



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**SEDIMENT YIELD MODELING USING SWAT, CASE
STUDY OF UPPER AWASH BASIN ETHIOPIA**

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Hydraulic stream)

By
Melka Lemma

Advisor: **Dr. Yenesew Mangiste**

June 2018

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Approved By Board of Examiners

Dr. Yenesew Mangiste	_____	_____
Advisor	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date
_____	_____	_____
Chairperson	Signature	Date

ABSTRACT

Sediments are very important parameter component in many water resource projects for studies of reservoir sedimentation, river morphology, soil and water conservation planning, water quality modelling and design of efficient erosion control structures. High sediment rates leads to filling of reservoirs and loss of live storage, which eventually commanding to loss of production potential. Furthermore, evacuation of sediments from reservoirs is a costly process that can have large environmental impacts. The Soil and Water Assessment Tool model, a physically based distributed hydrological model, was used to estimate sediment yield and runoff in the upper awash basin measuring of 11073 km² catchment area. The basin shows large heterogeneity in terms of hydrological parameters, land use land cover and soil features. This research has been undertaken to analyse the sediment yield at the outlet of the catchment and effects of LULC changes on sediment yield and flow values. The model has been calibrated and validated using observed runoff and sediment yield data of 11 years at the basin outlet. The average values for RSR and Nash-Sutcliffe efficiency (NSE) for sediment yield are found to be 0.67 and 0.66 and the average values for RSR and Nash-Sutcliffe efficiency (NSE) for run-off are found to be 0.71 and 0.71, which are within good limits for sediment and good limits for runoff respectively. So the overall average annual output for sediment at the out let point was estimated, which is 5167400Met ton/month or 0.046667 ton/ha/month is model monthly output. High sediment reduction was observed when agricultural land changed to cropland/savanna/bush land and the value of sediment is 0.03182 ton/ha from overall catchment because cropland/savanna/bush lands are denser than agricultural land. Here appropriate mitigation measures were recommended to reduce sediment yield of the catchment. As land development is a continuous process, for the optimum use of the land and water resources of the area, it is recommended that soil and watershed conservation practice should be undertaken in order to keep the sustainability of the reservoir concerning sediment reduction.

keywords: Sediment Yield; runoff; land use/land cover change; SWAT Model; Upper awash watershed; Ethiopia.

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LIST OF ABBREVIATION

AGNPS	Agricultural non-point source
ANNAGNPS	Annualized Agricultural non-point source
ANSWERS	Areal non-point source watershed environmental response simulation
CASC2D	CAScade of plant in 2 dimensions
CN	Curve number
DEM	Digital Elevation model
EEPC -	Ethiopian Electric Corporation
EFAP	Ethiopian Forestry Action Program
ERA	Ethiopia Road Authority
ET	Evapotranspiration
FAO	Food and Agricultural organization
FMWRE	Federal ministry of water resources of Ethiopia
GIS	Geographic Information System
Ha	Hectare
HRU	Hydrological response units
HSPF	Hydrologic simulation program factor
ITCZ	Inter-Tropical convergence Zone
KINEROS	Kinematic runoff and erosion model
Km	Kilometer
LULC	Land use land cover
m.a.s.l	Meter above sea level
Mm	Millimeter
MoWIE-	Ministry of water irrigation energy
MUSLE	Modified Universal soil loss equation
MW	Mega Watt
NMSA	National metrology service Agency
NSE	Nash-Sutcliffe efficiency coefficient
OADB	Oromia Agriculture and Development Bureau
OAT	One-at-a-time
PBIAS	Percent Bias
PET	Potential Evapotranspiration
PRMS	precipitation runoff modeling system
R2	Regression coefficient
RSR	Root mean square error observation standard deviation ratio
RUSLE	Revised universal soil loss equation
SCS	Soil conservation service
SUFI2	Sequential uncertainty analysis fitting version 2
SWAT	Soil Water Assessment Tools
SYLD	Sediment yield
USLE	Universal soil loss equation
WEPP	Water erosion prediction project

CHAPTER 1 INTRODUCTION

1.1 Background

Sediment yield estimations are needed for studies of reservoir sedimentation, river morphology, soil and water conservation planning, water quality modelling and design of efficient erosion control structures. Sediment yield refers to the amount of sediment exported at the basin outlet over a period. It is also referred as the amount, which would enter into a reservoir located at the downstream limit of the basin (Morris and Fan 1998). The process of soil erosion by rainfall and runoff mainly consists of the detachment and transport by raindrops and runoff.

Many reservoirs can no longer perform their design functions because much of their original active storage volume has been filled by sediment. For hydropower projects and water supply schemes, any loss of storage increases the risk of failure to meet the design objectives in extreme dry periods (Ijam and Al Mahamid, *et al* 2012) Several factors are effects on reservoir sedimentation, such as sediment transportation rate, mode of sediment deposition, sediment production, sediment type, reservoir operation, reservoir geometry, and stream flow variability. Sediment is transported as suspended and bed-loads by streams and rivers coming into the reservoir. Due to flow deceleration when rivers approach a reservoir, the sediment transport capacity decreases, and some of the incoming sediment is trapped and deposited in the reservoir. In addition, the deposited sediment may consolidate by their weight and the weight of overlying water through time. Predicting the sediment coming into a reservoir, its deposition and its accumulation throughout the years, after construction of dam, have been considered as important problems in hydraulic engineering.

The heavy erosion rates from upper catchments will result in subsequent sedimentation of reservoirs reducing their storage capacity. Sedimentation due to soil erosion is the major problem threatening the lifespan of reservoirs in Ethiopia. Some before head studies indicate that the levels of some reservoirs (e.g., Gibe I reservoir), and lakes (e.g., Alemaya, Awassa, Abaya, and Langano) in Ethiopia have decreased. The problem is so challenging that the initial water carrying capacity of the dams has been reduced (Gizaw *et al.*, 2004). Some studies in the Awash basin also indicated that the challenges such as deforestation, urbanization, land degradation due to poor land management practices

associated with the rugged topography and the erosive rainfall in the basin pose a major threat to the lifespan of Koka reservoirs and other basin project like hydropower, water supply, irrigation etc (Habtamu *et al.*,2010). The problem of sedimentation in the Koka reservoir is a very severe. (Zelalem Biru Gonfa, Devendra Kumar, *et al* 2016) conducted a cross-sectional study on Application of Soil and Water Assessment Tool Model to Estimate Runoff and Sediment yield from Mojo Watershed and pointed out that erosion is the major problem.

Hydropower generation plays a significant role for the sustainable economic growth of Ethiopia. The country is endowed with high hydropower potential and there is a plan of generating and exporting power to neighboring countries. For instance, the government of Ethiopia is constructing a cascade of hydropower scheme on some river basin. These are an indication for the ongoing efforts of the government to enhance the role of hydropower in the overall development of the country. However, the potential trouble to the hydropower projects such as sedimentation is not addressed. These troubles might be exacerbated due to the changing of land use land cover and climate and has not been studied.

Therefore, objective of this study is to estimate the sediment yield of the upper Awash River catchment by using hydrologic model SWAT and the study result is based on hydrologic modelling under watershed change and might provide an insight to planners and decision makers regarding the impact of LULC change. The SWAT model was calibrated and validated for the stream flow and sediment. Following the calibration and validation of the model, the future land use land cover with respect to sediment was evaluated and some scenarios were used to construct future LULC series.

1.2 Statement of the Problem

The Awash River Basin faces land degradation, high population density, natural water degradation salinity and wetland degradation. Already desertification has started at lower Awash River Basin. In the high land part deforestation and sedimentation has increased in the past three decades. As more water is drawn from the river, there could be drastic climate and ecological changes, which endanger the basin habitat and human livelihood. Draining the water bodies for different purpose could imbalance the sustainability of the basin.

Worldwide reservoir sedimentation is a serious problem and considered as a salient enemy. The gradual loss of reservoir capacity reduces the effective life of dams and diminishes benefits from irrigation, hydropower generation, flood control, water supply, navigation and recreation. On other hand sediment, deposition propagates upstream and up tributaries raises local ground water table, reduces channel flood capacity and affect water division and withdrawal.

As for the Koka reservoir is in a awash basin the upper catchment is affected by the land use land cover changes, and this changes causes for high erosion which reduces the capacity of reservoir and capacity of the channel that cause for the reduction of power and may cause for flood. A koka reservoir is about 180 square kilometer wide. So unless the upstream flow of river and surrounding area are managed the koka Reservoir is affected by sediment problem and as a result the dam may be damaged because of load from sediment, the net power to the grid may be reduced, flood may be occur at the downstream and design period of the dam may become short. There are sediment control methods that may be applied easily and economical to reduce the all above risks of sediment. Depending on my research problem, SWAT was selected to assess and estimate internal state variables concerning sediment. The model has been widely applied for simulation of runoff, and sediment yield, from watersheds in different geographical locations, conditions and management practices

1.3 Significance of the Study

In upper Awash watershed land use change occurred at faster rate than expected and information about the magnitude and rate of these change, resources degradation, and loss is urgently needed. The present status of soil erosion found in upper awash watershed will lead to further degradation of the area and in the long run aggravate the poverty of farmers living in the watershed. This change reduces the capacity of reservoir and capacity of the channels, which cause for the reduction of power and may cause for flood. In order to design efficient conservation strategies for the sustainable development, it is essential to know the patterns of land use change of the area over time and space and to quantify the extent to which these changes influence the hydrological processes of the watershed. In the past, the lack of decision support tools and limitations

of data were the main factors that significantly hindered research and development in the study area.

Moreover, the reliable estimates of the various hydrological processes of a watershed are tedious and time consuming by the use of conventional methods especially in remote and inaccessible areas like in awash watershed. Therefore, there is an urgent need for developing integrated watershed management plan based on hydrological simulation studies using suitable modeling techniques. Considering the hydrological behavior of the watershed and applicability of the existing models for the solutions of aforementioned problems, this study was undertaken using the Soil Water Assessment Tool (SWAT) model, GIS.

1.4 Objective

1.4.1 General objective

The main objective of this study is to estimate the sediment yield of the upper Awash River catchment by using advanced distributed parameter hydrologic model SWAT (soil and water Assessment Tool) and develop strategies to reduce sedimentation of the catchment.

1.4.2 Specific objectives

The specific objectives of this study are:

- To estimate the sediment yield (SYLD).
- To assess the impacts of land use-land cover changes over the watershed area with respect to sediment yield.
- To manipulate the appropriate measures to reduce sediment yield of the catchment.

1.5 Scope of the Study

The biophysical and climatic characteristics of a watershed are different at different scales. The scientific study of the determinants and impacts of land use change cannot be limited or confined to a single scale. Variations in explanatory variables of land use change analysis with scale follow a consistent pattern: at farm scale, mostly social and accessibility variables do influence land use, at landscape scale, topography and agro

climatic factors are the key determinants, while at regional to national scale, climatic variables as well as macro-economic and demographic factors seem to drive land use. The larger the scale of assessment, the higher is the physical and meteorological heterogeneity and the smaller the scale of assessment, the higher is the physical and meteorological homogeneity.

In this study, analysis was carried out at watershed scale to describe the land use change and sediment yield of the study area over time, measure the rate of change, and relate these changes to the hydrologic processes of the watershed and put directions for mitigation measures.

1.6 Thesis Layout

The organization of the thesis is as follows:

1. Chapter one contains Introduction, Statement of the Problem, Significance of the Study, Objectives, Scope of the Study and thesis layout.
2. Chapter two contains Literature Reviews which includes land use/cover change analysis, simulation of hydrological processes of a watershed using SWAT model, and effect of land use/cover changes and management practices on the hydrological processes of a watershed.
3. Chapter three contains materials and methodology that deals with descriptions of the study area such as location, topography, climate, and socio economic situations; description of SWAT model; Input data used; methods for analyzing land use/cover change, Simulation of hydrological processes of a watershed by SWAT model.
4. Chapter four contains results and discussions that summarize the main findings of the research work. It deals with Simulation of hydrological processes in the study watershed, the Effects of land use change, and management practices on sediment yields with respect to appropriate mitigation measures for the observed impacts, which happen due to the land degradation on the study area.
5. Chapter five contains the conclusion and recommendation that summarizes the whole research work.

CHAPTER 2 LITERATURE REVIEW

2.1 Sediment Property and Sediment Load

Soils are at the heart of terrestrial ecosystems. Their physical and chemical properties profoundly influence how soils function in an ecosystem and how they can best be managed (Brady and Weil, *et al.*, 2008). Accordingly, the nature and properties of the soils affect the rainfall runoff-sediment relationship. The physical properties of the soil govern the movement of water and air in the soil profile and have major impacts on the cycling of water within the soil. Similarly, the chemical properties of soil affect nutrient availability and plant growth. The soil organic matter, on the other hand, exerts a profound influence on the physical, chemical properties of soils. For instance, it enhances formation and stabilization of soil aggregates and hence, improves infiltration and water holding capacity of the soil. In addition, the resistance of the soil to erosion mainly depends on those characteristics. However, the lack of reliable and harmonized soil data has considerably hampered land degradation assessments, environmental impact studies and adapted sustainable land management interventions.

2.2 Sediment Transport Capacity and Over Land Flow

Soil erosion by rainfall is one of the major hazards threatening the productivity of farmland. The physical processes governing the movement of sediments by rainfall are very complex. The rate of soil erosion depends mainly on the detachment of soil particles and on the transporting capacity of overland runoff (Kilinc, 1972). Fundamental relationships for sediment transport in turbulent stream flows have been used as a basis for the analysis of sediment transport capacity by overland flow. The sediment transport capacity depends on many factors, including runoff velocity, sediment grain size, and the specific gravity of sediment practices in a particular river (yuang, *et. al*, 2005).

Sediment moves in the stream as suspended load (fine particles) in the flowing water, and as bed load (large particles), which slides or rolls along the channel bottom. Sometimes, the particles (small particles of sand and gravel) move by bouncing along the bed, which is termed as 'saltation', which is a transitional stage between bed and suspended load. The material, which moves as bed load at one section may be in suspension at another section.

2.3 Soil Erosion and Sediment Yield Relationship

The relationship between the amount of soil eroded at some upstream point and waterborne sediment delivered to a downstream location is important for designing hydrological facilities, planning water resource development, and determining water pollution loadings. Rill and interrill erosion, two common forms of water erosion, involve detachment and transport of soil particles from top soil layers, degrading soil quality and reducing the productivity of affected lands. In addition, excessive sedimentation clogs stream channels and increases costs for maintaining water conveyances. Sediment delivered into water bodies may also be a source of contamination, adversely influencing the aquatic biota (Novotny and Olem, et al 1994). Consequently, the need to quantify the amount of erosion and sediment delivery in a spatially distributed form has become essential at the watershed scale and in the implementation of conservation efforts. Sediment yield from a watershed is an integrated result of all water erosion and transport processes occurring in the entire contributing area (Lane et al., 2000).

The total sediment yield thus depends on both erosion at the various sediment sources such as crop, range, and forestlands, and the efficiency of the system to transport the eroded material out of the watershed (USDA-SCS, et al 1983). Sediment delivery ratio, the ratio of sediment delivered to the stream or watershed outlet to the total erosion from the contributing areas, is a commonly used indicator of the watershed sediment transport efficiency (Dickinson and Collins, et. al, 1998). The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), the soil characteristics, the local climatic conditions, and the land use and management practices implemented on the watershed. The Universal Soil Loss Equation (USLE), a plot- or field-scale model, incorporates most of these factors to estimate long-term water erosion from interrill and rill areas (Wischmeier and Smith, et. al, 1978).

A revised version of this model (RUSLE) further enhanced its capability to predict water erosion by incorporating new information that has become available through the last 40 years of research (Renard et al., 1997). RUSLE, with great acceptance and wide use, is simple and easy to parameterize, and requires less data and time to run than most other models dealing with rill and interrill erosion (Jones et al., 1996). The strength of the raindrop splashes and depth of the surface runoff occurring from precipitation

determines the detachability of the individual soil aggregate and bulk transport of the detached soil particles. The detachability of the soil aggregate from the parent soil depends on the strength with which individual soil particles are bound together. The stronger the particles are bound together, the less they will be susceptible to erosion. The soil susceptibility to erosion is expressed by a soil erodibility factor. Soil erodibility can be assessed by any of three established methods, namely the direct measurement on a natural runoff plot, rainfall simulation studies and predictive relationships.

FAO soil classification with respect sediment

In the FAO soil naming, the prefix or first name describes the soil's diagnostic horizon while the second name denotes the actual naming. The description of each soil property is based on the second name of the FAO soil. Land use and soil type have a direct impact on the sediment yield, speed and potential to create damage that the study should give attention for land use and land cover of the sub basin. The definition & characterization of each FAO soil predominantly available in the study is described below.

Acrisols: Acrisols are referred to as strongly weathered acid soils with low base saturation. They have higher clay content in their sub soils than in their top soils. Acrisols exist in the hilly or undulating topography of wet tropical or subtropical climate zones. They are also characterized by their suitability for forest vegetation growth. There is a high risk of susceptibility of soil to erosion and sediment production on hilly areas.

Andosols: Andosols are common in the volcanic and silicate rich areas of humid climates. The soils cover areas of mountainous and undulating topography in regions ranging in climate from arctic to tropic. These soils are favorable for a wide range of vegetation cover. As a result, these soils have a high potential for agricultural activity because of their fertility, ease of cultivation and root ability. In areas covered by such soils, there is less probability of occurrence of erosion.

Cambisols: Cambisols show variations in color, structure, carbon and clay content along the different soil depth profiles. The soils have medium to fine textured materials that result from the decomposition of a wide range of rocks. Cambisols exist on a level to mountainous topography of all-weather climates. They are favorable for a wide range of vegetation growth and have good potential for agricultural activities. Under uncontrolled agricultural activities and poor land management, there is a high potential of erosion occurrence and sediment production

Fluvisols: Fluvisols are a soil category of alluvial deposits in riverbanks, lacustrine and marine zones. They exist in flat topography and are the results of deposition during flood seasons. These soils are good for agricultural activities because of their high potential of fertility supplied from eroded upland areas.

Gleysols: Gleysols are predominantly observed in wetland areas where there is shallow ground water. These soils are formed from a wide range of unconsolidated fluvial sediments, lacustrine and marine deposits.

Leptosols: Leptosols are very shallow soils that overlay rocky and very coarse soil textures. They are also coarse in texture size and mixed with gravel materials. These soils are available at high altitudes, with mostly dissected topography of all climates. Erosion is the greatest threat to leptosols. As a result, severe erosion problems may be observed on leptosols under high anthropogenic effects. Shallow rooted crops can be grown on such soils and so they can be considered as acceptable for agricultural activities.

Luvisols: Luvisols are characterized by their high clay content in lower soil depths. The soils originate from a wide variety of unconsolidated materials including glacial till aeolian, alluvial and colluvial deposits. Luvisols are most common on flat or gently sloped land in both cool and warm temperate climate with distinct dry and wet seasons. Most luvisols are suitable for agriculture activities with erosion control on sloped land. The risk of erosion is low for areas covered by luvisols

Nitisols: Nitisols are well-drained tropical soils with more than 30% clay in their subsurface horizons. The soils are dominantly found in flat and hilly land under tropical and savanna vegetation. Nitisols are most productive soils in humid tropics. The erosion risk is high on hilly side where there are no proper land management practices.

Solonchaks: Solonchaks are characterized by high salt concentration and predominantly available in arid and semiarid climate zones and coastal regions. Agriculture should be preceded by actions like leaching the excess salt by using irrigation water for washing the soil.

Vertisols: Vertisols are heavy soils, with a high clay proportion and swelling characteristics. The soils form deep and wide cracks when drying out. Vertisols are dominant in depressions leveled to undulating topography of tropical, sub-tropical, humid and semi-arid to sub humid climates with an alternation of wet and dry seasons.

Xerosols: Xerosols are characterized by their accumulation of gypsum sulphate. These soils are formed from the weathering of unconsolidated alluvial, colluvial and aeolin

deposits. Xerosols exist in depressions and leveled to hilly topography of arid climates. Sparse vegetation and shrubs are adapted to the soils. The soils are suitable for the production of small grain crops.

2.4 Hydrological Model Development History

Comprehensive and physically based watershed models have the capability of simulating hydrologic, sediment and water quality processes at a watershed scale. For watershed sediment modeling, careful attention should be given to select the appropriate model. Model capability to compute the sediment yield, good model documentation and model support and proven record of application is a minimum criterion for model selection (Kalin and Mohammed *et. al*, 2003). Different comprehensive watershed models have been developed to assess non-point source pollutants including watershed sediment yield. In reference to (Borah and Bera *et al* 2003), different types of watershed models are summarized below differentiating between models representing long term simulation (continuous time step) and single event based simulation.

2.4.1 Continuous time step simulation models

Continuous time step models are characterized by their capability of simulating stream flow and sediment fluxes on a long-term time basis. In the following, some of the most popular continuous time step simulation models are explained briefly.

AnnAGNPS (Annualized Agricultural Nonpoint Source): In the model, a watershed is represented based on homogeneity of land areas, river reaches and impoundments. The model can simulate hydrology, sediment transport and nutrients transport on a long term, daily or sub daily time steps.

Overland flow is computed by the runoff curve number method and the peak flow by the soil conservation service (SCS) TR-55 method, while subsurface flow is computed from Darcy's equation or Hooghoudt's equation. Manning's equation, with a trapezoidal cross section is used for the computation of runoff in channels for peak flow estimation by TR-55 method.

Overland sediment transport is estimated from sheet and rill erosion generated by using the RUSLE equation. The rate of sediment deposition is based on the distribution of

particle size and fall velocity. The sediment transport in a channel is estimated using the modified Einstein equation and the transport capacity of flow.

ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation): This model has sediment detachment and sediment transport components. It is capable to simulate long-term processes based on daily time steps. The watershed is found based on a square grid with uniform hydrologic characteristics. Manning's and continuity equations are used to calculate the overland runoff of each grid cell. The subsurface flow is determined using Darcy's gravity flow equation. In a similar way to the overland flow, Manning's equation and the continuity equation are used to determine the runoff in the channels.

Overland sediment flow is determined from the raindrop detachment, soil erosion and a sediment transport equation. The raindrop detachment is computed from rainfall intensity and the USLE factors. Soil erosion is determined by unit width flow and the USLE factors whereas transport and deposition of sediments are computed using Yalin's equation. However, the model does not simulate channel sediment separately.

HSPF (Hydrologic Simulation Program Fortran): This model is intended to simulate the water quantity and its quality in a watershed. In HSPF, pervious (agriculture) and impervious (urban) land areas represent a watershed. This model has the capability to simulate stream flow and sediment transport on a long term based for hourly time steps. The overland flow is computed using the empirical outflow depth to the detention storage relation and the Chezy-Manning's equation. Interflow, percolation and ground water flow are computed from different empirical relations. Channel flow is computed based on the continuity equation with the assumption that all flows enter the channel at one point in the upstream section. The outflow is determined based on the reach volume or user supplied demand.

