

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



**MEGECH DAM RESERVOIR SEDIMENT ESTIMATION
USING SWAT MODEL**

**A Thesis Submitted to the School of Graduate Studies of Addis
Ababa University in Partial Fulfillment of the Degree of Master of
Science in Civil & Environmental Engineering**

(Major in Hydraulic Engineering)

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Approval by Board of Examiners

Chairman (department of graduate committee)

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Advisor

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ABSTRACT

Erosion is a major watershed problem causing significant loss of soil fertility and productivity. Increased sediment loads that shorten the useful life of the reservoir, the lives of other water related structures, and increase the cost of maintenance and sediment remediation are off-site impacts of erosion. The main objective of this study is to predict the sediment yield to Megech dam reservoir. In this study Soil and Water Assessment Tool (SWAT 2012) having an interface with ArcView GIS software was used to estimate sediment yield and identify spatial distribution of sediment yield in the watershed. The hydro-meteorological data were collected from the nearby stations and the quality of those data was checked. Weather generator was also created to fill-in missing gaps and generates climate data. The detail land use data was updated by the current land use/cover data and the soil map were used as per FAO classification. The SWAT model is calibrated and validated at the Azezo gauging station. Flow calibration gives coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (ENS) 0.8 and 0.74 respectively and validation test gives R^2 and ENS 0.87 and 0.86. Sediment calibration gives R^2 and ENS 0.97 and 0.98 respectively and validation test gives R^2 and ENS 0.97 and 0.97 respectively. This indicated that the observed values show good agreement with simulated value for both flow and sediment yield. The model prediction result shown that the annual sediment yield leaving the watershed was found to be 13.48 ton/ha/Yr. This result is within the sediment yield estimates given by the studies in the basin such as BCEOM (1999), USBR (1964) and studio Pietrangeli (2005), which is in the range of 12 ton/ha/Yr to 16 ton/ha/Yr. This study also shows that 47% of the watershed has high erosion potential and this is a real threat of reducing the operational life of the dam due to decreasing its active storage. Management and conservation practices are recommended to be applied for the sub-basin with high quantities of erosion and sediment yield.

Key Words: Sedimentation, SWAT model, Megech Dam Reservoir

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LIST OF ACRONYMS

AGRC	SWAT	land use/land cover Classification for Agricultural land
ANSWERS		Areal Non-Point Source Watershed Environmental Response
AVSWAT		ArcView Soil Water Assessment Tools
BCEOM		French Engineering Consultants
BCM		Billion Cubic Meter
CN		Curve Number
Cn2		Moisture Condition Curve Number
DEM		Digital Elevation Model
EPIC		Erosion/Productivity Impact Calculator Service
ESCO		Soil Evaporation Compensation factor
FAO		Food and Agriculture Organization
GIS		Geographic Information System
GPS		Global Position System
HRU		Hydrologic Response Unit
ISO		International Standards Organization
ISRIC		International Soil Reference and Information Center
masl		Mean at sea level
MoARD		Ministry of Agriculture and Rural Development
MoWE		Ministry of Water and Energy
MRS		Mean Relative Sensitivity
MUSLE		Modified Universal Soil Loss Equation
NMSA		National Metrological Service Agency
NSE		Nash-Sutcliffe Efficiency
Obs		Observed
PET		Potential Evapotranspiration
RUSLE		Revised Universal Soil Loss Equation
SCS		Soil Conservation Service
Sim		Simulated
SWAT		Soil Water Assessment Tools
USDA		United States Department of Agriculture
USDA-ARS		United States Department of Agriculture – Agriculture Research
USDA-SCS		United States Department of Agriculture Soil Conservation Service

USLE	Universal Soil Loss Equation
WHAT	Web-based Hydrograph Analysis Tool
WWDSE	Water Works Design and Supervision Enterprise
WXGEN	Weather Generator
WXPARM	Weather Parameter Calculator Program

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Soil erosion is the removal of surface material by wind and water. It is one of the normal aspects of landscape development. Soil erosion by water is caused by detachment and transport action of rainfall and runoff, usually when the soil surface is left uncovered with protective vegetation. Generally, soil erosion reduces agricultural productivity due to farmland dissection or reduction and fragmentation by rills and gullies. Besides this, deposition of unwanted sediment on downstream result in loss of farmland, reservoirs, irrigation canals and other water bodies.

According to Constable (1985), soil erosion considered to be a major agricultural problem in Ethiopia, particularly in the high lands (above 1500 m.a.s.l), which constitute 43% of the total area of the country. The Ethiopian highlands contain 88% of the countries population, 67% of its livestock and over 90% of its permanently cultivated area. Because of population pressure, all possible arable lands including steep slopes up to 60% have been cultivated.

Soil erosion has a serious ecological impact that costs a nation due to both on-site and offsite damages. Three major universal impacts of erosion are reduction in productivity of crops, flood hazards, and the decrease of the life expectancy of water storage structures (EL-Swaefy and Dangler, 1982).

Sediment degrades water quality, and carries soil- adsorbed polluting chemicals. Sediment deposition in irrigation canals, stream channels, reservoirs, water conveyance structures, reduces their capacity and would require costly operation for removal (Foster, 1982).

Rainfall and runoff are the main cause of sediment yield from watershed and transport of the same to the reservoirs. When sediment enters a reservoir, the velocity and

turbulence are greatly reduced. The dense fluid-solid mixture close to the bottom of the reservoir moves slowly in the form of density current or stratified flow, which is a diffused colloidal suspension having a density slightly different from that of the main body of the reservoir water. Hence it doesn't mix readily with the reservoir water; smaller particles may be deposited near the base of the dam.

The silting of dam reservoirs is the most challenging problem in Ethiopia. Sedimentation adversely affects the reservoir capacity. The consequences are very complex.

The loss of storage capacity is particularly felt in connection with energy production, water supply for domestic use, industry and agriculture, and in flood control. Sedimentation also affects the surface area of reservoir by reducing water depth and favoring development of aquatic growth, bottom outlets, gates and valves. These problems could be seen in different regions of the nation. Many dams constructed to store water for irrigation and/or drinking purposes are being silted up while they were under construction.

Many reservoirs are suffering from excessive sedimentation often due to the fact that either the upstream sediment supply was never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data. Change in sediment yield due to changed land use in the upstream catchments causes detrimental sedimentation. A systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects. Although empirical formulas are adopted, which simply simulates rainfall runoff relationship which is developed in other similar agro climatic zone; there is a great uncertainty on the estimations because it does not consider complex interaction that takes place in the watershed. Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use

practices, a hydrologic cycle is a complex system. As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes. Hence to analyze the sediment yield of Megech dam watershed with respect to quantity and quality of runoff is essential for the proper and sustainable utilization of Megech dam Irrigation Project. A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource. If these are not investigated the life of Megech dam reservoir is shortened by sedimentation. The main intention of this thesis is to estimate the sediment load at Megech Dam. Generally, this study can be achieved through the integration of Remote Sensing, Geographic Information System (GIS) and Soil and Water Assessment Tool (SWAT model).

1.2 Statement of the Problem

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard in worldwide (Eckhardt et al, 2001). Specially, accelerated erosion due to human-induced environmental alterations at global scale is causing extravagant increase of geomorphic process activity and sediment fluxes in many parts of the world (Turner et al, 1990).

The Lake Tana basin is densely populated with a total population of about two million (Surur, 2010). Megech watershed, which is one of the sub watersheds of Lake Tana basin, is also densely populated according to CSA (central statistics authority). This causes various effects on resource bases like deforestation, expansion of residential area, and agricultural land. Many farmers in Ethiopian highlands cultivate sloped or hilly land, causing topsoil to be washed away during the torrential rains of the rainy season. The rains also leach much of the fertile soils from the highland. The watershed is also facing high erosion by the effects of intense rainfall of the watershed which aggravates the land cover change of the watershed.

