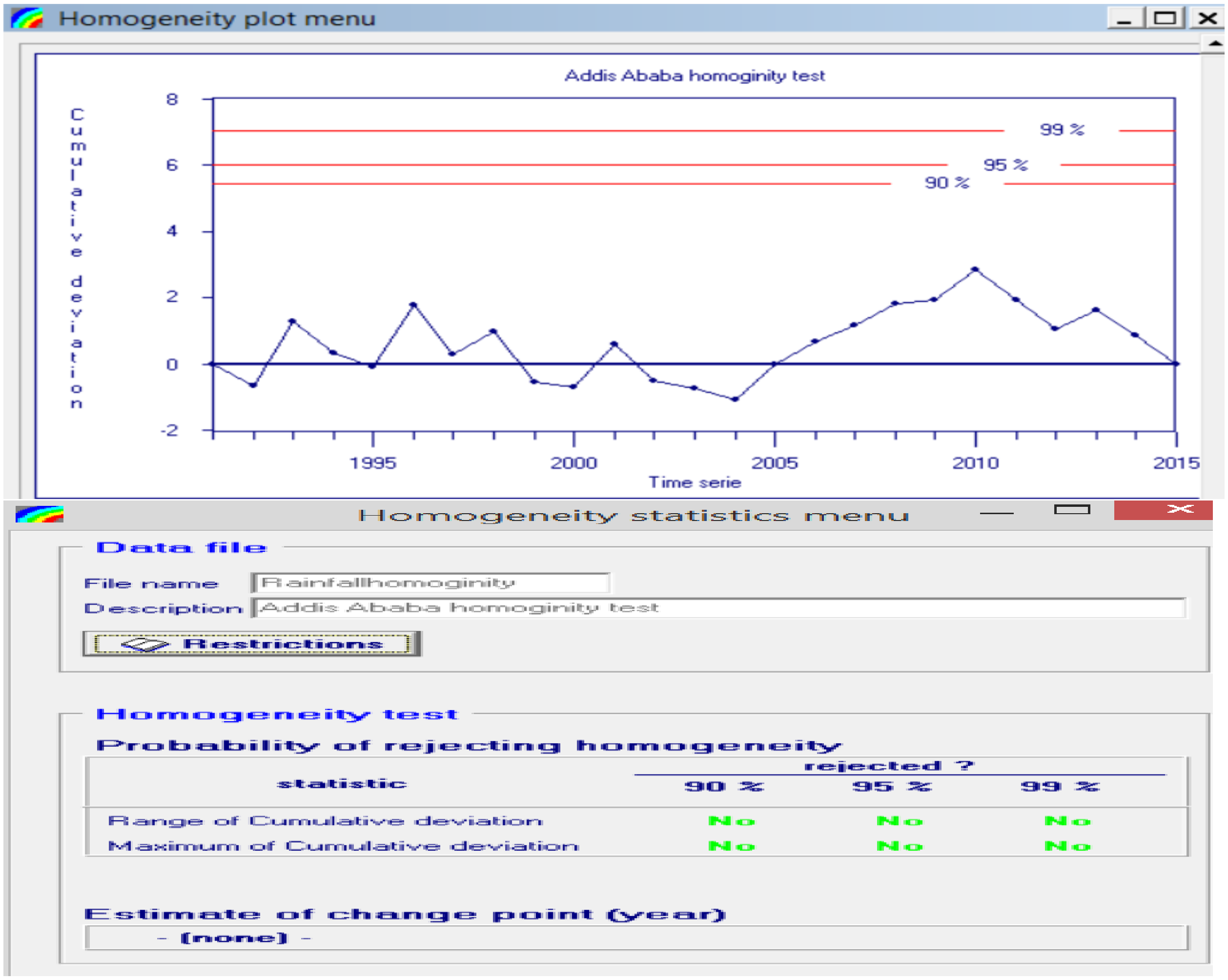


Figure3. 8: Homogeneity test result of Addis Ababa rainfall Station

3.3.2.3 Checking the Consistency of Data

Adjusting for gauge consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result from any one of a number of events; specifically, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gauge, changes in land use that make it unreasonable to maintain the gauge at the old location, and where vandalism frequently occurs. Double-mass-curve analysis is the method that is used to check for an inconsistency in a gauge record. The curve is a plot on arithmetic graph paper of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region. The method for checking consistency of a hydrological or meteorological record is considered to be an essential tool for taking it for analysis purposes. It is determined by plotting the cumulative values of observed time series of station for which consistency need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x-axis. The station affected by trend or a break in slope of the curve would indicate that conditions have changed that location. The data series, which is inconsistency, has been adjusted to consistent values by proportionality. Therefore, the station to be adjusted for consistency by using the equation:-

$$Si = \frac{\Delta Yi}{\Delta Xi} \qquad (3.2)$$

Where, Si: is the slope of section i,

Yi: is the change in the cumulative catchment for gauge Y between the end point of the section i,

Xi: is the change in the cumulative catchment for the sum of the regional gages between the endpoints of sections.

Consistency of precipitation data from individual stations used in this study was checked using a double mass analysis and any of the stations used in this study have not undergone a significance change during the base line period (1992-2015) of the study.

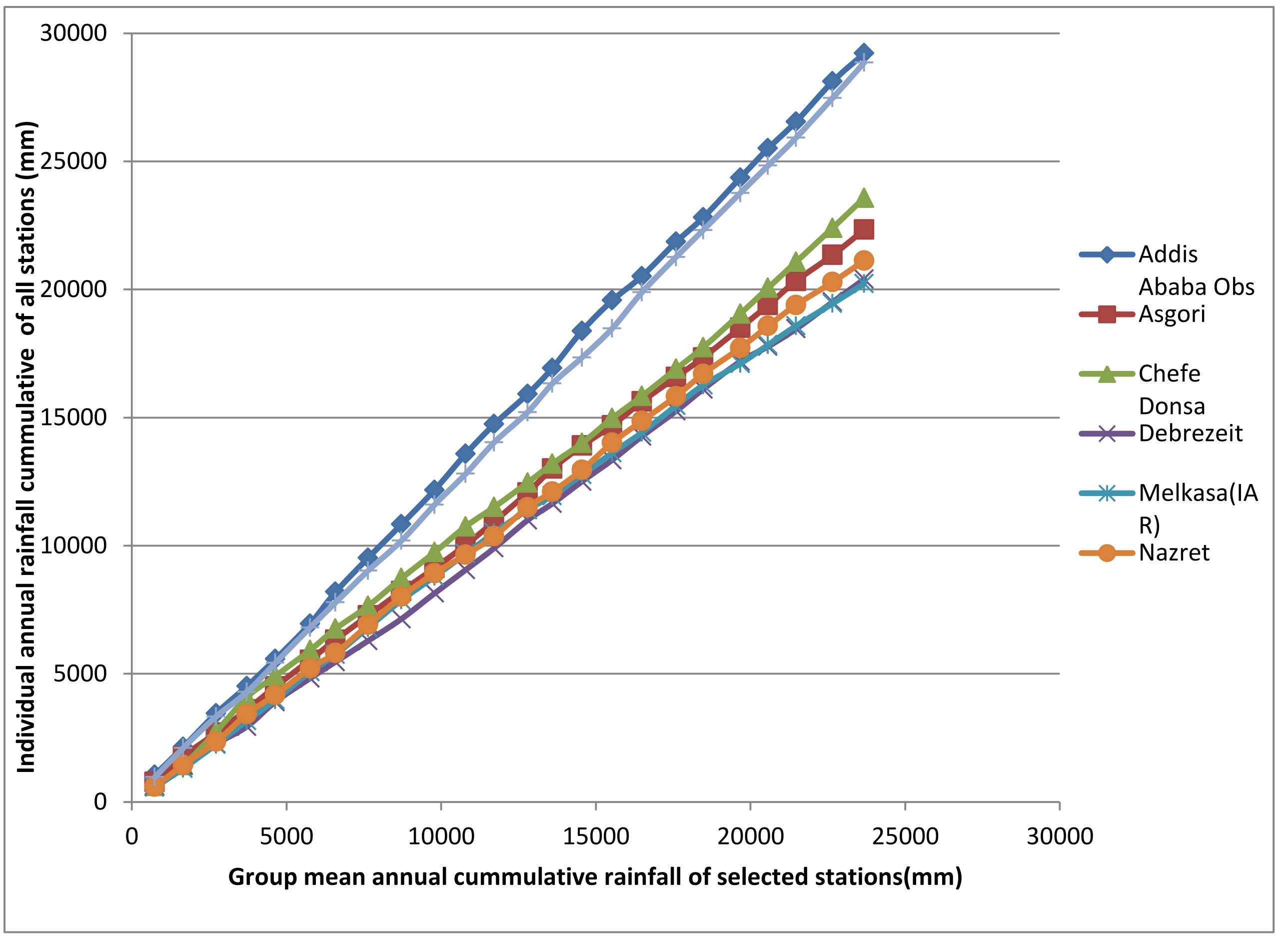


Figure3. 9: Double mass curve of all the stations used for the study

3.3.2.4 Aerial rainfall computation

Hydrological analysis requires knowledge of the precipitation over an area. Since rain gauge represents only point sampling of the areal distribution of a precipitation, Station average, over a catchment is required. To convert the point rainfall values of these stations into an average value of over a catchment the following methods can be used: (i) Arithmetic Mean, (ii) Thiessen Polygon, (iii) Isohyetal, (iv) Grid Point, (v) Percent Normal,(vi) Hypsometric, etc. are available for estimating average precipitation over a drainage basin. Among those methods, Theissen polygon method was used for this study due to its simplicity to use. The average rainfall over the catchment was calculated by:

$$P_{av} = \frac{P1A1+P2A2+P3A3+\cdots+PnAn}{A1+A2+A3+\cdots+An} \qquad 3.2$$

Where, Pav is average areal rainfall (mm), $P1$, $P2$, $P3$ … Pn are precipitation of stations 1, 2, 3, n respectively and $A1$, $A2$, $A3$, … An are area coverage of stations 1, 2, 3, ….n respectively in the Thiessen polygon.

However, the method is not used in the model, thiessen polygon is important to visualize the location, area coverage and distribution of the weather data.

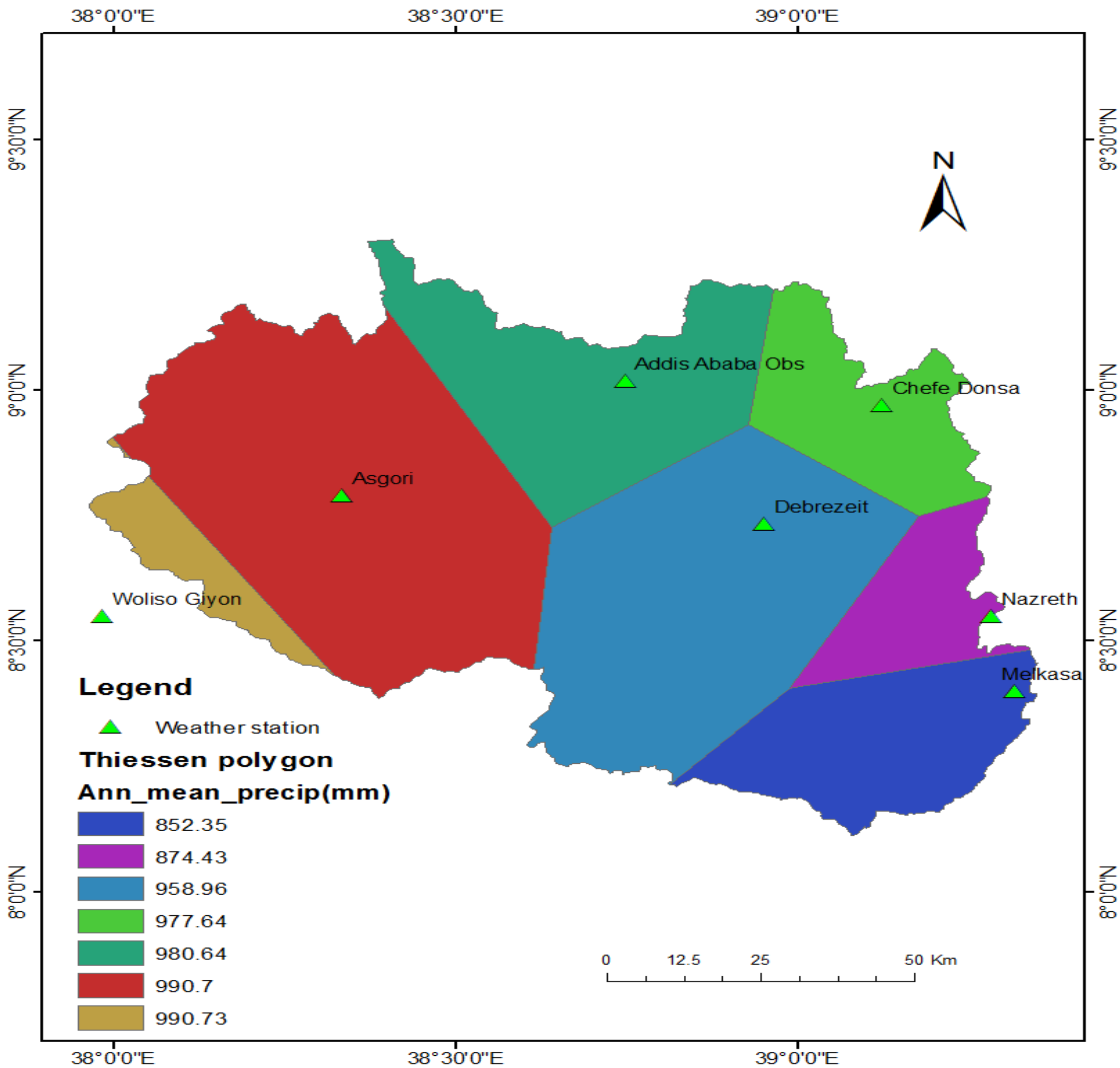


Figure3. 10: Thiessen polygon map of the rainfall stations

3.3.3 Hydrological data

The observed stream flow and sediment yield data were obtained from the Hydrology Department of the Ministry of Water, Irrigation and Electricity. The collected data was not at the outlet of the watershed (Awash Melkasa dam site). However, Wonji gauging station which is located upstream of the dam site has sufficient hydrological data and it gauges about 96% of the area coverage of Awash Melkasa Dam watershed. The remaining 4% (ungauged area) also has relatively similar in Weather and spatial characteristics. Therefore, the remaining ungauged area does not affect the calibration and validation of the watershed.

3.3.3.1 Filling of missing stream flow data

Procedures for correction and completion depend on the type of error, its duration, and the availability of suitable source records with which to estimate. Unlike rainfall, streamflow shows strong serial correlation; the value on one day is closely related to the value on the previous and following days especially during periods of low flow or recession. The selected gauging station was at Wonji. There was no or few missing flow data at Wonji gauging station on the base line of the record (2004 – 2013). Linear interpolation between the last stream flow before the gap and the first stream flow recorded value after it or same day average method was used to fill the gap of data.

3.3.3.2 Sediment rating curve preparation

The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is mainly applied to obtain the value of sediment concentration for a given discharge. Along with the flow duration curve at a given location, the sediment rating curve can also be used to estimate the amount of sediment transport over a period of time.

Sediment measurement in the selected gauging stations of Wonji was not in a continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step.

So that using rating curve, the records of discharges are transformed into records of sediment concentration or load and the general relationship can be written as

$$S=aQ+C \qquad 3.1$$

Where; S is sediment load in ton/day, Q is the discharge in m^3/sec and a is regression constants. C is a constant of proportionality. This formula was selected based on the best curve fitting (regression analysis which is displayed on the figure3.11) obtained was linear.

The available sediment concentration data was converted to sediment load in order to develop rating curve. Sediment load is calculated from the discharge and sediment concentration as follows.

$$S = 0.0864 * Q * C \qquad 3.2$$

Where: S = sediment load (ton/day), Q = discharge (m^3/s), C = sediment concentration (mg/l) and 0.0864 = conversion factor.

Then, using a continuous time step sediment load and measured stream flow a rating curve has been developed at Wonji sediment gauging stations.