Overland sediment is estimated from the transport capacity function, which is based on rainfall splash detachment and wash off processes.

SWAT (Soil Water Assessment Tool): SWAT is also a nonpoint source pollution model with the capability of simulating hydrology, missing weather elements, sediment and pollutants transport. Temporally, it can simulate long term and daily time steps. It is capable to simulate long-term processes based on daily time steps.

Overland flow is computed using the curve number method and the modified rational formula. The curve number approach is used to determine the runoff volume and SCS TR-55 or the modified rational method is used for peak flow computation. In case of subsurface flow, which joins the river before reaching the ground water, the Kinematic storage model (Sloan *et. al*, 1983) is used, whereas for ground water flow empirical relations are used. Flow in a channel is determined using Manning's equation and routed based on either the variable storage coefficient method or the Muskingum method.

Overland sediment movement is estimated using RUSLE (Williams and Berndt *et al* 1977). The sediment transport in channels is determined from the combination of stream power concept of Bagnold (Bagnold *et al* 1977) and the soil erodibility factor from USLE (Wischmeier and Smith *et al* 1978).

WEPP (Water Erosion Prediction Project): WEPP is a process based soil erosion estimation model. It incorporates the spatial variability of the topographic conditions, soil characteristics and different land management activities. The model can be used for estimation of sediment yield for small watersheds. Moreover, inter rill and rill erosion are considered. Inter rill erosion is the result of rainfall impact mainly the rainfall intensity and the sediment transport in the rill channels is as a result of inter rill runoff. For watershed sediment yield prediction, the model assumes that sediments are transportable if the channel flow shear stress exceeds the critical shear stress and the sediment supply to the channel does not exceed the channel sediment transport capacity. The spatially varied flow equation is used for computation of the flow shear stress in channels.

2.4.2 Single event based simulation models

The common single event based simulation models are described below.

AGNPS (Agricultural Non-Point Source): This model has the capability to simulate hydrology, land erosion and sediment transport. It simulates single storm events. The watershed is analyzed based on a uniform square area. The runoff curve number method is used to compute overland and channel flow. Nevertheless, the model does not simulate subsurface flow. Overland sediment transport, including channel sediment transport is computed using the USLE.

CASC2D (CASCade of planes in 2-dimensions): The model can be used to analyze the flow and the sediment of a storm event as well as on a long-term basis. Similarly, to the

other models, CASC2D has the capability of simulating hydrology and sediment transport at a watershed scale using spatially varying input parameters. 2-D square grids for the overland flow and 1-D for the channel flow represent watershed. The 2-D diffusive wave equation solved by the finite difference method is used to compute overland flow.

Overland sediment transport is estimated using the modified Kilinc-Richardson equation with USLE factors and conservation of mass. Yang's unit stream power equation is used for computation of in stream sediment transport.

KINEROS (Kinematic Runoff and Erosion Model): In this model, the watershed is represented as planes for surface runoff and conduits or channels. Overland and channel sediment is computed based on the raindrop detachment and scour, while deposition of sediment is based on the sediment transport capacity and a mass balance equation.

PRMS (Precipitation Runoff Modeling System): The model developed to evaluate the watershed response to various parameters: for example, precipitation, climate and land use. The watershed is represented as flow planes and channel segments. The Green-Ampt equation is used for computing the excess of rainfall and the kinematic wave equation is used for the overland and channel flow calculation.

Overland sediment transport is determined from a combination of rainfall intensity, overland flow detachment and the sediment continuity equation. Sediment transport in channels is calculated based on the sediment delivery from the upland without considering detachment and deposition.

As mentioned in the above section, there are different kinds of watershed models. However, the selection of the model is based on its applicability, which depends on the intended purpose of the study and the available data for the model setup. Watershed sediment yield modeling, model comprehensiveness and its capability to include major natural processes need prior attention. In addition, the availability of input data, good model documentation and application and success history are other points to be considered.

2.4.3 SWAT model and its components

Among the above-described models, the SWAT model has widely applicability in different parts of the world. As a result, it has a comprehensive success history. The

capability of the SWAT model to generate the missing weather elements makes it more preferable to be applicable in data limited areas. The model capability to compute watershed geomorphologic parameters like watershed area, watershed and river slopes as well as watershed and river lengths in the watershed configuration component of the model is another advantage. The result of this watershed configuration is useful input parameters for statistical analysis and formulation of the alternative empirical model to be proposed for sediment yield estimation. Therefore, with a due consideration to the above-described reasons SWAT has been selected to be calibrated and used for the extraction of basic watershed parameters, surface runoff depth, stream flow, soil loss rate and total sediment yield.

The sub basin/sub-watershed components of SWAT can be classified into eight major components - hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Hydrology and sediment transport are the main components of the SWAT model. Each of the components is described below. SWAT includes the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, nutrient yielding, groundwater flow, crop growth, pesticide yielding, water routing and the long-term effects of varying agricultural management practices. The subbasin/sub-watershed components of SWAT can be classified into eight major components.

- a) **Hydrology:** The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snow melt, transmission losses and ponds. The percolation and return flow or base flow considered in SWAT for hydrological modelling is only the percolation to shallow aquifer from vadose zone and base flow to the channel from the shallow aquifer (Stednick, *et al* 1996; Bowling *et al.*, 2000). The groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream flow somewhere outside the watershed (Slaymaker, *et al* 2003). The water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer. The water percolated to the deep aquifer is assumed lost from the watershed system and is not included in the water balance.

- b) Weather:** The weather variables required to run the SWAT are precipitation, air temperature, relative humidity, wind speed and solar radiation. These variables can be entered directly in to the SWAT model as daily or sub-daily values. (Neitsch *et al*, 2011).
- c) Sediment:** SWAT generates the sediment from the watershed using Revised Universal Soil Loss Equation (RUSLE).
- d) Soil Temperature:** Soil temperature is important for movement of water through the soil since water cannot flow through the frozen soil. Therefore, for the water to infiltrate through the soil layers and all the way to saturated zone, the soil temperature must be above the freezing point. Daily average soil temperature is calculated at the soil surface and the center of each layer (Neitsch *et al*, 2011).
- e) Crop Growth/Plant Growth/Land Cover:** This SWAT component is a simplified version of the EPIC (Erosion-Productivity Impact factor) plant growth model. As in EPIC, the phenological plant development in SWAT, is based on daily accumulated heat units, Monteith's method for potential biomass, a harvest index to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen or phosphorus stress.
- f) Nutrients:** SWAT tracks the movement of different forms of Nitrogen and Phosphorus in the watershed. These nutrients are very important for plant growth. Amounts of NO (N_3) contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. The amount of soluble phosphorous (P) removed in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor.
- g) Pesticides:** In SWAT, the movement of pesticides in to the stream network by runoff and percolation (in solution form) is modelled by equations adopted from GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Neitsch *et al*, 2011).
- h) Agricultural Management:** For the computation SWAT uses physically based inputs such as weather variables (precipitation, air temperature, relative humidity, wind speed and solar radiation), soil types and properties, topography, and land use/land cover of the catchment under study and directly models all the processes

associated with water flow, sediment transport, crop growth and nutrient cycling, etc. (Arnold *et al.*, 1998).

In this study, the ArcSWAT2012 was used, where the ArcGIS (version 10.3) environment was used for project development. Spatial parameterization of the SWAT model was performed by dividing a watershed into subbasins based on topography, soil, land use, and slope. This subdivision resulted in a smallest spatial unit in a watershed. These units, referred to as hydrologic response units (HRUs), are used as the basis of the water balance calculation. Water, sediment, and nutrient transformations and losses were determined for each HRU, aggregated at the subbasin level, and then routed to the associated reach and catchment outlet through the channel network (Abbaspour *et al.*, 2009).

Some of the advantages of the SWAT model includes: modelling of ungauged catchments, prediction of the relative impacts of scenarios (alternative input data) such as changes in management practices, climate, and vegetation on water quality, quantity or other variables (Mulungu and Munishi, *et al.*, 2007)

2.4.4 SWAT to estimate sediment yields and runoff

Sediment yield refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which is also the amount, which will enter a reservoir located at the downstream limit of its tributary watershed (Neitsch *et al.*, 2011). The most common unit for sediment yield is tones/year. The specific sediment yield is the yield per unit of land area, which is most commonly given in tones/km²/year. Long-term sediment yield estimates have been used for sizing storage reservoirs and estimating reservoir life (Srinivasan *et al.* (1998).

Accurate estimation of sediment yield is very important in order to plan a reservoir and efficiently manage its sediment so that the reservoir can meet its requirements. Sediment yield is affected by geology, slope, climate, drainage density and patterns of human disturbance and therefore, no single parameter or simple combination of parameters explains the wide variability in sediment yields ((Abbaspour, *et al.*, 2013, and Lustig, *et.al.* 1965).

Sediment yield from drier areas tends to be limited because of low runoff and yield in wetter areas is limited by the protective soil cover and reduced erodibility of humid zone soils (Neitsch *et al.*, 2011).

The model has been widely applied for simulation of runoff, sediment yield, and total phosphorus losses from watersheds in different geographical locations, conditions and management practices (Saleh *et al.*, 2000; Santhi *et al.*, 2001; Kirsch *et al.*, 2002; Van Liew *et al.*, 2003; White *et al.*, 2004; white and Chaubery, 2005; Gassman *et al.*, 2007) and extensively used across US for flow and sediment yield modeling (Arnold and Allen, 1999). However, few studies have been conducted on the applicability of SWAT model in Ethiopia particularly in Nile Basin (Chekol *et al.*, 2007; Dr Habtum *et al.*, 2010; Tadele and Forch, 2007; Zeray *et al.*, 2007).

Shimelis *et al.* (2007) applied SWAT model in order to test the performance and feasibility of the model in predicting stream flow from the Lake Tana Basin of Ethiopia. It was reported that the model accurately tracked the measured stream flows and simulated well. Xue-song *et al.*, (2003) also applied the SWAT model in the Huanghe yellow river basin of China in order to examine the applicability of the model in simulating runoff volumes and sediment yields.

Saleh *et al.* (2000) conducted a comprehensive SWAT evaluation for the 932.5 km² Upper North Bosque River Watershed, north central Texas and found that predicted monthly sediment losses matched measured data well but that SWAT daily output was poor. Srinivasan *et al.* (1998) concluded that SWAT sediment accumulation predictions were satisfactory for the 279-km² Mill Creek Watershed, again located in north central Texas. Santhi *et al.* (2001) found that SWAT simulated sediment loads matched measured sediment loads well for two Bosque River (4,277 km²) sub-watersheds, except in March. Arnold *et al.* (1999) compared estimated and SWAT simulated average annual sediment loads for five major Texas river basins (20,593 to 569,000 km²) and concluded that in all the river basins, SWAT simulated sediment yields compared reasonably well with estimated sediment yields obtained from rating curves. Habtamu Itefa conducted that how to apply SWAT for watershed Sediment Yield modeling for data scarce areas. SWAT model has been applied to the awash basin and two selected subbasins (Fincha and Gudar) of the Blue Nile basin. The model has been calibrated to measured sediment data available at different locations in the selected river basins.

2.5 Impact of Land Use Land Cover Change on Sediment Yields and Runoff

Quantifying the effects of land use and land cover change on sediment and runoff dynamics of a river basin has been an area of interest for hydrologists in recent years. In water resources planning and management, a study of the land use changes and their effects on runoff and sediment yield patterns for a watershed is essential. Information on changing land-use within a watershed is vital for evaluating the hydrological impacts. Various studies in different countries showed that SWAT, a river basin scale model developed to quantify the impact of land management practices on water, sediment, and agricultural chemical yields, can adequately simulate the effects of land use on runoff volumes, sediment yield and stream flows.

In the earlier days, assessment of the impact of land use changes on runoff was mainly done through catchment experiments and different results had been obtained, with some even opposing the findings of the others. Langford *et al*, 1976, for example, found out that there is no significant increase in runoff because of burning down of a stand of Eucalyptus. In contrast, after reviewing results from a number of catchment experiments, Hibbert *et al* ,(1967) concluded that there is clearly an increase in runoff volume due to reduction of forest cover, while he underlines on the unpredictability of the response. Bosch and Hewlett *et al.*, (1982) argued on Hibbert's later conclusion, giving specific figures on the changes of runoff volume due to changes in the amount of cover of different types of vegetation. On the other hand, some studies have indicated that urbanization leads to an increase in runoff. After synthesizing a number of studies, Hollis *et al.*, (1975) concluded that whilst small frequent floods are increased many times by urbanization, large rare floods are not significantly affected.

A study conducted by Nathaniel *et al.* (2009) in the selected Manipuai River sub watersheds with an aggregate area of 200 ha to simulate the effects of land use on runoff volumes, sediment yield, and stream flows showed that ArcSWAT adequately predicted peak flows and temporal variation of runoff volumes and sediment yields. They reported that both runoff volumes and sediment yields were increased and a decrease in stream flows was observed when 50% of the pasture area and grasslands are converted to agricultural lands.

2.6 Model Performance Criteria

The evaluation of the model accuracy has been based on performance ratings: very good, good, satisfactory and unsatisfactory. Moriasi *et al.* (2007) suggested SWAT model performance evaluation criteria (table 2.1).

Table 2-1: Model performance rating criteria (adopted from Moriasi *et Al.* 2007).

Rating	RSR	NSE	PBIAS		
			Flow	sediment	P,N
Very good	0.00 to 0.50	0.75 to 1	<10	<15	<25
Good	0.5 to 0.60	0.65 to 0.75	10 to 15	15 to 30	25 to 40
Satisfactory	0.60 to 0.70	0.50 to 0.65	15 to 25	30 to 55	40 to 70
Unsatisfactory	>0.70	< 0.50	>25	>55	<70

Notes: NSE, Nash-Sutcliffe efficiency; PBIAS, percent bias; RSR, observations standard deviation ratio.

2.7 Reservoir Sedimentation Problems in Hydropower Plants

Dealing with reservoir-sedimentation problems, engineers are challenged by the difficult questions emerging. How to incorporate reservoir problems in feasibility studies (cost benefit analyses) including environmental and technical effects, limitations on benefit and possible measures? On the other hand, what is the impact of silting and desilting of the reservoir? By focusing on sediment impacts in hydropower plant, the following impacts may be notified:

- The effect of reservoir sedimentation on regulating water resources and its impact on power generation.
- The effect of sediment inflow to power intakes and its impacts on turbine system and other components of the hydropower plant.

For Run-of-river, projects are constructed to utilize the available water throughout the year without having any storage. The most important distribution principles of these sediments in the reservoir can be subdivided into the following group.

CHAPTER 3 MATERIALS AND METHOD

3.1 Description of the Study Area

3.1.1 Location

Ethiopia is located in East Africa between 3° 30' to 14° 50' N latitudes and 32° 42' to 48° 12' E longitudes Figure below. It has a surface area of about 1.127 million km². Based on topography and geographic location, the country is categorized into three major climatic zones: the cool zone (elevation > 2,400 masl), temperate zone (elevation between 1,500 to 2,400 masl), and hot zone (elevation < 1,500 masl).

Ethiopia has three distinct climatic zones, namely Dega (humid), Wayne Dega (semiarid) and Kola (arid). The humid climate zone has been divided into three sub sections: humid, moist sub humid and dry sub humid (Lemma *et al* 1996). The humid part of the country includes areas receiving annual rainfall of greater than 1280 mm with a temperature of about 16 °C and with elevations greater than 2440 m above mean sea level (a.s.l). Semiarid parts are areas with annual rainfall between 500 mm and 1530 mm, temperatures of about 22 °C and elevations of 1830 to 2240 m a.s.l. The arid part of the country receives an annual rainfall of less than 510 mm, its temperature is about 27 °C and its elevation is less than 1830 m a.s.l. The population is concentrated in the humid and semiarid climate zones where agriculture is the base for the economy of the country. As a result, there is high anthropogenic pressure on the ecosystem especially on land and water.

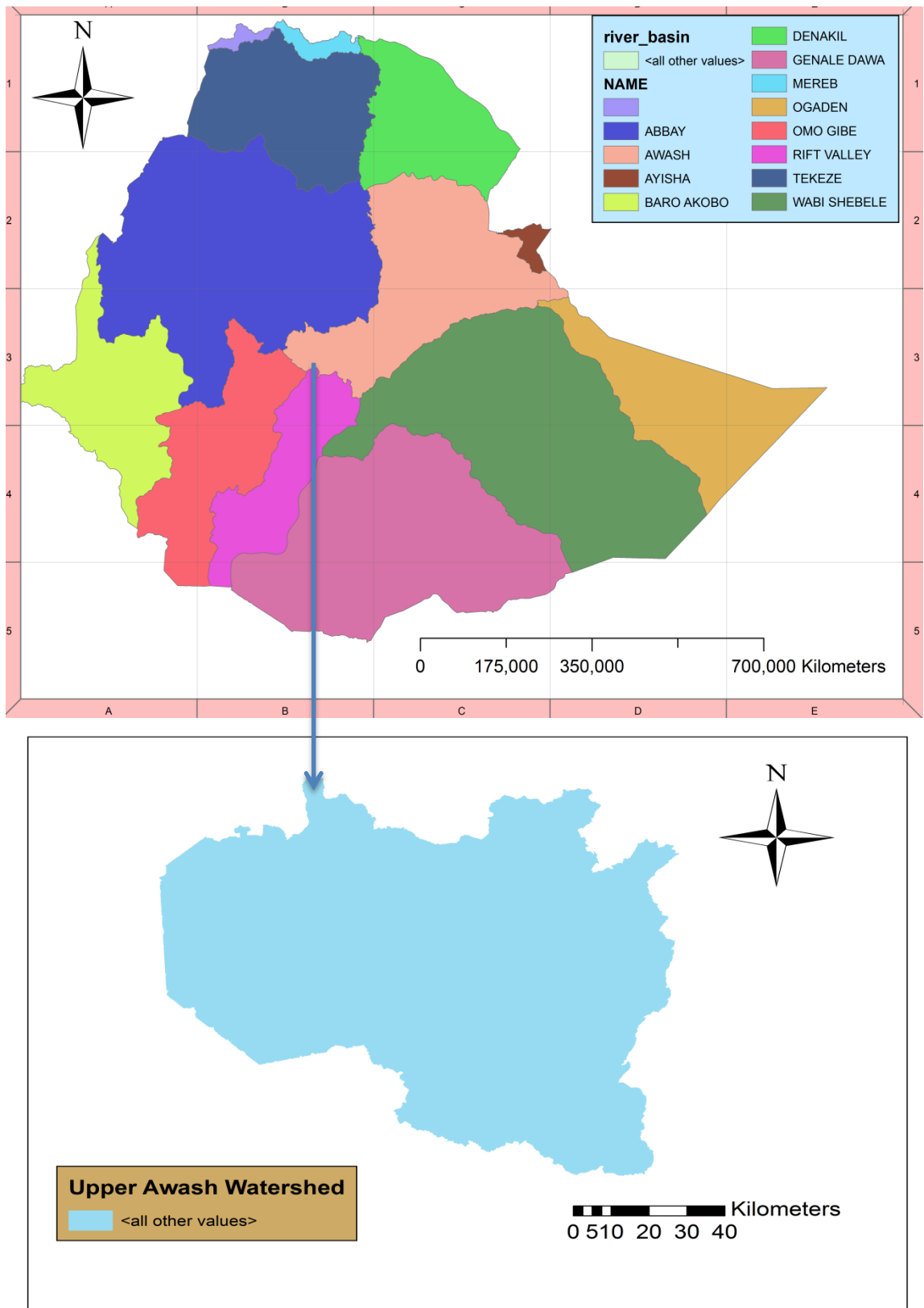


Figure 3-1: Location of the Selected Study Areas (Upper Awash Watershed).

Awash River Basin

There are 12 major river basins in Ethiopia: eight are perennial river basins, one is a lake basin and three (Danakil, Aisha and Ogaden basins) are intermittent river basins with almost no or insignificant flow. Utilization of water resources of the country are focused on the eight river basins, as they are located in a climate zone favorable for human settlement. Awash basin and Blue Nile basin are the most widely utilized and are being developed for water resources projects mainly for hydropower and irrigation purposes. The Awash basin covers 70 % of the country's area for irrigated agriculture and provides hydropower with installed power of 46 Mega Watt (MW). The Koka dam located in the basin is the main source of water for irrigation and hydropower purposes. Nevertheless, the dam has lost 40 % of its storage capacity due to sedimentation problems in the 30 years of its service period (EEPC 2002). Awash river basin is located in Eastern part of Ethiopia, between 38° E to 43.50°E longitudes and 8° N to 12.2° N latitudes.

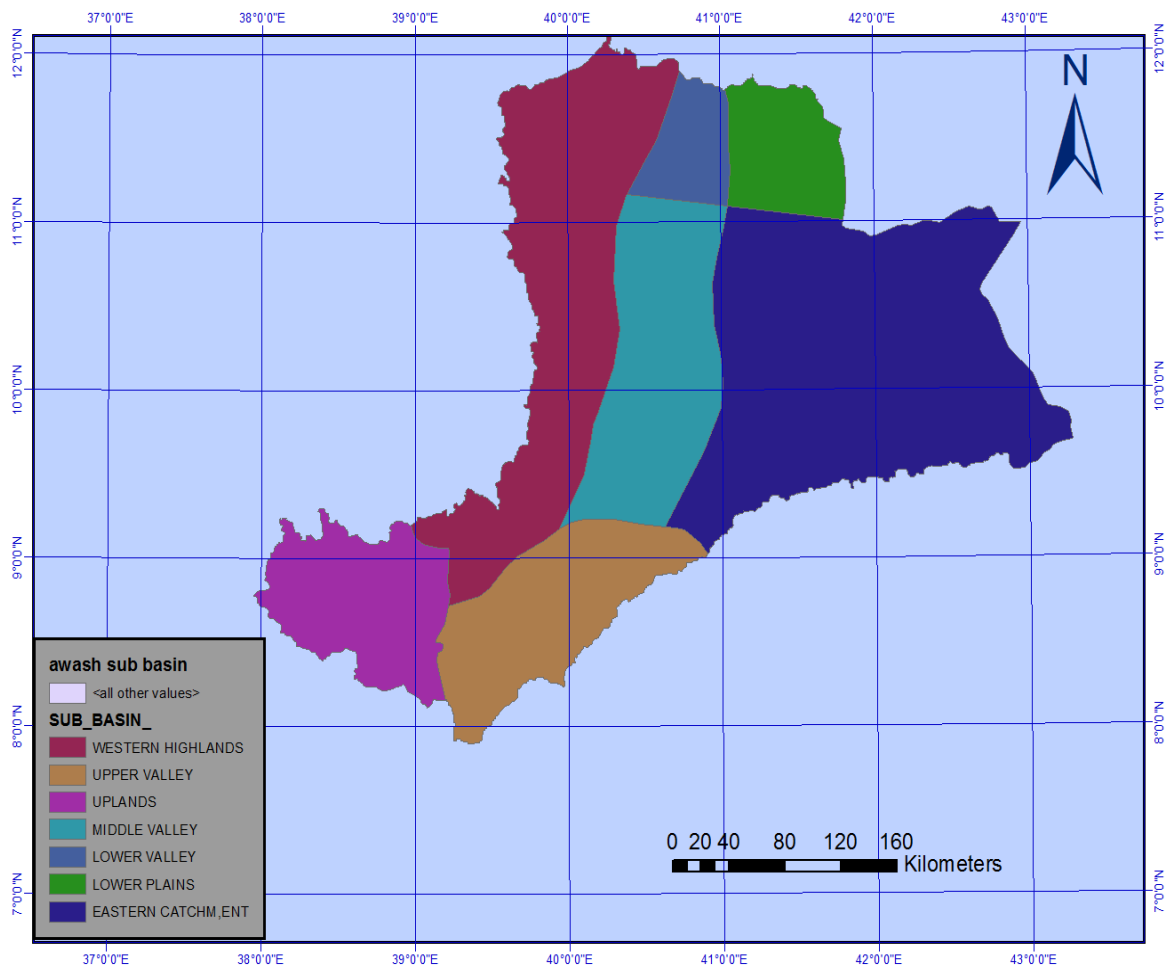


Figure 3-2: Awash River Sub-Basin.