Megech Dam is found at the outlet of Megech Watershed and currently this dam is under construction. Many reservoirs are suffering from excessive sedimentation often

due to the fact that either the upstream sediment supply was never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data. Change in sediment yield due to changed land use in the upstream catchments causes detrimental sedimentation. A systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects. Although empirical formulas are adopted, which simply simulates rainfall runoff relationship which is developed in other similar agro climatic zone; there is a great uncertainty on the estimations because it does not consider complex interaction that takes place in the watershed. Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes. Hence to analyze the sediment yield of Megech dam watershed with respect to quantity and quality of runoff is essential for the proper and sustainable utilization of Megech dam Irrigation Project. A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource. If these are not investigated the life of Megech dam reservoir is shortened by sedimentation. Therefore, the main intention of this thesis is to estimate the sediment load at Megech Dam.

1.3 Objective of the Research

1.3.1 General Objective

To estimate the sediment inflow at inlet to Megech dam reservoir using SWAT model.

1.4 Specific Objective

- To appropriately develop the spatial and temporal database for SWAT modeling of the Megech watershed

- To assess and evaluate the spatial variability of sediment yield in the watershed
- To forecast the sediment yield of each sub catchment
- To identify hot spot areas for site specific management intervention

1.5 Thesis structure

The thesis is organized in five chapters: Chapter 1 provides brief introduction about sediment yield and effect in the water resources utilization, about the problem that initializes this study, the objective of the study and the structure of the thesis. Chapter two describes the reviewed literature related to the study on the concept of sedimentation, hydrological models and overview of the SWAT model. Chapter three gives detail description of Megech Watershade, topography of the basin, the climate, hydrology, and soil and land use type of the watershed were well described and deals with the methodology adopted for the study. In Chapter four the main part of research study, data analysis and model simulations, model calibration and validation and results are presented in this chapter. Finally, Chapter five presents conclusion and recommendations based on the results of the models and the data used for this study. In addition to this References and Appendixes are attached at the end.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Erosion and Sedimentation

Soil erosion, soil loss, and sediment yield are terms with distinct meanings in soil erosion processes. Soil erosion is the gross amount of soil moved by drop detachment or runoff. Soil loss is the soil moved off a particular slope or field. Sediment yield is the soil loss delivered to a point under evaluation.

The process of soil erosion involves detachment, transport and subsequent deposition (Meyer & Wischmeier, 1969). Sediment is detached from soil surface both by the raindrop impact and the shearing force of flowing water. The detached sediment is transported down slope primarily by flowing water, although there is a small amount of down slope transport by rain drop splash also.

Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. However, if transport capacity is less than the amount of eroded soil material available, then the amount of sediment exceeding the transport capacity gets deposited (Meyer & Wischmeier, 1969).

A basin sediment yield refers to the amount of sediment exported by a basin over a period of time which is also the amount that will enter a reservoir located at the downstream limit of the basin (Morris & Fan, 2009).

The sediment yield from any drainage system is calculated by averaging the data collected over a period of years. It is, therefore, an average of the results of many different hydrologic events. The sediment yield for each storm or flood will vary, depending on the character of the storm event and the resulting hydrologic character of the floods. High-intensity storms may produce sediment yields above the normal, whereas an equal amount of precipitation occurring over a longer period of time may

yield relatively little sediment. During short spans of time (days or years), sediment yields may fluctuate greatly because of natural or man-induced accidents. Collecting sediment flow data over a decade and periodic reservoir survey information are some resources demanding methods for estimating sediment yield rates at a catchment level (Silva et al, 2007). Others have also cautioned that long term sediment monitoring of suspended sediment loads does not necessarily give better results. Some workers have suggested that an excellent sediment-rating curve could be constructed from detailed sediment flow data of short period of sampling programs (Summer et al, 1992). However, (Ferguson, 1986) indicated that most of the sediment-rating curves underestimate the actual loads. Besides, other researchers such as (Bogen & Bønsnes, 2003) have cautioned that such relationships should be used on catchment where no significant landforms, land use and sediment supply source changes are expected.

Sediment yield is generally expressed in two ways: either as a volume or as a weight, or as tons. In order to adjust for very different sizes of drainage basins, the yield frequently is expressed as a volume or weight per unit area of drainage basin, as tons per square mile or per square kilometer. The conversion between the two forms of expression is made by obtaining an average weight for the sediment and calculating the total weight from the measured volume of sediment.

According to (Altunkaynak, 2009), estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. The sediment transportation monitoring requires good sample techniques which is very lengthy and costly. Therefore, it is important to develop a model that can estimate accurately the suspended sediment yield from the basin.

If the input layer contains variable(s) different from those of the output layer then the term estimation is preferred than the term forecasting. Forecasting is used as in the case of having the same variable in both input and output layers (Cigizoglu, 2006).

2.1.1 Factors Affecting Soil Erosion

Among the factors which influence soil erosion are climate, soil, topography, vegetation, management practices. The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity (Foster, 1988).

Soil erosion by water is also a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. As (Foster, 1988) put when the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport.

The erodibility of soil also affects soil erosion. It refers to the resistance of the soil to both detachment and transport by the eroding agent. (Wischmeier & Smith, 1978) defines erodibility as the specific property of soil, which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances and established a regression equation for the parameters to estimate soil erodibility (K). Soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content. According to (Foster, 1988) soil aggregate stability and infiltration rates can be affected by aggregate size and bulk density, soil texture and soil structure. High aggregate densities generally are related with high clay content and increased aggregate strength.

The other factor that contributes to soil erosion is soil sealing. Soil sealing is the formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling, or sedimentation, which is relatively impermeable

to air and water (Bergsma et al, 1996). It is due to the effect of raindrop on bare soil, which results in reduction of infiltration; and increase in runoff and the potential for the soil erosion.

Vegetation Cover and Management also have a direct link to soil erosion. Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. The canopy intercepts raindrops, and if it is close to the ground, water dripping off the leaves has much less energy than unhindered raindrops (Wischmeier & Smith, 1978). Materials in contact with the soil surface reduce erosion more effectively than a canopy. No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy. Besides, such materials slow the runoff, which increases the flow depth.

2.1.2 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster, 1988). The major forces originate from raindrop impact and flowing water. Figure 2.1 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

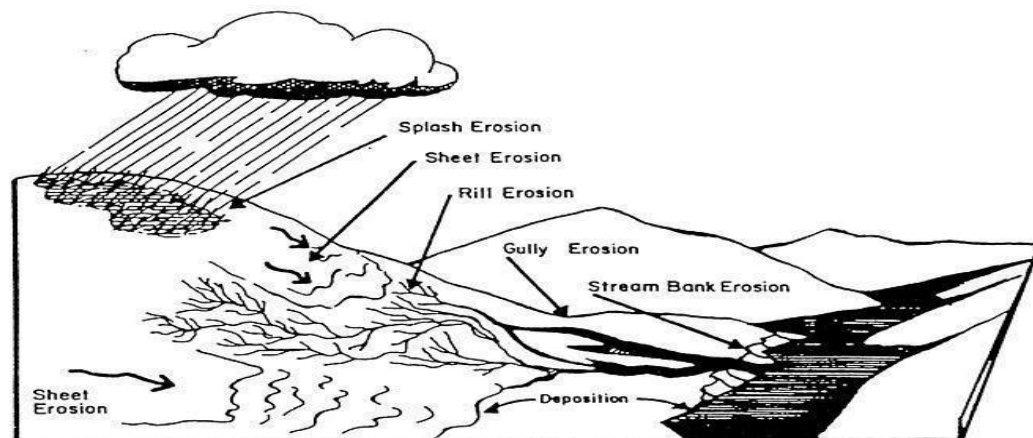


Figure 2. 1 The mechanisms of soil erosion (USACE, 1985)

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by (Wischmeier & Smith, 1978) in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots. The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley, 1989) and Unit Stream Power - based Erosion Deposition (USPED) are based on the USLE and represent an improvement of the former. In 1996, when the U.S. Department of Agriculture (USDA, 1972) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new calculation procedure to calculate the cover vegetation factor, and the revision of the length and gradient of slope.