The daily sediment yield for the Wonji gauging station was developed by using the rating curve equation (Equation 3.1 and Equation 3.2) which has obtained from the data plot(figure 3.12).

$$S = 77.518Q - 1432.9 \quad (3.3)$$

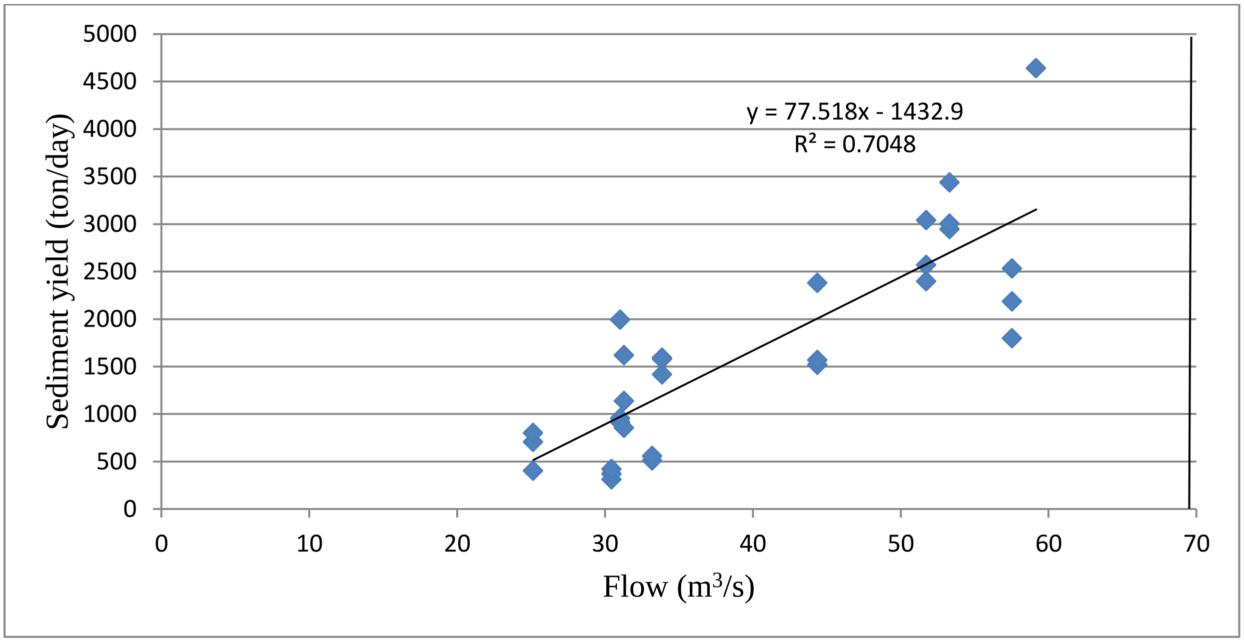


Figure3. 11: Sediment rating curve of Awash River at wonji gauging station

3.3.4 Reservoir input data

Reservoirs are an impoundments located on main stream network of the watershed. Reservoirs receive loadings from all upstream sub-basins. In Upper Awash River basin (above Awash Melkasa reservoir) there are three reservoirs (Geffersa, Legedadi and Koka). The three reservoirs were included in the SWAT model during simulations. Reservoir input data such as: reservoir surface area when the reservoir is filled to the emergency and principal spill way, Volume of water needed to fill the reservoir to the emergency and principal spill way and initial reservoir volume were collected from MoWIE / Hydrology Department, EEPC (1999), Booker (2005) and Wasu (2017).

Table3.4: Significant reservoirs of upper Awash River basin and data used during SWAT modeling

S/no	Name of reservoir		Gefersa	Legedadi	Koka
1	Location	Easting (m)	460664	495816	517166
		Northing (m)	1001861	1001861	935966
2	Year of become operational		1943	1967	1960
3	Reservoir surface area when field up to emergency spillway (ha)		136.6	348.6	13,100
4	Reservoir volume when field up to emergency spillway (ha-m)		735.4	5,868.50	130,500
5	Reservoir surface area when field up to principal spillway (ha)		123	325	13,100
6	Reservoir volume when field up to principal spillway (ha-m)		625	5,380	125,000
7	Initial reservoir volume (ha-m)		404.9	2668	45100
8	Average water daily withdrawn from reservoir for each month for consumptive use (10^4 m^3)		3	16.22	_

3.3.5 Water abstraction (irrigation and domestic water supply) input data

Awash River is actively and potentially utilizing river for various levels of irrigation developments and domestic water supply. The potential of irrigable land inside the basin, geographical suitable for ease diversion of river, accessible condition along the river basin are some of the factors that make the river more utilizable than others. Most of the irrigation schemes in the watershed are located along the main stream of Awash river. Wonji-shoa irrigation scheme and Adama water supply are located in the upper Awash watershed. Wonji/Shoa sugar estate lies approximately 12 km downstream of the koka dam; one main pump station is used to lift water from the River Awash to supply the main irrigation area of 7000 ha. The significant available water demand for urban supplies is Nazereth with relatively low abstractions. The Nazereth water supply is abstracted by a pipeline from a point between Koka dam and Wonji/Shoa. A few kilometers downstream of the Wonji shoa estate there is a second smaller reservoir at Melkasa, which is the outlet of the study area. SWAT model allows the user to consider the water abstractions during modeling if there is utilization of the basin water before it reaches the target outlet. In this study, water abstractions for consumptive water use and irrigation purposes have been considered.

On the other hand, Gefersa and Legedadi reservoirs which are covering the demand of Addis Ababa water supply were considered as reservoir based consumptive water use sources. These data were collected from Addis Ababa Water Supply Authority. The average daily water removal for consumptive use from Gefersa and Legedadi water supply dams were set at average daily withdrawn from the reservoir for each month found under reservoir input data set (table3.4).

Table3.5: Abstracted water for Adama Water Supply and Wonji shoa irrigation

S/no	Location	Northing	Easting	Abstracted /diverted water ($10^4 m^3$/day)
1	Wonji shoa	934927	525563	33
2	Adama water supply	937344	519830	5.3

Source: Wasu (2017)

3.4 Preparation of SWAT-model input data

The SWAT model build up process involves the preparation of the input data. This input data is classified mainly as spatial data (DEM, land use, soil type), weather input data (rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed) and hydrological data (stream flow and sediment concentration).

Spatial data is usually prepared in a GIS environment, which allows a relatively comfortable incorporation of all relevant maps of the watershed. The maps of the study area such as DEM, soil and land use land cover map was processed using Arc GIS; all layers have the same coordinates and projection systems. A user lookup table was created that identifies the SWAT code for different categories of Land cover/Land use and soil type on the map as per the required format.

The meteorological stations in the study area that have full data have been selected to be principal station for the weather generator. Those principal stations were Addis Ababa and Melkasa stations. The statistical variables of meteorological data generation system (weather generator data) have been calculated using Excel, PCPSTAT and dew 02. The missing Values which is common in the existing data sets were filled with no dataset identifier (-99) and generated by the Program embedded in the model. The geographical coordinate names of the weather stations of the study area were introduced into Arc SWAT database.

The prepared weather generator parameters have been loaded into a WGEN-user of SWAT database. The weather variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate text format. Solar radiation is converted from sun shine hour based on the latitude of the location, monthly average daily bright sunshine duration and the monthly average maximum possible daily bright sunshine duration (Angstrom, 1924). The empirical equation used to drive solar radiation is shown in Appendix D.

Finally, streamflow and suspended sediment load observations, which are the ultimate calibration and validation target, were prepared accordingly.

3.5 Model setup

Arc SWAT 2012, with an interface in ArcGIS 10.1, were used to setup the model in this work. The model setup includes: watershed delineation, HRU definition, editing weather input tables, editing SWAT input and SWAT simulation.

3.5.1 Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameters for Ethiopia. A watershed was partitioned into 68 sub-basins, for modeling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold area based stream definition option was used. In this study, from the total area of the threshold area was taken 9,700 ha. This threshold was selected by considering the Gefersa reservoir which is located at the starting point of stream network. Because small stream flow is created as the threshold area is small. Finally, the watershed outlet and the reservoirs outlet in the watershed were manually added and selected for finalizing the watershed delineation. Based on the above information, the model automatically delineates a watershed area of 12,060 km^2 with 68 sub-basins.

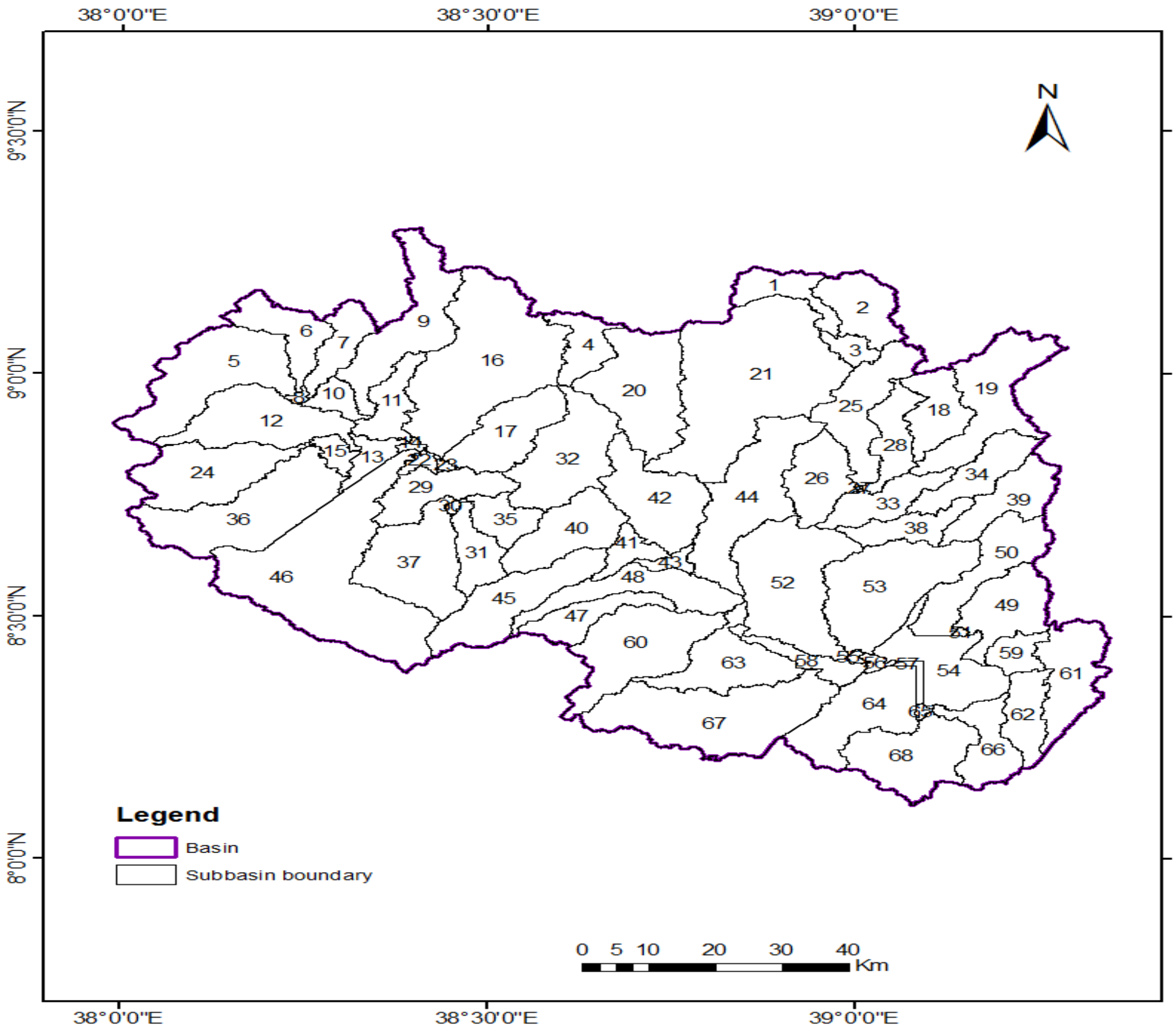


Figure3. 12: Delineated watersheds and its sub basin

3.5.2 Hydrological Response Units (HRUs)

After watershed delineation, HRU definition is a task to be prepared before attempting to the next steps. The Hydrologic Response Unit in the Arc SWAT requires the land use and soil maps to be loaded to the project and also classification of the slope of the sub basins. The land use, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled. For this specific study a 10% threshold value for land use, 10% for soil and 12% for slope were used.

3.5.3 Importing Weather, Reservoir and Water Abstraction input data.

The weather variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate text format. Then the climatic input variables imported together with their weather location

The SWAT input section was used for selecting a sub basin having reservoirs: Gefersa, Legedad and koka reservoir and their sub basin numbers were 4, 3 and 51 respectively. By selecting these sub basins, the input parameters (Table3.5) were edited under reservoir file (*.res) category.

SWAT model able to consider the water that has to be abstracted from the sub basin or reach through consumptive water use (*.wus) file category to manage irrigation water supply and urban water supply. The water abstraction of surface water from the reach (sub basin) 49 for Adama water supply and Wonji shoa irrigation projects were included in the simulation (Table3.6).

3.5.4 SWAT Simulation

SWAT simulation run was carried out on the 1992-2015 weather data. Three year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. It enables the establishment of the basic flow conditions for the simulations to occur and brings the hydrologic processes to an equilibrium condition. The run output data imported to database and the simulation results were saved in the files of SWAT output. From the generated output of SWAT, sensitivity analysis, calibration and validation were followed using SWAT-CUP to evaluate the model performance.

3.6 Sensitivity analysis

When SWAT model simulation takes place, there was a discrepancy between measured data and simulated results. So, to minimize this discrepancy, it was required to identify the parameters affecting the results and in the extent of variation. Hence, Sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Lenhart et al., 2000).

In this study, sensitivity analysis of streamflow followed by sediment yield was performed by SWAT_CUP using SUFI-2 algorism. The sensitivity analysis was carried out for a period of 9years, which included both the calibration period from January 1st, 2004 to December 31st, 2009 and the warm up period from January 1st, 2001 to December 31st, 2003. Global sensitivity analysis uses t-test and p-values to determine the sensitivity of each parameter. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance (Abbaspour, 2014).

3.7 Calibration

Calibration is an integral part of the modelling process, since it is in practice impossible to measure all hydrological properties of a system. In general, model calibration aims to ensure that model components such as hydrological processes and parameters to retain their physical meaning; however results are influenced by multiple sources of uncertainty (uncertainty in the data, model parameters and model structure). It is therefore important to develop models that can better exploit the information content of the available data.

There are five calibration approaches widely used by the scientific community. These are the Sequential uncertainty Fitting (SUFI2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), Markov Chain Monte Carlo (MCMC) and Particle Swarm Optimization (Pso) (Abbaspour, 2015). In this study Sequential uncertainty Fitting (SUFI2) was applied to get the best model parameters.

After sensitive parameters have been identified, manual and automatic calibration methods were applied. The calibration was done using both methods, because for a very complicated watershed with many sub basins, 68 sub basins and 588 HRUs, calibrating automatically needs high computer processer speed or time of simulation is too much. The automatic process can provide more objectivity and reduce the need for expertise with the particular model. However, automatic calibration methods have not yet matured to the point that they can entirely replace manual methods due to the difficulty of constructing objective functions and optimization algorithms which replicate human judgement; and hence automatic calibration is often most successful when used in conjunction with a manual procedure (Pechlivanidis, 2011).

The stream flow and sediment yield calibration was performed from january1, 2004 to December 31, 2009. After calibration, checking the statistical criteria and calibrating at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 ,PBIAS ≤ ± 15% and 0 ≤ RSR ≤ 0.75 (Moriasi etal., 2007 and Moriasi et al., 2015).

3.8 Validation

Verification (also known as validation) takes place after calibration to test if the model performs well on a portion of data, which was not used in calibration. Model verification aims to validate the model's robustness and ability to describe the catchment's hydrological response, and further detect any biases in the calibrated parameters (Gupta *et al*., 2005; Pechlivanidiset al., 2011). In this study, stream flow and sediment yield validation was performed from january1, 2010 to December 31, 2013, without any further adjustment of calibrated parameters. The statistical criteria of R^2, ENS, RSR and PBIAS were used in the validation procedure to make sure that the simulated result is within the accuracy limits.

3.9 Evaluation of model

a) Graphical comparison of observed and simulated hydrographs and sediment yields

A graphical display of simulated and observed flow or sediment data is a key way of model performance testing than evaluating model performance by statistical measures with limitations. Statistical indices are not effective on explaining qualitative information, such as, types of errors and distribution patterns or trends. So, the result not depend on a single statistical measure of model performance alone, which is sometimes misleading because of the high possibility of compensation of errors from season to season or over years in a long term calibration. On both calibration and validation processes the simulated and observed hydrographs have been compared graphically.

b) Model performance evaluation statically

The performance of SWAT model was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficients of determination (R^2), Nash-Sutcliffe simulation efficiency (NSE), Percent bias (PBIAS) and Root mean Square Error Standard Deviation Ratio (RSR) were used as measure of the goodness of fit to evaluate model prediction.

The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (NSE) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, NSE is 1. If the NSE is between 0 and 1, it indicates deviations between measured and predicted values. If NSE is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Suttcliffe, 1970).

The regression coefficient (R^2) is the square of the Pearson product moment correlation coefficient and implies the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to 1 implies the higher the agreement between the simulated and measured data.

Percent bias (PBIAS) evaluates the average tendency of the simulated output data to be larger or smaller their observed data counterparts, being the optimum value zero, while, low magnitude values indicating accurate model simulation. Positive values imply model underestimation bias, and a negative value indicates model overestimation bias (Gupta, et al, 1999).