Upper Awash Sub Basin

This research was undertaken on the upper part of the Awash River Basin in Ethiopia, which lies upstream of Koka dam and it is located between latitudes of 8°16' and 9° 18' and longitudes of 37° 57' and 39°17'. It covers about 11073.341km². It lies in the Ethiopian highland plateau in elevation ranging from 1500 to 3500 above sea level. The major tributaries to the upper Awash are Akaki and Mojo rivers. Akaki River starts from the mountainous areas of the northern part of Addis Ababa and join the main Awash River between Melka-Kunture and Melka-Hombole gauging stations. Mojo River, the other main tributary to Awash, originates from the high lands northeast of Addis Ababa. The basin is characterized mainly by agricultural land, forest and in limited parts by urban areas, wetland and pasture. Agricultural land and grass/pasture land coverage is about 90 % and the forestland and the rest is 10 % of the area. Eutric vertisols, are the dominant soil types in the area, which covers 46.73 % of the basin. Leptosols, Dystric Nitosols, Chromic Cambisols, and Chromic Luvisols are also the most common soil types. The average basin slope ranges from 4.49 % to 95.51 % for 0-2 and 2-999 respectively. The study area has elevation range of 1548 m a.s.l to 3388 m a.s.l.

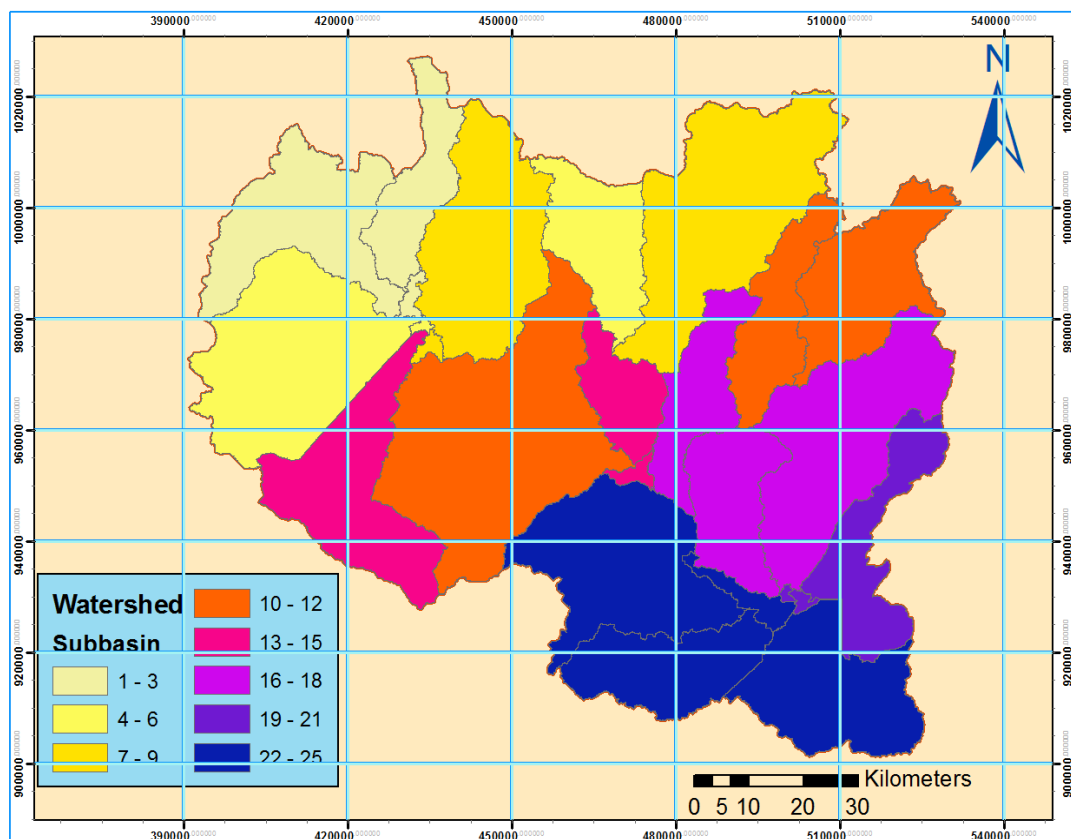


Figure 3-3: Upper Awash Sub Basin.

3.1.2 Topography

Various inter-related factors like location, altitude, climate, topography, agricultural development, inhabitants, administrative boundaries etc contribute to the classification of the basin in to zones. Taking climate and altitude as main factors, the basin has been habitually divided into four distinct zones. These are upper basin, upper valley, middle valley and lower plains. (Halcrow, 1989)

Upper basin or uplands:-All lands in the basin above 1500m altitude, generally with a mean annual rainfall in excess of 800mm. The uplands are further sub-divided regionally into eastern and western catchments and upper basin catchment upstream of Koka.

Upper valley: - the area between Koka reservoir and Awash station which lies between 1500m and 1000m altitude.

Middle valley: - the area of the basin between awash station and the confluence of Mile river lying between 1000m and 500m with mean annual rainfall variation from about 600mm to 200mm.

Lower plains: - are the deltaic alluvial plains in the Tendaho, Asayita, and Dit Bahari areas as well as the terminal lake environs. The area lies between 500m and 250m altitude with a mean annual rainfall of less than 200mm.

3.2 Input Data

To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modelling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of Digital Elevation Model (DEM), Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The length of period of weather and climatic data also affect the SWAT model performance. The output from the SWAT model can be affected by the DEM data resolution, mesh size, soil data resolution and soil map scale, watershed subdivision which on the other hand is affected by DEM data resolution. Bosch et al., (2004) found that SWAT stream flow estimates were more accurate when using high-resolution topographic data, land use/land cover data, and soil data. The required DEM data, soil data, land use/land cover data, flow data, climatic and sediment data was collected from the Federal Ministry of Water Resources of Ethiopia (FMWRE) and the National Metrology Service Agency

(NMSA) are the major sources of data required for this research. FAO (1998) soil map was another source of data utilized for the definition and characterization of the different soil properties. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the upcoming sections.

3.2.1 Digital elevation model (DEM)

The spatial variability of the basin's physiographic factors can be extracted from different digital maps which are the main building blocks of watershed configuration parameters in SWAT model. Digital elevation model (DEM), land use land cover (LULC) maps and soil maps of (1:3,000,000 scale) obtained from Federal Ministry of Water Resources of Ethiopia (FMWRE) have been used as an input for the model setup. Climate data such as precipitation, temperature, relative humidity, wind speed and hours of sunshine for 30 years were obtained from NMSA. Stream flow data for 30 years and randomly measured suspended sediment load data have been obtained from FMWRE. Prior to the application of the maps in the model, preprocessing work was carried out. Similarly, the land use map has been re-classified into SWAT land use classes.

The soil map has been referenced with FAO (1998) world soil database to obtain the physical properties of the individual soils. The properties of the soils are mainly parameters related to soil texture and grain size percentage composition which is helpful to compute other necessary physical soil characteristics. Apart from the properties of the soils obtained from FAO (1998) soil map, additional soil characteristics are required to set up SWAT model. Soil saturated hydraulic conductivity, bulk density, soil available water and texture class at different soil depths are crucial for modeling with SWAT.

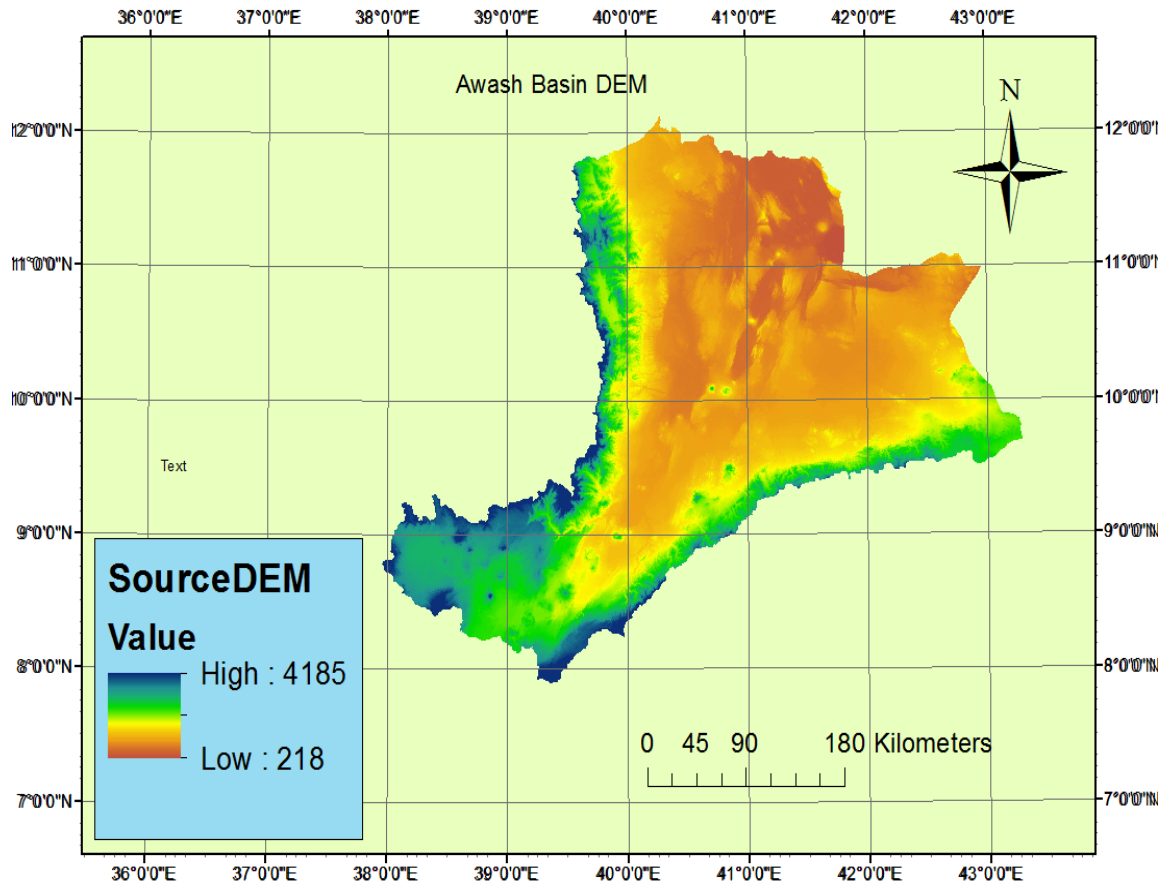


Figure 3-4: Awash basin DEM

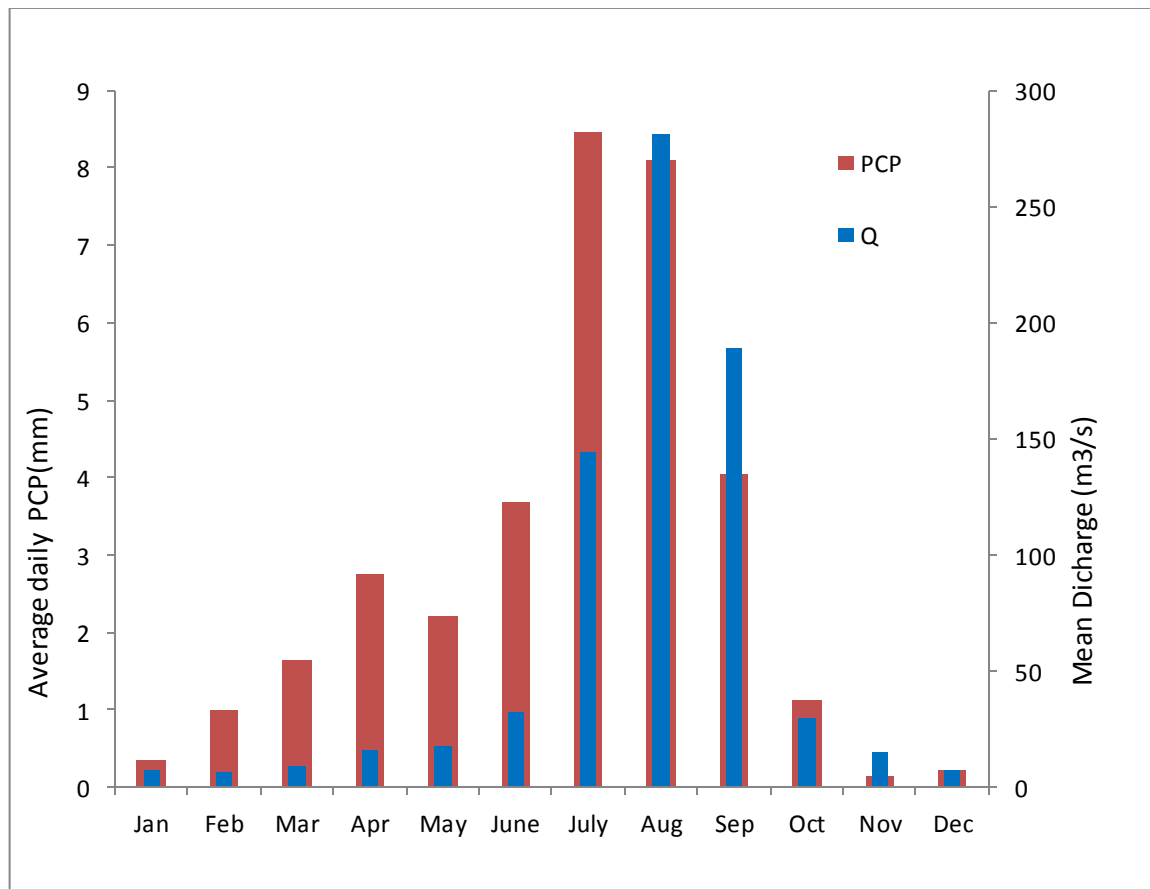
3.2.2 Meteorological data

The climate of the Awash Basin comes under the influence of the Inter-Tropical Convergence Zone (ITCZ). This zone of low-pressure marks the convergence of dry tropical easterlies and the moist equatorial westerlies. The seasonal rainfall distribution within the basin results from the annual migration of the ITCZ. In March, the ITCZ advances across the Basin from the south, bringing the small or spring rains. In June and July it reaches its most northerly location beyond the basin that then experiences the heavy or summer rains. It then returns southwards during August to October, restoring the drier easterly airstreams which prevails until the cycle repeats itself in March (1).

The annual rainfall distribution resulting from this cycle is exhibited most clearly in the two distinct rainy periods, which are characteristic of the northern plains of the basin. Moving southwards the more prolonged exposure to the moist air-stream is evident in the tendency for the two dominant rainy periods to merge into a more contiguous distribution. On the high plateau to the west of Addis Ababa, the rainfall distribution

shows a continuous increase from the spring rains to the summer peak rainfall. The distribution of rainfall over the highland areas is modified by orographic effects and is significantly correlated with altitude. (Shimelis Behailu *et al.* 2004).

Potential evapotranspiration (PET) is also significantly correlated with altitude. At Wonji, in the Upper Valley, the mean annual PET is 1 150.6 mm, over twice the mean annual rainfall, with average monthly rainfall exceeding average monthly evapotranspiration only in July and August. The hydro-climatology of the basin is variable both seasonally and annually. Months from May to September are the monsoon season, which contributes to the occurrence of high runoff. As a result, the peak stream flows in rivers are observed during these periods, while for the remaining months of the year, flows in the perennial rivers are contributed by base flow during dry periods. From 2004 to 2014 data records at Hombole gauging station, the average maximum and average minimum discharge was observed to be 280.972m³/s in August and 7.045m³/s in February respectively Figure 3.5. Similarly, maximum rainfall was observed in the month of July.



PCP=Precipitation, Q=Discharge

Figure 3-5: Average discharge and precipitation in upper awash basin.

The temperatures of two meteorological stations in the study area are shown on figure below. The temperature in the study area ranges from 4.5°C to 28.3 °C. From the graph the spatial variability of the temperatures is not so significant. However, at low land areas of the basin where there is no data available, especially near Meki and Nazeret meteorological stations, the temperatures are much higher than what is observed at the stations indicated on figure 3.6.

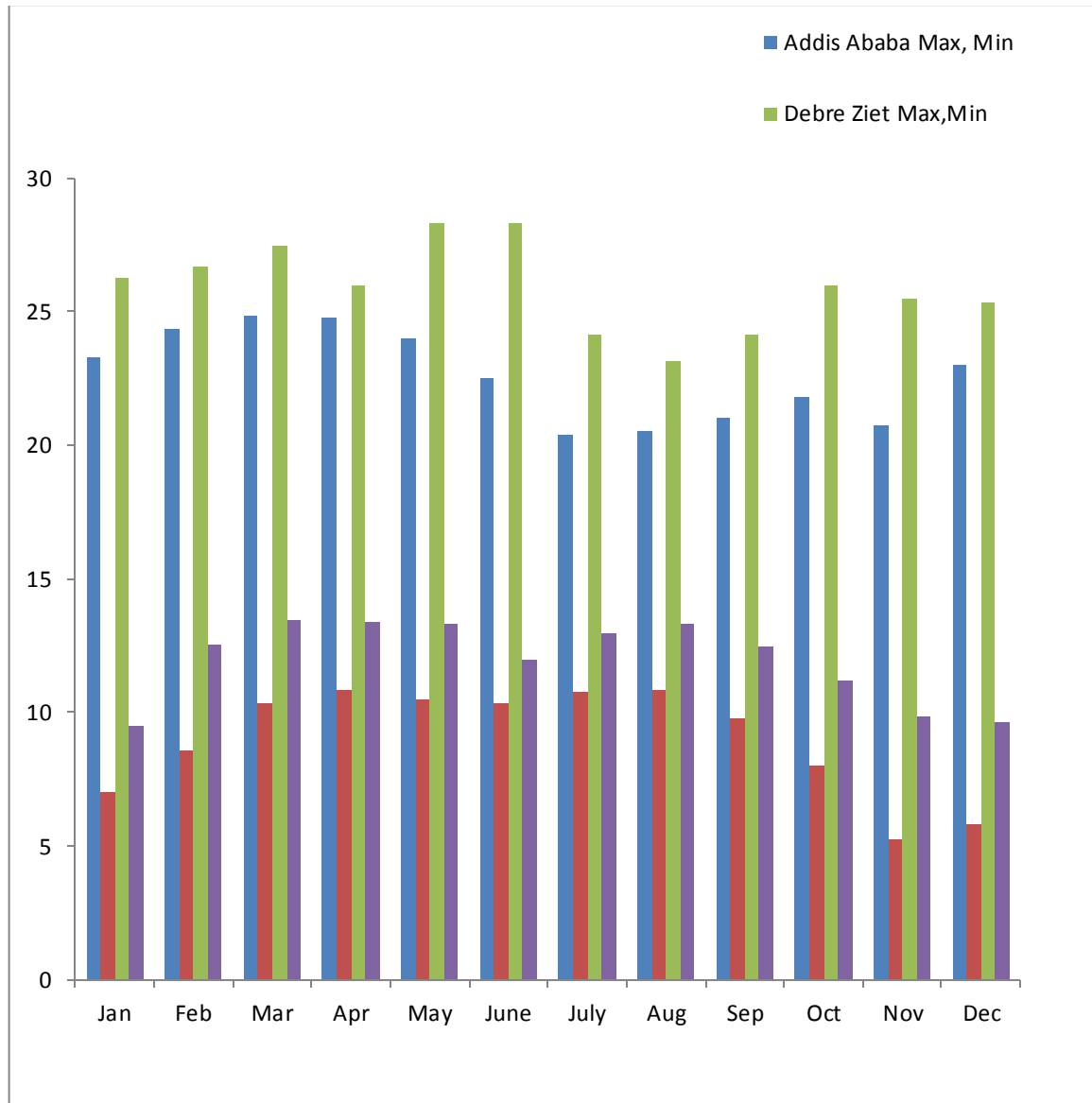


Figure 3-6: Average Temperature Observed in Upper Awash Basin (1986-2015).

3.2.3 Land use land cover (LULC)

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 LULC data combined with the soil cover data generates the hydrologic characteristics of the basin or for the study area, which in turn determines the excess amounts of precipitation, recharge to the ground

water system and the storage in the soil layers. The LULC data for this study area was obtained from Ethiopian Ministry of water, Irrigation and Energy bureau GIS Department. The land use condition in the Upper Awash catchments includes mainly of cultivated agricultural land, grassland, and forestland, rural and urban settlements. It is estimated that 92,614,572ha (83.64%) was agricultural land, 1,118,373ha (1.07%) was forest land, 9,500,634 ha (7.51%) was grass/pasture land, 1,683,096 ha (1.52%) was shrub and bush land, and the remaining 5,813,325 ha (5.26%) was under Residential and water body.