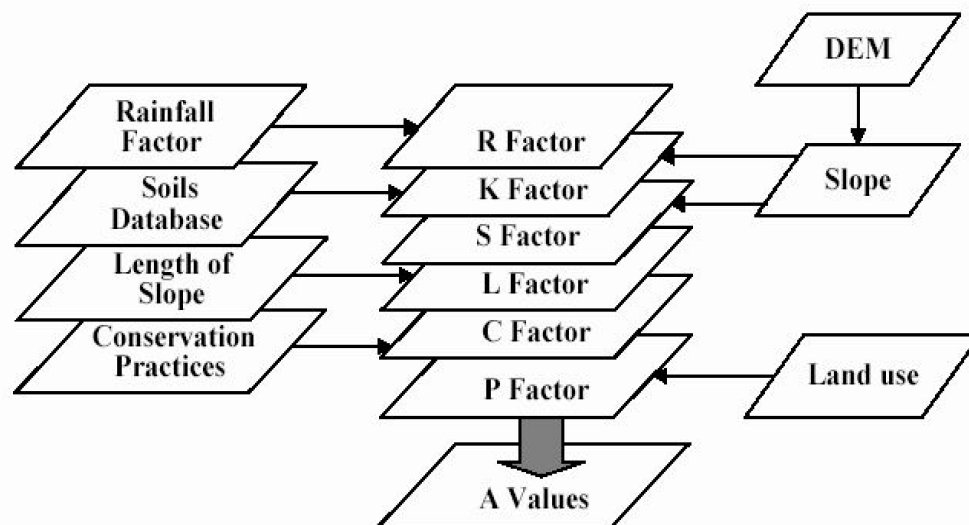


Figure 2. 2 Procedures of RUSLE implementation in GIS
(Beasley, 1989)

The use of the USLE and its derivatives is limited to the estimation of gross erosion, and lacks the capability to compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS. USDA developed the Water Erosion Prediction Project (WEPP) model (Flanagan & Nearing, 1995) to replace the USLE family of models and expand the capabilities for erosion prediction in a variety of landscapes and settings. This model is a physically based, distributed parameter, single-event simulation erosion prediction model. Processes within the model include erosion, sediment transport and deposition across the landscape and in channel via a transport equation.

2.1.3 Sediment Transport Equations

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by (Wischmeier & Smith, 1978). USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield

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

Modified Universal Soil Loss Equation (MUSLE)

The modified universal soil loss equation (Williams, 1975) is

$$\text{Sed} = 118 * (Q_{\text{surf}} * q_{\text{peak}} * A_{\text{hru}})^{0.56} * K_{\text{USLE}} * C_{\text{USLE}} * P_{\text{USLE}} * L_{\text{USLE}} * C_{\text{FRG}} \dots\dots\dots 2.1$$

Where Sed, the sediment yield on a given day in metric tons, Q_{surf} , the surface runoff from the watershed in mm/ha, Q_{peak} , the peak runoff rate in cubic meter per second, A_{hru} the area of HRU, K_{USLE} , the USLE soil erodability factor, C_{USLE} , the USLE land cover and management factor, P_{USLE} , the USLE support practice factor, L_{USLE} , the USLE topographic factor, and C_{FRG} , the coarse fragment factor.

2.2 Principles of Sediment Transport

2.2.1 General

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition, the predominant material being quartz. Once the sediment particles are detached, they may either be transported by gravity, wind or/and water. When the transporting agent is water, it is called fluvial or marine sediment transport. The process of moving and removing from their original source or resting place is called erosion. In a channel, the water flow erodes the

available material in the banks and/ or the stream bed until the flow is “loaded” with as much sediment particles as the energy of the stream will allow it to carry.

Usually, three modes of particle motion are distinguished:

- Rolling and/ or sliding particle motion
- Saltating or hopping particle motion
- Suspended particle motion

When the value of the bed-shear velocity just exceeds the critical value for initiation of motion, bed material particles will be rolling and/or sliding in continuous contact with the bed. For increasing values of the bed-shear velocity the particles will be moving along the bed by more or less regular jumps, which are called saltation.

When the value of the bed-shear velocity begins to exceed the fall velocity of the particles, the sediment particles can be lifted to a level at which the upward turbulent forces will be of comparable or higher order than the submerged weight of the particles and as a result the particles may go into suspension.

Usually, the transport of particles by rolling, sliding and saltating is called bed-load transport, while the suspended particles are transport as suspended load transport.

The suspended load may also include the fine silt particles brought into suspension from the catchment area rather than from streambed material (bed material load) and is called the wash load. A grain size of 50 μ m is frequently used to make the separation between bed material load and wash load. Sometimes a value of 63 μ m is used (USA). Another method of discrimination is given by (Bagnold, 1977). Based on energy considerations it can be shown that all particles with a fall velocity smaller than $1.6\bar{u}l$ (\bar{u} = depth-averaged velocity, l = water surface gradient) can be transported in unlimited quantities, the latter being a typical feature of wash load transport. Bed load and

suspended load may occur simultaneously, but the transition zone between both modes of transport is not well-defined.

Sediment transport by flowing water is strongly linked to surface soil erosion due to rain. Water seeping into the ground can contribute to landslides (sub surface erosion) which may become major sources of sediments for rivers.

The following classification and definitions in accordance with the ISO- standards (ISO 4363) are given

Bed material: The material, the particle sizes of which are found in appreciable quantities in that part of the bed that is affected by transport.

Bed material load: The part of the total sediment transport which consists of the bed material and which rate of movement is governed by the transport capacity of the channel.

Suspended load: The part of the total sediment transport which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water.

Bed load: The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

Wash load: That part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the bed material. It is in near-permanent suspension and, therefore, is transported through the stream without deposition. The discharge of the wash load through a reach depends only on the rate with which these particles become available.

2.2.2 Sediment Properties

Density and Porosity

The density of quartz and clay minerals is approximately equal to $\rho = 2650 \text{ kg/m}^3$. The density of carbonate material may be somewhat smaller gravity is defined as the ratio of the sediment density and the fluid density. The porosity of sediment material is often related to the deposition history of the sediment bed. Loose packing occurs when sediments settle from suspension in still water. Basically, four packing arrangements are possible for spherical particles. The most unstable arrangement is the cubic arrangement with the sphere centers forming a cube yielding a porosity of 48%. The arrangement with the spheres in the hollows of each other yields the most stable packing and the smallest porosity of 36%. Random packing of spheres yields porosity ranges from 36% to 40%.

Natural sediments with particles of various sizes have relatively small porosity values because the smaller particles can occupy the large void spaces. A poorly sorted (many sizes) coarse sand has a porosity of about 40%. Well sorted (almost uniform) fine sand has a porosity of about 45%. The porosity of coral sand (mixture of coral and shell fragments) has been found in the range from 0.5 to 0.65.

Shape

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

The shape of particles generally is represented by the Corey shape factor, defined as:

$$SF = \frac{C}{(ab)^{0.5}} \dots\dots\dots 2.2.2$$

Where a is length along longest axis perpendicular to other two axes, b is length along intermediate axis perpendicular to other two axes and c is length along short axis perpendicular to other two axes. The SF- factor for natural sand is approximately 0.7.

The shape factor is essentially a flatness ratio and does not take into account the distribution of the surface area and the volume of the particle. For example, a cube of a given length and a shape of a diameter equal to the length of the cube have the same shape factor (SF = 1).

To overcome this, another shape factor is also applied, defined as:

$$SF^* = SF \frac{ds}{dn} \dots\dots\dots 2.2.3$$

Where SF* Shape factor, ds Diameter of a shaper having the same surface area as that of the particle, dn Diameter of a sphere having the same volume as that of the particle SF* approaching unity implies increasing sphericity of the particles (sphericity is ratio of surface area of a sphere and surface area of the particle at equal volume). A behavioral measure of shape is expressed by the roll ability parameter (Winkelmolen, 1971). The roll ability is a functional shape property measured by the time it takes for grains of equal size and density to travel the length of a cylinder revolving with its axis inclined at an angle of 2.50 to the horizontal.