Root mean Square Error Standard Deviation Ratio (RSR) is calculated as the ratio of Root Mean Square Error (RMSE) and standard deviation of measured data. RMSE is an error index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating the higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

It would be calculated using the following equation:

$$R^2 = \frac{[\sum(Xi - Xav)(Yi - Yav)]^2}{\sqrt{\sum[(Xi - Xav)^2 \sum(Yi - Yav)^2]}} \qquad 3.4$$

Where, Xi – measured value (m3/s), Xav – average measured value (m3/s), Yi – simulated value (m3/s) and Yav – average simulated value (m3/s)

$$\text{NSE} = 1 - \frac{\sum(Xi - Yi)^2}{\sum(Xi - Xav)^2} \qquad 3.5$$

Where, Xi – measured value, Yi – simulated value and Xav – average measured value

$$PBIAS = 100 * \frac{\sum_{i=1}^{n}(Xi - Yi)}{\sum_{i=1}^{n} Xi} \qquad 3.6$$

Where, Xi – measured value (m^3/s), Yi – simulated value (m^3/s)

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Xi - Yi)}}{\sqrt{\sum_{i=1}^{n}(Xi - \overline{Xi})^2}} \qquad 3.7$$

Where, Xi – measured value, Yi – simulated value and $\overline{Xi}$ – average measured value

c) Uncertainty measure: P – Factor and r – Factor

The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). Another measure quantifying the strength of a calibration/uncertainty analysis is the r-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data.

Theoretically, the value for p-factor ranges between 0 and 100%, while that of r-factor ranges between 0 and infinity. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to measured data.

A larger p-factor can be achieved at the expense of a larger r- factor. Hence, often a balance must be reached between the two. When acceptable values of r-factor and p-factor are reached, then the parameter uncertainties are the desired parameter ranges. For p-factor the suggested value is >70% for discharge, while having r-factor of around 1. For sediment, a smaller p-factor and a larger r-factor could be acceptable (Abbaspour, 2015).

CHAPTER FOUR: RESULTS AND DISCUSSIONS

The SWAT simulation was performed for Awash Melkasa dam watershed and calibrated at Wonji hydrometric guaging station. The result of sensitive parameters, calibrated and validated values on this catchment were discussed as below**.**

4.1 Stream flow modelling

4.1.1 Sensitivity Analysis

Parameter ranking by sensitivity analysis improves the identification of most sensitive elements with significant influence on output data of stream flow simulations. This process makes the calibration more effective. The sensitivity analysis was based on results from the first simulations. Flow sensitivity analysis was carried out for a period of 9 years, which includes 3 years (from 2001 to 2009) warm-up period. According to the results obtained from the sensitivity analysis using SUFI2, the ranks of the parameters was assigned depending on t - stat and p – value. During sensitivity analysis, 480 iterations have been done and 24 parameters were tested for flow sensitivity analysis. The first seventeen parameters showed a relatively high sensitivity from the flow parameters (Table 4.1). Effective hydraulic conductivity of main channel alluvium, Available water capacity of the soil layer, SCS runoff curve number, Moist bulk density, Plant uptake compensation factor, Deep aquifer percolation fraction, Hydraulic conductivity of the reservoir bottom, Maximum canopy storage , Soil evaporation compensation factor, Manning's "n" value for the main channel and Ground water revap coefficient were found to be the most sensitive with their effect on the simulated result when their value is changed and selected for calibration. Some of the selected parameters were filtered based on the sub basin numbers.

Table4.1: Result of sensitivity analysis of flow parameters in Melkasa dam watershed.

S/no	Parameter Name	Parameter description	t-Stat	P-Value	Sensitivity Rank
1	CH_K2(D)	Effective hydraulic conductivity of main channel alluvium	-32.22	0	1
2	CH_K2(U)	Effective hydraulic conductivity of main channel alluvium	-21.32	0	2
3	SOL_AWC	Available water capacity of the soil layer	-16.48	0	3
4	CN2(U)	SCS runoff curve number	15.87	0	4
5	SOL_BD(U)	Moist bulk density.	13.39	0	5
6	EPCO(U)	Plant uptake compensation factor	-11.51	0	6
7	SOL_BD(D)	Moist bulk density.	10.36	0	7
8	RCHRG_DP	Deep aquifer percolation fraction	9.89	0	8
9	RES_K	Hydraulic conductivity of the reservoir bottom.	-9.84	0	9
10	CANMX(U)	Maximum canopy storage	-9.35	0	10
11	ESCO(U)	Soil evaporation compensation factor	5.64	0	11
12	EPCO(D)	Plant uptake compensation factor	-4.82	0	12
13	CN2(D)	SCS runoff curve number	3.93	0	13
14	CH_N2	Manning’s “n” value for the main channel	-3.55	0	14
15	GW_REVAP	Groundwater revap coefficient	-2.87	0	15
16	ESCO(D)	Soil evaporation compensation factor	2.52	0.01	16
17	CANMX(D)	Maximum canopy storage	-2.02	0.04	17

U: upstream sub basins number 1-17,20-24,29-32,35-37,40-48,60

D: downstream sub basins number 18-19,25-31,33-34,38-39,49-59,61-68

4.1.2 Model Calibration for Stream flow

The model was calibrated using seventeen parameters which were recorded as the most sensitive parameters were used for the stream flow measurement. First the parameters were manually calibrated for the period of 2004 to 2009 until the model simulation results were acceptable as per the model performance measures. Next, the final parameters values that were manually calibrated were used as the initial values for the auto calibration Procedure. The analysis of simulated result and observed flow data comparison was done on a monthly basis.

The SWAT parameters and ranges of the selected parameters for calibration and calibrated values were shown in table4.2

Table4.2: Summary of calibrated flow parameters

S/no	Parameter	Description of parameters	Lower bound	Upper bound	Calibrated value
1	R__CN2.mgt(U)	SCS runoff curve number	-0.2	0.2	0.03
2	R__CN2.mgt(D)	SCS runoff curve number	-0.2	0.2	-0.09
3	R__SOL_AWC(..).sol	Available water capacity of the soil layer	-0.2	0.4	0.28
4	R__SOL_BD(..).sol(U)	Moist bulk density.	-0.5	0.6	-0.39
5	R__SOL_BD(..).sol(D)	Moist bulk density.	-0.5	0.6	0.07
6	V__CANMX.hru(U)	Maximum canopy storage	0	10	1.73
7	V__CANMX.hru(D)	Maximum canopy storage	0	1	4.37
8	V__CH_K2.rte(U)	Effective hydraulic conductivity of main channel alluvium	0	130	3.88
9	V__CH_K2.rte(D)	Effective hydraulic conductivity of main channel alluvium	0	130	34.17
10	V__CH_N2.rte	Manning's "n" value for the main channel	0	0.3	0.24
11	V__EPCO.hru(U)	Plant uptake compensation factor	0	1	0.41
12	V__EPCO.hru(D)	Soil evaporation compensation factor	0	1	0.41
13	V__ESCO.hru(U)	Soil evaporation compensation factor	0.8	1	0.88
14	V__ESCO.hru(D)	Soil evaporation compensation factor	0.8	1	0.84
15	V__GW_REVAP.gw	Groundwater revap coefficient	0	10	0.11
16	V__RCHRG_DP.gw	Deep aquifer percolation fraction	0	1	0.35
17	V__RES_K.res	Hydraulic conductivity of the reservoir bottom.	0	1	0.9

The extension (e.g., hru) refers to the SWAT input file where the parameter occurs.

The qualifier (V_) refers to the substitution (replace) of a parameter by a value from the given range.

The qualifier (R_) refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range.

U: upstream sub basins number 1-17,20-24,29-32,35-37,40-48,60

D: downstream sub basins number 18-19,25-31,33-34,38-39,49-59,61-68

The calibration period has shown a good agreement between monthly measured and simulated flows (Figure4.1). The Calibration result showed that the coefficient of determinations (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.78 and 0.75 respectively. The scatter plot of the values of the measured and the simulated monthly stream flow data have also shown a fair linear correlation between the two data sets. The trend and the magnitude of the two data set values are shown in (Figure 4.2).

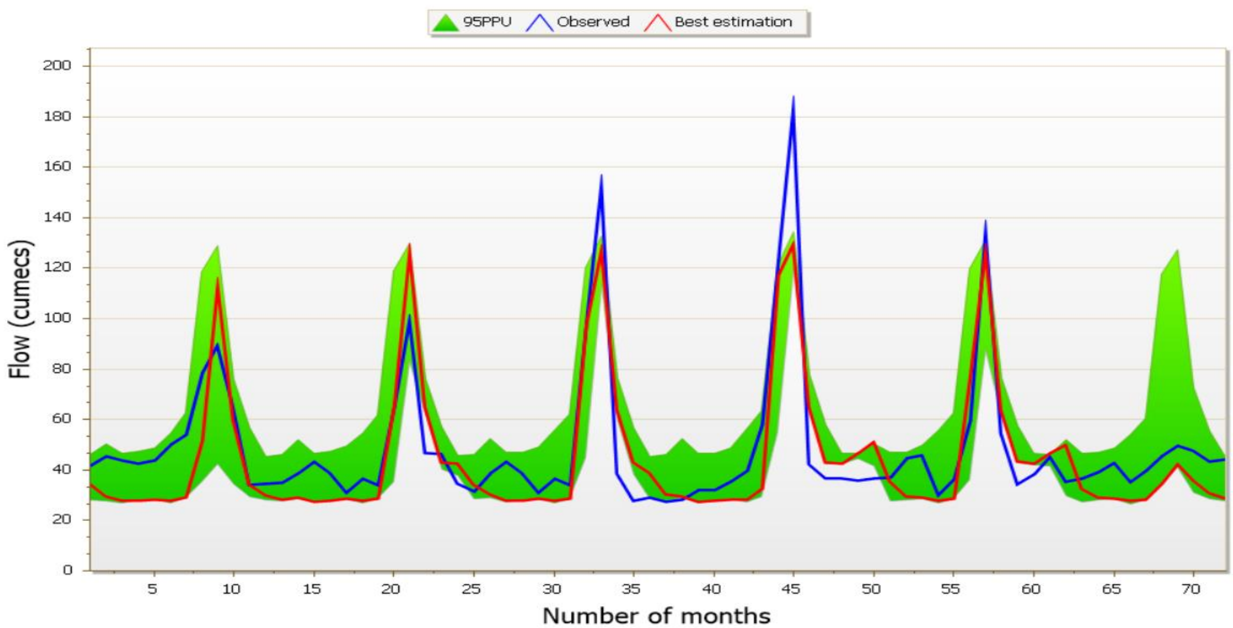


Figure4. 1: Monthly Calibrated flow hydrograph at Wonji gauging station (2004-2009)

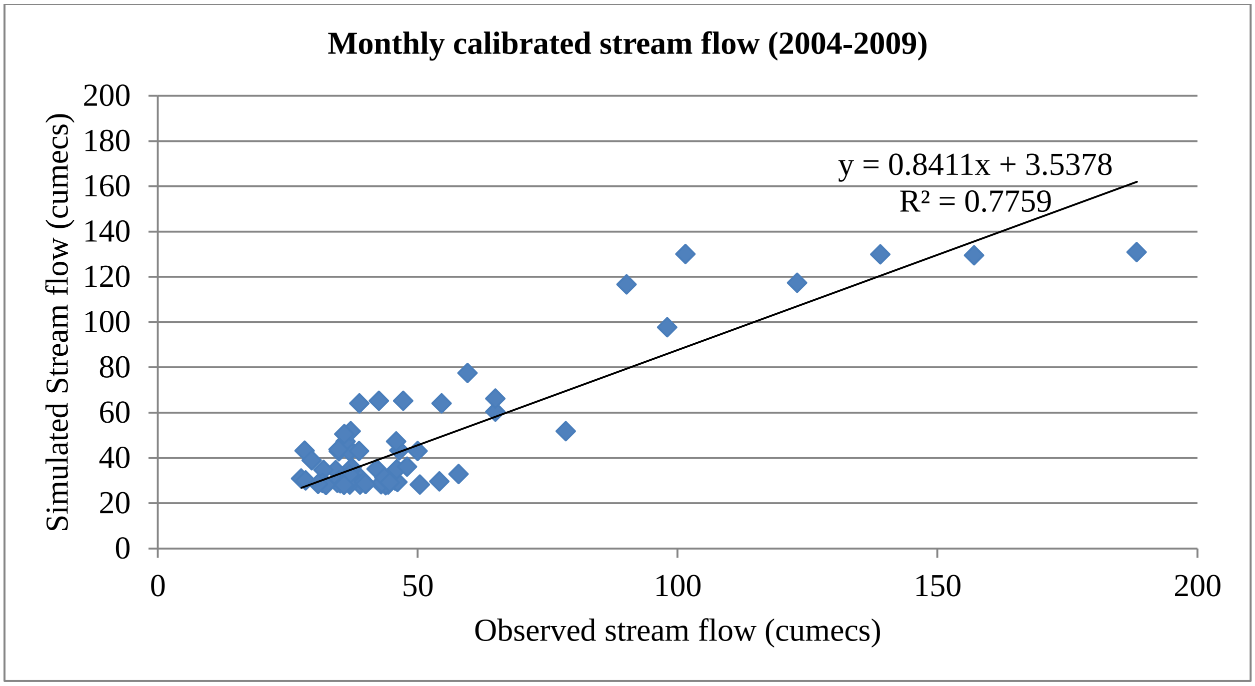


Figure4. 2: Scatter plot of observed and simulated stream flow at Wonji gauging station during calibration period

The hydrograph of the calibration period (2004 – 2009) of the observed and simulated flow in monthly estimation, the model slightly under estimates some of the peak and low flows of the months in the year 2006, 2007 and 2008 (Figure 4.1). This may be due to the quality of weather or flow data and the presence of flow regulation at upstream (koka reservoir) of the gauging station used as an input to the model. The availability of reservoir in the upstream of the gauging station regulates the flow and it affects the shape of the hydrograph during peak and low flow occurs.

4.1.3 Model validation for Stream flow

The stream flow validation was carried out using the calibrated parameters. For model validation the remaining observed stream flow data from 2010 to 2013 were used. In the validation process, the model was run with input parameters set during the calibration process without any change. During validation period, monthly measured and simulated flows have also shown a good agreement between each other. The comparison made between the observed and simulated stream flow indicated that a good agreement were obtained between the observed and simulated flow, which was verified using both graphical technique and quantitative statistics. The value of coefficient of determination (R^2=0.83), Nash-Sutcliffe efficiency (NSE=0.79), and percent bias

(PBIAS=0.1) obtained during validation justify that the model is very good in simulating runoff from Awash Melkasa watershed.

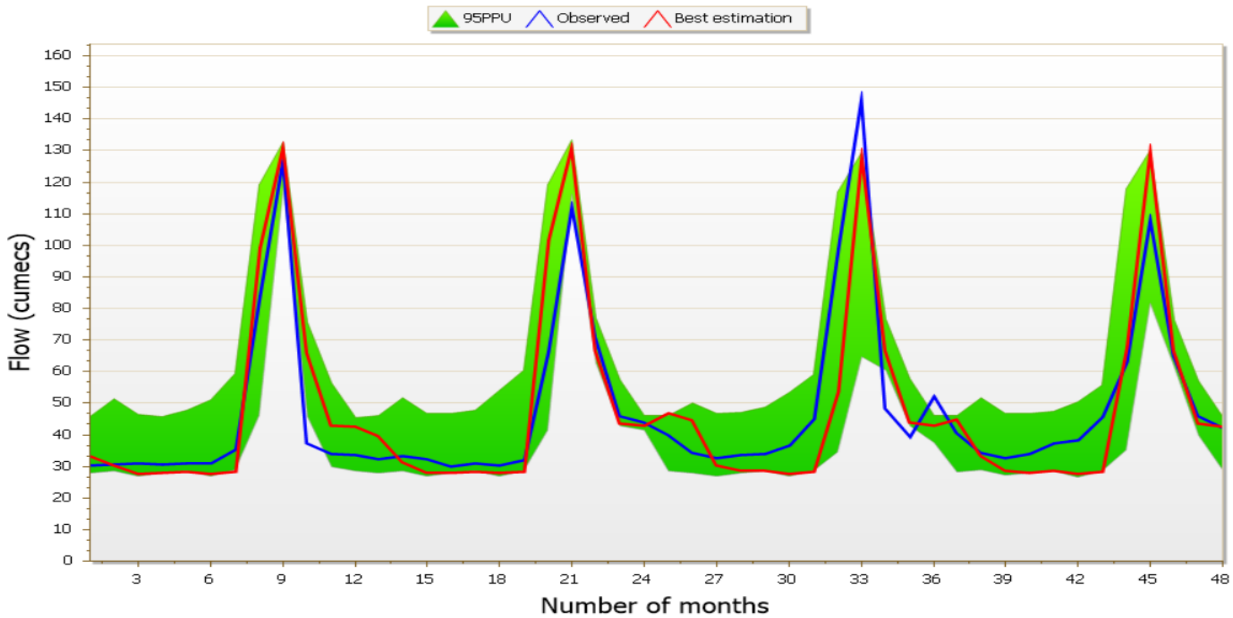


Figure4. 3: Monthly Validated flow hydrograph at Wonji gauging station (2010-2013)