Table 3-1: Upper awash catchment LULC coverage (model Output)

Land use/ Land cover (LULC)	SWAT Code	Area (Ha)	Cover Percentage (%)
Pasture	PAST	46562.9664	4.20
Cropland/Grassland Mosaic	CRGR	51091.8979	4.61
Agricultural Land-Generic	AGRL	818022.6233	73.87
Cropland/Woodland Mosaic	CRWO	56052.8224	5.06
Forest-Evergreen	FRSE	4382.0271	0.40
Grassland	GRAS	41543.3950	3.75
Wetlands-Mixed	WETL	17102.9190	1.04
Water	WATR	18019.7063	1.63
Shrubland	SHRB	1417.5269	0.16
Forest-Mixed	FRST	2161.6901	0.20
Urban	URBN	26503.0070	2.82
Mixed Grassland/Shrubland	MIGS	5008.4553	0.45
Mixed Tundra	TUMI	10578.0799	0.96
Forest-Deciduous	FRSD	3380.3360	0.31
Corn	CORN	5987.4351	0.54

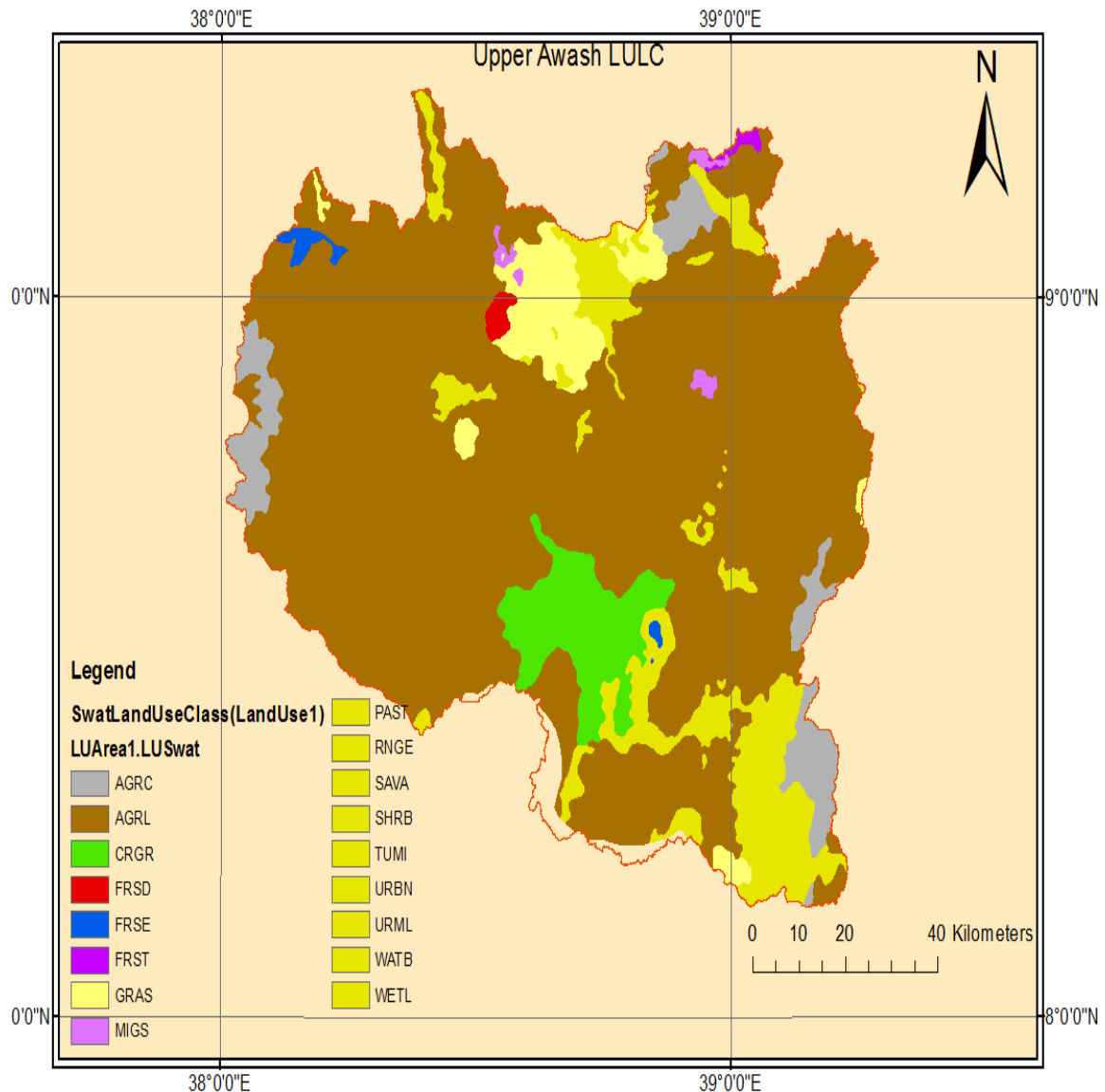


Figure 3-7: Upper Awash land use land cover (LULC).

3.2.4 Soil data

Like the Digital Elevation Model, soil data resolution has also a significant impact on the modelling of stream flow, sediment load and nutrient content. This on the other hand affected the runoff and sediment prediction. If the low resolution soil data is used to generate the HRUs it assigns same soil type for larger area of the watershed that actually may have different soil types. Different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity etc. that affects the water balance and sediment yield from the watershed. Therefore, using high spatial resolution soil map will increase the prediction accuracy of the model. In this study, the soil data was obtained from MoWIE. Therefore, all required soil properties were adopted from database since

there was no possibility of measuring all soil properties in the field due to time constraint. The soil map obtained from MoWIE was projected to WGS1984 UTM Zone37N using the raster projection in ArcMap before it was imported to ArcSWAT. Soil of Ethiopia is not available in SWAT data bases. The compared properties of Ethiopian soils with the SWAT data base soils then edit and represent with it in the look up table. The physical properties of the soils in Upper Awash basin have been extracted from FAO (1998) world soil database. The corresponding soil properties for each soil type are indicated in table 3.2. The soil map and classification of upper awash watershed used in the HRU definition in this study is shown in Figure 3.8 below.

Table 3-2: Upper awash catchment soil coverage (model Output)

Soil Type	SWAT Soil	Percent of coverage
Chromic Cambisols	ADAMS	5.42
Orthic Solonchaks	ADRIAN	2.66
Calcic Xerosols	CHARLES	1.12
Dystric Gleysols	COLTON	1.73
Lithic Leptosols	CROGHAN	12.80
Calcic Fluvisols	ENCHANTED	1.55
Dystric Nitisols	HINCKLEY	5.69
Eutric Cambisols	LUPTON	1.71
Eutric Nitisols	LYME	7.35
Dystric Vertisols	MEDOMAK	2.12
Haplic Xerosols	MUNSON	3.64
Chromic Luvisols	OCCUM	4.18
Mollic Andosols	PINNEBOG	1.18
Eutric Vertisols	PLAISTED	46.73
Orthic Luvisols	WATER	1.62
Chromic Vertisols	PITS	0.50

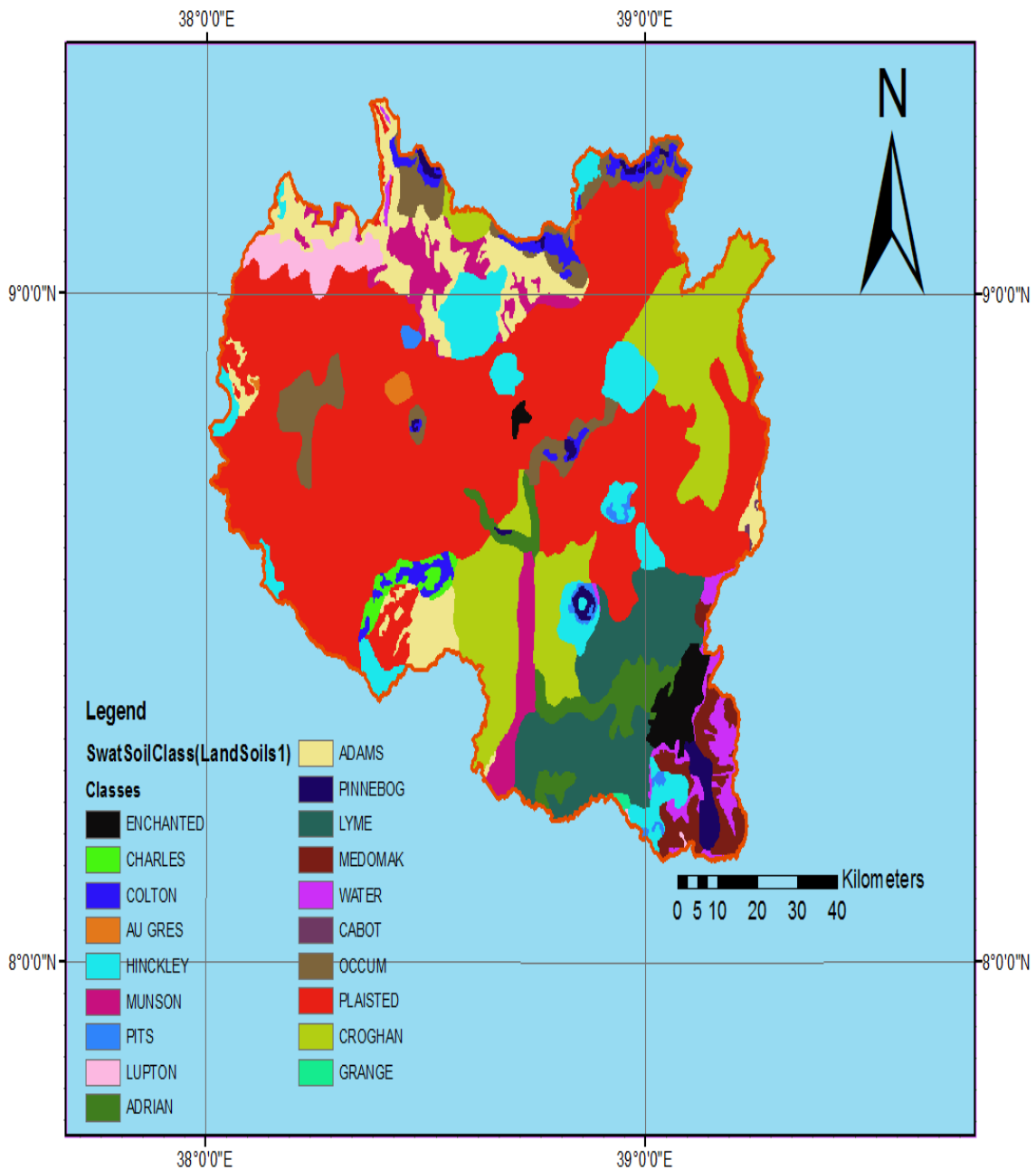


Figure 3-8: Soil map of the upper awash basin.

3.2.5 Stream flow data

SWAT simulates stream flow and sediment yield transport at catchment scale, on a continuous, daily time step (Neitsch, et al., 2011). SWAT CUP uses this data values in comparing the observed values and simulated flow data was formatted as to the requirement of the SWAT model and used for model calibration and validation. Daily stream flow was obtained from Ethiopian Ministry of water, Irrigation and Energy bureau hydrology Department.

3.2.6 Sediment data

SWAT CUP also uses this data values in comparing the observed values with simulated sediment data was formatted as to the requirement of the SWAT model and used for model calibration and validation. The sediment data also collected from MOWIE which recorded at different years (1989- 2015) at river station and used to compare with the sediment data that generated by the model during the validation period. The rating curve is to develop an equation between the relationship of flow and sediment.

Sediment rating curve: a sediment-rating curve expresses the average relation between discharge and suspended sediment concentration for a certain location. The sediment rating curve is usually expressed as a power function of discharge.

$$Q_s = aQ^b \quad 3.1$$

Where Q_s is the suspended sediment transport (M tons/day)

Q is water discharge (m^3/s)

a and b are regression coefficient and exponent respectively The sediment rating curve was constructed using the linear least squares fit of the Power.

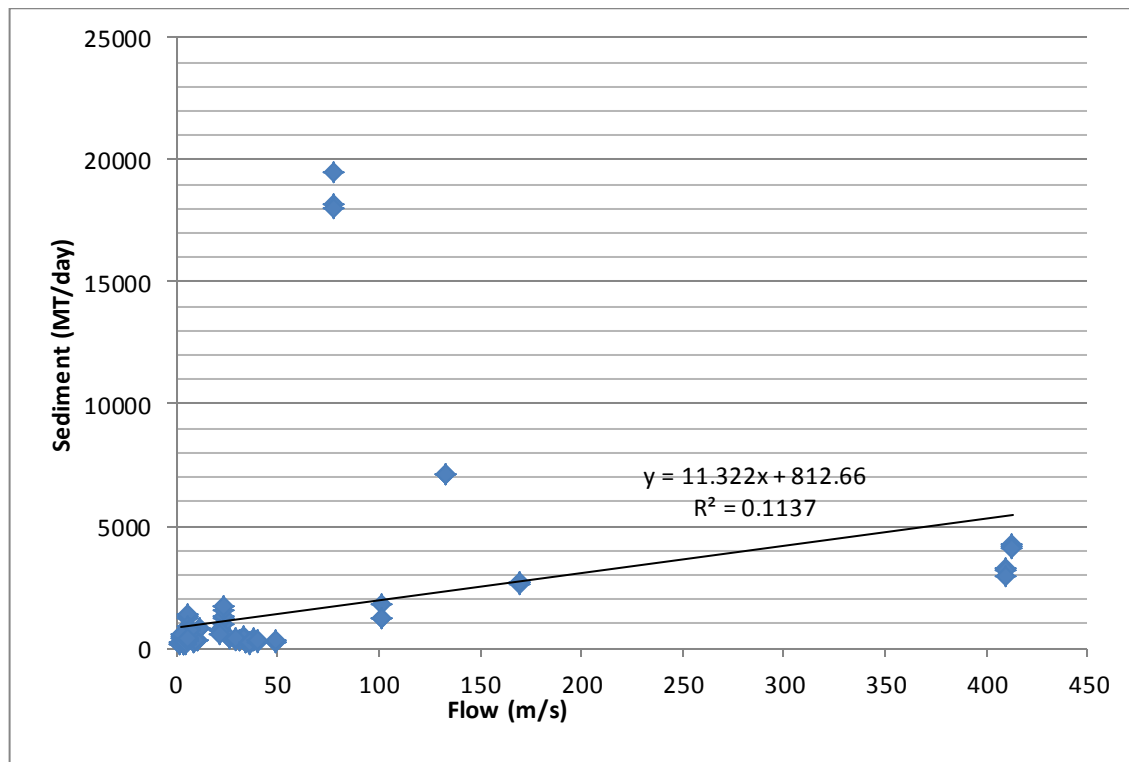


Figure 3-9: Suspended sediment concentration rating curve for U/S of Koka Dam station.

3.3 Methodology

The main tools (materials) used for input data preparation, analysis were Arc SWAT, SWAT-CUP, pcpSTAT, Dew02.exe, Automated base flow separator, Microsoft Excel, DEM, Meteorological, Hydrological map and data. The methodology of this work has the following components: Data collection, Data processing, Running model, Sensitivity Analysis, Calibration and validation of the model, Model result analysis.

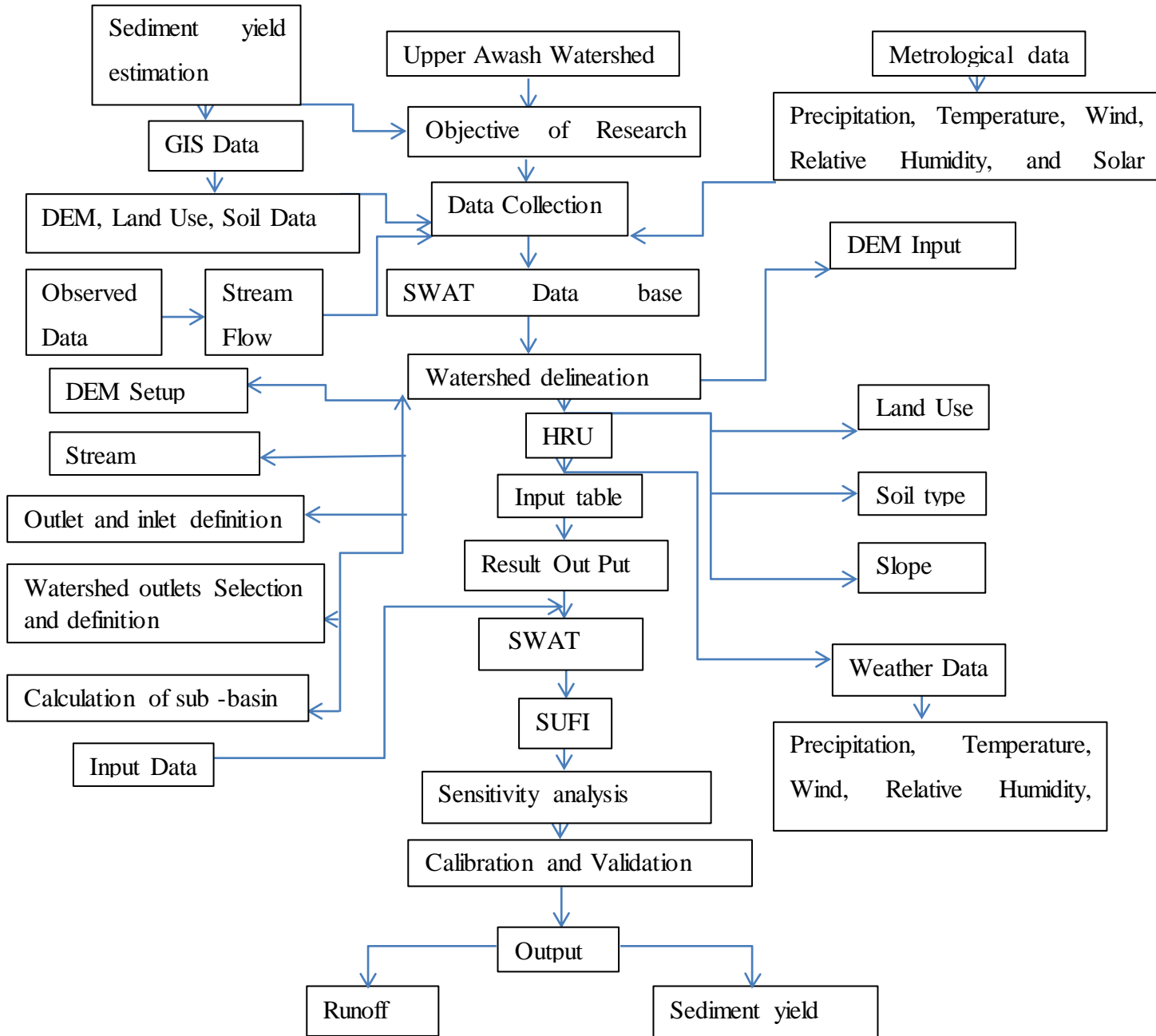


Figure 3-10: Flow chart of arc swats processing Steps.

For this purpose SUFI-2, calibration and Uncertainty analysis algorithms were used. Finally, calibration, validation and evaluation of the land use land cover by appropriate systems to check the performance of the model with observed data. The SWAT model serve as modeling approaches, brief descriptions of the model are given below. The overall methodology of the study was presented in figure 3.10

3.3.1 Data quality control

The raw data must be checked for qualities, which mean that its continuity and consistency ahead of used it for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any. This will help to identify if there are any gaps or unphysical peaks in data series and correct them before the data is used or input to the model. Otherwise, using the erroneous data as input to the model will give erroneous output from the model.

3.3.2 Visual inspection

The precipitation data must be checked for continuity and consistency before it is used for further analysis. After the rainfall, data is obtained from NMA it must be checked for its quality. The first step in data quality control is by visual inspection. This can be done by checking if date and time record is complete, unphysical values (negatives), flat regions (sensor or transfer system fall out) and unphysical variation patterns (sensor malfunctioning).

3.3.3 Filling of missing data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. Here, the station whose data was missing was called interpolation station and gauging stations whose data are used to calculate the missing station data are called index stations. There are methods to fill in missing data. These are arithmetic mean method, normal ratio method and inverse distance weighing method. Inverse distance weighing method has been used in this study to fill in the missing data. However, the data filled by this method was not used as input to the SWAT (Soil and Water Assessment Tool) model since the model itself has a built in function to fill in the missing data.

3.3.4 Statistical parameters calculation for precipitation data

After the precipitation, data was checked for quality and the appropriate station selected the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programme **pcpSTAT.exe**: This programme calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (Liersch, 2003). to reduce the amount of time required for the computing a minimum of seventy two parameters.

3.3.5 Statistical parameters calculation for temperature data

The temperature data record was available from one weather station: Debrezeit, The daily maximum and minimum air temperature was available with some missing data. The missing data was filled using regression formula for checking the trend of the air temperature over time.

Dew02.exe: is used to calculate the dew point temperature using minimum and maximum daily temperature and the average daily humidity. The data must be an ASCII text file format with three columns. The first column stores the maximum dailt temperature data the second column the minimum temperature data and the third column the average daily humidity data is used to generate maximum and minimum temperature and relative humidity and dewpoint.

3.3.6 Sediment Data

The sediment data collected from MOWIE that recorded at different years (1989-2015) was not recorded continuously. Therefore, the missing value of concentration sediment converted to total sediment load by rating curve method using continuously recorded stream flow data.

3.4 Model Input Description

3.4.1 Spatial data

The spatial data elements such as DEM, soil and land use are the major spatial input. DEM are used to delineate the watershed and to analyze the drainage patterns of the land topography. Land use and soil type have a direct impact on the sediment yield, speed and potential to create damage that the study should give attention for land use and land cover of the sub basin. The LULC data combined with the soil cover data generates the

hydrologic characteristics of the basin or for the study area, which in turn determines the excess amounts of precipitation, recharge to the ground water system and the storage in the soil layers.

3.4.2 Hydro-climatic data

Climate data is among the most important data required for the SWAT model. Obtaining representative meteorological data for watershed-scale hydrological modelling can be difficult and time consuming. Land-based weather stations do not always adequately represent the weather occurring over a watershed, since they can be far from the watershed of interest and can have a missing data series, or recent data are not available (Fuka *et al.*, 2014). It is beneficial to have a meteorological station within the watershed of interest. Rain gauge data are point measurements that may not represent the whole watershed. This problem can be reduced only when there are multiple rain gauges within the watershed. Otherwise, the problem exists specially for large watersheds, which may have large hydro-climatic gradients.

The meteorological data elements such as daily precipitation, maximum and minimum temperature, daily wind speed, daily solar radiation, daily relative humidity, flow and sediment data are basic hydro-climatic elements to set up the SWAT model. The data for the weather elements should be provided on a daily basis. For Awash basin, seven meteorological data stations are available within and nearby the study area. The stations record daily precipitation data since 30 years (1986-2015).

The average rainfall depth recorded at each meteorological station is shown in figure 3.11. In all the stations, the maximum rainfall has been observed in months of July and August while the minimum rainfall has been observed in months of November to January. The maximum rainfall occurs at Addis Ababa meteorological station. Addis Ababa, Addis Alem, and Debrezeit are located at the highest elevation of the basin and as a result, they receive high rainfall depth. However, at Meki meteorological station minimum rainfall occurs as the places are in low land area of the basin.