Size

Usually, sediments are referred to as gravel, sand, silt or clay. These terms refer to the size of the sediment particle. Various methods are available to determine the particle size. Cobbles can be measured directly with a ruler. Gravel, sand and silt are analyzed by wet or dry sieving methods yielding sieve diameters. Clay materials are analyzed hydraulically by using setting methods yielding the particle fall velocity from which the standard fall diameter is computed. Clay materials can also be analyzed with various

electronic techniques such as the Coulter counter and the Laser Diffraction technique (Van Griensven & Srinivasan, 2005).

Typical diameters are:

Sieve Diameter which is the diameter of a sphere equal to the length of the side a square sieve opening through which the given particles will just pass. Nominal Diameter which is the diameter of a sphere that has the same volume as the particle Standard Fall Diameter which is the diameter of a sphere that has a specific gravity of 2.65 and has the same fall velocity as the particle in still, distilled water of 24°C.

2.2.3 Particle Fall Velocity

Sphere Falling in a Still Fluid

Basically, the fall velocity is a behavioral property. The terminal fall velocity (W_s) of a sphere is the fall velocity when the fluid drag force on the particle is in equilibrium with the Gravitational force

$$W_s = \left(\frac{4(S-1)gd}{3 C_D} \right)^{0.5} \dots\dots\dots 2.2.4$$

Where W_s is Terminal fall velocity of a sphere in a still fluid, d is Sphere diameter, s is Specific gravity (=2.65), C_D drag coefficient and g is Acceleration of gravity.

The drag coefficient C_D is a function of the Reynolds number $Re = W_s \frac{d}{\nu}$ and shape factor in the Stokes region ($Re < 1$) the drag coefficient is given by:

$$C_D = 24 / Re, \text{ yielding: } W_s = \frac{(S-1)gd^2}{18\nu} \dots\dots\dots 2.2.5$$

Outside the Stokes region there is no simple expression for the drag coefficient. The C_D value decreases rapidly outside the Stokes region ($Re < 1$) and becomes nearly constant for $10 < RE < 10^3$ yielding was proportional to $d_{0.5}$.

The effect of temperature on the fall velocity is taken into account by the kinematic viscosity coefficient ν . The largest effect occurs for the smallest sphere diameters

Non Spherical Particles

The expressions valid for a sphere cannot be applied for a natural sediment particle because of the differences in shape. The shape effect is largest for relatively large particles ($> 300\mu\text{m}$) which deviate more from a sphere than a small particle. Experiments show differences in fall velocity of the order to 30% for SF in the range from 0.5 to 1. The terminal fall velocity of nonspherical sediment particles can be determined from the following formulae:

$$W_s = \frac{(s-1)gd^2}{18\nu} \quad \text{For } 1 < d < 100 \mu\text{m}$$

$$W_s = \frac{10\nu}{d} \left(\left(1 + \frac{0.01(s-1)gd^3}{\nu^3} \right)^{0.5} - 1 \right) \quad \text{For } 100 < d < 1000 \mu\text{m}$$

$$W_s = 1.1 (s-1)gd^{0.5} \quad \text{For } d \geq 1000 \mu\text{m}$$

Where d is sieve diameter,
 s is specific gravity (=2.65)
 ν is kinematic viscosity coefficient

The fall velocity of coral sand (particles larger than $300\mu\text{m}$) that of quartz sand (Van der Meulen 1988). The differences are mainly caused by differences in shape. Coral sand particles are more angular and have, therefore, a smaller fall velocity. The density of coral sand may also be somewhat smaller (2500 to 2650 kg/m^3).

2.2.4 Angle of Repose

The angle of (natural) repose is a behavioral property of sand particles. Grains piled up on each other have an equilibrium slope which is called the angle of natural repose (ϕ_n). This parameter appears to be a function of size, shape and porosity. The angle increases with decreasing roundness. Values from the literature are in the range of $\phi_n = 300$ to 400 for sand sizes from 0.001 to 0.01m . Observations in

nature on the avalanche less slope of desert dunes and river bed dunes also show values in the range of 300 to 400.

The angle of repose (ϕ_n) also referred to as the angle of internal friction is a characteristics angle related to the particle stability on a horizontal or sloping bed. The angle of repose (ϕ_n) may differ from the angle of natural repose (ϕ_n). Usually, the angle of repose is determined from initiation of motion experiments for horizontal and sloping beds. The critical bed-shear stress for a particle on a sloping bed can be expressed as:

$$\tau_{b,Cr} = \tau_{b,Cr,0} \frac{\sin(\phi - \beta)}{\sin \phi} \dots\dots\dots 2.2.6$$

In which $\tau_{b,Cr}$ is Critical bed-shear stress on a sloping bottom, $\tau_{b,Cr,0}$ is Critical bed-shear stress on a horizontal bottom, ϕ_n is Angle of repose and ϕ_n is Angle of (longitudinal) bottom slope. For a given β value the $\tau_{b,Cr}$ and the $\tau_{b,Cr,0}$ values can be determined from the measured variables then the above equation used to determine the angle of repose (ϕ_n).

2.3 Runoff Mechanisms

The two prevailing theories describing mechanisms of runoff (overland flow) generation are infiltration excess, or Hortonian overland flow, and saturation excess. Infiltration excess is based on the concept that runoff begins when rainfall rates exceed soil infiltration capacities (Horton 1933, 1940) assuming runoff amounts are directly controlled by factors that determine soil infiltration rate, such as land use and soil type. Hortonian overland flow is important in region, such as arid regions, where soil crusting and/or surface sealing occurs during rainstorms, and also in urban areas, where impervious surfaces cause surface runoff; it also occurs in extremely heavy intensity storms in nearly all regions. Therefore, a management perspective based on the infiltration excess concept will identify on the basis of land use and, possibly, soil type.

The second concept of runoff generation, the saturation excess theory, assumes that runoff is generated by direct precipitation on, from, saturated areas in the landscape (Dunne and Black, 1970), and that once the soils in these areas become saturated to the surface, all additional rain that falls (regardless of intensity) becomes overland flow. The extent of these saturated areas can vary with season and from storm to storm; thus, the saturation excess theory has been extended to encompass variable source area (VSA) hydrology, attributed primarily to Dunne and Black (1970) and Hewlett and Hibbert (1967).

The most common approach to predicting runoff model, such as SWAT (Arnold et al., 1993), is through the Soil Conservation Service Curve Number (SCS-CN) (USDA-SCS, 1972) method. The SCS-CN method is theoretically consistent with the infiltration excess theory (e.g., Hjelmfelt, 1980) as well as the saturation excess theory (e.g., Steenhuis et al., 1995), but is most commonly used in a way that implicitly assumes infiltration excess as the primary runoff mechanism by using land use and soil class to assign runoff potential. In contrast, methods that assume saturation excess theory use landscape and topographical factors rarely used in the SCS-CN method as indicators of runoff potential (Steve et al, 2006).

Models based on either the infiltration-excess or the saturation-excess theory can be calibrated to correctly simulate flow at the watershed outlet at a wide range of temporal scales, regardless of the true runoff generation process. To date, because of their intrinsic simplicity, runoff models that use the SCS-CN method in a manner consistent with infiltration excess theory have been the choice of land managers and regulatory agencies to predict runoff generation. These models may not be representative of the true runoff generation processes that occur at the watershed scale and may therefore incorrectly predict the locations where the runoff is generated. Accurate characterization of runoff generation is essential in biogeochemical models to correctly estimate flow and nutrient flux. The widespread commitment to models based on the SCS-CN method creates an urgent need to

incorporate saturation excess theory for use in watersheds where saturation excess hydrology dominates (Steve et al, 2006)

2.4 Hydrological Models

Modeling is defined as the process of organizing, synthesizing, and integrating component parts into a realistic representation of the prototype. (USDA, 1972) Lists the following benefits of modeling: Models help sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiments instead of conducting the experiments on the watershed itself.

Hydrological models are characterizations of the real world system. Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 1985). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungauged catchments and into the future to assess the likely impact of future hydrological changes. A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes for which the modeling is made (Beven, 1985). Stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models, it is very important to understand how the catchment responds to rainfall under different conditions.