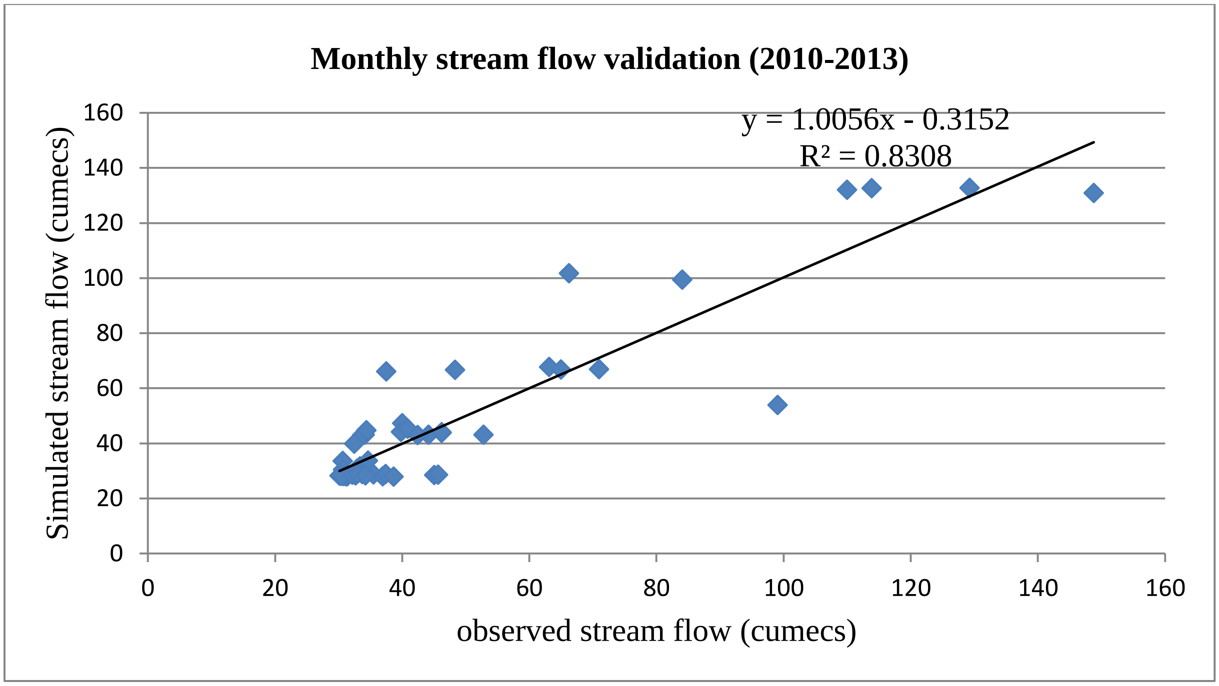


Figure4. 4: Scatter plot of observed and simulated stream flow for Wonji gauging station during validation period

Unlike calibration of flow period, the hydrograph of the validation period (2010 – 2013) of the observed and simulated flow in monthly basis estimation, the model estimates accurately with small value under estimation (Figure 4.3). During calibration and validation period the percent of bias (PBIAS) value obtained was 8.8 and 0.1 respectively (Table4.3). The Positive values PBIAS indicates the model under estimation. Since the PBIAS obtained during validation period approaches to zero it implies accurate model simulation

Table4.3: Summary of calibrated and validated performance indicators for monthly flow simulations and model uncertainty measurements

Simulation (months)	Uncertainty measures		Performance indicators			
	p-factor	r-factor	R2	NS	RSR	PBIAS
Calibration (2004 - 2009)	0.74	0.76	0.78	0.75	0.5	8.8
Validation (2010 -2013)	0.92	0.96	0.83	0.79	0.45	0.1

4.2 Sediment yield modelling

4.2.1 Sensitivity analysis

The potential of SWAT model in sediment yield prediction by accepting the most sensitive sediment parameters for sediment yield calibration and validation in the study watershed would be checked after identification of sensitive parameters. During sensitivity analysis of sediment yield, 14 sediment parameters were analyzed. From those parameters, the first seven were highly sensitive and given to high priority for calibration. These parameters were normal sediment concentration in the reservoir, Channel cover factor, USLE support Practice factor, Initial sediment concentration in the reservoir, USLE support Practice factor, Average slope length and Linear parameter for calculating the maximum amount of sediment that can be restrained during channel sediment routing.

Table4.4: Sensitivity analysis of sediment yield parameters

S/no	Parameter Name	Parameter description	t-Stat	P-Value	Sensetivity Rank
1	RES_NSED.res	Normal sediment concentration in the reservoir	8.76	0	1
2	CH_COV2.rte(D)	Channel cover factor	2.46	0.01	2
3	USLE_P.mgt(D)	USLE support Practice factor	2.41	0.02	3
4	RES_SED.res	Initial sediment concentration in the reservoir.	2.28	0.02	4
5	USLE_P.mgt(U)	USLE support Practice factor	-1.94	0.05	5
6	SLSUBBSN.hru(U)	Average slope length	1.7	0.09	6
7	SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	-1.46	0.14	7
8	HRU_SLP.hru(U)	Average slope steepness	-1.32	0.19	8
9	SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment routing	1.16	0.25	9
10	HRU_SLP.hru(D)	Average slope steepness	-0.91	0.36	10
11	BIOMIX.mgt(D)	Biological mixing efficiency	0.52	0.6	11
12	CH_COV1.rte(U)	Channel erodibility factor	-0.33	0.74	12
13	BIOMIX.mgt(U)	Biological mixing efficiency	-0.25	0.81	13
14	CH_COV1.rte(D)	Channel erodibility factor	-0.07	0.94	14

U: upstream sub basins number 1-17, 20-24, 29-32, 35-37, 40-48, 60

D: downstream sub basins number 18-19, 25-31, 33-34, 38-39, 49-59, 61-68

4.2.2 Model Calibration for Sediment yield

The calibration of sediment yield was done after the model has been validated for stream flow. The sediment parameters used for calibration was selected based on the sensitivity analysis performed. The SWAT model was calibrated for sediment by comparing the model simulated sediment yield with the measured sediment data on Awash River at Wonji gauging station.

Table4.5: Summary of calibrated sediment parameters

S/no	parameter	parameter description	lower bound	upper bound	calibrated value
1.	V__USLE_P.mgt(U)	USLE support Practice factor	0.02	1	0.571
2.	R__SLSUBBSN.hu*	Average slope length	0	0.2	0.098
3.	V__SPCON.bsn***	Linear parameter for channel sediment routing	0.001	0.01	0.005
4.	V__CH_COV2.rte**	Channel cover factor	-0.001	1	0.153
5.	V__USLE_P.mgt(D)	USLE support Practice factor	0.02	1	0.359
6.	V__RES_SED.res	Initial sediment concentration in the reservoir.	0	5000	1959.689
7.	V__RES_NSED.res	Normal sediment concentration in the reservoir	0	5000	1042.122

****The extension (e.g., .bsn) refers to the SWAT input file where the parameter occurs.*

***The qualifier (V_) refers to the substitution (replace) of a parameter by a value from the given range.*

**The qualifier (R_) refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range.*

The SWAT - CUP (SUFI2) model was found to simulate well on monthly basis of sediment yield. Coefficient of determination (R^2) value and Nash - Sutcliffe model efficiency (NSE) calculated on monthly basis between the simulated and observed monthly sediment yield for the calibration periods were 0.82 for both of them. Calibration results show that model performance is good with simulation of monthly sediment yield. The P-factor is the measures of the degrees to which all uncertainties are accounted, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU) and have been calculated as 0.53. The strength of the model calibration and uncertainty procedure has been analyzed using the r-factor. The r-factor shows the average thicknesses of 95PPU band divided by the standard deviation of the observed data and have been calculated as 0.61.

The observed and simulated sediment yield in monthly basis were plotted for visual comparison to explore the similarity within the peak values resulting from the procedures of SUFI-2 algorithm and the scatter plot of monthly sediment yield showing a well-fitting relationship of the observed and simulated values for calibration shown in figure 4.6.

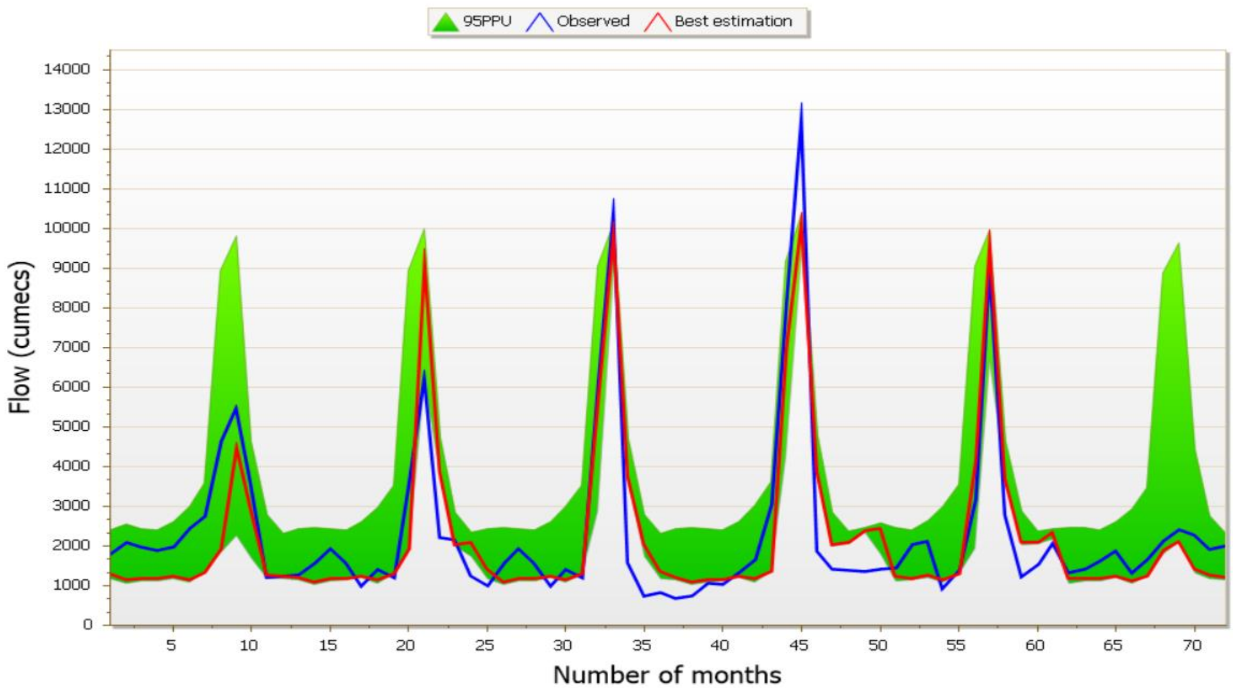


Figure4. 5: Monthly Calibrated Sediment yield results at Wonji gauging station (2004-2009)

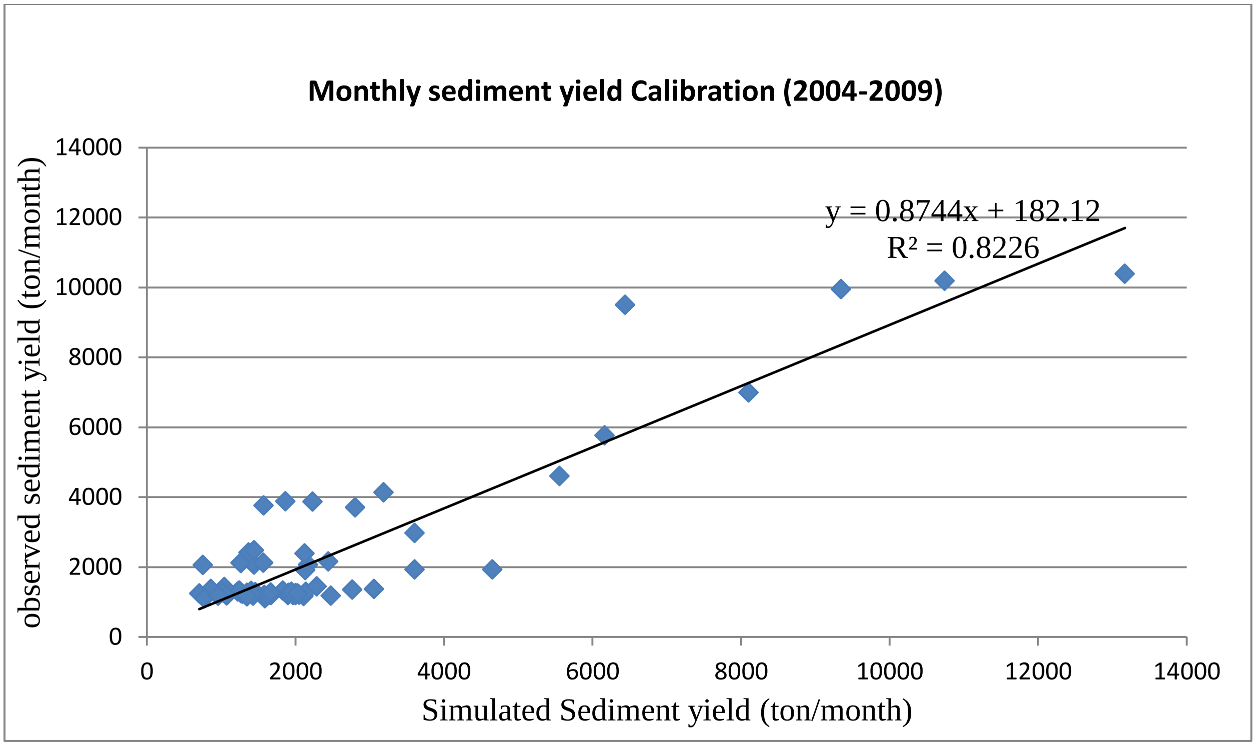


Figure4. 6: Scatter plot of observed and simulated sediment yield at Wonji gauging station during calibration period

4.2.2 Model Validation for Sediment yield

The model performance in validation was carried out from 2010 to 2013, without further adjustment of the parameters of sediment. Accordingly, good match between monthly measured and simulated sediment yield in the validation period were demonstrated by the coefficient of Determination (R^2) of 0.78, Nash - Sutcliffe simulation efficiency (ENS) of 0.76, Percent bias (PBIAS) of 4.9, Root mean Square error standard deviation ratio (RSR) of 0.49, p - Factor of 0.58 and r – Factor of the monthly flow was found to be 0.65.

The scatter plot of the values of the measured and the simulated monthly sediment load data have also shown a fair linear correlation between the two data sets. The trend and the magnitude of the two data set values are shown in (Figure 4.8).

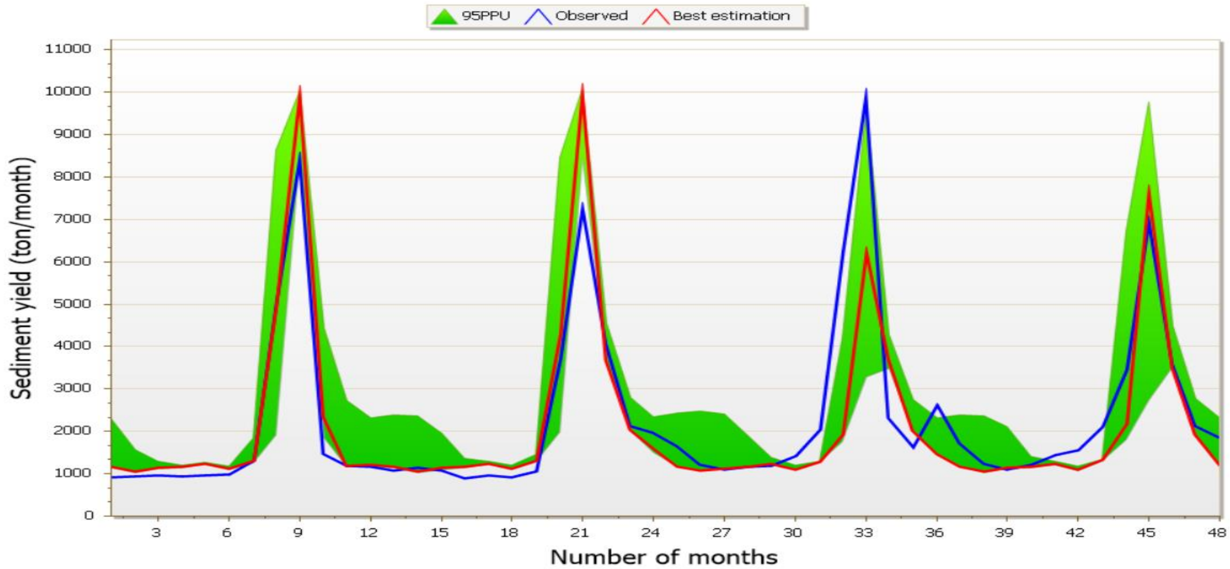


Figure4. 7: Monthly Validated Sediment yield results at Wonji gauging station (2010-2013)