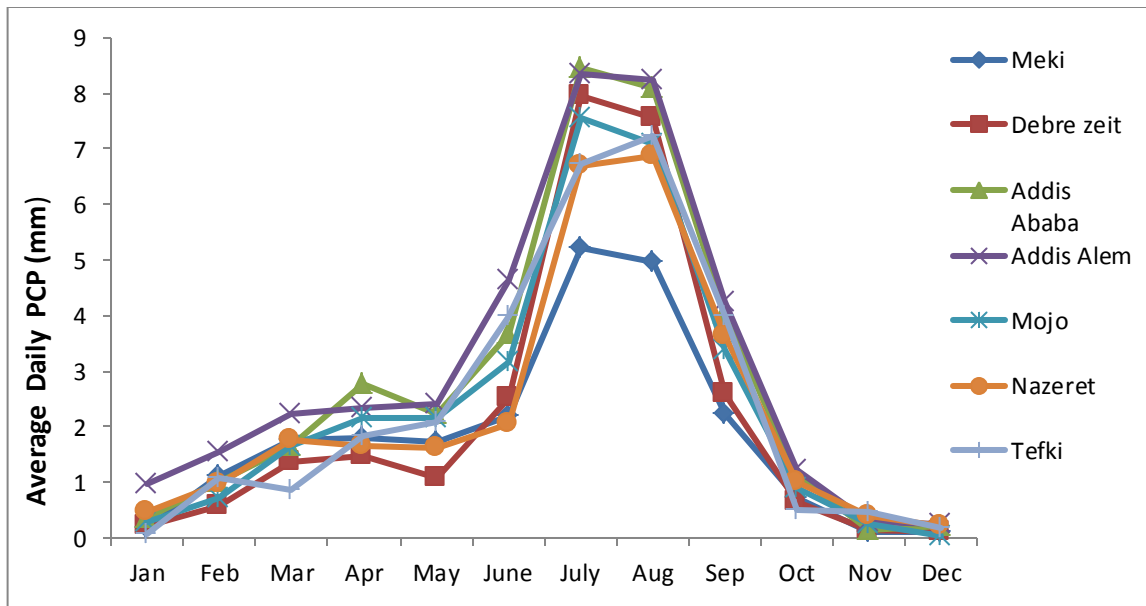


Figure 3-11: Average Precipitation Depth Observed in Upper Awash Basin (1986-2015).

3.4.3 Weather generator

SWAT model has a built-in weather generator to generate climate data for the whole basin using time series data of a single gauging station, which was used by (Schoul & Abbaspour, 2006). The weather generator is one of the main components of the SWAT model. It helps to estimate the values of the missing data for the climatic parameters of the study area. The missing values of climate elements like precipitation, temperature, wind speed, relative humidity solar radiation and Potential evapotranspiration are generated by the weather generator component. The data required for this study was collected from seven stations within and around the study area: Adisalem, Addis Ababa, Debrezeit, Meki, Mojo, Tefki, Nazret. SWAT requires daily precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity as inputs.

The weather generator component requires statistical parameters, such as a standard deviation for the maximum and minimum temperature, daily precipitation, average daily solar radiation, average amount of precipitation falling in a month, probability of wet day followed by dry day, probability of wet day followed by wet day and average dew point temperature. The statistical parameters are computed using the computer program developed by Liersch (2003). This program requires daily time series data of precipitation and temperature and provides all input parameters pertaining to the weather generator component in SWAT. For the Upper Awash basin one meteorology stations (Debre Ziet) have been analyzed and used to establish the weather generator database. the following

supplementary software was used to generate weather data which is very difficult to calculate manually.

HRU Definition: The Hydrologic Response Units (HRUs) Analysis tool in Arc SWAT helps to load land use and soil layers to the project. The delineated watershed by Arc SWAT and the prepared land use overlapped analysis in Arc SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option for considering different slope classes for HRU definition) 10%, 15% and 20% for Land use, soil and Slope class respectively was selected for this study. Based on the above classification, we have 743 hru in the upper awash catchment.

3.4.4 Stream flow and sediment data

SWAT simulates stream flow and sediment yield transport at catchment scale, on a continuous, daily time step (Neitsch, *et al.*, 2011). SWAT CUP uses this data values in comparing the observed values and the simulated values in calibration and validation periods.

3.5 Application of SWAT Model

SWAT operates on a daily time step and is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in watersheds. The model is process based, computationally efficient, and capable of continuous simulation over long periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. 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, topographical, and soil characteristics. The HRUs are represented as a percentage of the sub watershed area and may not be contiguous or spatially identified 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.

3.5.1 The main processes and principle in SWAT

Hydrologic processes

The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snowmelt, transmission losses and ponds. The percolation and return flow or base flow considered in SWAT for hydrological modeling is only the percolation to shallow aquifer from vadose zone and base flow to the channel from the shallow aquifer. The groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream flow somewhere outside the watershed. According to (Arnold *et al.*, 1993), the water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer.

The water balance is the backbone of the hydrologic and hydraulic modeling in a watershed. In SWAT, the water balance is computed from the soil water content, which is described by the following equation.

$$SW_t = \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (3-2)$$

where

SW_t final soil water content (mm)

SW_o initial soil water content (mm)

t time (days)

R_{day} amount of precipitation (mm)

Q_{surf} amount of surface runoff (mm)

E_a amount of evapotranspiration (mm)

W_{seep} amount of water entering vadose zone (mm)

Q_{gw} amount of return flow day (mm)

Surface runoff/overland flow

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch *et al.*, 2011). When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the rate of application is higher than the infiltration rate, surface

depressions begin to fill. If the application rate continues to be higher than the infiltration rate once the all surface depressions have filled, surface runoff will commence (Neitsch *et al.*, 2011). SWAT provides two methods for estimating the surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911).

The SCS curve number is a function of the soil's permeability, land use and antecedent moisture conditions (SCS, 1972) whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity (Green and Ampt, 1911). SWAT uses the daily and hourly time steps to calculate surface runoff. For daily time steps, SWAT uses an empirical SCS curve number (CN) method and for hourly time steps SWAT uses the Green and Ampt equation. For this project the SCS curve number was adopted for the simulation of surface runoff in SWAT since it requires the readily available daily data that can be obtained from easily from government ministries and/or offices. The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \left(\frac{(R_{day} - I_a)}{(R_{day} - I_a + S)} \right) \quad (3-3)$$

where

Q_{surf} is the accumulated runoff or rainfall excess (mm H₂O), R_{day} is the rainfall depth for the day (mm H₂O),

I = initial abstraction (mm)

S = retention parameter (mm)

The retention parameter (S) is defined as:

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \quad (3-4)$$

Where CN is the curve number for the day

To compute the surface runoff depth using the above stated equation 3-4, CN is the major parameter to be used in the SWAT model. The SCS curve number is a function of the soil's permeability, land use and antecedent moisture conditions: 1-dry (wilting point), 2- (average moisture), and 3- wet (field capacity). The moisture condition 1, curve number

is the lowest value that the daily curve number can assume in dry conditions. The curve numbers 2 and 3 are calculated from equations below.

$$CN_1 = CN_2 - \frac{20*(100-CN_2)}{(100-CN_2 + \exp(2.533 - 0.0636*(100-CN_2))} \quad (3-5)$$

Where, CN1 is the moisture condition 1 curve number, CN2 is moisture condition 2 curve numbers, and CN3 is the moisture condition 3-curve number (Neitsch et al., 2011). The initial abstractions, I_a , is commonly approximated as 0.2S and the above equation above becomes:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} + 0.8S)} \quad (3-6)$$

Referring to the above equations, runoff will occur when $R_{day} > I_a$. Therefore, there is some amount of rainfall I_a (initial abstraction before ponding) for which no runoff will occur (i.e., runoff is zero) (Chow et al., 1998). The peak runoff rate is the maximum is the maximum runoff rate that occurs with a given rainfall event (Neitsch et al., 2011). The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT uses a modified rational method to calculate the peak runoff rate.

$$q_{peak} = \frac{\alpha_k Q_{surf} Area}{3.6 t_{conc}} \quad (3-7)$$

Where, q_{peak} is the peak runoff rate (m^3 / s), α_k is the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm), Area is the sub basin area (km^2), t_{conc} is the time of concentration for the sub basin (hr) and 3.6 is a unit conversion factor.

Hydraulic component

In SWAT model, the open channel cross section is assumed as trapezoidal with side slope of 2:1 figure below. Manning's equation is used for the computation of channel flow velocity. The channel Manning's roughness coefficient is entered as an input data. The channel cross section and longitudinal slope are computed from the digital elevation model (DEM). Flow is routed through the channel network using the variable storage routing method or Muskingum routing methods (Chow *et al.* 1988).

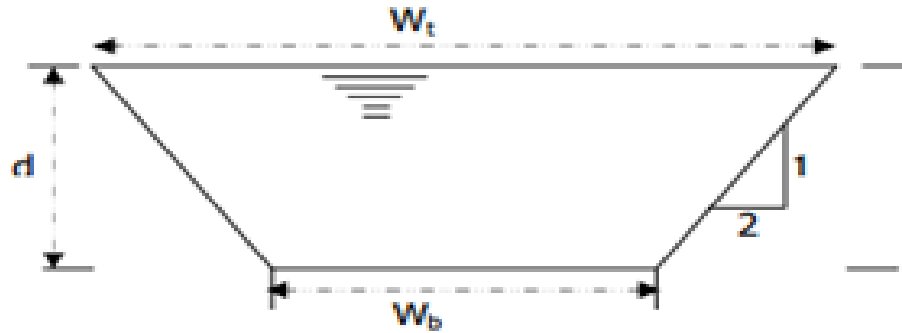


Figure 3-12: Trapezoidal Channel Dimension (from Chow *et al.* 1988).

Sediment component

For a watershed in which erosion and sedimentation process is significant, it is important to identify the source erosion and what causes it. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied.

Semi-distributed, physics-based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study. SWAT uses a Modified Universal Soil Loss Equation (MUSLE) developed by Williams *et al* 1975 to simulate sediment yield from the upland watersheds. MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

The sediment supply from the individual HRUs is computed by the modified universal soil loss equation.

$$Sed = 11.8(Q_{surf} * q_{peak} * A_{hru})^2 K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \quad (3-8)$$

where

S_{ed} =sediment yield (t/day)

Q_{surf} =surface runoff volume (mm)

Q_{peak} =peak runoff rate (m/s)

A_{hru} =area of HRU (ha)

K_{USLE} =USLE erodibility factor

C_{USLE} =USLE cover and management factor

P_{USLE} =USLE support practice factor

LS_{USLE} =USLE topographic factor

CFRG=coarse fragment factor

The peak runoff is an indicator of the erosive power of a storm event and is used to estimate the sediment yield in the MUSLE equation. The modified rational equation is used to calculate the peak runoff. The method assumes that if a rainfall of certain intensity i begins at time $t=0$ and continues indefinitely, the rate of runoff increases until the time of concentration $t=t_{conc}$, and the entire subbasin area is contributing to the flow at the outlet. The corresponding equation is:

$$Q_{peak} = \frac{C * i * A}{3.6} \quad (3-9)$$

where

Q_{peak} = peak runoff rate (m^3/s)

C = runoff coefficient

i = rainfall intensity (mm/h)

A = subbasin area (km)

The formula can be further described in terms of surface runoff depth and time of concentration: coefficient

$$\frac{\alpha_{tc} * Q * A}{3.6 t_{conc}} \quad (3-10)$$

$$\alpha_{tc} = 1 - \exp(2 * t_{conc} * \ln(1 - a_{0.5})) \quad (3-1)$$

where

t_{conc} = time of concentration for the subbasin (h)

$\alpha_{0.5}$ = friction of daily rainfall falling in half hour highest

Sediment Routing

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach (Neitsch *et al.*, 2011). There are two options in SWAT to compute deposition and degradation in the reach. The first and traditional way is to keep the channel dimensions constant so that SWAT will compute deposition and degradation using the same channel dimensions throughout the simulation and the second is to activate channel degradation and allow channel dimensions to change and updated as a result of down cutting and widening (Neitsch *et al.*, 2011).

Landscape contribution to sub-basin routing reach

From the landscape component, SWAT keep tracks of the particle size distribution of eroded sediments and routes them through ponds, channels, and surface water bodies (Neitsch *et al.*, 2011). The sediment yield from the landscape is lagged and routed through grassed waterway, vegetative filter strips, and ponds, if available, before reaching the stream channel. Thus, the sediment yield reaching the stream channel is the sum of total sediment yield calculated by MUSLE minus the lag, and the sediment trapped in grassed waterway, vegetative filter strips and/or ponds (Neitsch *et al.*, 2011).

Sediment routing in stream channels

The sediment supplied from the HRUs is routed to the downstream section of river networks to compute the net sediment flux. In the SWAT model, the Bagnold's equation as a function of maximum channel velocity is used to determine sediment transport, re-entrainment and deposition. The maximum amount of sediment that can be transported out of the reach is expressed as:

$$Conc_{sed} = C_{sp} * V_{ch,pk}^{spex} \quad (3-12)$$

where

Conc = maximum sediment that can be transported (t/m)

Csp = linear parameter for maximum sediment reentrainment

Vch,pk = peak channel velocity

Spex = exponential parameter for maximum sediment reentrainment

The model considers different watershed parameters for sediment yield modeling. However, not all parameters play an equal role in the sediment yield of the subbasins. Hence, the identification of the most and least flow and sediment governing parameters is a priority for the model calibration and validation. The parameter identification can be done by using a sensitivity analysis.

3.5.2 Sensitivity Analysis, Calibration and Validation of SWAT Model by SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. SWAT-CUP is designed to integrate various sensitivity analysis, calibration, validation and uncertainty programs for SWAT using different interface. The main function of an interface is to provide a connection between the output/input of a calibration program and the model. Using this

generic interface, any calibration, validation/uncertainty or sensitivity program can easily be linked to SWAT.

Sensitivity Analysis

SWAT (Soil and Water Assessment Tool) is known to have a large number of parameters. Over-parameterization is a well-known and often described problem in hydrological models, especially for distributed models such as SWAT.

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed (Abbaspour et al 2013). Therefore, methods to reduce the number of parameters via sensitivity analysis are important for the efficient use of these models (Van Griensven *et al.*, 2006). Sensitivity analysis is a process of testing and identifying model parameters that affects most the output from the model when changed. In other words, sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters) (Abbaspour, 2013). A parameter sensitivity analysis provides insights on which parameters contribute most to the output variance due to input variability (Holvoet *et al.*, 2005). Therefore, a parameter is considered sensitive when the change in that parameter causes large change on model output.

In general identifying sensitive parameters prior to model calibration helps to allow the possible reduction in the number of parameters that must be calibrated thereby reducing the computational time required for model calibration. Once the sensitivity analysis is done calibration can be performed for limited number of influential parameters.

The current version of SWAT model, SWAT2012, provides the algorithmic techniques for sensitivity analysis. Two types of sensitivity analysis are allowed when using SUFI2 (Sequential Uncertainty Fitting version 2). Global Sensitivity and One-at-a-time sensitivity analysis. The two aforementioned sensitivity analysis methods may yield different results since the sensitivity of one parameter depends on the value of other related parameters. In this study global sensitivity analysis were performed and the ranking of the parameters is compared.

Before applying SUFI-2 for calibration the most sensitive parameters were selected by running the sensitivity analysis. Twenty two parameters were considered for the model

parameterization sensitivity analysis, only twenty of them were effective for monthly flow simulation analysis. The thirteen most sensitive parameters, most responsible for the sediment yield assessment for the Upper Awash catchment have been considered for the model parameterization and calibration process used for the model were depicted in table below with their fitted value.

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

The one-at-a-time (OAT) sensitivity analysis is performed for one parameter at a time only by keeping the value of other parameters constant. OAT sensitivity analysis shows the sensitivity of a variable to changes in a parameter if all other parameters are kept constant at some reasonable value. This constant value can be the value of parameters from the best simulation (simulation with the best objective function value) of the last iteration. The drawback with the OAT sensitivity analysis is that the correct value of other parameters that are fixed are never known (Abbaspour, 2013). The objective function used in this project for ranking of the parameters based on OAT sensitivity analysis was the sum of the squares of the difference of the measured and simulated values after ranking (SSQR). The SSQR method aims at the fitting of the frequency distributions of the observed and the simulated series (Abbaspour, 2013).

Global sensitivity analysis

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

3.5.3 Model calibration and validation

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

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

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

The overall programme structure of SWAT_CUP is shown in Figure 3.13. The programme shows that the parameters of SWAT model should be edited in SWAT model after each iteration using SUFI2 or other programme. The SWAT model should be updated with a new set of parameters and then run the SWAT model. After the model was run using the new set of parameters, the new SWAT output must be used for the next iteration and so on.

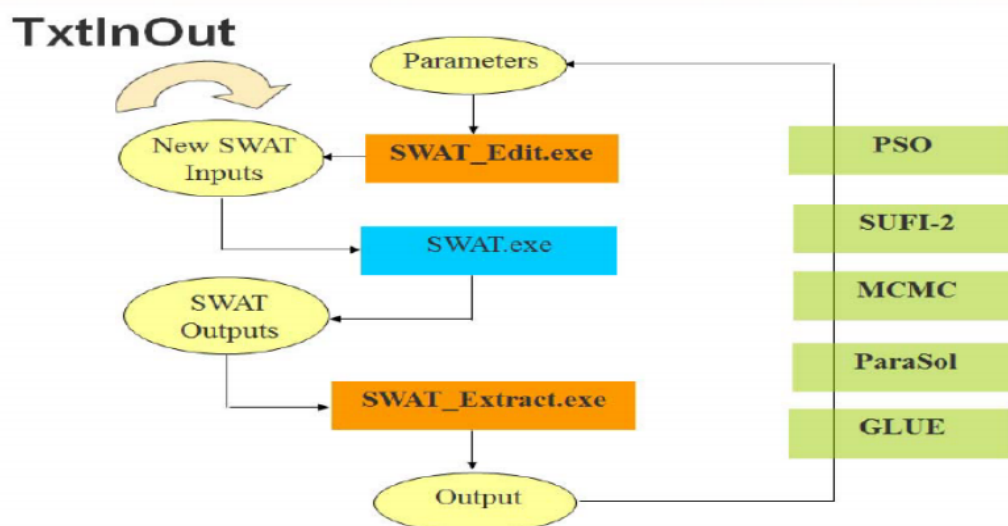


Figure 3-13: Overall Program Structure of SWAT CUP (From Swat Cup Manual).

3.5.4 Model efficiency

The performance of a model must be evaluated on the extent of its accuracy, consistency, and adaptability (Goswami, *et al.*, 2005). The performance of the model in simulating stream flow and sediment yield is evaluated using SWAT-CUP. There are Two methods for the goodness-of-fit measures of model predictions used during the calibration and validation periods, these numerical model performance measures the fraction of the variation in the measured data that is replicated in the simulated model results are coefficient of regression (R^2) and the NashSutcliffe simulation efficiency (NSE) and The values of R^2 ranges from 0.0 to 1.0 with higher values indicating better agreement (Legates & McCabe, 1999) and the value of NSE ranges from minus infinity to 1.0, with the higher values indicating better agreement (Legates & McCabe, 1999). A value of 0.0 for R^2 indicates that none of the variance in the measured data is simulated by the model predictions. In other ways, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

Coefficient of determination (R^2): Is the index of correlation of measured and simulated values. The value of R^2 ranges from 0 to 1. The more the value of R^2 approaches 1, the better is the performance of the model and the values of R^2 less than 0.5 indicate a poor performance of the model. R^2 is calculated by the following equation:

$$R^2 = \frac{[\sum(Q_{mj} - \bar{Q}_m)(Q_{sj} - \bar{Q}_s)]^2}{\sum((Q_{mj} - \bar{Q}_m))^2(Q_{sj} - \bar{Q}_s)^2} \quad (3-13)$$

Coefficient of determination R^2 where Q is a variable (e.g. discharge), and m and s stands for measured and simulated, i is the i^{th} measured or simulated data and \bar{Q}_s the mean of the simulated value, \bar{Q}_m is the mean of the observed value.

Nash-Sutcliffe Efficiency (NSE): NSE is the normalized statistics which measures the relative magnitude of the residual variance as compared to measured data variance. Similar to R^2 , the more the NSE approaches 1, the better will be the model performance and vice versa.

$$NSE = 1 - \frac{\sum((Q_m - Q_s)^2)_i}{\sum(Q_{mj} - \bar{Q}_m)^2} \quad (3-14)$$

Nash-sutcliffe, where Q is a variable (e.g, discharge), m and s stand for measured and simulated, respectively, and the bar stands for average.

Root mean square error observation standard deviation ratio (RSR): It is an error index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{[\sqrt{\sum_{i=1}^n (O_i - S_i)^2}]}{[\sqrt{\sum_{i=1}^n (O_i - \bar{S})^2}]} \quad (3-15)$$

Percent Bias (PBIAS): Percent Bias measures the average tendency of the simulated data to large or smaller than the observations. The optimum value is zero, where low magnitude values indicate better simulations. Positive values indicate model underestimation and negative values indicate model over estimation (Gupta et.,1999).

Percent Bias (PBIAS) is calculated by the following equation:

$$RPBIAS = 100 * \frac{\sum_{i=1}^n (Q_m - Q_s)_i}{\sum_{i=1}^n Q_{mj}} \quad (3-16)$$

Where Q is a variable (e.g, discharge), and m and s stands for measured and simulated, respectively.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Sensitive Parameters

The sensitivity analysis was done for flow and sediment separately since some parameters are sensitive to both flow and sediment, some sensitive to flow only and others sensitive to sediment only (Abbaspour *et al.*, 2007). Therefore, it is wise to test the sensitivity of the parameters for flow and sediment separately. Sensitivity analysis was carried out before calibrating the model to save time during calibration. Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. Some parameters does not have any influence on the model output while some may have little effect.

4.1.1 Parameters sensitive to flow

The parameter identification was done by using the monthly flow data from 2004 to 2010. Table 4.1 shows all the parameters used in the sensitivity analysis for flow calibration.

Global sensitivity analysis for flow

Global sensitivity analysis was done for the 16 parameters shown in Table 4.1. According to the result from the global sensitivity analysis, the curve number (CN2) was found to be the most sensitive parameter followed by Base flow alpha factor (ALPHA_BF), Groundwater delay (GW_DELAY), Available water content of soil (SOL_AWC), and Groundwater revap coefficient (GW_REVAP).

The sensitivity for each parameter was assigned depending on P-value and t-stat. Here, t-stat provides a measure of sensitivity and hence larger in absolute values are more sensitive. On the other hand, P-value indicates the significance of the sensitivity and hence a value close to zero has more significance. Therefore, ranking in both cases (t-stat or P-value) give the same result i.e. a parameter will have the same rank whether it is ranked based on the t-stat or P-value.

Table 4-1: Hydrological parameter selected for both flow calibration and validation.

S/No	Parameter	Description of Parameters	Range val
1	CN2	SCS runoff curve number	35-98
2	ALPHA_BF	Base flow alpha factor	0-1
3	ESCO	Soil evaporation compensation factor	0-1
4	CH_N2	Manning's "n" value for the main channel	-0.01-0.3
5	SURLAG	Surface runoff lag time	0.05-24
6	GW_DELAY	Groundwater delay	0-500
7	GW_REVAP	Groundwater revap coefficient	0.02-0.2
8	SOL_Z	Soil depth (for each layer)	0-3500
9	SOL_AWC	Available water content of soil	0-1
10	SOL_K	Saturated hydraulic conductivity(mm/hr)	0-2000
11	CH_K2	effective hydraulic conductivity in the main	0.025-250
12	BIOMIX	Biological mixing efficiency	0-1
13	EPCO	Plant uptake compensation factor	0-1
14	OV_N	Manning's "n" value for overland flow	0.01-30
15	REVAPMN	Threshold depth of water in the shallow	0-500

Table 4-2: Result of the sensitivity analysis parameters for flow calibration.