2.4.1 Types of Hydrological Models

Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Parameters of lumped

models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan et al, 1994). Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 1985).

Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 1985). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin.

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

2.4.2 Selection of model

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always research dependent, since every project has its own specific requirements and needs. Further, some criteria are

also user-dependent (and therefore subjective). Among the various research - dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 2003):

- Required model outputs important to the research and therefore to be estimated by the model (Does the model predict the variables required by the research such as long-term sequence of flow?)
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?)
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the research?)
- Price (Does the investment appear to be worthwhile for the objectives of the research?)

Reasons for selecting SWAT model

The reasons behind for selecting SWAT model for this study are;

- The model was applied for land use and land cover change impact assessment in different parts of the world.
- The model simulates the major hydrological process in the watersheds
- It is less demanding on input data, and
- It is readily and freely available.

A major limitation to large area hydrologic modeling of SWAT is the spatial detail required to correctly simulate environmental processes. For example, it is difficult to capture the spatial variability associated with precipitation within a watershed. Another limitation is data files can be difficult to manipulate and can contain several missing records. The model simulations can only be as accurate as the input data.

2.4.3 Related Previous Works Using SWAT Model

In recent time there have been arugmentation of SWAT model application in tropical countries. Several reserchers reported in Ndomba & Birhanu (2008) have satisfactorily applied SWAT model for sediment yield modeling in poorly gauged catchments in Tanzania and the region at large. The study in Hare River basin concluded that the SWAT model satisfactorily predicted monthly and annual flows; and the model is useful to analyze the impacts of land use/land cover changes on stream flow even in basins with limited data (Tadele and Forch, 2007).

Assessment of the spatial distribution of water resources and evaluation of the impacts of different land management practices on hydrologic response and soil erosion in the upper part of the Awash River basin in Ethiopia by Chekol et al.(2007) was concluded that the SWAT model accurately tracked the measured flows and simulated well the monthly sediment yield and also the Studies by Andualem and Yonas (2008) shows that prediction of sediment inflow to Legedadi reservoir, the model performs well to predict the sediment inflow.

Setegn et al. (2010) used SWAT to simulate the sediment yield simulations for the Anjeni, a small watershed (1.35 km²) in the northern highlands of Ethiopia, using different slope classifications. And Betrie et al. (2011) used SWAT to evaluate effects of several best management scenarios (filter strips, stone bunds, and reforestation) for the upper Blue Nile basin in Ethiopia.

Betrie et al. (2011) used SWAT to evaluate effects of several best management scenarios (filter strip, stone bunds, and reforestation) for the upper Blue Nile basin in Ethiopia. The result showed a very high spatial variability for the obtained annual sediment yields, ranging from 0 to ore than 150 t ha⁻¹.

Easton et al. (2010) simulated the hydrologic balance and sediment loss for the Blue Nile watershed that lies mainly in Ethiopia using SWAT-WB, a modified SWAT model that captures variable source area hydrologic phenomena.

Setegn et al. (2009a) used SWAT to model the hydrological water balance of the Lake Tana basin in Ethiopia with the objective of testing the performance of the SWAT model for stream flow prediction. These authors calibrated and validated on four tributaries of Lake Tana using SUFI-2, GLUE and ParaSol algorithms. This paper reported that the SWAT model was more sensitive to HRU definition thresholds than to sub-basin discretization. Further, the paper reported that more than 60% of the observed river discharge falls within the 95% confidence bounds.

Gessese (2008) used the SWAT model performed to predict the Legedadi reservoir sedimentation. According to this study, the SWAT model performed well in Predicting sediment yield to the Legedadi reservoir. The study further put that the model proved to be worthwhile in capturing the process of stream flow and sediment transport of the watershed of the Legedadi reservoir. Mekonnen et al. (2009) developed a generic rainfall-runoff model better suited to Ethiopian catchments. They used a spectrum analysis method to extract the relationships between different temporal scales of available daily rainfall and runoff series that reflect the temporal and spatial scales of 25 discharges in two watersheds in Ethiopia. The paper reported that frequencies in rainfall and stream discharge longer than 50 days had a sufficient coherence to warrant model calibration.

In addition to the above, Tibebe and Bewket (2011) assessed surface runoff generation and soil erosion rates for a small watershed in the Awash River basin of Ethiopia using the SWAT model. Comparing monthly predicted runoff against the measured values, the study demonstrates that distribution of observed and simulated runoff was quite uniform throughout the simulation period. The study presents a high correlation value of 0.831. It further reports a NSE of 0.789 to demonstrate that the model was able to generate monthly runoff close to the observed.

Even though the model is data intensive, studies by Mulungu & Munishi (2007) and critical review of model applications in Nilotic catchments by Ndomba &

Birhanu (2008) have shown that high resolution of spatial data does not necessarily improve the model performance.

The literature reviewed and presented above showed that SWAT is capable of simulating hydrological and soil erosion process with reasonable accuracy and can be applied to large and complex watersheds.

2.4.4 Limitation of SWAT

The popularity of the SWAT model is largely due to the multi-disciplinary coverage of processes representing the hydrology, soil science, erosion/sediment transport, crop growth, in-stream water quality and the agricultural management. Even though SWAT contains many processes, certain processes may still not be well represented. For example, Ndomba and van Griensven (2011) indicated in their paper that certain landscape elements, such as wetlands, are not well represented in the SWAT model, while they may have a huge impact on the hydrological and nutrient cycle. One may also wonder whether the concepts behind the way the processes are represented in the SWAT model are generally applicable all over the globe. Several of these processes have an empirical background whereby the equations were derived from large data sets in the US. They used curve number approach and the USLE soil loss equations are good examples.

While SWAT is a process-based model, it intentionally incorporates simplified representations of most processes so that many parameters can be obtained from readily available geospatial coverages. For upland generation of flow and sediment, SWAT relies on the well-tested, semi-empirical approaches of the SCS Curve Number and MUSLE. The basic time step of the model is one day (although hydrology can be simulated at a finer scale using Green -Ampt infiltration); so actual flow hydrographs are not represented. The MUSLE approach is most applicable to the estimation of cumulative loads, rather than loads from individual events. It should also be noted that the default SWAT algorithm may yield unrealistic results from

HRUs that contain a mix of urban pervious and impervious land cover because MUSLE is calculated with the peak flow.

2.5 SWAT Model Development and Interface

SWAT (Arnold et al, 1998) is a semi-distributed, time continuous watershed simulator operating on a daily time step. It is developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds. The major components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The program is provided with an interface in Arc GIS (Winchell et al, 2007) for the definition of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data.

2.5.1 Theoretical Description of SWAT

The large scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further discretized into a series of hydrologic response units (HRU), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated at each HRU and then aggregated for the sub basin by a weighted average. Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. For climate, SWAT uses the data from the station nearest to the center of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method. The water in each HRU in SWAT is stored in four storage volumes: shallow soil profile (0-2m), snow shallow aquifer (typically 2-20m), and deep aquifer. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are

based on a modification of the Rational Formula (Chow et al, 1988). The watershed concentration time is estimated using Manning's formula, considering both overland and channel flow.

The soil profile is subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone. Down ward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer.

Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal to 0°C, no percolation is allowed from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation.

The model computes evaporation from soils and plants separately. Potential evapotranspiration can be modeled with the Penman-Monteith (Monteith, 1965), Priestly-Taylor or Hargreaves methods, depending on data availability. Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index, and root depth, and can be limited by soil water content. Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by (Wischmeier & Smith, 1978). The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stokes law (Chow et al, 1988) and is calculated as a function of particle diameter squared. The depth

of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold's stream power concept (Bagnold, 1977).

2.5.2 Hydrological Component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream.

Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SW_{st} = SW_0 + \sum_{i=1}^{\infty} (R_{day} - Q_{suf} - E_a - W_{seep} - Q_{gw}) \dots\dots\dots 2.5.1$$

Where: SW_{st} is final soil water content (mm H₂O), SW_0 is initial soil water content on day 1 (mm), t is time (days), R_{day} is the amount of precipitation on day i (mm H₂O), Q_{suf} is amount of surface runoff on day i (mm H₂O), W_{seep} is amount of water entering vadose zone from the soil profile on day 1 (mm H₂O), E_a amount of evapotranspiration on day 1 (mm H₂O), Q_{gw} amount of return flow in day 1 (mm H₂O).