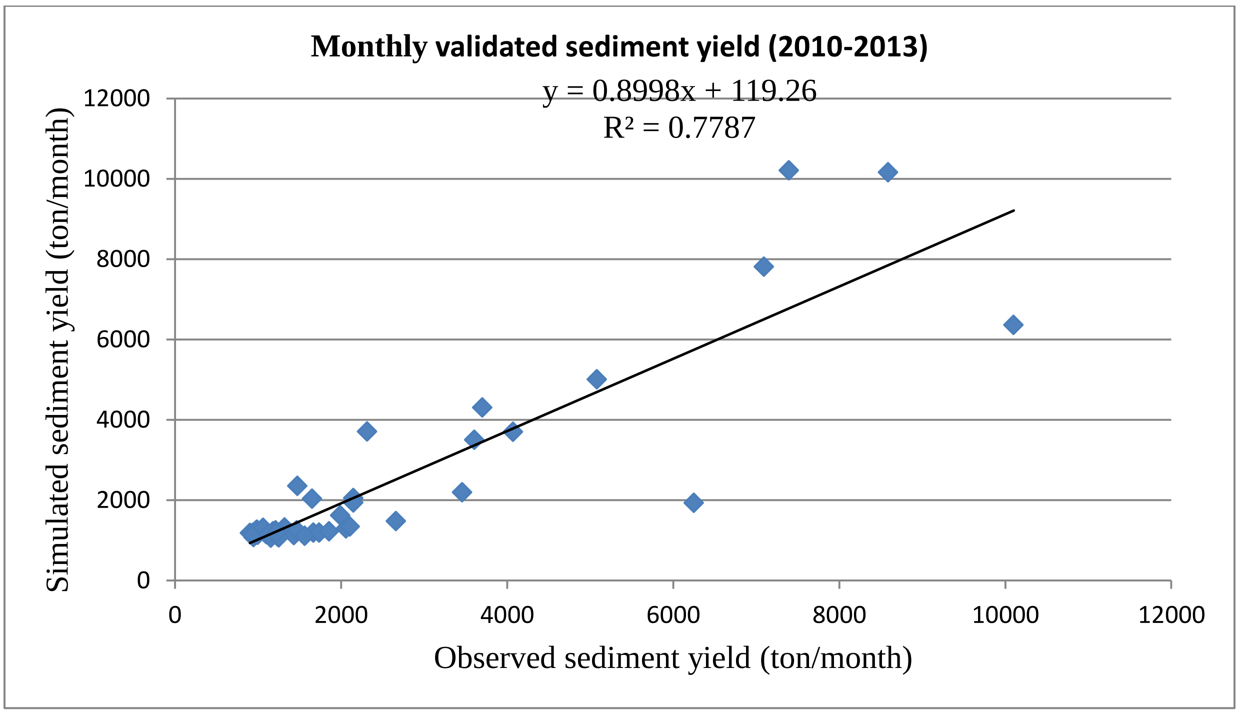


Figure4. 8: Scatter plot of observed and simulated sediment yield at Wonji gauging station during validation period

The model calibration and validation results also showed that the monthly predicted and observed sediment yields matched well. The indicators have been found to be within the range of very good performance level. The uncertainty measure of SUFI-2 shows 53% of the observed sediment yield monthly data of Wonji gauging station was bracketed by the 95PPU for calibration with a better strength of estimation (r – factor < 1). Similarly, the validation period was also with the acceptable range of model uncertainty. The performance indicators for both calibration and validation were summarized as table 4.6.

Table4.6: Summary of calibrated and validated performance indicators for monthly sediment yield simulations and model uncertainty measurements

simulation (months)	uncertainity measures		performance indicators			
	P-factor	r-factor	R^2	NS	RSR	PBIAS
Calibration (2004 - 2009)	0.53	0.61	0.82	0.82	0.43	5
Validation (2010-2013)	0.58	0.65	0.78	0.76	0.49	4.9

The model evaluation with statically (table 4.6) and graphical (figure 4.7 and 4.8) method shows the monthly sediment yield confirmed with the actual condition on the watershed. And also the calibrated and validated result for both stream flow and sediment load predicted with acceptable range. And also the uncertainty measure of r-factor is slightly large, but it falls in the recommended range (r-factor <1) which makes acceptable.

Hence, it is possible to determine the rate of sediment inflow to the reservoir per year and to identify the most erodible sub basin based on their sediment delivery to their respective downstream.

4.3 Sediment yield inflow rate of Awash Melkasa Reservoir

After calibration and validation of both stream flow and sediment yield have carried out, the average annual sediment yield of the watershed estimated at the Awash Melkasa reservoir (outlet) was 22,109.5ton/yr. The result obtained at the Awash Melkasa reservoir was relatively medium with compared to other reservoirs. But, the Melkasa reservoir watershed is not on a safe side. Because of the Awash Melkasa dam site is located on downstream of the koka reservoir the sediment inflow to the reservoir may decrease as the flow decrease. And also some water abstractions for water supply and irrigation are available at upstream of the Melkasa reservoir that reduce the inflow of sediment.

4.4 Spatial Variability of Sediment Yield Rate

After successful calibration and validation of the flow and sediment yield, the model was run for 24 years (1992-2015) to set the best parameter values and to get average annual sediment yield of the watershed. Then, the sediment outflow from each of the sub basin or reach has been modeled. Spatial variability of sediment yield for the entire watershed was identified from the simulated annual sediment yield rate, and the analysis reveals the range is between 0 to 18.54 tons/ha/yr with an average of 6.52 tons/ha/yr for the sub-basins. The sediment spatial variability map was generated by using the average annual sediment yield from each sub basin based on erosion severity class and/or sediment yield (ton/ha/yr). After calibration have performed, 19 sub basins were identified as critically affected areas, 19 sub basins as moderately affected, 6 sub basins with acceptable erosion and the remaining 24 sub basins were very low (negligible) erosion prone areas.

Table4.7: Soil erosion delivery classes of sub-basins

S/no	sediment interval(ton/ha/yr)	erosion class
1	below 3	Negligible erosion
2	3-4.5	Acceptable erosion
3	4.5-9.4	Moderately eroded
4	above 9.4	Severely eroded

Source: Asmelash et al. (2016)

SWAT sub basins, 19 sub-basins produce average annual sediment yields ranging from 10-18.54 ton/ha/yr, while most of the low land and wetland areas are in the range of 0-3 ton/ha/yr. The spatial variation of the sediment yield or eroded soil delivery classes of sub basins based on the classification of table 4.7 were mapped as shown in Figure 4.9

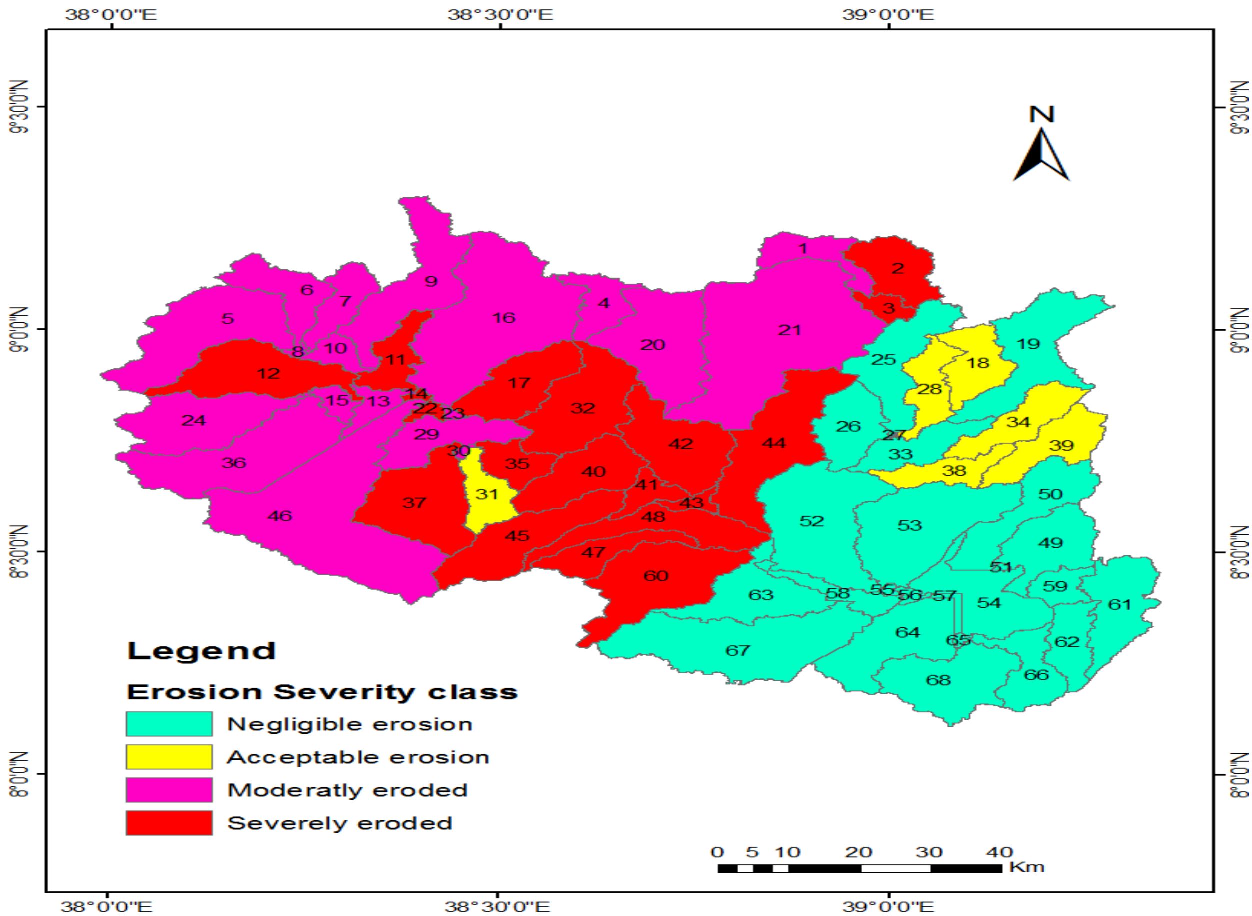


Figure4. 9: Spatial variability of sediment yield map in the Awash Melkasa Dam watershed

The sub basins with severely and moderately eroded area cover 26.16% and 36.17% of the total watershed area respectively. The majorities of the severely eroded area are relatively steeper in slope and dominantly covered with agricultural, grass and range brush lands. Vertisols, cambisols and luvisols are the dominantly distributed soil types in the identified critical sub basins (table4.8).

The most upstream sub basins contribute the majority of the annual sediment yield due to their dominant sediment yield rate compared to sub basins nearest to the Melkasa dam. Sub basin 31 classified in the range of acceptable erosion due to its contribution of erosion potential is slightly fall in the range of 3 to 4.5 ton/ha/year. But, its characteristics are almost similar with the soil erosion classified as moderately eroded with the sediment yield potential of 4.46ton/ha/yr. The upper part of the watershed is mainly classified as moderately eroded while the middle one is severely eroded. These may be because of the frequent and intensive precipitation occur at upstream than the lower sub basins. The annual precipitation in the upstream part of the watershed is relatively larger than the lower part of the watershed (see table 3.4)

The SWAT based sediment yield output of the Awash Melkasa dam watershed was compared with some of related studies. The annual averaged sediment yield of the proposed Middle Awash dam watershed (7.23t/ha/yr) by Wasu (2017) approaches the average annual sediment yield of the Awash Melkasa dam watershed. And also the range of its spatial sediment yield was 0.2-20.48 ton/ha/yr except one sub basin is 30.05ton/ha/yr. This is may be the calibration he undertakes at Hombole gauging station was not at its real location. The real location of the Hombole gauging station is nearest to koka reservoir but he undertake at upstream of the Hombole gauging station which is far from the station. Then, Wasu (2017) generated sediment data from sediment rating curve that was prepared by Golla et al. (2006). The prepared sediment rating curve was at hombole gauging station but the calibration was applied at upstream of the station. This implies for small area of watershed the model calibrates higher flow that was delivered from the larger area of watershed. As the stream flow increase, the sediment yield also increases significantly. So this may affect the spatial distribution of the sediment yield including the quality of sediment data used. However, the spatial sediment yield obtained was almost similar with this study.

The results of this study agreed with that conducted by Tenaw and Awulachew (2009) using SWAT for Runoff and Sediment Yield, Gumera watershed where the spatial sediment yields were in the range of 0-22ton/ha/yr. From the study, they concluded that about 72% of the watershed is erosion potential area with an average annual sediment load ranging from 11 to 22 tonnes/ha/yr while most of the low land and wetland areas were in the range of 0-10 ton/ha/yr.

Table4.8: severely affected sub basins with their dominant LULC, soil types and sediment yield rate in the study area

Subbasin	Area (ha)	Dominant Landuse/land cover*	% coverage	Dominant soil type**	% coverage	SED yield (ton/ha/yr)
40	19430	FRST, AGRC, RNGB and SUGC	99%	EUTRICFLUV and PELLVERTI	94%	18.54
2	14280	RNGE,RNGB,SUGC, AGRC and URHD	92%	PELLVERTI, CALCER and ORTHSLON	95%	18.23
3	4145	SUGC and AGRC	83%	PELLVERTI	100%	16.52
37	28533	AGRC and SUGC	86%	PELLVERTI and CALCFLUV	93%	15.38
47	10632	AGRC SUGC and FRST	91%	VERCAMB, CHROMVER and EUTRINCT	100%	14.10
42	24884	AGRC, RNGB and FRST	97%	PELLVERT,ORTHSLON, VERCAMB and EUTRFLUV	93%	13.69
60	30790	AGRC,MIXC and SUGC	98%	VERCAMB, PELLVERTI, CHROMVER	99%	13.63
14	821.6	AGRC and RNGB	90%	PELLVERTI and CHROMCAM	100%	12.76
32	28120	AGRC, RNGB and FRST	93%	PELLVERTI and CHROMLUV	100%	12.41
35	8831	AGRC	86%	PELLVERTI	100%	12.07
22	1817.4	AGRC, RNGB and FRST	86%	PELLVERTI	100%	11.74
41	5827.1	AGRC and SUGC	86%	VERCAM and EUTRICFLUV	90%	11.70
48	18825	AGRC and SUGC	88%	VERCAMB and CHROMVER	85%	11.69
45	24558	AGRC, SUGC and FRST	94%	EUTRNICT, VERCAMB and PELLVERTI	85%	11.21
17	19620	AGRC, MIXC and RNGB	93%	PELLVERT and CHROMLUV	83%	10.96
11	10639	RNGE,RNGB,SUGC and AGRC	87%	PELLVERTI	90%	10.63
44	34752	RNGB and AGRC	88%	VERCAMB, PELLVERTI and ORTHOSLON	86%	10.47
12	26283	RNGE,RNGB,SUGC and AGRC	97%	PELLVERTI and ORTHSLON	96%	10.41
43	2659.8	RNGB and AGRC	99%	VERCAMB, PELLVERTI and EUTRICFLUV	81%	10.02

* The SWAT codes of land use /land cover type are user codes of this study (see table 3.2),

** The user codes of soil types of this study (Apendix B)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The SWAT model was calibrated from 2004 to 2009 and validated from 2010 to 2013 on a monthly basis to determine its performance for modelling stream flows and sediment yields from the Melkasa dam watershed. The average monthly simulated flows and sediment yields were compared with the average monthly observed values using statistical and graphical methods. The results showed reliable estimates of average monthly flow and sediment yields with a very good coefficient of determination (R^2), Nash-Sutcliffe model efficiencies (ENS), Root mean Square Error Standard Deviation Ratio (RSR) and Percent bias (PBIAS) during both the calibration and validation periods. The results of the model calibration and validation showed reliable estimates of monthly stream flow (with R^2= 0.78, NSE = 0.75, PBIAS = 8.8 and RSR = 0.5) and (R^2= 0.83, NSE = 0.79, PBIAS = 0.1 and RSR = 0.45) respectively. Similarly, SWAT performed well (with R^2= 0.82, NSE = 0.82, PBIAS = 5 and RSR = 0.43) and (R^2= 0.78, NSE = 0.76, PBIAS = 4.9 and RSR = 0.49) during Sediment calibration and validation respectively.

After calibration has performed the simulated average annual sediment yield estimated was 22,109.5ton/yr at the outlet, with an average spatial distribution of 6.52 ton/ha/yr. The spatial variability of sediment yield distribution analysis showed that 19 sub basins were relatively high sediment yield rate (10 -18.54 ton/ha/yr), 19 sub basins as moderately affected, 6 sub basins with acceptable erosion and 24 sub basins were negligible erosion prone areas.

The most upstream sub basins are relatively the source of sediment and more vulnerable to soil erosion due to high runoff generated from relatively steeper and seasonal rainfall occurred from July to September. The sub basins with severely and moderately eroded area cover 26.16% and 36.17% of the total watershed area respectively. The majorities of the severely eroded area are relatively steeper in slope and dominantly covered with agricultural, grass and range brush lands. The dominantly distributed soil types in the identified critical sub basins were vertisols, cambisols and luvisols. Sub basins with the relatively a higher sediment delivery rate were considered as the most severely eroded sub basins and needs prior mitigation measures to minimize soil losses from the watershed.

In general, the SWAT model performed well in simulating both the stream flow and sediment yields from the Melkasa watershed and the results were acceptable. It is a capable tool for further analysis of the hydrological responses in the watershed. Thus it can be used as a planning tool for watershed management.