Par -Name	Parameter description	t-Stat	P-Val	Range value
CN2	SCS runoff curve number	6.38	0.00008	1
ALPHA_BF	Base flow alpha factor	-2.39	0.037	2
ESCO	Soil evaporation compensation factor	0.011	0.991	10
CH_N2	Manning's "n" value for the main	0.45	0.662	7
SURLAG	Surface runoff lag time	0.56	0.591	6
GW_DELAY	Groundwater delay	1.59	0.144	3
GW_REVAP	Groundwater revap coefficient	0.57	0.580	5
SOL_Z	Soil depth (for each layer)	0.21	0.781	8
SOL_AWC	Available water content of soil	0.96	0.360	4
SOL_K	Saturated hydraulic conductivity	-0.07	0.953	9
OV_N	Manning's "n" value for overland	0.002	0.999	13
BIOMIX	Biological mixing efficiency	0.003	0.998	12
CH_K2	effective hydraulic conductivity	-0.01	0.992	11

4.1.2 Parameters sensitive to sediment

The most sensitive parameters for erosion simulations were: SCS runoff curve number (CN2), USLE soil erodibility factor (USLE_K), channel re-entrainment exponent parameter (SPEXP), Sediment concentration in lateral flow (LAT-SED), channel re-entrainment linear parameter (SPCON), channel erodibility factor (CH_EROD).

Table 4-3: Hydrological parameter selected for both sediment calibration and validation.

S/N	Parameters	Description of parameters	Range of value
1	CN2	SCS runoff curve number	(35-98)
2	SPCON	Linear parameter calculating the (max) sediment	(0.0001-0.01)
3	USLE_K	USLE equation soil erodibility (K) factor	(0-0.6)
4	USLE_P	USLE equation support practic factore	(0-1)
5	BIOMIX	Biological mixing efficiency	(0-1)
6	SPEXP	Exponent parameter for calculating sediment	1-1.5
7	CH_EROD	Channel erodibility factor	(0-1)
8	CH_COV2	Channel cover factor	(0.001-1)
9	EROS-SPL	The splash erosion coefficient	(0.9-3.1)
10	CH-EQN	Sediment routing method	(0-4)
11	LAT-SED	Sediment concentration in lateral flow	(0-5000)
12	ADJ_PKR	Peak rate adjustment factor for sediment rout	(0.5-1)
13	ALPHA_BF	Base flow alpha factor	(0-1)

Other parameters included in the table 4.3 were also affecting the soil erosion simulation to some extent. These sediment parameters are used to compute the amount of sediment from a catchment (from upland) and from the channel (in stream sediment). The parameters that were used to evaluate the sensitivity to sediment are shown in Table 4.3.

4.2 Model Calibration and Validation for Stream Flow

The sediment outflow from each HRU and subbasin is primarily governed by soil, hydrologic and hydraulic parameters such as soil erodibility, surface runoff, stream discharge and stream flow velocity. Therefore, prior to sediment calibration, stream flow should be calibrated. As SWAT model considers many parameters, it is mandatory to

identify which of the basin parameters are most important to govern stream flow, and sediment yield. For both calibration of stream flow and sediment yield, governing parameters should be prioritized according to their order of influence. Prioritization of the parameters has been done using the robust Latin Hypercube Global sensitivity analysis method.

The entire study area has been divided into 27 subbasins and 743 HRUs. For each subbasin, the parameters have been ranked according to their order of influence. The frequency of each parameter in the first five top rank orders has been calculated. The computation result of the sensitivity analysis for stream flow and sediment yield is indicated in table 4.4 and 4.5.

4.2.1 Model calibration for stream flow

The calibration of SWAT model for stream flow was done by using the monthly observed stream flow data at the Hombole gauging station for the years 2004 and 2010. The stream flow was not actually measured at the koka reservoir out let rather it was calculated by area ratio method from Hombole gauging station to point of interest. During the calibration period from 2004- 2010, the simulated average monthly flow matched well with the average monthly measured flow (with $R^2 = 0.71$, ENS = 0.71 and PBIAS = -5.1). Figure 4.1 shows the comparison of the simulated versus observed average monthly flow.

The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volume (Example in August 2006). However, the model overestimated the peak monthly flow during the first two years (2004-2005) of the simulation periods and underestimated the peak monthly flow from (2006-2010) Figure 4.2. Nevertheless, as it can be clearly seen on the scatter plot of the simulated versus observed average monthly flow (Figure 4.3), the predicted values were all most underestimated by the model.

The monthly calibrated and validated statistical results are presented in Table 4.4 and 4.5. The results clearly showed that means and standard deviations of the average monthly simulated and observed flows are within a difference of 5.58% , 13.61%, and 4.28% , 9.2% , during flow calibration and validation period respectively.

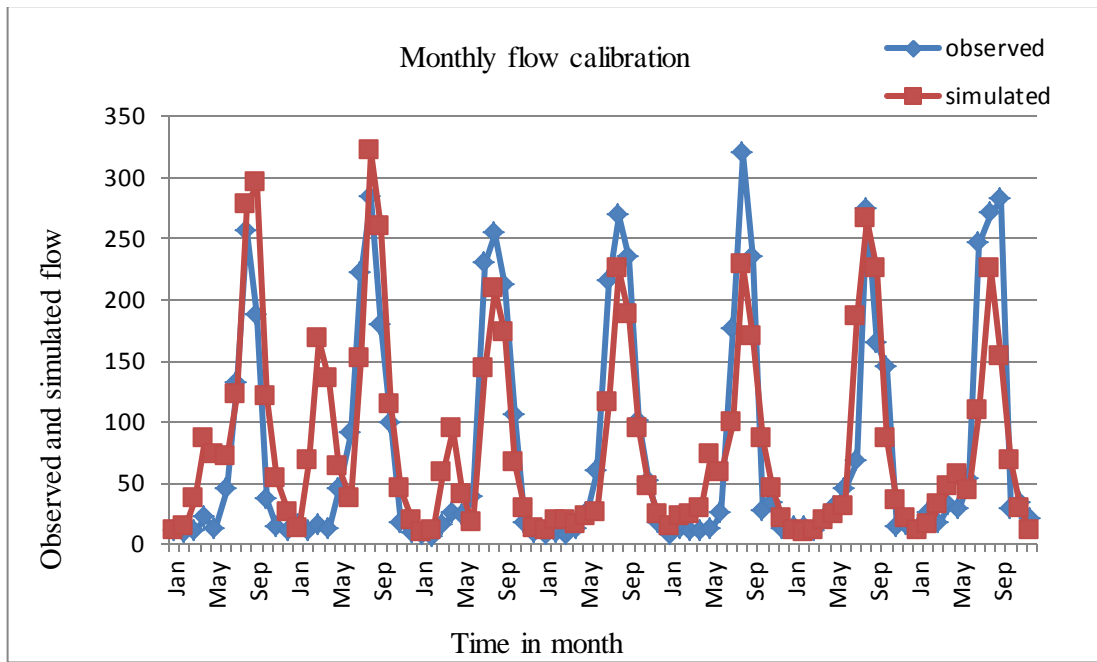


Figure 4-1 Simulated and observed average monthly flows by excel during calibration.

FLOW_OUT_19

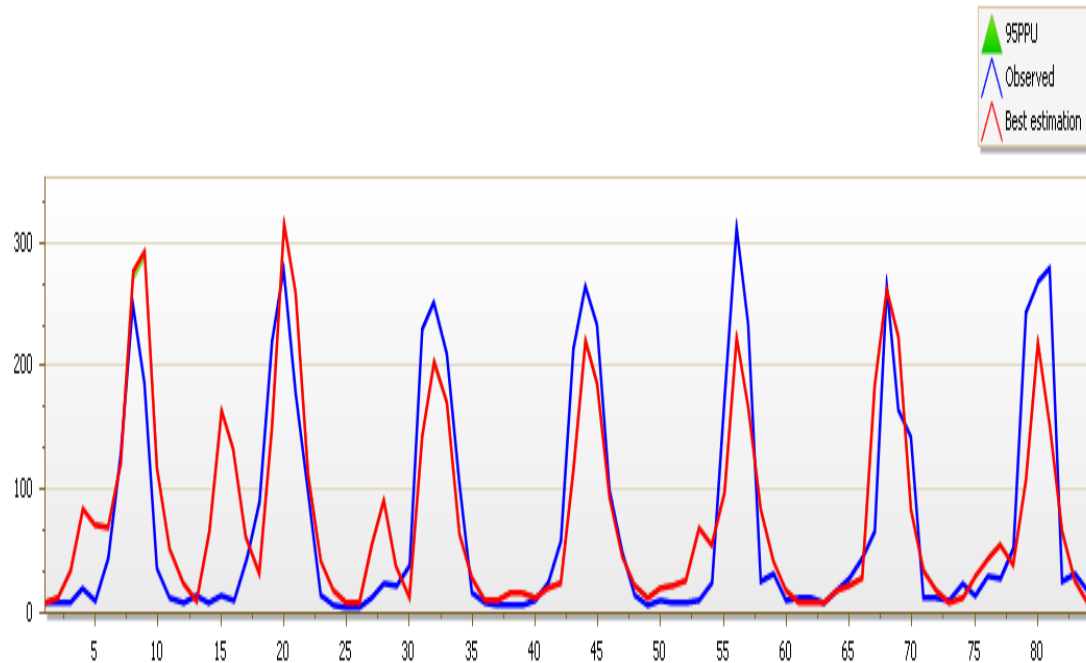


Figure 4-2: Simulated and observed average monthly flows generated from SWAT CUP during Calibration.

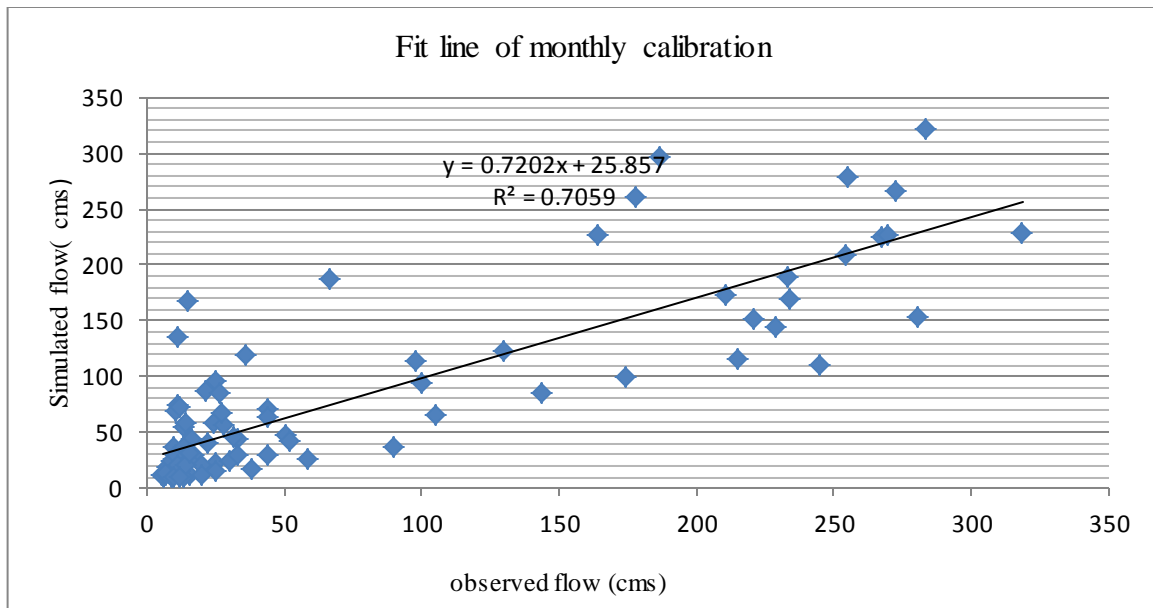


Figure 4-3: Scatter plot of the simulated vs. observed average monthly flow during calibration.

4.2.2 Model validation for stream flow

SWAT model were successfully validated for flow from 2011 to 2014 Table 4.4 below . Monthly flow rates were well predicted and measured and simulated monthly flows matched well (with $R^2 = 0.71$, ENS = 0.70 and PBIAS = -15.9). The model over predicted the flow during dry season and under predicted during rainy season. Generally, the trend of seasonal variability and monthly average discharges were generally well captive.

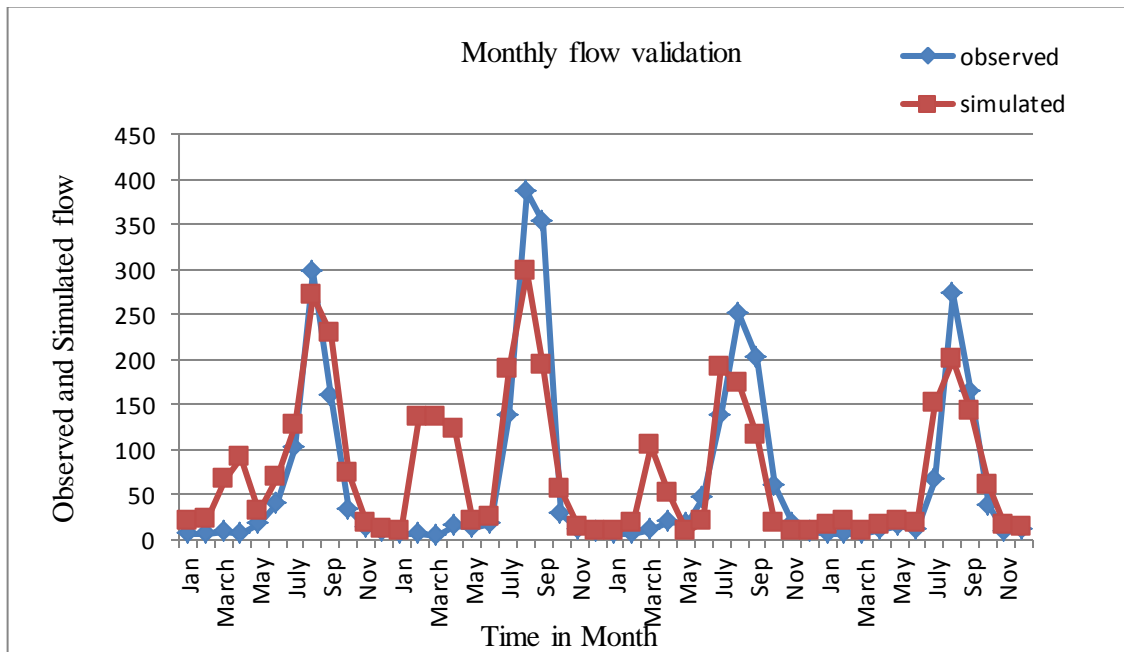


Figure 4-4: Simulated and observed average monthly flows by excel during validation.

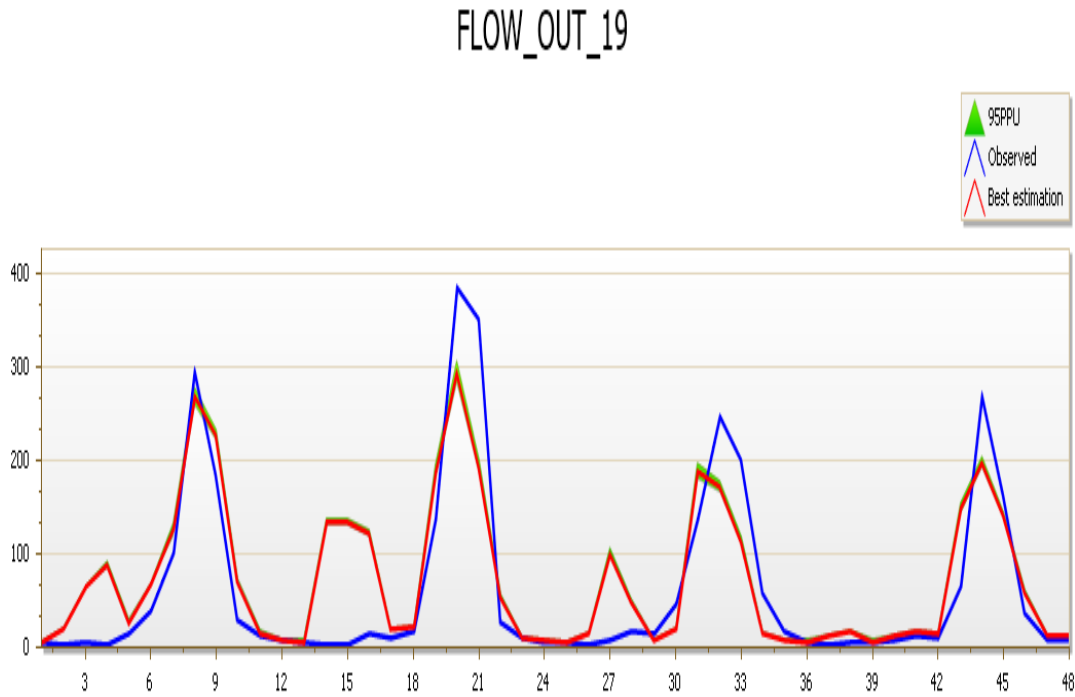


Figure 4-5: Simulated and observed average monthly flows by generated from SWAT CUP during validation.

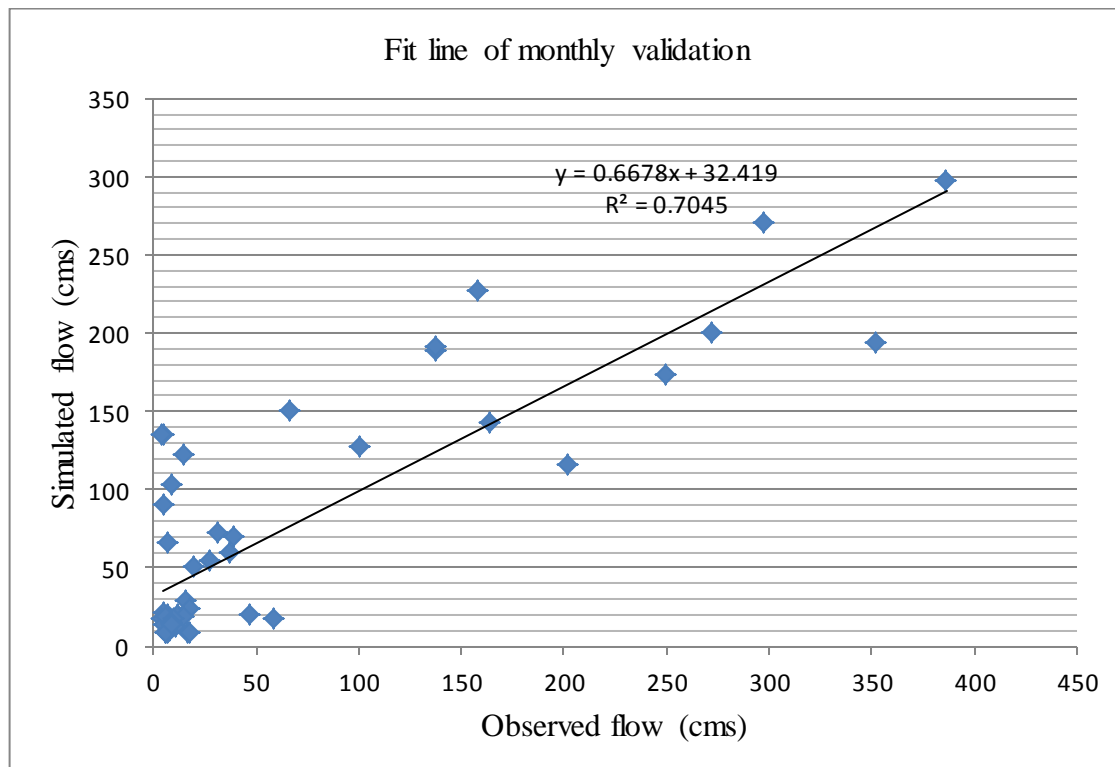


Figure 4-6: Scatter plot of the simulated vs. observed average monthly flows during validation.

4.3 Model Calibration and Validation for Sediment

4.3.1 Model calibration for sediment

The model also showed adequacy in predicting the average monthly sediment yields in the study area with R^2 , ENS and PBIAS values of 0.67, 0.66 and 4.3, respectively during calibration Table 4.5. It is clearly indicated that means and standard deviations of the average monthly simulated and observed sediment yields are within a difference of 11.61%, 18.81%, and 3.03%, 27.39%, respectively during calibration and validation.

During this period, the simulated average monthly sediment yields matched well with the computed average monthly sediment yields. However, the scatter plot of the simulated versus observed average monthly sediment yields shown on Figure 4.9 clearly indicated that the model under-predicted the sediment yield values during wet season from 1999 and 2003. and for the last wet season period (1997-1998) the average monthly sediment yield values were over predicted by the model which could be the result of siltation of more sediments into the reservoir. Moreover, such behavior of the simulated sediment yields indicated the high deposition of sediments as they travel along the channel.

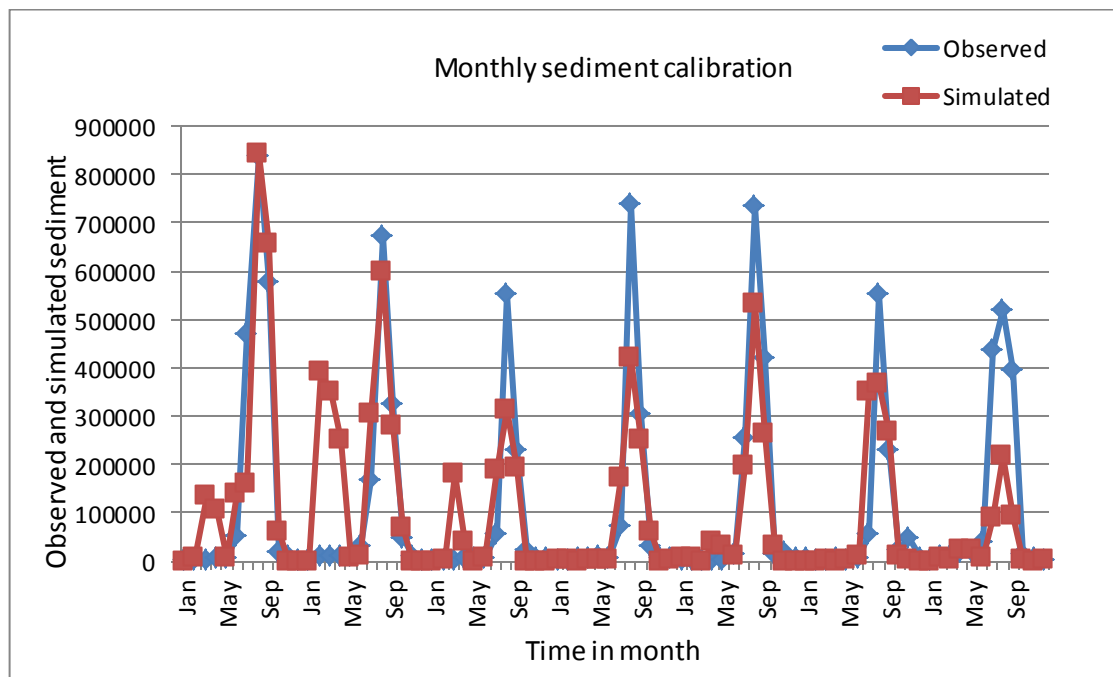


Figure 4-7: Simulated and observed average monthly sediment generated by excel during calibration.