Potential evapotranspiration

For PET estimation, SWAT provides three alternatives for its calculation:

Penman-Monteith (Monteith, 1965), Priestley-Taylor and Hargreaves methods. As an option, measured values can also be used as an input data. These methods have various needs for a number and type of climate variables: Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only.

Surface Runoff

Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. SWAT provides two methods for estimating surface runoff volume: the SCS curve number method and the Green & Ampt infiltration method (Green & Ampt, 1911). Even though the latter method is better in estimating runoff volume accurately, its subdaily time step data requirement makes it difficult to be used for this study. Hence, the SCS curve number method was adopted; and the model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types SCS curve number method (USDA-SCS, 1972) calculates the runoff as follow:

$$Q_{\text{Surf}} = \frac{(R_{\text{day}} - I_a)^2}{(R - I_a + S)} \quad \dots\dots\dots 2.5.2$$

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

$$S = 25.4 * \left(\frac{1000}{\text{CN}} - 10 \right) \quad \dots\dots\dots 2.5.3$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition. Commonly I_a is approximated by $0.2S$ and equation 2.5.2 can be rewrite as follow

$$Q_{\text{Surf}} = \frac{(R_{\text{day}} - 0.2s)^2}{(R + 0.8S)} \dots\dots\dots 2.5.4$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified into four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively.

Peak runoff rate

The peak runoff rate is an indication of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with modified rational method for each HRU as follows.

$$Q_{\text{peak}} = \frac{Q_{\text{surf}} * \sigma_{tc} * A}{t_{\text{conc}}} \dots\dots\dots 2.5.5$$

Where Q_{peak} is peak runoff rate (m³/s), α_{tc} the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm); A is the sub-basin area (km²), t_{conc} Time of concentration (hr) and 3.6 is conversion factor

SWAT estimates the value of α_{tc} by using:

$$\alpha_{tc} = 1 - \exp(-2 * t_{\text{conc}} * \ln(\alpha + \beta)) \dots\dots\dots 2.5.6$$

Where $\alpha_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall, t_{conc} is the time of concentration for the sub basin (hr).

2.5.3 Sediment Component of SWAT

SWAT computes erosion for each HRU caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE). The modified universal soil loss equation (Williams, 1975) is given by equation 2.5.7

$$\text{Sed} = 118 * (Q_{\text{surf}} * q_{\text{peak}} * A_{\text{hru}})^{0.56} * K_{\text{USLE}} * LS_{\text{USLE}} * C_{\text{USLE}} * P_{\text{USLE}} * C_{\text{FRG}} \dots\dots 2.5.7$$

Where Sed is the sediment yield on a given day in metric tons, Q_{surf} is the surface runoff from the watershed in mm/ha, q_{peak} is the peak runoff rate in cubic meter per second, A_{hru} is the area of HRU, K_{USLE} is the USLE soil erodability factor, C_{USLE} is the USLE land cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and C_{FRG} is the coarse fragment factor.

In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

Soil Erodibility Factor

Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself. (Wischmeier & Smith, 1978), define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.1m (72.6-ft) long, with a uniform length-wise slope of 9%, in continuous fallow, tilled up and down the slope. Continuous fallow is defined as land that has been tilled and kept free of vegetation for more than two years. As noted that a soil type usually becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or clay fraction.

Cover and Management Factor

The USLE cover and management factor, C_{USLE}, is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-

tilled, continuous fallow. (Wischmeier & Smith, 1978) The plant canopy affects erosion by reducing the effective rainfall energy of intercepted raindrops. Water drops falling from the canopy may regain appreciable velocity but it will be less than the terminal velocity of free-falling raindrops. The average fall height of drops from the canopy and the density of the canopy will determine the reduction in rainfall energy expended at the soil surface.

Support Practice Factor

The support practice factor, PUSLE, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip-cropping on the contour, and terrace systems. Stabilized waterways for the disposal of excess rainfall are a necessary part of each of these practices. Contour tillage and planting provides almost complete protection against erosion from storms of low to moderate intensity, but little or no protection against occasional severe storms that cause extensive break over of contoured rows. Contouring is most effective on slopes of 3 to 8 percent.

The conservation practice factor and cover & management factor for universal soil loss equation (USLE) are presented in Table 2.1, 2.2 & 2.3 for some conservation practices.

Land Slope (%)	PUSLE	Maximum Length (m)
1 to 2	06	122
3 to 5	05	91
6 to 8	05	61
9 to 12	06	37
13 to 16	07	24
17 to 20	08	18
21 to 25	09	15

Source (Wischmeier & Smith 1978)

Table 2. 1 P factor values and slope-length limits for contouring

Parameter Description	P-value
Contour Ploughing	0.9
Ploughing up and down slope	1
Applying mulch	0.6
Strip cropping	0.8
Terraces	0.6
Protected area	0.5

The parameters, which were defined for Ethiopia by (Humi 1985)

Table 2. 2 Support practice factor (P-Value) defined for Ethiopia

Parameter Description	C-value
Cover or management factor (USLE_C) (Teff)	0.25
Cover or management factor (USLE_C) (Barley & Wheat)	0.15
Cover or management factor (USLE_C) (Maize & Sorghum)	0.1
Cover or management factor (USLE_C) (Bush Shrub)	0.02
Cover (USLE_C) (Forest)	0.003
Cover or management factor (USLE_C) (Dense grass)	0.01
Cover or management factor (USLE_C) (Degraded grass)	0.05

The parameters, which were defined for Ethiopia by (Humi 1985)

Table 2. 3 Cover and management factors (C-Values) defined for Ethiopia

Sediment transport

Sediment transport in the channel network is a function of two processes, deposition and degradation; SWAT compute both of them by using the same channel dimensions for the entire simulation. The amount of sediment degradation in the channel can be calculated by the model by using equation 2.5.8 and the net amount of sediment deposited in the reach segment is calculated by equation 2.5.9

$$\text{Sed}_{\text{deg}} = (\text{Conc}_{\text{sed,ch,mx}} - \text{Conc}_{\text{sed,ch,j}}) * V_{\text{ch}} * K_{\text{ch}} * C_{\text{ch}} \quad \dots\dots\dots 2.5.8$$

$$\text{Sed}_{\text{dep}} = (\text{Conc}_{\text{sed,ch,i}} - \text{Conc}_{\text{mx}}) * V_{\text{ch}} \quad \dots\dots\dots 2.5.9$$

Where: Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), $Conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m³), $Conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m³), K_{ch} is the channel erodibility factor (cm/hr/pa), C_{ch} is the channel cover factor and V_{ch} is the volume of water in the reach segment (m³), Sed_{dep} is the amount of sediment deposited in the reach (metric tons).

Once the amount of degradation and deposition has been calculated by the above equations 2.5.8 and 2.5.9 respectively, then the final amount of sediment in the reach is determined by equation 2.5.10 and the amount of sediment transported out of the reach is calculated by equation 2.5.11 by the model.

$$Sed_{ch} = (Sed_{ch,i} - Sed_{deg}) + Sed_{dep} \dots\dots\dots 2.5.10$$

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V} \dots\dots\dots 2.5.11$$

Where sed_{ch} is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons), Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), Sed_{out} is the amount of sediment transported out of the reach (metric tons), Sed_{ch} is the amount of suspended sediment in the reach (metric tons), V_{out} is the volume of outflow during the time step (m³) and V_{ch} is the volume of water in the reach segment (m³).