5.2 RECOMMENDATION

This study has tried to model the sediment yield of the Awash Melkasa dam watershed by using a semi- distributed soil and water assessment tool(SWAT) using the available input data. However, Watershed modelling with scarce data has challenges and model prediction efficiency depends on the quality of the input data. In Awash Melkasa watershed the availability of meteorological stations in number is good but some of the station has no data (not recorded continuously). And also around reservoir site there is no hydrological gauging station. For example koka and Awash Melkasa reservoir has no gauging station. Lack of well representative meteorological stations, continuously measured sediment and flow data; generally affect the quality of data and the model performance. In order to solve these problems, continuous sampling and measurement of sedimentation and other water quality parameters have to be addressed by responsible bodies together for a better weather and hydrological datasets.

The model simulation in this study considers the spatial analysis of erosion prone areas and quantification of sediment yields. Therefore, future studies should evaluate best management practices to address different sediment reduction methods and climate change impacts on water recourses availability in the watershed. And also land use land cover changes that contribute great impact on hydrological process of the catchment should be considered.

The result of the study could help different stakeholders to plan and implement appropriate soil and water conservation strategies. To minimize the sediment load of the Awash Melkasa watershed, more intensive soil and water conservation works are required especially for the severely eroded sub basin.

REFERENCE

Abbaspour, K. (2015). SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs: A User Manual. Department of Systems Analysis Integrated Assessment and Modelling (SIAM), Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland.

Angstrom A., 1924. Solar and terrestrial radiation, Quarterly Journal of Royal Meteorological Society, 50, 121–125

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams (1998). Large area hydrologic modeling and assessment part I: model development. J. American Water Resources Association 34(1):73-89

Arnold, J., Moriasi, D., Gassman, P., Abbaspour, K., White, M., Srinivasan, R., et al., (2012). SWAT: model use, calibration, and validation. Trans. ASABE 55, 1491–1508.

Arnold JG, Williams JR, Maidment DR.(1995). Continuous-time water and sediment routing model for large basins. Journal of Hydraulic Engineering; 121(2): 171-183.

Asmelash Tilahun Asfaw (2015). Sediment inflow estimation and its spatial variability at sub basin scale (the case study of Tendaho dam, Afar). Unpublished MSc Thesis. Arba minch University, Ethiopia.

Asmelash Tilahun , Hayle A.SH., Bogale G.(2016). Sediment inflow estimation and Mapping its spatial distribution at sub basin scale: The case of Tendaho dam, Afar Region, Ethiopia. Ethiopian journal of Environmental studies and management; 10 (3): 315-339

Awulachew, S. B.; Yilma, A. D.; Loulseged, M.; Loiskandl, W., Ayana, M.; Alamirew, T. (2007). Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: *International Water Management Institute*. 78p. (Working Paper 123)

Ayana, A.B., Desalegn Chemeda Edossa and Ekasit Kositsakulchai (2012). Simulation of Sediment Yield using SWAT Model in Fincha Watershed, Ethiopia. Kasetsart J. (Nat. Sci.) 46: 283-297.

Azazh, B. T. (2008). *Water Allocation Study of Upper Awash Valley for Existing and Future Demands*. Unpublished MSc Thesis, Addis Ababa University, Ethiopia.

Beven K., (2001). Rainfall-Runoff modelling. The Primer John Wiley and Sons, Chichester, UK, 1-360 pp.

Bingner, R.L., Theurer, F.D., and Yuan, Y. (2015). AnnAGNPS technical processes documentation version Version 5.4. USDA-ARS. National Sedimentation Laboratory.

Booker Tate Limited/ Yerer Engineering (2005). *Feasibility study of land development for the Cane production for Metahara Sugar Factory*. Final report, vol. 1, Awash River Basin Authority. Addis Ababa. Ethiopia.

Chekol, D.A., B. Tischbein, H. Eggers and P. Vlek. (2007). Application of SWAT for assessment of spatial distribution of water resources and analyzing impact of different land management practices on soil erosion in Upper Awash River Basin watershed. *FWU Water Resources Publications* 6: 110–117

Chow, V.T., Maidment, D.R., Mays, L.W. (1988). *Applied Hydrology*. McGraw-Hill: New York, USA.

Clarke, R.T. (1994). Statistical modeling in Hydrology. John Wiley and Sons, pp 412.

Cunderlik M. Juraj (2003). Hydrologic model selection fort the CFCAS project: Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions, Project Report I, 40pp.

Dile, Y.T., Karlberg, L., Daggupati, P., Srinivasan, R., Wiberg, D., Rockström, J., (2016). Assessing the implications of water harvesting intensification on upstream–downstream ecosystem services: a case study in the Lake Tana basin. Sci. Total Environ. 542 (Part A), 22–35

Duraes,Matheus Fonseca, Carlos Rogerio de Mello, Mauro Naghettini (2011).Applicability of the SWAT model for hydrologic simulation in paraopeba river basin. *Network of Scientific Journals from Latin America*. 17(4), 481-488

El-Nasr, A.A., Arnold, J.G., Feyen, J., and Berlamont, J. (2005). Modelling the hydrology of a catchment using a distributed and a semi-distributed model. Hydrological Processes *19*, 573–587.

Ethiopian Electric Power Corporation, (1999): Koka Dam sedimentation study: Unpublished Recommendations report. Addis Ababa, Ethiopia.

Foster, G. R. and Meyer, L. D. (1977). “Soil erosion and sedimentation by water-an overview” Procs National Symposium on Soil Erosion and Sedimentation by Water, *Am. Soc. Of Agric. Eng., St. Joseph*, Michigan, 1-13

Gassman, P. W., M. R. Reyes, C. H. Green, J. G. Arnold (2007). The soil and water assessment tool: historical development, applications, and future research directions. *Trans. ASABE* . 50(4): 1211-1250

Gayathri K Devia, Ganasri B P, Dwarakish G S (2015). International conference on water resources, coastal and ocean engineering. Journal of Aquatic Procedia 4 (2015), 1001 – 1007

Geleta, H. I. (2011). Watershed Sediment Yield Modeling for Data Scarce Areas. PhD thesis. Stuttgart University, Germany.

Golla, S., EL-Sersawy, H., Ahmed, A.A., Vanacker, V. (2006). Modelling Water and Sediment Fluxes in Steep River Channels: Case of Awash Basin

Gonfa, Z. B. and Kumar, D. (2016). Application of Soil and Water Assessment Tool Model to Estimate Runoff and Sediment Yield from Mojo Watershed. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5(2):2081-2091

Green, W.H., and Ampt,G.A.(1911). Studies on soil physics, 1.The flow of air and water through soils. J. Ag. Sci. 4:1-24.

Goodchild, M. F., 2000. The Current Status of GIS and Spatial Analysis, Geographical Systems, 2:5-10

Gupta H.V., Beven K. and Wagener T., (2005), Model calibration and uncertainty estimation,

Encyclopedia of Hydrological Sciences, 11(131), 1-17

Hurni, H. (1985). Soil conservation manual for Ethiopía. Ministry of Agriculture, Addis Abeba, Ethiopía

Jansson M. B. (1988), “A Global Survey of Sediment Yield”, Geogr. Ann. 70, ser. A (1-2): 8198.

Julien, P. Y. (1998). “Erosion and sedimentation” Cambridge University Press, Cambridge, New York

Leirsch, S. (2003a).The program PCPSTAT user’s manual. Berlin

Leirsch, S. (2003b). The Programs dew.exe and dew02.exe, user's manual. Berlin

Lemma Tufa Bokan (2015). Simulation of Sediment Yield Using SWAT Model: A case of Kulekhani Watershed, Nepal. MSc Thesis. Norwegian University

Lenhart,T., Eckhardt, K., Fohrer, N., Frede, H. G. (2002).Comparison of two different approaches of sensitivity analysis. *Physics and Chemistry of the Earth* 27: 645-654

Pechlivanidis G.I, Jackson M.B., Mcintyre R.N., and H.S. Wheater S.H.(2011) .Catchment scale hydrological modelling: a review of model Types, calibration approaches and uncertainty analysis methods In the context of recent developments in technology and Applications. *Global NEST Journal*. 13(3), 193-214

Halcrow, W. (1989). *Master Plan for the Development of Surface Water Resources in the Awash River Basin*. Final Report, vol. 2, Ethiopian Valleys Development Authority, Addis Ababa.

Johanson, R.C., Imhoff, J.C., Kittle, J.L., and Donigan, A.S. (1984). Hydrologic Simulation Program - FORTRAN (HSPF) User’s Manual for Release 8.

Katherine Chambers (2017). Flood Modelling and Assessments for Downstream Communities of Koka Dam, Ethiopia. University of Colorado Boulder Environmental Engineering and Engineering for Developing Communities

Morias, D.N., Gitau, M.W., Pai, N., and Daggupati, P. (2015). Hydrological and water quality models: Performance measures and criteria. *Trans. ASABE* 58(6), 1763-1785

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., and Veith T.L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *T. ASABE* 50(3), 885-900.

MoWR, 1999. Koka Dam survey report from Hydrology Department. Addis Ababa, Ethiopia.

Naomi Cambien (2017). Evaluation of the soil and water assessment tool (SWAT) to simulate pesticide dynamics in the Guayas River Basin (Ecuador). MSc Thesis. Ghent University

Nash, J.E. and J.V. Sutcliffe. (1970). River flow forecasting through conceptual models, part I. A discussion of principles. *J. Hydrol*. 10 (3): 282–290.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry and J.R. Williams. 2005. Soil and Water Assessment Tool: Theoretical Documentation. Blackland Research Center, Grassland, Soil and Water Research Laboratory, Agricultural Research Service: Temple, TX, USA. 476 pp.

Neitch, S.L., Arnold, J. R., Kiniry, J. R., & Williams, J. R. (2011). *Soil and Water Assessment Tool (SWAT) Theoretical Documentation Version2009*. Texas Water Resources Institute Technical Report No.406, Texas A&M University System, College Station, Texas.

Orellana B., Pechlivanidis I.G., McIntyre N., Wheater H.S. and Wagener T., (2008). A toolbox for the identification of parsimonious semi-distributed rainfall-runoff models: Application to the Upper Lee catchment. *International Congress on Environmental Modelling and Software*, **1**, 670-677, 7-10 July, Barcelona, Spain.

Pandey, A., Himanshu, S.K., Mishra, S.K., and Singh, V.P. (2016). Physically based soil erosion and sediment yield models revisited. CATENA *147*, 595–620.

Ralison, R. E. & Miller. (1981). Past, present and future SCS runoff procedure. In V.P. Singh (ed.). Rain fall runoff relationship. Water resources publication, Littleton, CO8, PP. 353-364

USDA Soil Conservation Service (SCS), 1972. National Engineering Handbook, Sec. 4, Hydrology, Washington DC.

Setegn, Shimelis G., Ragahavan Srinivasan, Bijan Dargahi (2008).Hydrological Modelling in the Lake Tana Basin, Ethiopia using SWAT model. *The Open Hydrology Journal* 2(2008): 24-40

Singh V.P., (1995). Computer models of watershed hydrology. *Water Resources Publications*, LLC, USA.

Singh V.P. and Frevert D., (2006). Watershed models. Boca Raton, Taylor & Francis

Sharma, K. D., Sorooshian, S. and Wheater, H., 2008. *Hydrological Modelling in Arid and Semi-Arid Areas. New York*: Cambridge University Press. 223 p. ISBN-13 978-0-511-37710-5.

Tenaw, Mequanint and Awulachew, Seleshi Bekele (2009). Soil and Water Assessment Tool (SWAT)-Based Runoff and Sediment Yield Modeling: A Case of the Gumera Watershed in Lake Tana Sub basin. *Intermediate Results Dissemination Workshop held at the International Livestock Research Institute (ILRI), Addis Ababa, and Ethiopia.pp.100*-111

Tuo Ye, Zheng Duan, Markus Disse, Gabriele Chiogna (2016). Evaluation of precipitation input for SWAT modeling in Alpine catchment: A case study in the Adige river basin (Italy). Science of the Total Environment journal 573: 66-82

Tsegaye, G. S. (2009). Surface Water – Groundwater Interactions and Effects of Irrigation on Water and Soil Resources in the Awash Valley. Unpublished MSc Thesis. Addis Ababa University, Ethiopia

Wasu Manawko (2017). Assessing effectiveness of watershed management options for sediment yield reduction using SWAT model (A Case Study of the Proposed Middle Awash Dam Watershed). MSc Thesis. Arba Minch University, Ethiopia.

Wheater H.S., Jakeman A.J., Beven K.J., Beck M.B. and McAleer M.J., (1993). Progress and directions in rainfall-runoff modelling. Modelling change in environmental systems, New York, pp. 101-132.

Williams, J.R. and Hann, R.W., 1973. HYMO: problem oriented computer language for hydrologic modeling. USDA ARS-S-9, US Government Printing Office, 76 pp.

Williams, J.R. and H.D. Berndt, 1977. Sediment Yield Prediction Based on Watershed Hydrology. Transactions of American Society of Agricultural Engineers 20(6):1100-1104. Wischmeier, W.H. and Smith, D.D. (1978) "Predicting rainfall erosion losses –A guide to conservation planning." U.S. Department of Agriculture handbook No. 537

Winchell, M., R. Srinivasan, M. Di Luzio, J.Arnold (2013). ARCSWAT interface for SWAT2012 user's guide. *Blackland Research Center, Texas Agricultural Experiment station and USDA Agricul-tural Research Service*

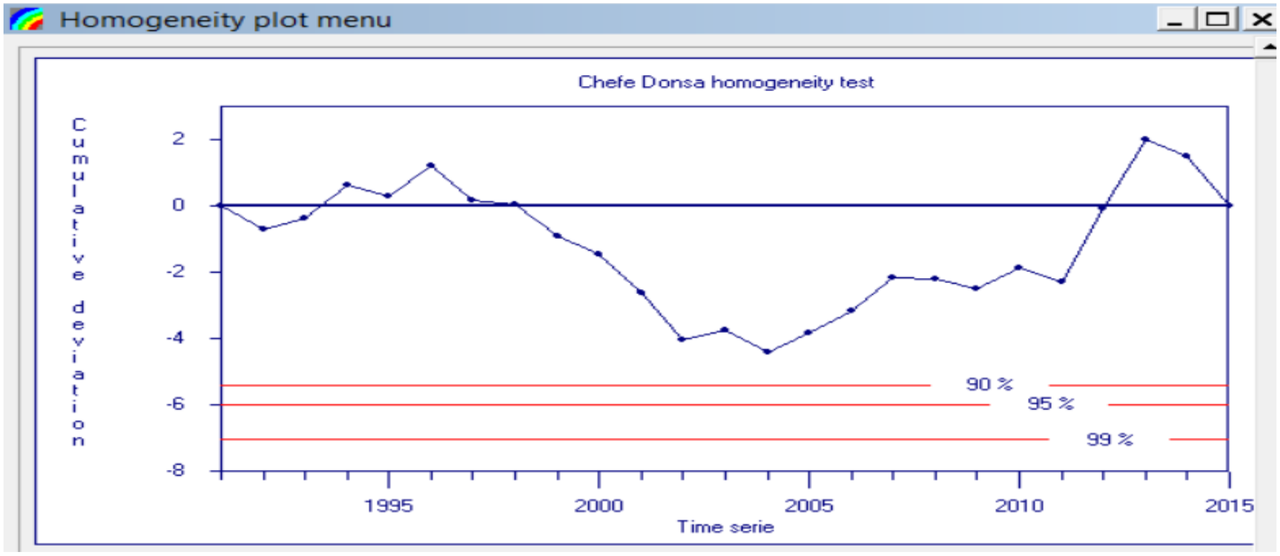
Wubetu Lemenh (2014). SWAT based evaluation of the effect of land use/ land cover change on reservoir sedimentation (Case study in watershed of Ribb reservoir, Ethiopia). MSc. Thesis.Arba Minch University

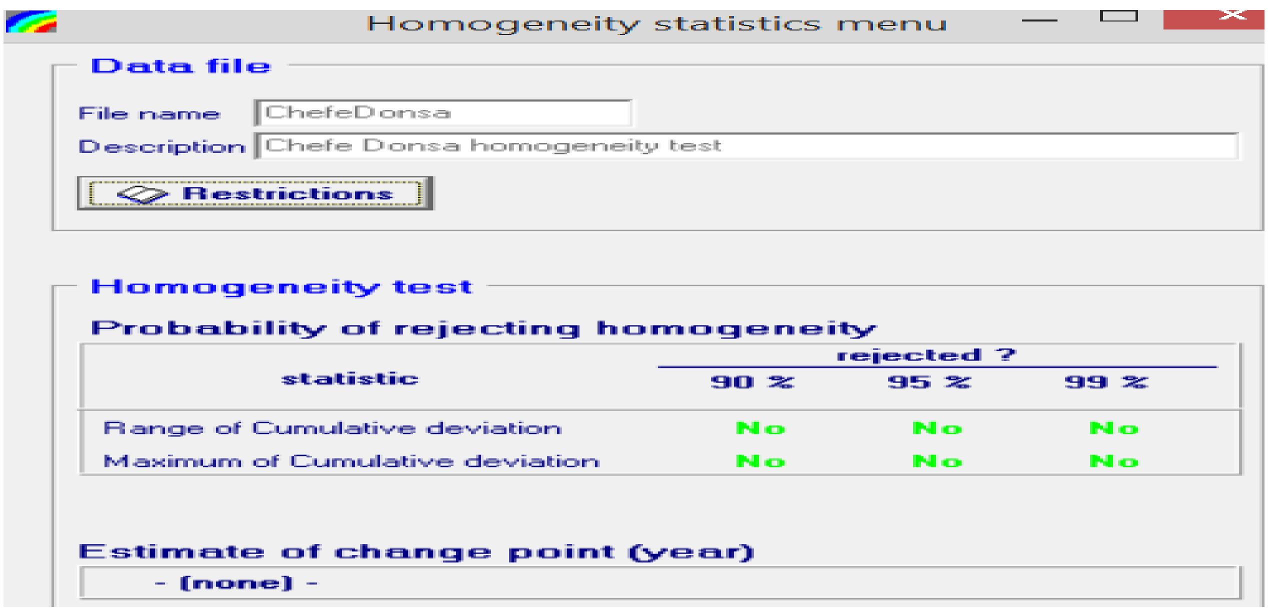
Yang, X., Liu, Q., Fu, G., He, Y., Luo, X., Zheng, Z., 2016. Spatiotemporal patterns and source attribution of nitrogen load in a river basin with complex pollution sources. *Water Res*. 94, 187-199.