SED_OUT_19

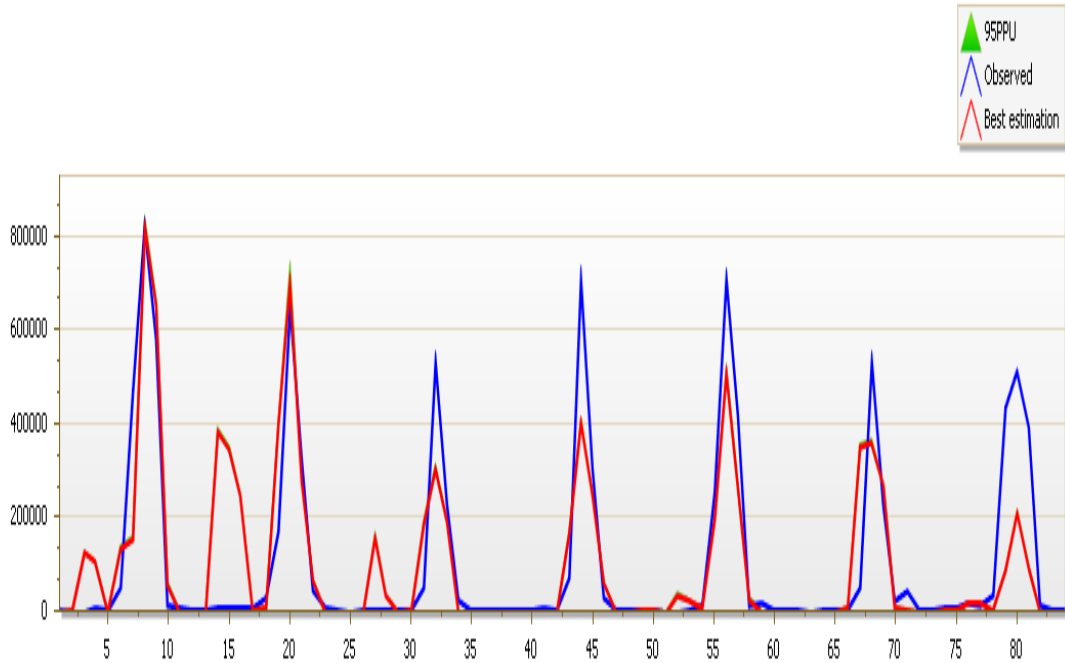


Figure 4-8: Simulated and observed average monthly sediment generated from SWAT CUP during calibration.

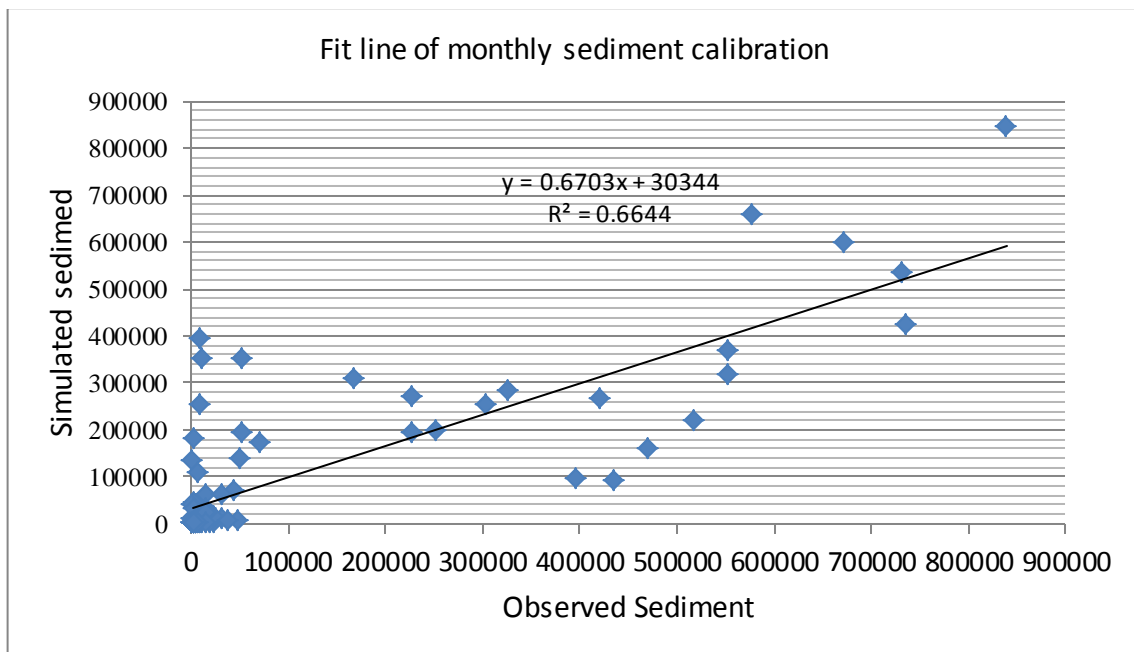


Figure 4-9: Scatter plot of the simulated vs. observed average monthly sediment during calibration.

4.3.2 Model validation for sediment

Model validation results were showed that the monthly predicted and observed sediment yields matched well with R^2 , ENS and PBIAS values of 0.66, 0.65 and 9.8, respectively. The scatter plot of the observed versus simulated sediment yields is shown on Figure 4-12 below.

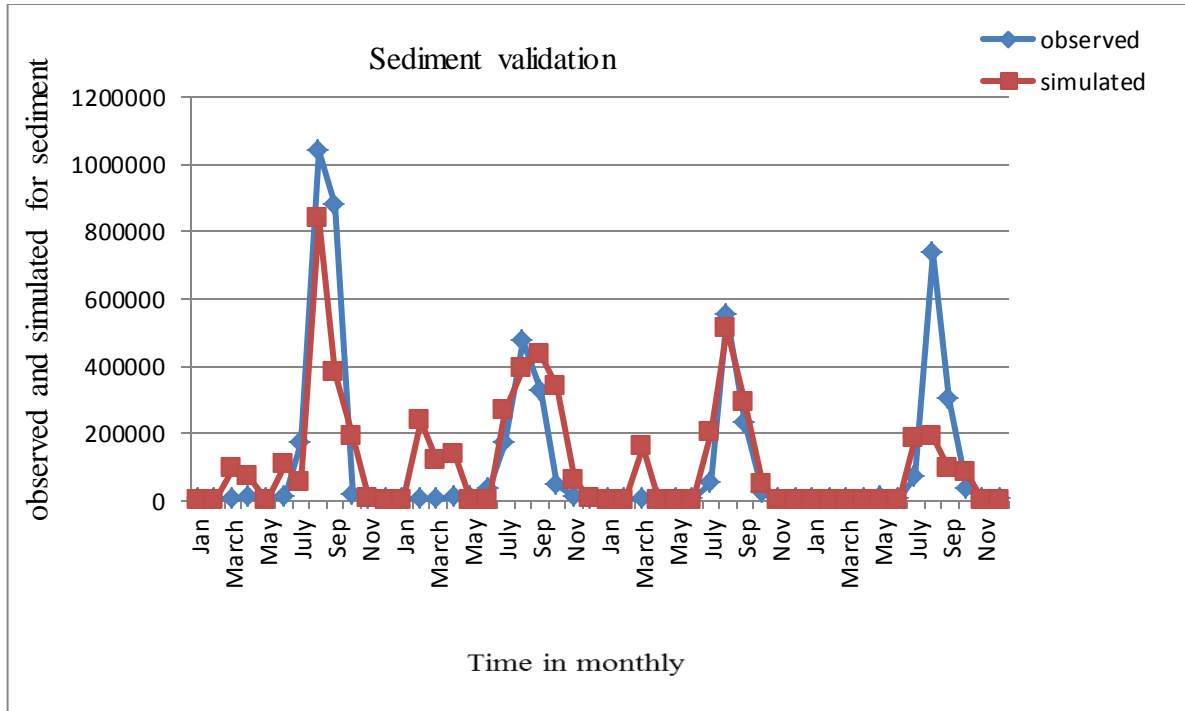


Figure 4-10: Simulated and observed average monthly sediment generated by excel during validation.

SED_OUT_19

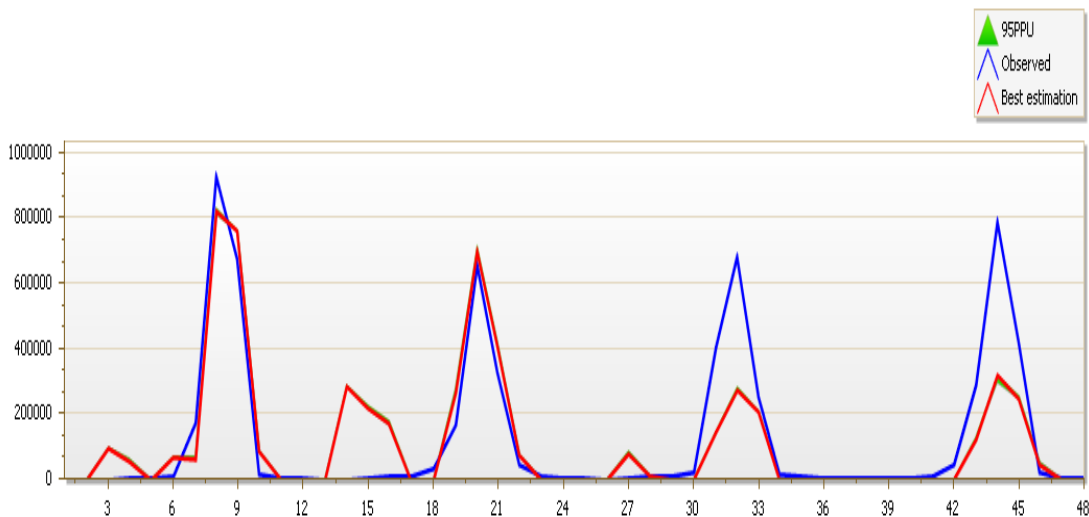


Figure 4-11: Simulated and observed average monthly sediment generated from SWAT CUP during validation.

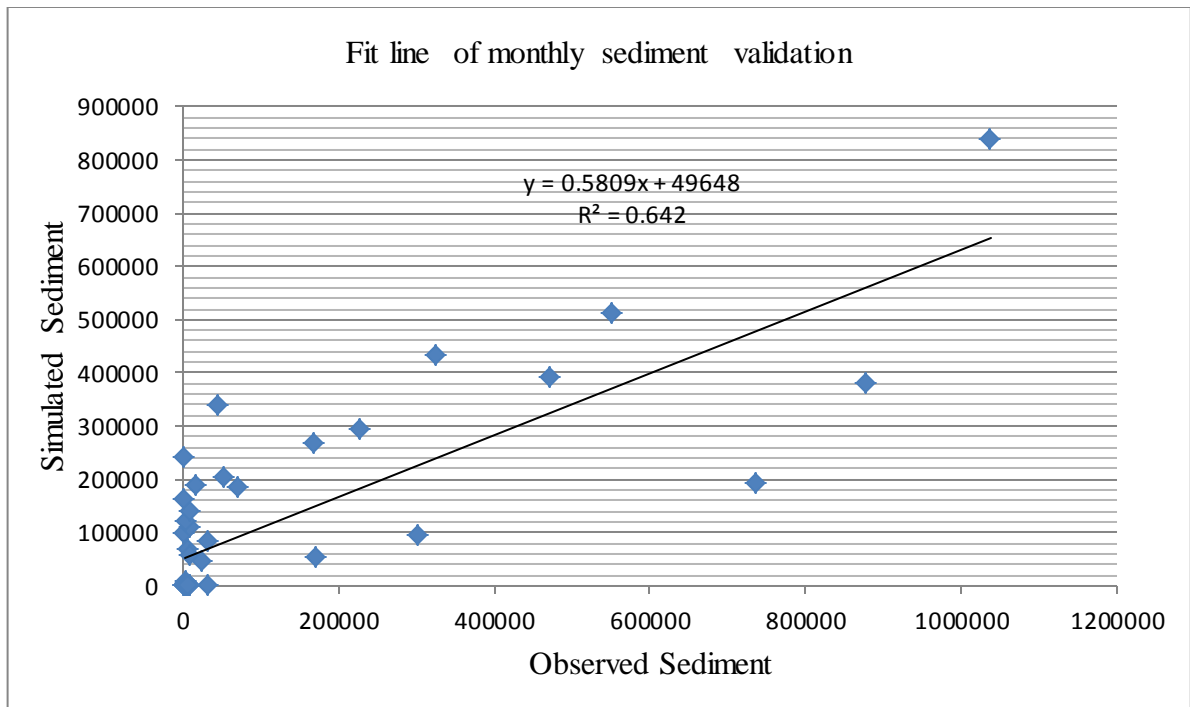


Figure 4-12: Scatter plot of the simulated vs. observed average monthly sediment during validation.

Table 4-4: Stream flow calibration and validation results on monthly basis (models evaluation performance results).

Description	R ²	NS	Mean		Standard Deviation		
			Observed	Simulated	Observed	simulated	
PBIAS							
Flows (cms)							
Calibration	0.71	0.71	-5.9	68.91	80.82	98.38	92.31
Validation	0.71	0.70	-15.8	64.75	74.98	98.82	104.37

Table 4-5: Sediment calibration and validation results on monthly basis (models evaluation performance results).

Description	R ²	NSE	PBIAS	Mean		Standard Deviation	
				Observed	Simulated	Observed	simulated
Sediment Yield (t/ha/month)							
Calibration	0.67	0.66	4.3	110458.37	105722.52	294051.31	238732.09
Validation	0.66	0.65	9.8	129117.51	116430.56	235322.78	170974.36

The sediment yield is directly related to the amount of discharge observed at each month. As depicted in Figure 4.7 the sediment load is high in rainy season July, August and September, this is directly related to rainy season where surface runoff is high. Average Annual average sediment load and surface runoff of Upstream Koka catchment is about 0.55 ton/ha and 101.83mm respectively.

Overall, the calibration and validation of the both stream flows and sediment show that the model successfully simulated with measured data. When stream flow compared with sediment yield, the stream flow was well matched more.

4.3.3 Evaluation of the stream flow calibration and validation

The performance of the model to simulate the stream flow during the calibration and the validation periods has been evaluated based on the computed results of the indicators and the suggested model performance rating standards. The computed statistical indicators from 0.71 for R^2 , 0.71 for NSE, 0.54 for RSR and -5.9 % for PBIAS. The values of all statistical indicators fall in the range of good model performance in accordance with Moriasi *et al.* (2007) recommendations. Likewise, the model was evaluated for the performance of the validation period. The computed statistical indicators range from 0.71 for R^2 , 0.71 for NSE, 0.55 for RSR -15.9 for PBIAS. Similar to the calibration period, the model performance rating was evaluated in terms of Moriasi *et al.* (2007) model performance evaluation criteria and was found to be a good performing model.

4.3.4 Evaluation of the sediment yield calibration and validation

The performance of the model for the sediment yield modeling differs for the calibration and the validation periods. Therefore, the following discussion of then results is separately made for both periods. The performance of the results of the model has been evaluated in a similar way as for the stream flow. The computed statistical indicators range from 0.67 for R^2 , 0.66 for NSE, 0.59 for RSR and 4.3 for PBIAS at the station during the calibration periods. The indicators have been found to be within the range of a good performance level. Similarly, for the validation period, the computed statistical indicators have been computed as 0.66 for R^2 , 0.65 for NSE, and 0.53 for RSR and 9.8 for PBIAS. These values of the statistical indicators are in the good performance range. As the indicator results are predominantly in the range of good model rating, the overall model calibration and validation result can be rated as good model performance.

Generally as observed during the model calibration and validation for stream flow and sediment yield, different ranges of the model performance can be recognized. The model performance was good for both flow and sediment. Therefore, it can be noted that the more reliable and relatively accurate the input data for model calibration is, the better is the model performance.

Table 4-6: Summary of simulated and observed sediment load of the Upper awash watershed.

Year	Summary of Upper awash watershed sediment load	
	Observed sediment in (ton/year)	Simulated sediment in (ton/year)
1997	166122.14	175263.83
1998	108725.83	187927.50
1999	74619.98	76770.08
2000	99493.29	75619.87
2001	123036.40	92870.08
2002	78432.94	84032.29
2003	122777.91	67293.67
Total sediment load in ton/year	110458.4	108539.6
Watershed area in km ²	11073	

The total observed and simulated sediment yield (load) from upper awash sub-catchment during the period from 1997 to 2003 was 110458.4 tons/year and 108539.6 tons/year respectively

Table 4-7: Annual Sediment Load of Upstream Koka Sub Basin (Awash basin sedimentation modelling project, June 2017).

Upstream Koka Sub Basin	Annual Sediment Load (Met Tone/Month)
Akaki	11,527.73
Kunture	493,555.92
Hombole	54,108.07
Modjo	5,976.41
Upstream Koka	11,5447.69

Therefore the annual average sediment load which was estimated by (Awash basin sedimentation modelling project, on 2017), for upper awash catchment is about 8,167,390 ton/month and the annual monthly sediment load that I was estimate is about 5,167,769.1ton/month or 0.04667ton/ha/month. Certain difference was observed on estimated sediment yield because the basin analysis was based on disintegrating the upper awash into five subbasins, for this reason there was value overlapping and also river sedimentation may be take place throughout the river length.

Table 4-8: average monthly basin values.

Month	Rain (MM)	Surf Q (MM)	Lat Q (MM)	Water Yield (MM)	ET (MM)	Sed Yield (T/HA)	PET (MM)
January	13.11	0.85	0.33	2.91	14.59	0.01	66.53
February	25.30	3.43	0.82	5.12	18.97	0.05	81.66
March	49.73	7.80	1.81	10.31	40.66	0.11	112.03
April	54.08	5.33	2.05	8.69	73.94	0.03	121.87
May	50.93	3.61	1.80	6.98	68.89	0.02	136.32
June	87.07	6.27	3.29	10.49	40.27	0.02	114.00
July	183.07	28.87	10.49	41.71	52.18	0.11	96.59
August	165.77	28.07	10.94	48.02	51.69	0.11	91.90
September	87.32	12.00	5.45	30.42	44.43	0.06	91.67
October	26.72	3.65	1.56	16.26	28.96	0.02	91.31
November	13.86	1.17	0.61	8.43	17.69	0.01	69.71
December	11.73	0.76	0.33	4.79	14.84	0.01	62.45

The model result can be a basis for further analysis or can be used as a guideline for sediment management at watershed scale.

4.4 Mitigation Measures

4.4.1 Effects of Land Use Change on Runoff and Sediment Yields

4.4.2 Scenario development

The advantage of the SWAT model is the ability to build different scenarios. LULC scenarios enable the modeling of flow and sediment movement in relation to sets of developed scenarios. Land change models were firstly used to develop land use change to ensure these were realistic scenarios and characterize LULC dynamics. The transition from one land use type to another type is summarized as:

- The forest area reduction is due to an increase in agriculture area.
- The increase in agriculture area is due to an increase in population size.
- The increase in urban area is affected by the number of industries and due to different city infrastructures

As upper Awash is in the central part of the country the area is exposed to different socio-economic factors. The area is dominated by forest area reduction, increases of agriculture, an expected population increase and a number of industries expansion since the area is near to the capital city of the country. Therefore this is the critical situation for the land transformation.

LULC scenarios simulated were time-dependent hence were not meant to predict future land use, but rather to aid spatial planning of future land use for sustainable management of land and water resources. The scenarios were developed using simplified consistent set of assumptions based on biophysical parameters and socio-economic factors driving land use change in the study area.

The scenario analyses were performed considering one variable at a time and keeping other values constant. These scenarios are based on the field experience and the actual existence of the land use type change that most of the agricultural land is occurring while the existing forest type is being transformed to agricultural land use type. The baseline scenario was selected on the basis of the results obtained from the analysis of input data.

The land use change scenarios included:

- Scenario A: Base scenario (land use of 2005).
- Scenario B: Conversion of (10%) of agricultural land to forest land
- Scenario C: Conversion of (10%) of agricultural land to grass land.

- Scenario D: Conversion of (10%) of agricultural land to pasture land.
- Scenario E: Conversion of (10%) of each agricultural land to shrub and bush land.
- Scenario F: Conversion of (15%) of each agricultural land to cropland /savana / bush land/ mossic land.

Complete foresting the cultivated and Agricultural fields is impractical and impossible for many reasons. In the scenario B,C,D,E the 10% Agricultural land was converted to each forest,grass, pasture and shrub bush land. Scenario F: Conversion of (15%) of each agricultural land to cropland /savana / bush land mossic land and it gives an 7.95% sediment value reduction more than the other scenarios with keeping the original land use characteristics. In practical sense some degraded areas around the watershed have been converted and used for Eucalyptus planting. This shows that the areas have been already changing the degraded agricultural fields on the upstream watershed. Thus, this scenario was established by replacing the Agricultural fields to the Forest and cropland /savana / bush land mossic land of the entire upper Awash watershed.

The first Scenario A (Figure 4.13), is the land use map of the study area for the year 2005; that is 92,614,572ha (83.64%) was agricultural land, 1,118,373ha (1.07%) was forest land, 9,500,634 ha (8.51%) was grass/pasture land, 1,683,096 ha (1.52%) was shrub and bush land, and the remaining 5,813,325 ha (5.25%) was under Residential and water body. In Scenario B, 10% of Agricultural land was converted to forest land and other land uses did not change; therefore, forest land rised to 12,191,373 ha (10.5%) and agricultural land dropped to 81,541,572 ha (73.64%). In Scenario C, 10% of agricultural land was converted to grass land, which resulted in grass land area that rose to 18159720 ha (12.47%) and agricultural land to drop to 81,541,572 ha (73.64%). In Scenario D, 10% of agricultural land was converted to pasture land. Hence pasture land increased to 13,398,330 ha (11.15%) and agricultural land reduced to 81,541,572 ha (73.64%). In Scenario E, 10% of each of agricultural lands was simultaneously converted to shrub and bush land. As the result, the area under shrub and bush land increased to 12,756,096 ha (12.37%) and that of agricultural lands decreased to 81,541,572 ha (73.64%). In Scenario F, 15% of of each agricultural land converted to cropland /savana / bush/ mossic land simultaneously. As the result, the area under agricultural land decrease to 75,960,780 ha (68.60%) and that of cropland /savana / bush/ mossic land increased to 23,696,220 ha.