Surface Runoff and Sediment lag

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated and also Sediment in the surface runoff is lagged as well. SWAT incorporates a surface runoff storage feature to lag part of the surface runoff release to the main channel. Once

surface runoff is calculated, the amount of surface runoff released to the main channel is calculated by equation 2.5.12 and after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using equation 2.5.13 by the model

$$Q_{\text{surf}} = (Q''_{\text{surf}} + Q_{\text{stor } j-1}) \left(1 - \exp \left[\frac{-\text{Sur lag}}{t_{\text{conc}}} \right] \right) \dots\dots\dots 2.5.12$$

$$\text{Sed} = (\text{Sed}'' + \text{Sed}_{\text{stor } j-1}) \left(1 - \exp \left[\frac{-\text{Sur lag}}{t_{\text{conc}}} \right] \right) \dots\dots\dots 2.5.13$$

Where: Q_{surf} is amount of surface runoff discharged to main channel in a day (mm), Q' is amount of surface runoff generated in a sub basin in a day (mm), $Q_{\text{stor}, i-1}$ is the surface runoff stored or lagged from the previous day (mm), Surlag is the surface runoff lag coefficient, t_{conc} is the time of concentration for the sub basin (hrs) and in equation 2.5.13, Sed is the amount of sediment discharged to the main channel on a given day (metric tons), Sed'' is the amount of sediment load generated in the HRU on a given day (metric tons), $\text{Sed}_{\text{stor}, i-1}$ is sediment stored or lagged from the previous day (metric tons) Sediment in lateral and ground water flow. Even though, it is small in proportion to the surface flow contribution, SWAT allows the lateral and groundwater flow to contribute sediment to the main channel and calculated:

$$\text{Sed}_{\text{lat}} = \frac{((Q_{\text{lat}} + Q) * \text{Area}_{\text{HRU}} * \text{Conc}_{\text{sed}})}{1000} \dots\dots\dots 2.5.14$$

Where Sed_{lat} is the sediment loading in lateral and ground water flow (metric tons), Q_{lat} is the lateral flow for a given day (mm water), Q_{gw} is the groundwater flow for a given day (mm water), Area_{HRU} is the area of the HRU (km^2), Conc_{sed} is the concentration of sediment in lateral and groundwater flow (mg/l).

2.6 Routing phase of the hydrologic cycle

The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. The change in channel dimensions with time due to down

cutting and widening is also included. Similar to the case for the overland flow, the rate and velocity of flow is calculated by using the Manning's equation. The main channels or reaches are assumed to have a trapezoidal shape by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model. For this study, the variable storage method was adopted. The method was developed by (Williams, 1975) and recommended (Arnold et al, 1995). The Storage routing is based on the continuity equation:

$$\Delta V_{\text{stored}} = V_{\text{in}} - V_{\text{out}} \dots\dots\dots 2.5.15$$

Where: V_{in} is volume of inflow during the time step (m^3), V_{out} is volume of outflow during the time step (m^3), and ΔV_{stored} is change in volume of storage during the time step (m^3). The above equation (2.5.15) can also be rewritten in detailed as follows:

$$V_{\text{stored},2} - V_{\text{stored},1} = \Delta t \left(\frac{q_{\text{in},1} + q_{\text{in},2}}{2} \right) - \Delta t * \left(\frac{q_{\text{out},1} + q_{\text{out},2}}{2} \right)$$

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

2.7 Model Efficiency Evaluation

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient

of determination (R^2), and Nash-Sutcliffe simulation efficiency (ENS) are the goodness of fit measures used to evaluate model prediction.

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

The Coefficient of determination R^2 value is an indicator of strength of relationship between the observed and simulated values. It indicates how well the dispersion of the measured data is.

The Nash-Sutcliffe simulation efficiency (ENS) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, ENS is 1. If the ENS is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash & Sutcliffe, 1970). This coefficient is calculated by equation

$$NSE = 1 - \frac{\left[\sum_{i=0}^n (Q_{obs} - Q_{sim})^2 \right]}{\left[\sum_{i=0}^n (Q_{obs} - \bar{Q}_{obs})^2 \right]}$$

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

$$PBIAS = \frac{\sum_{i=0}^n (Q_{obs} - Q_{sim})}{\sum_{i=0}^n (Q_{obs})} * 100$$

Where: n is the number of observations during the simulation period, Q_{obs} , is the Observed flow data; Q_{sim} , is the simulated flow value with the respected time; and Q_{sim} , Q_{obs} are the arithmetic means of the observed and simulated values.

2.8 Previous Study

Though they are not recent, in recognition of the severity of erosion and land degradation and their consequences, Ethiopia, with intense assistance from international donors, undertook major studies in the highland parts of the Country. Among others, the Ethiopian Highland Reclamation Study (EHLRS, 1986), Abbay Basin Study and Woody Biomass Inventory (2000) are the main studies conducted in the country with high emphasis on assessment of soil erosion, land degradation and natural resources management aspects.

i) Soil Erosion Assessment

According to the work of Hudson (1996), more than half of the highland areas in Ethiopia show signs of accelerated erosion. It was estimated that every year 3.5 billion tons of topsoil are washed away, i.e. on average 70 to 100 tons per ha from cultivated land. Annual losses of almost 300 tons per hectare/year have been recorded sloping cultivated fields.

A study by Soil Conservation Research Project (SCRIP, 2000) has estimated soil loss rates from cultivated land of more than 200 t/ha/year, based on test plot results. Estimates of soil erosion rates from various land use types are also given by Hurni (1986), according to which the erosion rate from all types of land-use in the highlands is 1.5 billion tons per year; out of which, 0.9 billion tons occur Amhara region, which includes the study area. Hurni (1993) also reported that soil loss rates from test plots in the Ethiopian Highlands ranged from 0 to 400 t/ha/yr, with average values of 42 t/ha/yr for cropland, 5 from grassland and 70 from barelands. This study also showed that sediment loss rates from small watersheds may exceed 60 t/ha/yr see Table 2.4.

Land Cover	Area, %	Estimated Soil loss	
		t/ha/yr	Mt/yr
Cropland	13.1	42	672
Perennial crops	1.7	8	17
Grazing and browsing land	51.0	5	312
Degraded lands	3.8	70	325
Currently uncultivable	18.7	5	114
Forest	3.6	1	4
Wood and bush land	8.1	5	49
Country Total	100.0	12	1493

Source: Hurni, 1993; (Mt = Million tons)

Table 2. 4 Estimated Rates of Soil Loss from Different Land Use Types in Ethiopia

ii) Ethiopian Highland Reclamation Study (EHRS)

The Ethiopian highlands study comprises areas at more than 1,500 meters above sea level (masl), which includes the present study area. The main purpose of the study was to identify the extent of land degradation and soil erosion problems. It has identified that soil erosion by water is the major environmental problem that confronts the crop production potentials of the Ethiopian highlands. The study found that 1.9 million tons of soil were annually removed from the Highlands of Ethiopia, out of which 0.9 million tons are from Amahra Region. It was estimated that between 1985 and 2010, the rate of land degradation would cost 6,500 million USD, of which 78% are due to soil losses from farmlands. Overall, 25% of the highlands of the country are seriously eroded. Already 4% of the total highlands are so seriously eroded that they will not be economically productive in the future. The study further suggested the need to incorporate soil and water conservation interventions as an integral part of the farming systems.

iii) Abbay Basin Master Plan Study

A study of the soil erosion situation and efforts made so far in soil and water conservation was carried out by BCEOM, 1999, as part of the Abbay Basin Master Plan study. This report is relevant to the target area of the present study. It indicates that soil erosion in Abbay basin, and generally in Ethiopia, has reached alarming

levels and is increasing under the combined pressures of increased population and deforestation, improper land-use practices, excessive livestock population, overgrazing, the free grazing habit etc.

BCEOM (1999) gave an estimate of suspended sediment yield of Megech River at the gauging site near Azezo (watershed area 462 km²) as 263,000 ton/year (562 ton/km²/year). The report provided the following rating equation for the gauging site:

$$Q_s = 15.05 Q^{1.353}$$

Where: Q_s = Suspended sediment mass transport rate (ton/day)
 Q = discharge (m³/s)

Based on the above rating equation and the historical monthly flows at the gauging site, monthly suspended sediment loads were estimated. Nearly 65% of the suspended sediment was found to be transported in the August months. The mean annual suspended sediment transport was estimated as 140,405 ton corresponding to the specific rate $G = 304$ ton/km²/year. This G value seems to be too low for a steep and nearly un-vegetated watershed such as the Megech watershed.