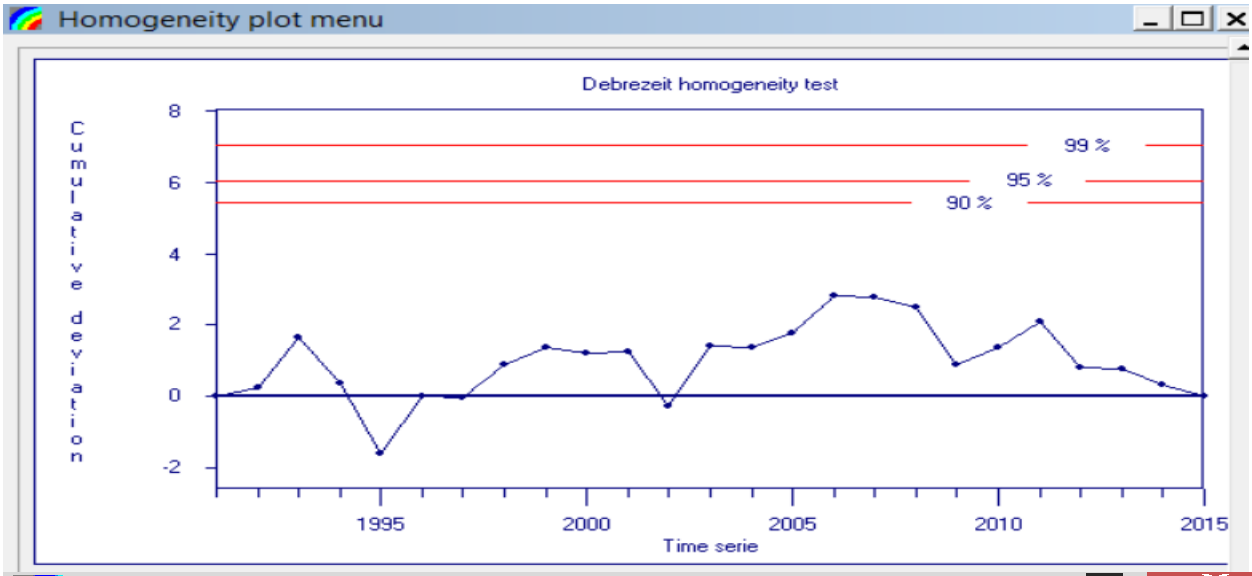
Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1987). Agnps, Agricultural Non-Point-Source Pollution Model: A Watershed Analysis Tool. Research Report. Agricultural Research Service, Albany, CA (USA). Western Utilization Research and Development Div.

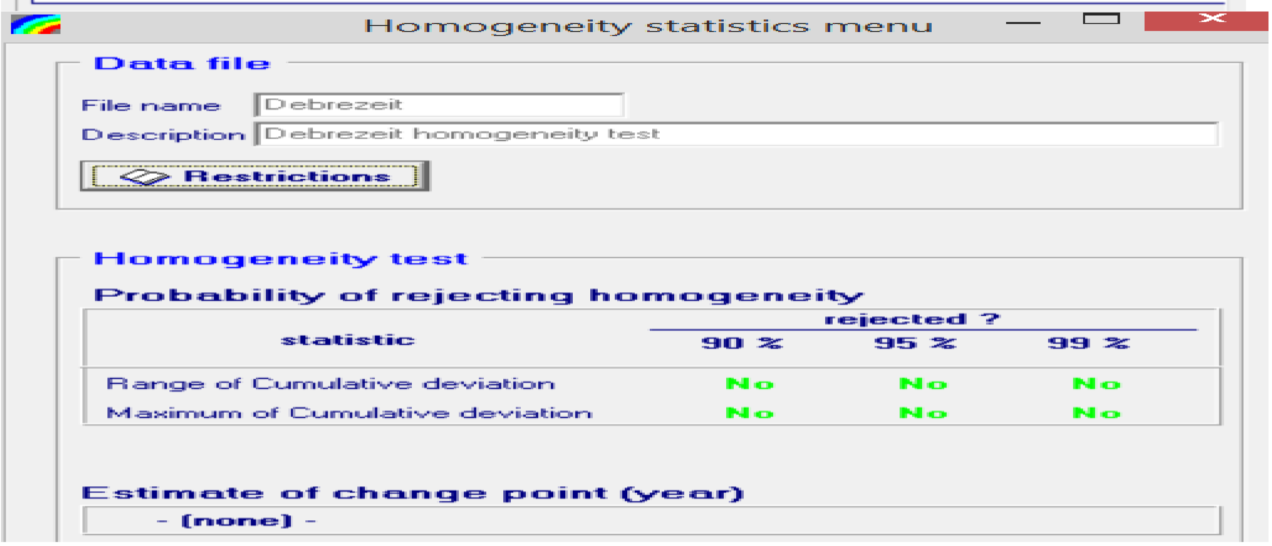
APPENDIX

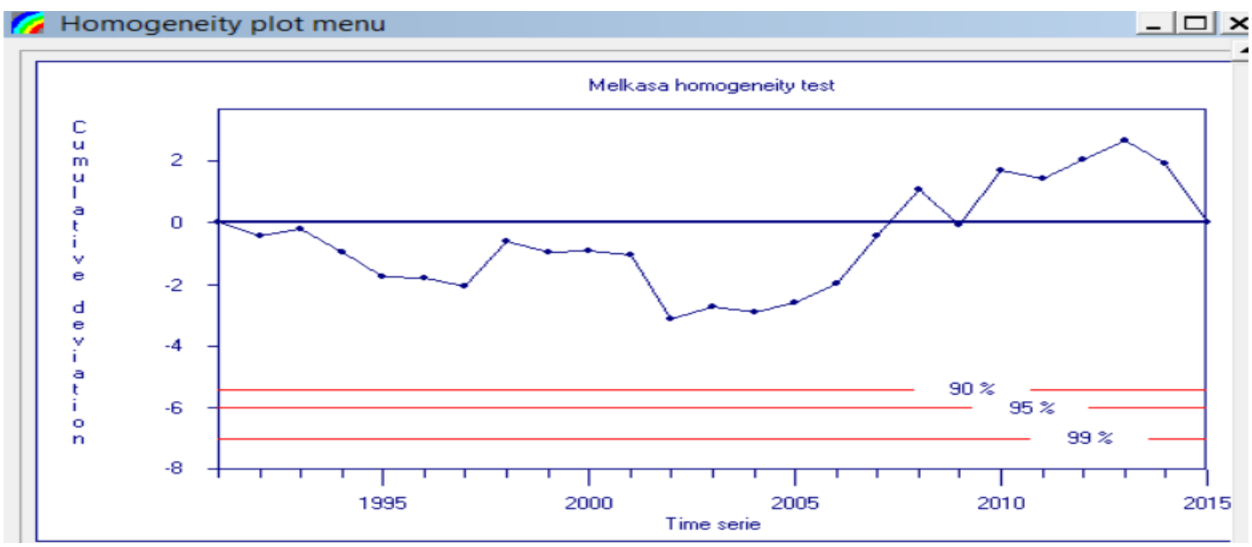
Appendix A: Homogeneity test results of selected meteorological stations.






Homogeneity plot menu
Debrezeit homogeneity test
99 %
95 %
90 %
Cumulative deviation
8
6
4
2
0
-2
1995
2000
2005
2010
2015
Time serie


Homogeneity statistics menu
Data file
File name
Debrezeit
Description
Debrezeit homogeneity test
Restrictions
Homogeneity test
Probability of rejecting homogeneity
rejected ?
statistic
90 %
95 %
99 %
Range of Cumulative deviation
No
No
No
Maximum of Cumulative deviation
No
No
No
Estimate of change point (year)
- [none] -


Homogeneity plot menu
Melkasa homogeneity test
90 %
95 %
99 %
Cumulative deviation
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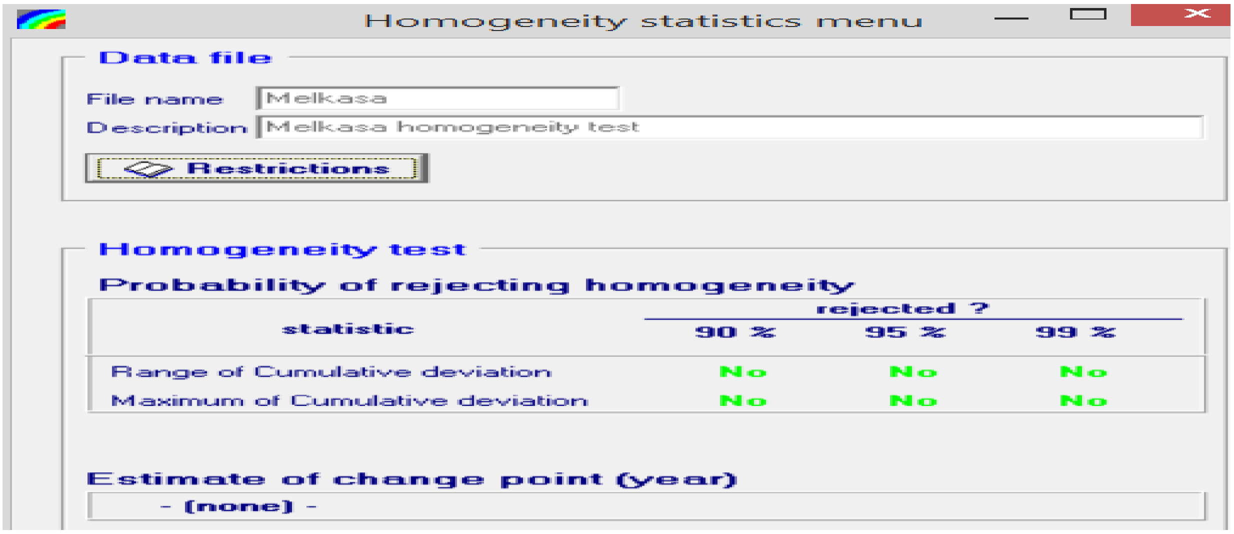
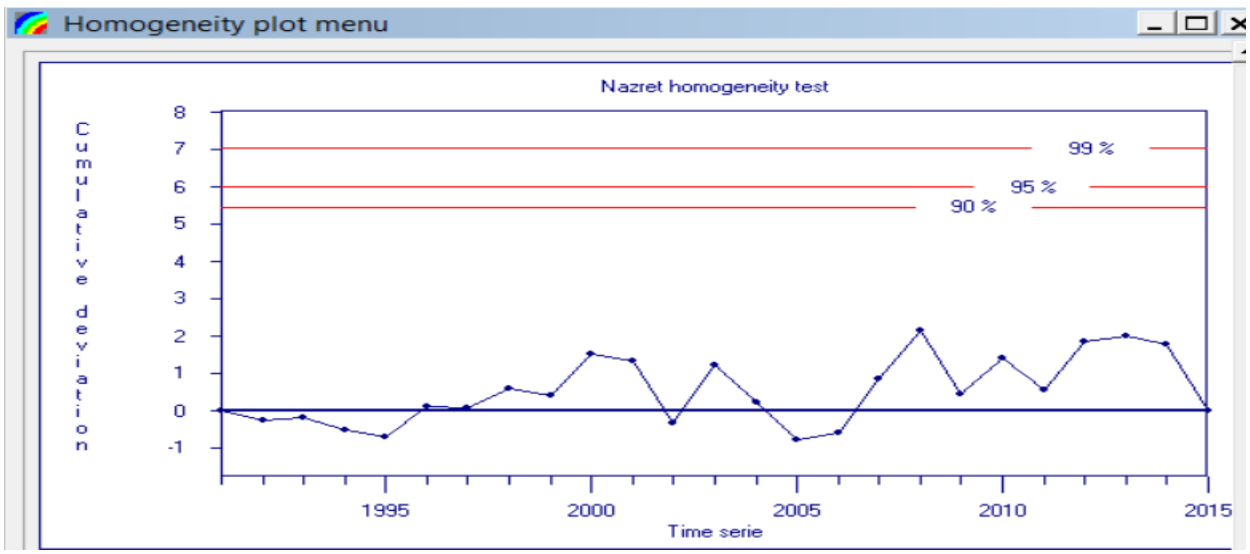
Time serie


Homogeneity statistics menu
Data file
File name
Melkasa
Description
Melkasa homogeneity test
Restrictions
Homogeneity test
Probability of rejecting homogeneity
statistic
rejected ?
90 %
95 %
99 %
Range of Cumulative deviation
No
No
No
Maximum of Cumulative deviation
No
No
No
Estimate of change point (year)
- (none) -