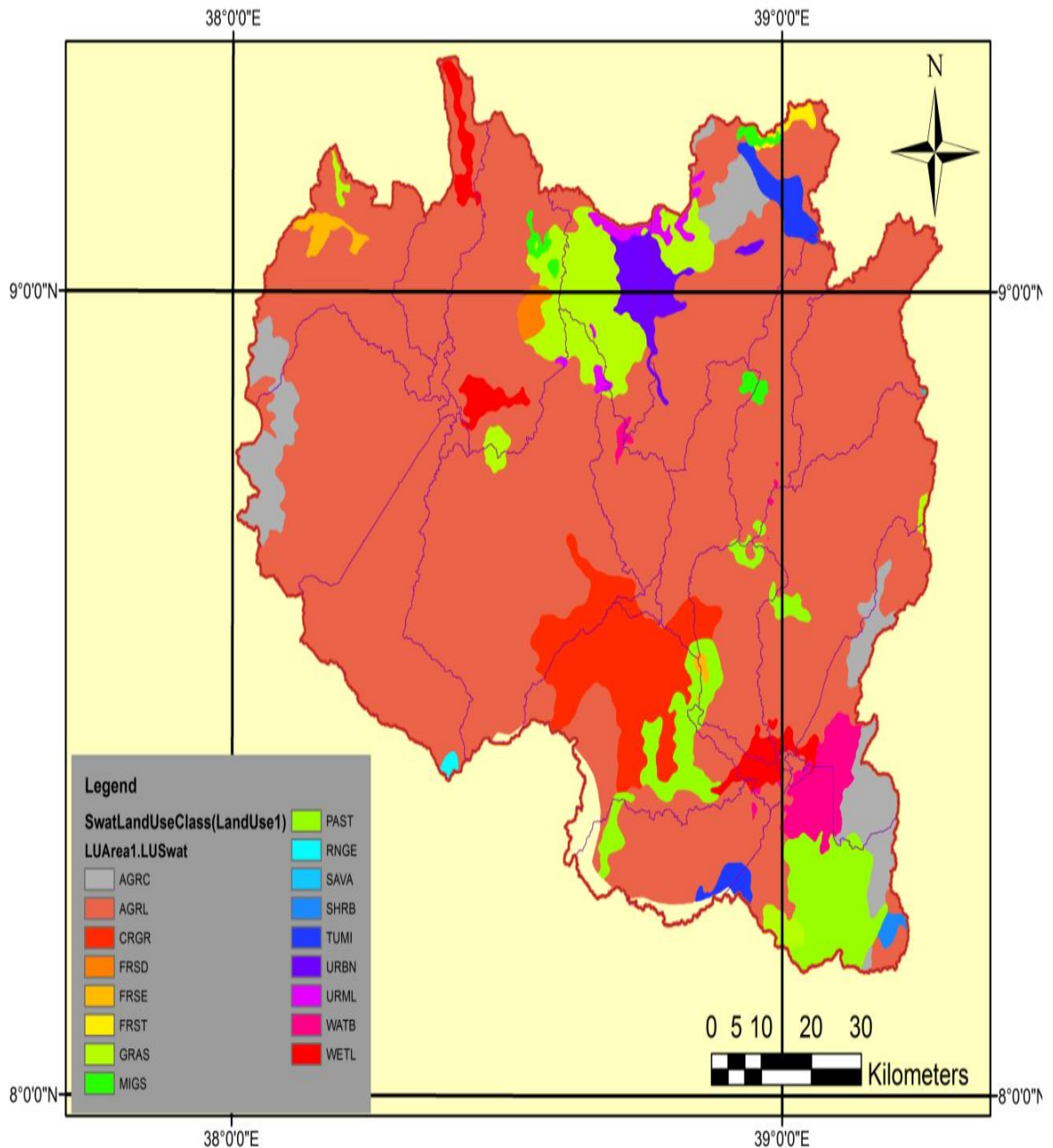


Figure 4-13: Land use land cover of the study area for base scenario (Scenario A).

4.4.3 Runoff

In order to evaluate the effect of land use/cover changes on the hydrological responses of the study watershed, the calibrated model was run to simulate runoff and sediment yields under various land use scenarios. The simulated runoff volumes under various land use scenarios are presented in Table 4.7. Simulation results under various land use scenarios showed that runoff volumes decreased by 7.121672mm (0.29%), 7.13185mm (0.15%), 7.127931mm (0.21%), and 7.12201mm (0.29%) and 7.1368 (0.08%) respectively.

Table 4-9: Average monthly-simulated runoff volumes under various land use scenarios.

Land use scenario	Run off (mm)	Difference	Change (%)
Scenario A	7.142643	-	-
Scenario B	7.121672	0.0209	0.29
Scenario C	7.131848	0.0108	0.15
Scenario D	7.127931	0.0147	0.21
Scenario E	7.12201	0.0206	0.29
Scenario F	7.13680	0.0058	0.08

4.4.4 Sediment yield

Sediment yield is the amount of overland soil loss due to erosion in the watershed. It reflects the integrated response of sediment generation processes and stream processes at watershed scale. The simulated sediment yields under various land use scenarios are presented in Table 4.9. Simulation results indicated that the sediment yields decreased by 0.002 t/ha (0.5%), 0.0099 t/ha (2.47%), and 0.0046 t/ha (1.15%), 0.0095 t/ha (2.37%), and 0.0318 t/ha (7.95%) respectively.

Table 4-10: Average monthly-simulated sediment yields under various land use scenarios

Land use scenario	Sediment yield (t/ha)	Difference	Change (%)
Scenario A	0.400377	-	-
Scenario B	0.398748	0.002	0.5
Scenario C	0.390404	0.0099	2.47
Scenario D	0.395749	0.0046	1.15
Scenario E	0.390911	0.0095	2.37
Scenario F	0.368559	0.0318	7.95

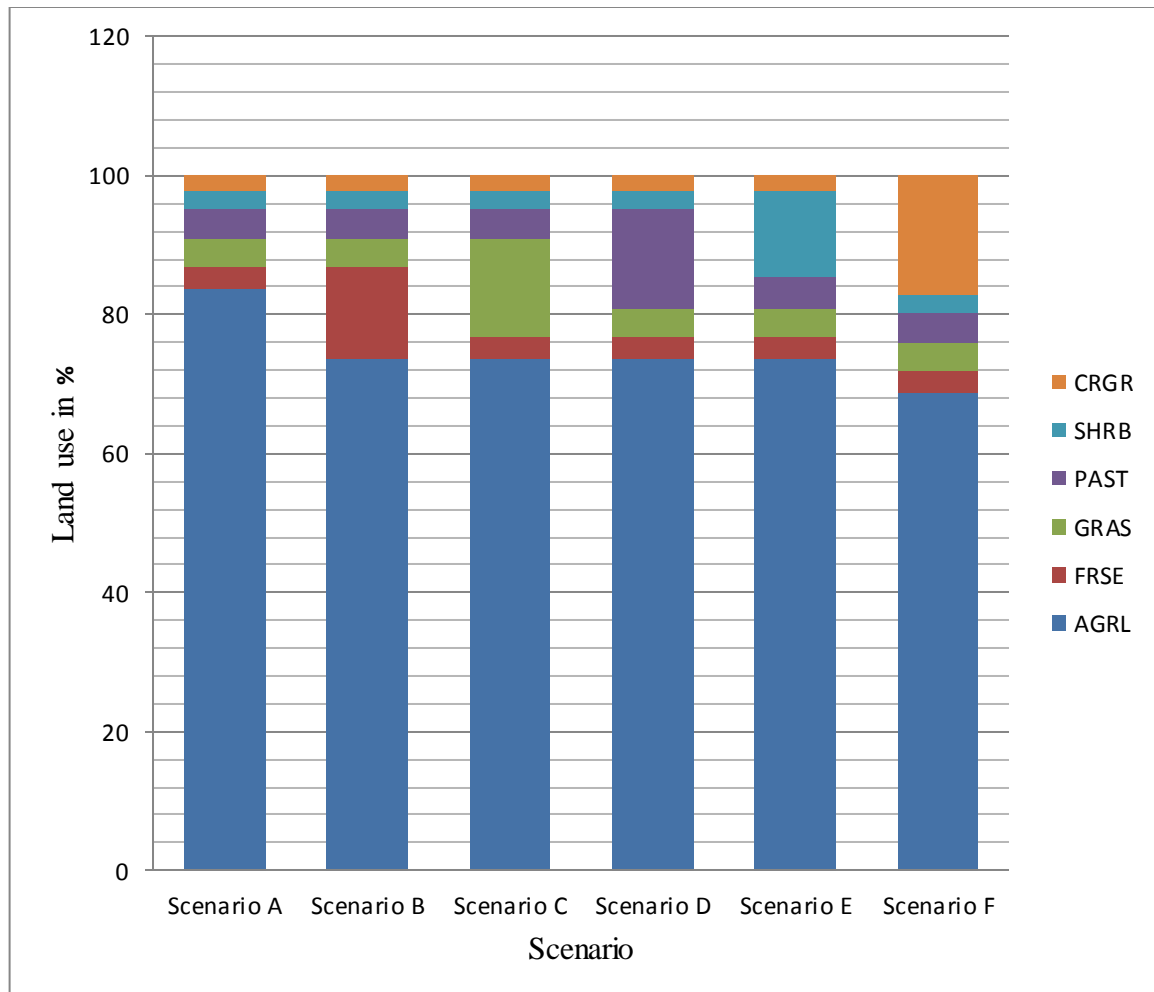


Figure 4-14: The resulting land use land cover change scenarios coverage area (km²) and percentage.

Generally the volumes of runoff and sediment yield that would be generated in any catchment increase with the reduction in the cover area and increases the cover area of the catchment reduce the volume of runoff and sediment yield.

4.4.5 Sediment management and scenario development

As hydrologic responses of a watershed are influenced by the type and degree of land use/cover conditions, the strongest relative impact of land use change can be observed for yields generated. For example under scenario B (when 10% of agricultural lands are converted to forestland), runoff and sediment yields decreased from 7.142643 to 7.121672 mm and from 0.400377 to 0.398748 t/ha, respectively. Similarly under scenario F (when 15% of each agricultural land converted to cropland /savana / bush land/ mossic land, runoff in Table 4.7 and sediment yields in Table 4.8 decreased from 7.142643 to 7.1368 mm and from 0.400377 to 0.368559 t/ha, respectively.

Because the soils of agricultural lands are bare and easily susceptible to erosion when repeatedly tilled and left without a protective cover, they are less protected against raindrop impact shortly after sowing, when the plants do not cover the soil completely and thus runoff rate and transportation of soil particles increased. Such condition will cause significant soil erosion and sedimentation. Therefore, the occasion that is happen under scenario F was the relative denser cropland /savanna /bush land than base scenario. It showed that hydrologic responses are an indicator of watershed conditions, and any change in land use/cover can affect the overall health and condition of the watershed.

4.4.6 Watershed management and soil conservation

The pretension of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system and to reservoirs. Conservation measures applied to these areas result in a significant reduction in sediment input to the reservoir. These measures include practices such as contour farming and terracing; strip cropping, crop rotation, no-till farming, grassed drainage ways, gully erosion control, and stabilization of critical areas by their return to grasslands or forests. Conservation measures take years to implement.

Among the problems involved in instituting such measures are the relative costs of various measures to farmers, and the need for farmers to make significant changes in their usual style of farming. The efficiency of watershed management in reducing sediment inflow to the reservoir varies from a low of 5% to a high of 40% (Bruk, 1985). More specifically three different soil conservation methods were examined. Use vegetative contour strip, consisting of grass or other permanent vegetation in a contoured field to help trap sediment and nutrients. Because the buffer strips are established following the contours, runoff flows slower and evenly across the grass strip, reducing sheet and rill erosion. Permanent vegetative contour strips are in fact an inexpensive substitute for terraces.

Overall combination of mechanical and agronomic land management strategies such as planting of trees and grass strips, waterways, contour ploughing and agroforestry would be suitable for these sites to reduce soil erosion, reduce environmental damage, pre-serve the fertility of the soil and maximize the productivity level of the watershed.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The findings show that this hydrological model is a useful tool to successfully estimate sediment yield and the contribution of land use land cover change on sediment yield and management practices on runoff and sediment yields with watershed area .

During calibration and validation, SWAT model adequately predicted runoff and sediment yields with coefficient of determinations (R^2) ranging from 0.71 to 0.67 for calibration and 0.71 to 0.66 for validation and Nash Sutcliffe Efficiencies (ENS) ranging from 0.71 to 0.66 for calibration and 0.70 to 0.65 for validation and Percent Bias (PBIAS) ranging from -5.7 to 4.3 for calibration and -15.9 and 9.8 for validation.

The geomorphologic and hydrologic parameters of a watershed are the fundamental factors governing its sediment delivery. Average watershed area and average slope as geomorphologic factors and stream flow and peak surface flow as hydrologic factors have been identified as the major parameters governing sediment yield in the Upper Awash basin. Generally, the area of the catchment is 11073 km² and SWAT classifies the basin into 27 sub-basins and 743 HRU with in providing slope classification. The estimated sediment load and surface runoff at the outlet of the catchment is about 5,167,769.10 ton/month or 0.04667 ton/ha/month and 101.83mm respectively.

Soil loss is different in different land use/land cover types, sub basins and slope classes. Agricultural areas (crop lands) have very high soil erosion followed by grazing lands and bush lands, respectively.

Simulation of various land use scenarios also evidently indicated that average monthly sediment yields decreased when agricultural land converted by 10% to forest, grass land, pasture land, shrub lands and 15% cropland /savana /bush land/ mossic respectively. A 7.95% sediment yield reduction result was observed when 15% of agricultural land were converted to cropland /savana/bush land/ mossic simultaneously.

5.2 Recommendations

- This study has vividly demonstrated that the SWAT model can be considered as a useful tool for simulating the hydrological processes of a watershed and modeling the impacts of land use change and management practices on runoff and sediment yields; and thus, can be further extended for simulating other hydrological processes such as annual water yield, base flows, and stream flows under various scenarios.
- As the SWAT model is capable of simulating the hydrological processes in a watershed, it can be further extended to similar watersheds in the country, particularly in the larger river Basin of Ethiopia, where quantifying the total volume of runoff and sediment yields generated from the basin is urgently required for better land and water resources planning and management purposes.
- The simulated effects of the conversion of forest, grazing, and shrub lands to agricultural land clearly indicated an alarming situation under all the land use scenarios in general and under scenario F in particular. Therefore, I recommend that policies addressing this issue should be formulated both at the local and national level. Parallel to this, an intensive information and educational campaign about the consequences of expansion of croplands on the expenses of forest, grazing, and shrub lands and ways of rehabilitating the watershed should be done. Finally, alternative livelihood opportunities for farmers living surrounding the Upper Awash catchment, and those living on the steep and mountainous areas within the watershed should be considered in policy implementation.
- As land development is a continuous process, for the optimum use of the land and water resources of the area, it is recommended that soil and water conservation such as construction of various terraces, water ways, rehabilitation of degraded areas, and land management practices such as crop residuals, contour tillage, strip cropping on the contour etc should be considered.

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APPENDIX

Appedex Table 1: flow and sediment of sub basin for 27 years from the model.

Year	Rainfall (mm)	Surface flow (mm)	Lateral flow (mm)	Base flow (mm)	Perco. (mm)	Soil water (mm)	Actual ET (mm)	Poten ET (mm)	Water yield (mm)	Sediment yield (t/ha)
1989	787.51	82.5	36.96	0.00	115.17	136.33	560.95	1251.09	125.43	0.59
1990	866.38	94.9	42.68	0.00	152.51	132.44	589.73	1256.10	144.90	0.87
1991	585.81	49.7	21.79	0.82	80.25	101.25	480.64	1263.84	77.41	0.33
1992	607.42	48.6	26.87	6.32	78.86	95.17	469.27	1256.89	85.62	0.37
1993	646.70	54.7	25.76	8.17	81.62	104.98	486.31	1246.61	92.75	0.37
1994	661.46	51.3	30.85	6.64	78.24	128.23	491.66	1280.38	92.71	0.38
1995	620.88	45.5	24.24	4.96	61.44	122.19	514.07	1285.03	78.07	0.16
1996	833.33	107.9	40.76	6.36	197.40	111.32	514.98	1223.39	162.99	0.27
1997	612.60	67.2	25.52	4.57	75.14	120.38	456.25	1320.43	102.57	0.16
1998	936.02	154.7	55.25	11.9	272.24	143.78	440.51	1036.72	232.40	0.67
1999	791.23	136.8	47.82	13.9	222.68	143.11	395.32	1050.93	210.29	0.78
2000	776.48	99.8	45.52	10.7	205.60	150.60	430.34	1126.32	166.57	0.42
2001	803.30	121.6	46.78	10.1	230.92	135.27	431.57	1042.96	190.69	0.60
2002	658.35	86.2	34.76	6.1	143.46	150.67	395.74	1084.42	135.11	0.33
2003	828.66	138.1	49.81	13.2	238.46	144.98	418.11	1027.51	211.52	0.87
2004	747.90	109.7	42.49	13.9	199.66	147.84	404.05	988.55	176.42	0.49
2005	830.14	144.1	48.12	66.9	227.90	141.08	423.37	1007.61	270.63	0.99
2006	855.54	155.5	49.45	63.9	227.31	147.61	428.08	980.84	280.07	0.73
2007	816.36	115.5	48.39	79.8	218.02	138.64	453.32	1084.73	254.64	0.56
2008	815.09	113.9	47.78	150.4	245.21	151.84	405.16	1044.71	323.18	0.44
2009	684.48	80.3	36.56	77.12	142.53	153.29	437.25	1064.48	203.00	0.90

2010	1030.7	164.4	55.69	187.1	314.55	180.44	478.05	924.65	420.89	0.70
2011	871.89	134.6	46.59	96.22	237.18	180.35	469.05	1003.97	288.49	0.57
2012	970.07	146.2	49.43	164.5	273.00	174.13	517.56	1026.96	375.09	0.65
2013	860.53	117.5	36.39	89.73	163.98	165.69	561.88	1283.64	253.25	0.55
2014	692.92	77.3	28.96	51.14	104.79	141.90	516.43	1296.01	163.49	0.72
2015	568.05	50.7	20.52	48.31	84.66	122.59	446.39	1231.88	124.32	0.26

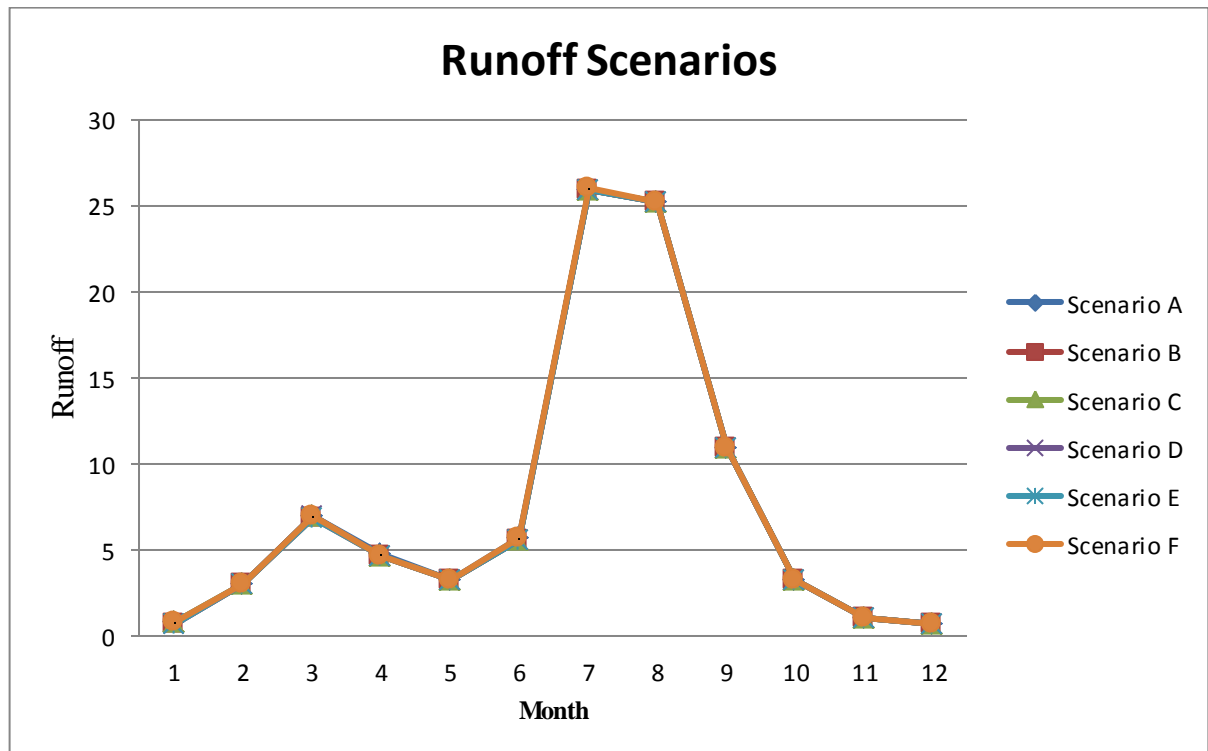
Appendix Table 3: Average monthly stream flow out put at each scenario.

Month	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F
January	0.74	0.73	0.74	0.73	0.73	0.74
February	3.02	3.02	3.02	3.02	3.02	3.03
March	6.92	6.89	6.9	6.9	6.89	6.9
April	4.69	4.67	4.68	4.67	4.67	4.67
May	3.24	3.22	3.23	3.22	3.22	3.21
June	5.63	5.61	5.61	5.61	5.6	5.62
July	25.93	25.85	25.89	25.88	25.85	25.95
August	25.23	25.14	25.19	25.18	25.15	25.22
September	10.92	10.87	10.89	10.89	10.87	10.9
October	3.29	3.28	3.29	3.28	3.28	3.29
November	1.05	1.04	1.05	1.04	1.04	1.05
December	0.64	0.64	0.64	0.64	0.64	0.64

Appendix Table 4: Average monthly Sediment yield out put at each scenario.

Month	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F
January	0.13	0.12	0.12	0.12	0.12	0.12
February	0.11	0.11	0.11	0.11	0.1	0.11
March	0.17	0.17	0.16	0.16	0.16	0.16
April	0.19	0.19	0.19	0.19	0.19	0.19
May	0.19	0.18	0.18	0.18	0.18	0.18
June	0.22	0.21	0.201	0.21	0.21	0.21
July	1.14	1.1	1.1	1.1	1.1	1.07
August	1.24	1.2	1.2	1.2	1.2	1.18
September	0.67	0.65	0.65	0.65	0.65	0.64
October	0.29	0.29	0.29	0.29	0.29	0.29
November	0.08	0.08	0.08	0.08	0.08	0.08
December	0.09	0.08	0.08	0.08	0.08	0.08

Appendix Figure 1: Simulated Average Monthly Runoff Volumes Under Various Land Use Scenarios.



Appendix Figure 2: Simulated Average Monthly Sediment Yields Under Various Land Use Scenarios.