Homogeneity plot menu
Nazret homogeneity test
Cumulative deviation
8
7
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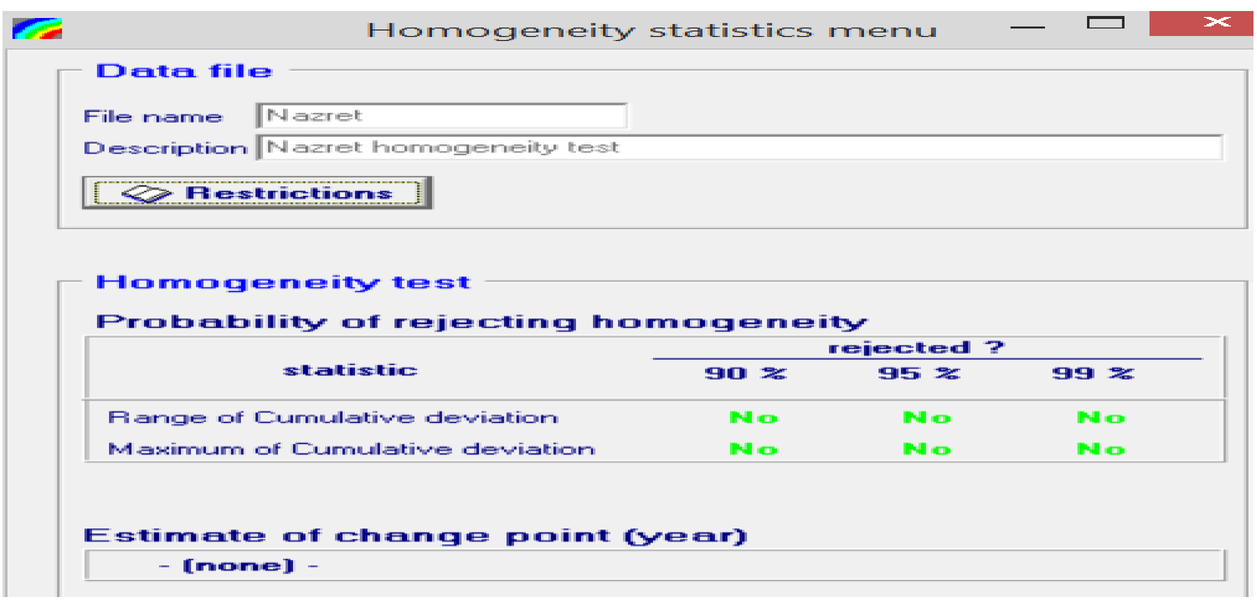
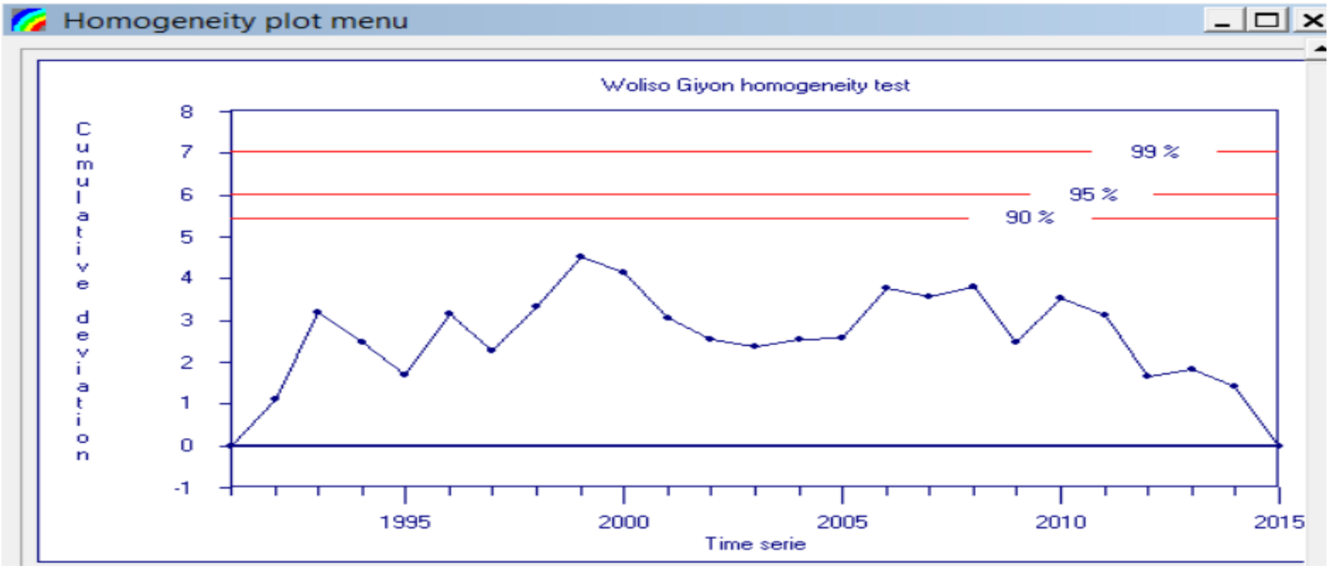
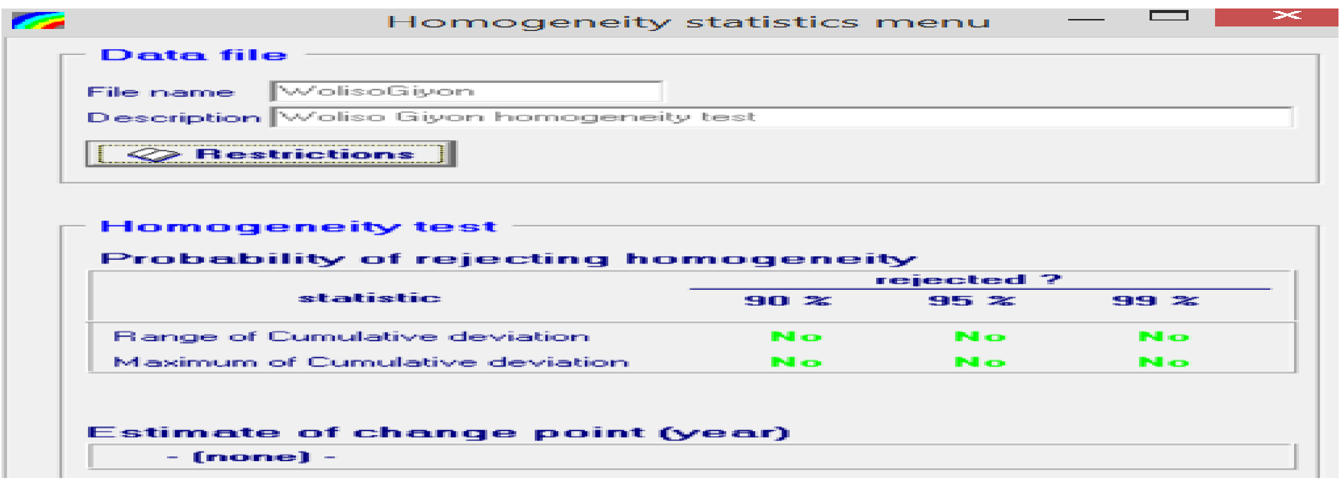
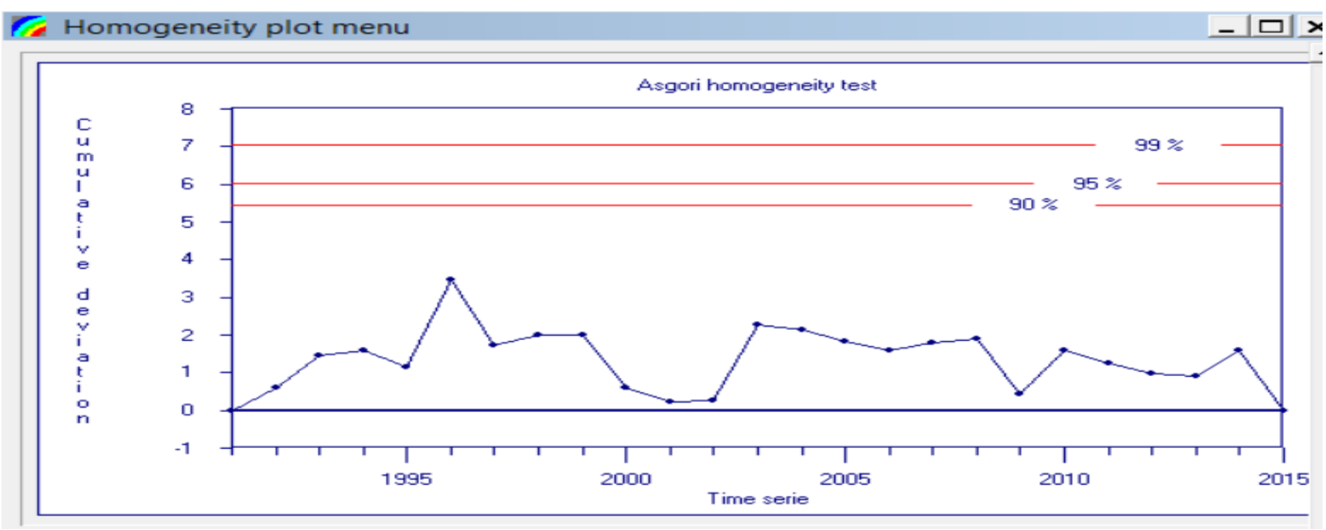
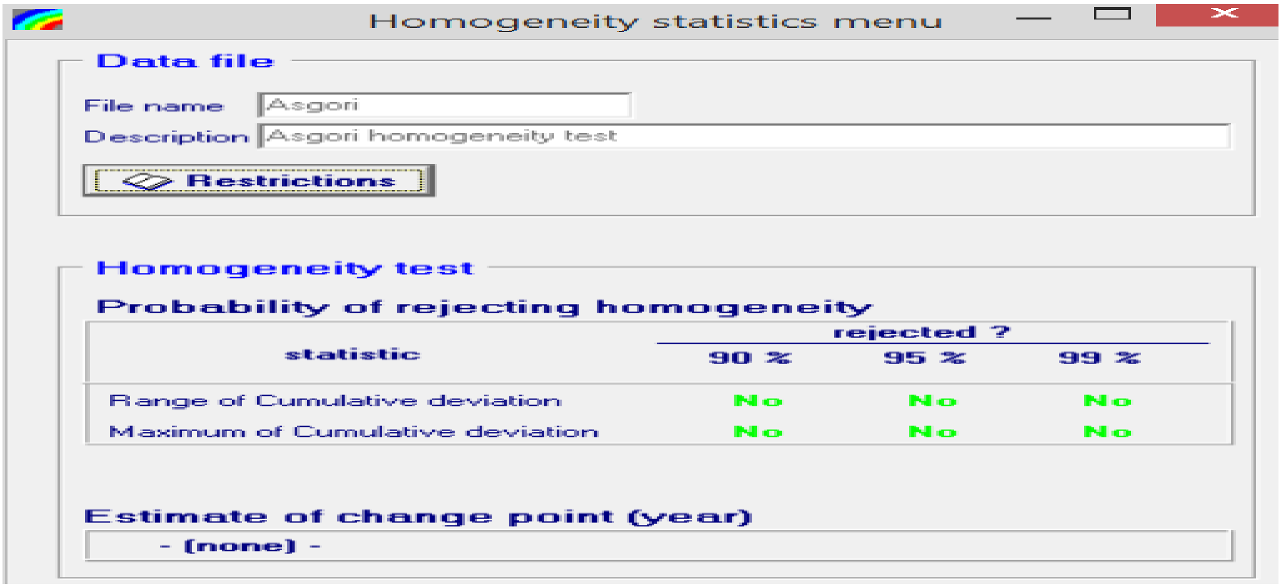
Time serie


Homogeneity statistics menu
Data file
File name
Nazret
Description
Nazret homogeneity test
Restrictions
Homogeneity test
Probability of rejecting homogeneity
statistic
rejected ?
90 %
95 %
99 %
Range of Cumulative deviation
No
No
No
Maximum of Cumulative deviation
No
No
No
Estimate of change point (year)
- (none) -


Homogeneity plot menu
Woliso Giyon homogeneity test
Cumulative deviation
99 %
95 %
90 %
1995
2000
2005
2010
2015
Time serie


Homogeneity statistics menu
Data file
File name WolisoGiyon
Description Woliso Giyon homogeneity test
Restrictions
Homogeneity test
Probability of rejecting homogeneity
statistic
rejected ?
90 % 95 % 99 %
Range of Cumulative deviation No No No
Maximum of Cumulative deviation No No No
Estimate of change point (year)
- (none) -


Homogeneity plot menu
Asgori homogeneity test
Cumulative deviation
99 %
95 %
90 %
1995
2000
2005
2010
2015
Time serie



Appendix B: Soil parameters used in the SWAT database

S/no	SOIL NAME	Nlayers	hydrolic	SOL_ZMX	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	SOL_ALR1	USLE_K1
1	Vertic Cambisols	1	C	1320	C	1320	1.12	0.14	0.39	2.2	42	30	28	0.1	0.38
2	Pellic Vertisols	1	D	1800	C-C-C	600	1.35	0.2	7.9	5.81	76	8	16	0	0.49
		2				1200	1.35	0.15	0.23	1.94	70	11	19	0	0.49
		3				1800	1.35	0.13	0.12	0.65	79	7	14	0.1	0.49
3	Orthic Slonchacks	1	B	1500	SIL-CL	1000	1.43	0.2	307	1.8	33	35	12	0.1	0.23
4	Orthic Luvisols	1	B	1800	C-C-C	600	1.35	0.19	1.7	5.81	62.5	27	11	0	0.49
		2				1200	1.35	0.13	0.14	0.58	75	18	7.4	0.1	0.49
		3				1800	1.35	0.12	0.1	0.19	75	18	7.4	0.2	0.49
5	Mollic Andosols	1	B	1250	SL-C-SCL	120	1.1	0.12	6.23	1.9	55	30	0	0.2	0.2
		2				450	1.19	0.09	5	1.67	68	27	5	0.2	0.2
		3				700	1.14	0.2	9.34	1.7	30	60	10	0.2	0.3
6	Luvic Phaeozems	1	C	1800	C-C-C	600	1.15	0.19	210	3.49	70	10	20	0	0.28

		2				1200	1.13	0.15	150	1.02	74	10	16	0	0.32
		3				1800	1.55	0.18	0.47	0.15	77	7	16	0.2	0.49
7	Leptosols	1	D	500	CL	500	1.44	0.19	287	1.8	35	38	27	0.1	0.21
8	ORTHSLON	1	B	1500	SIL-CL	1000	1.43	0.2	307	1.8	33	35	12	0.1	0.23
		2				520	1.27	0.11	4.54	1.5	23	50	27	0.1	0.22
		3				800	1.28	0.11	5.16	1.3	60	25	15	0.1	0.22
		4				1500	1.22	0.11	4.24	0.5	71	20	9	0.1	0.22
9	Eutric Regosols	1	B	1300	SL-C	250	1.08	0.12	6.8	1.6	54	26	21	0.1	0.23
		2				750	1.15	0.19	7	0.3	74	16	11	0.1	0.22
		3				1300	1.17	0.19	7	0.1	72	16	13	0.1	0.22
10	Eutric Nitisols	1	B	1500	C	1500	1.35	0.1	65.9	1.9	50	23	27	0.1	0.25
11	Eutric fuvisoils	1	B	1800	CL-CL-C	600	1.13	0.22	6.6	3.49	32	42	26	0	0.32
		2				1200	1.45	0.22	0.65	1.02	30	39	31	0	0.49
		3				1800	1.6	0.16	0.33	0.15	41	24	35	0.2	0.49
12	Eutric cambisoils	1	B	900	ML-M	600	1.5	0.2	33.6	1.63	21	33		0	0.31
		2				900	1.46	0.18	40	1.1	13	46	41	0	0.34
13	Distric Nitisols	1	D	1651		2003	1.35	0.2	7.9	5.81	35	48	17	0	0.49
		2				610	1.35	0.15	0.23	1.94	75	18	7.4	0	0.49
		3				1651	1.35	0.13	0.12	0.65	75	18	7.4	0.1	0.49
14	Chromic Vertisols	1	D	1750	SIL-CL	1750	1.2	0.15	1000	0.63	36	54	10	0.1	0.1
15	Chromic Luvisols	1	B	1800	SIL-SIL-S	210	1.45	0.22	38.4	1.2	11	67	22	0.1	0.3
		2				470	1.46	0.21	37.2	0.3	14	66	20	0.1	0.3
		3				1800	1.45	0.2	34.8	0.21	19	59	22	0.1	0.3
16	Chromic Cambisols	1	B	1651	LS-S-SL	203	1.7	0.14	700	1.74	3	17	80	0	0.24
		2				813	1.7	0.06	600	0.58	3	1.5	96	0.1	0.24
		3				1651	1.6	0.13	54	0.19	10.5	26	64	0.2	0.43
17	Calsic Xerosols	1	D	1800	C-C-	600	1.25	0.19	26	3.49	64.5	9	27	0	0.32

					C										
		2				1200	1.35	0.14	15	0.29	72	8	20	0.1	0.28
		3				1800	1.83	0.09	6.8	0.29	75	7	18	0.1	0.2
18	Calsic Fluvisols	1	B	1300	C-C-CL	200	1.1	0.11	25	2	50	34	17	0.1	0.22
		2				500	1.04	0.11	25	2.3	51	22	27	0.1	0.2
		3				1300	1.05	0.11	25	2.5	39	31	30	0.1	0.2
19	Orthic Acrisols	3	B	930	C-C-C	210	1.45	0.22	38.4	1.2	11	67	22	0.1	0.3
						470	1.45	0.22	38.4	1.2	11	67	22	0.1	0.3
						930	1.45	0.2	34.8	1.2	19	59	22	0.1	0.3
20	WATRBD	1	D	25		25.4	1.72	0	260	0	0	0	0	0.2	0

NLAYERS: Number of layers in the soil (min 1 max 10)

HYDGRP: Soil hydrographic group (A, B, C, D)

SOL_ZMX: Maximum root depth of the soil profile (mm)

TEXTURE: Texture of the layer

SOIL_Z: Minimum depth from soil surface to bottom of layer (mm)

SOL_BD: Moist bulk density (g/cm3)

SOL_AWC: Available water capacity of soil surface to bottom of the layer (mm/mm)

SOL_K: Saturated hydraulic conductivity (mm/hr)

SOL_CBN: Organic carbon content (%)

CLAY: Clay content (%)

SILT: Silt content (%)

SAND: Sand content (%)

SOL_ALB: Moist soil albedo

USLE_K: Soil erodibility factor (K)

Appendix C: List of Soils and their user codes in SWAT database of this study

S/no	Soil name	user code name	S/no	Soil name	user code name
1	Calsic Fluvisols	CALCFLUV	11	Leptosols	LEPTOSOLS
2	Calsic Xerosols	CALCXER	12	Luvic Phaeozems	LUVICPHAE
3	Chromic Cambisols	CHROMCAM	13	Mollic Andosols	MOLLANDO
4	Chromic Luvisols	CHROMLUV	14	Orthic Luvisols	ORTHLUVI
5	Chromic Vertisols	CHROMVER	15	Orthic Slonchacks	ORTHSLON
6	Distric Nitisols	DISTRICNIT	16	Pellic Vertisols	PELLVERTI
7	Eutric cambisols	EUTRICCAM	17	Vertic Cambisols	VERCAMB
8	Eutric fluvisoils	EUTRICFLUV	18	vertic Andosols	VERANDO
9	Eutric Nitisols	EUTRICNIT	19	Water Body	WATRBD
10	Eutric Regosols	EUTRICREG	20	Orthic Acrisols	ORTHACR

APPENDIX D: Empirical equation used to drive solar radiation

$$\frac{H}{H_o} = a + b\left(\frac{n}{N}\right)$$

Where *H* is the monthly average daily global radiation, *Ho* is the monthly average daily extraterrestrial radiation, *n* is the day length, *N* is the maximum possible sunshine duration, and *a* and *b* are empirical coefficients. The values of the monthly average daily extraterrestrial radiation (*Ho*) are calculated for days giving average of each month. *H*o was calculated from the following equation

$$H_o = \frac{24 * I_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]x \quad \left[\cos\varphi\cos\delta\sin w_s + \left(\frac{2\pi . w_s}{360}\right)\sin\varphi\sin\delta\right]$$

Where *I*sc is the solar constant (=1367 W/m^2), φ is the latitude of the site, δ is the sun declination and *ws* is the mean sunrise hour angle for the given month. δ, *ws* and *N* can be computed by the following equations

$$\delta = 23.45\sin\left[360(n + 284)/365\right]$$

Where n is the day number of the year starting 1st of January.