Due to its low sediment yield value, neither the BCEOM (1999) sediment yield estimate nor the result based on the above mentioned BCEOM rating equation could be adopted for the Megech dam site sediments rate estimate. In August 13, 1995 a major sediment measurement was carried out in Megech River during a medium flow of 95.9 m³/s with a corresponding suspended sediment concentration of 2,759 p.p.m. The sediment transport of that day was about 22,860 ton, pointing at a much higher suspended sediment rate than the BCEOM (1999) estimate.

iv) Water Works Design and Supervision Enterprize (2008)

The final study made by the then Water Works and Design Enterprize (2008), the final mean annual suspended sediment transported at Megech at the gauging site was then estimated using monthly flows over the period 1960-2004 using sediment rating equation found to be 496,066 ton, which corresponds to 1,170 ton/km²/year.

CHAPTER THREE

3. MATERIAL AND METHODS

3.1 Description of Study Area

The Megech watershed upstream of the dam site is characterized as a steep mountainous watershed with circular shape. Gondar town and Angereb reservoir are located within the watershed the boundaries of which were marked on 1:50,000 maps (Map 1). During the rainy months, Megech River flow has high velocity and the sediments transported by the floods are mainly boulders, gravel, sand and silt. This is a typical behavior of a mountainous river such as the Megech River.

The watershed highest elevation is 2,991m above mean sea level, in its north-eastern part. The watershed is highly vulnerable to sheet, rill and gully erosions. Gullies which directly ran into Megech River were being formed as a result of the increased agricultural activities performed in the watershed such as steep area farming, and aggressive grazing.

Map 1 Megech River and its watershed near the dam site

3.1.1 Climate Characteristics

Most of Ethiopia is characterized by tropical climate moderated by altitude with a marked wet season. The eastern lowlands (elevation less than ~900m above mean sea level) are much drier with a hot semi and to a desert climate. In contrast the southwestern Ethiopia is characterized by humid tropical climate with rainfall higher than 1,000mm. In the highlands of Ethiopia, temperatures are reasonably warm the year round but rarely hot.

In Ethiopia in general there are three seasons: the first is the dry season (locally known as Bega) which prevails from October to January; the second is the small rainy season (Belg) that runs from February to May and the third is the main rainy season (Kiremt) which prevails from June to September. Rainfall is above 1,000mm a year almost everywhere in the highlands and it rises to as much as 2,000 – 3,000mm in the wetter southwestern parts. Annual rainfall decreases when one moves to the east and north of the country. Night time temperatures fall to nearly or below freezing in mountainous area (higher than 2,500m). In the northern lowlands, Dankil depression, the southern lowlands, and Ogaden, rainfall is low (below 300mm/year) and temperatures are high (higher than $> 30^{\circ}\text{C}$) during the whole year.

Since Ethiopia is situated in the North-eastern part of Africa, it is influenced from the Northeast, to the Southeast and Southwest (West Africa) by monsoons bringing moisture from the Indian and Atlantic Oceans. In the northern hemisphere summer, moisture-laden winds gradually penetrate into the countries as the African sector of the inter-Tropical Convergence Zone (ITCZ) progresses northward. The July ITCZ patterns are presented by Table 3.1.

The main synoptic features that affect the Ethiopia rainfall including the project area are presented by Table 3.1 The project area receives its main rainfall from June to September. The orographic influence on rainfall depth values is also marked in the mountainous area that prevails in the area under study.

Major synoptic features affecting rainfall over Ethiopia				
Season	ITCZ (south Atlantic ocean effect / El Nino, SOI)	North Indian Ocean effect	Low level Jet and Tropical easterly Jet	Remarks
June – Sept (main rainy season)	ITCZ MOVES NORTHWARDS TO RED SEA. MOST OF ETHIOPIA RECEIVES RAINS	SST condition influence the main rains	Active and moves northwards	South and southeastern parts of Ethiopia do not receive rains.
Feb – May (small rainy season)	ITCZ is in south Ethiopia bringing rains to south and southwestern Ethiopia.	Moisture source for eastern, southeaster n, and some central highlands part of Ethiopia receives useful rains.	Moves northwards	As important as the main rain season for eastern and northeastern Ethiopia
Oct – Jan (“dry season”)	ITCZ is located further south and brings rain for extreme south and southeastern Ethiopia.	Occasionally causes some untimely rainfall in most part of Ethiopia	Weak and migrate southwards	Crop harvesting time in most of Ethiopia

Table 3. 1 Main synoptic features affecting Ethiopian rainfall

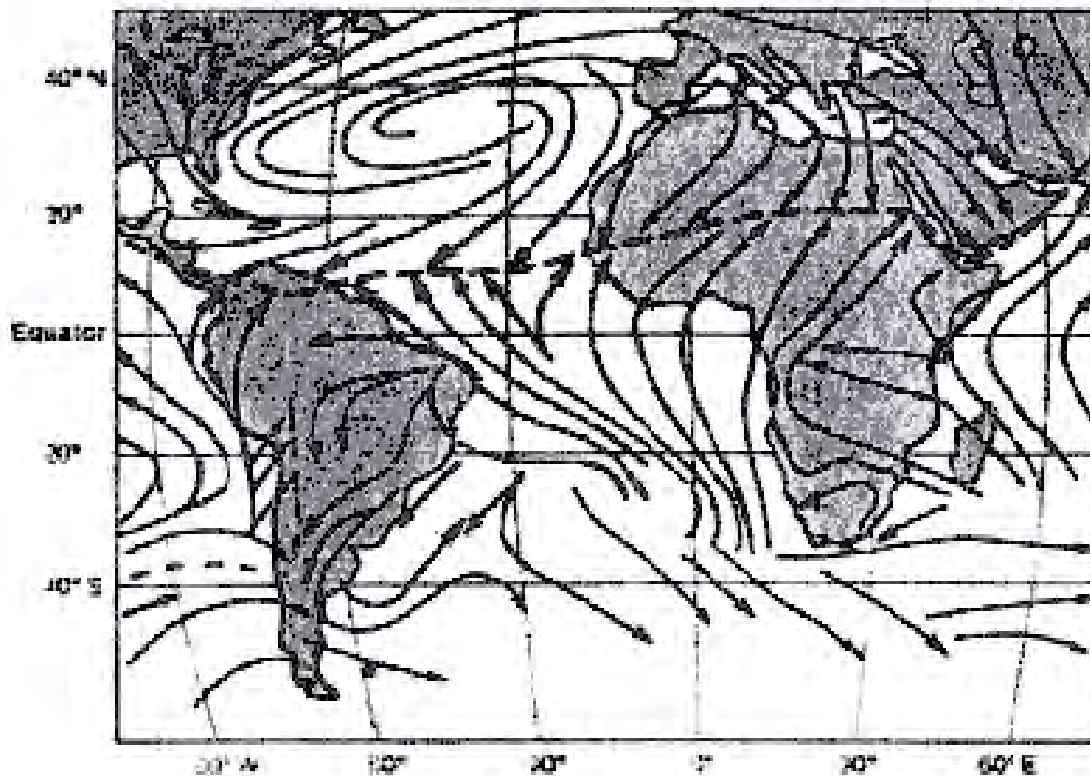


Figure 3. 1 July mean position of the Inter-tropical Convergence Zone (ITCZ) in July and average winds near the surface

Rainfall over the Megech watershed is mono-modal nearly 79% of the annual rainfall occurs in the period of June – September.

Annual Isohyets over Tana Sub basin are shown in Figure 3.2. The highest rainfall occurs over the Gilegel Abbay (~1,600mm) watershed. By comparison, the mean annual precipitation of the Gumara and Ribb (~1,300mm) and Megech (1,000mm) watersheds is lower. The mean annual rainfall depth over Lake Tana is about 1,000mm, where Bahir Dar mean annual rainfall at the Lake's outlet being the highest point.

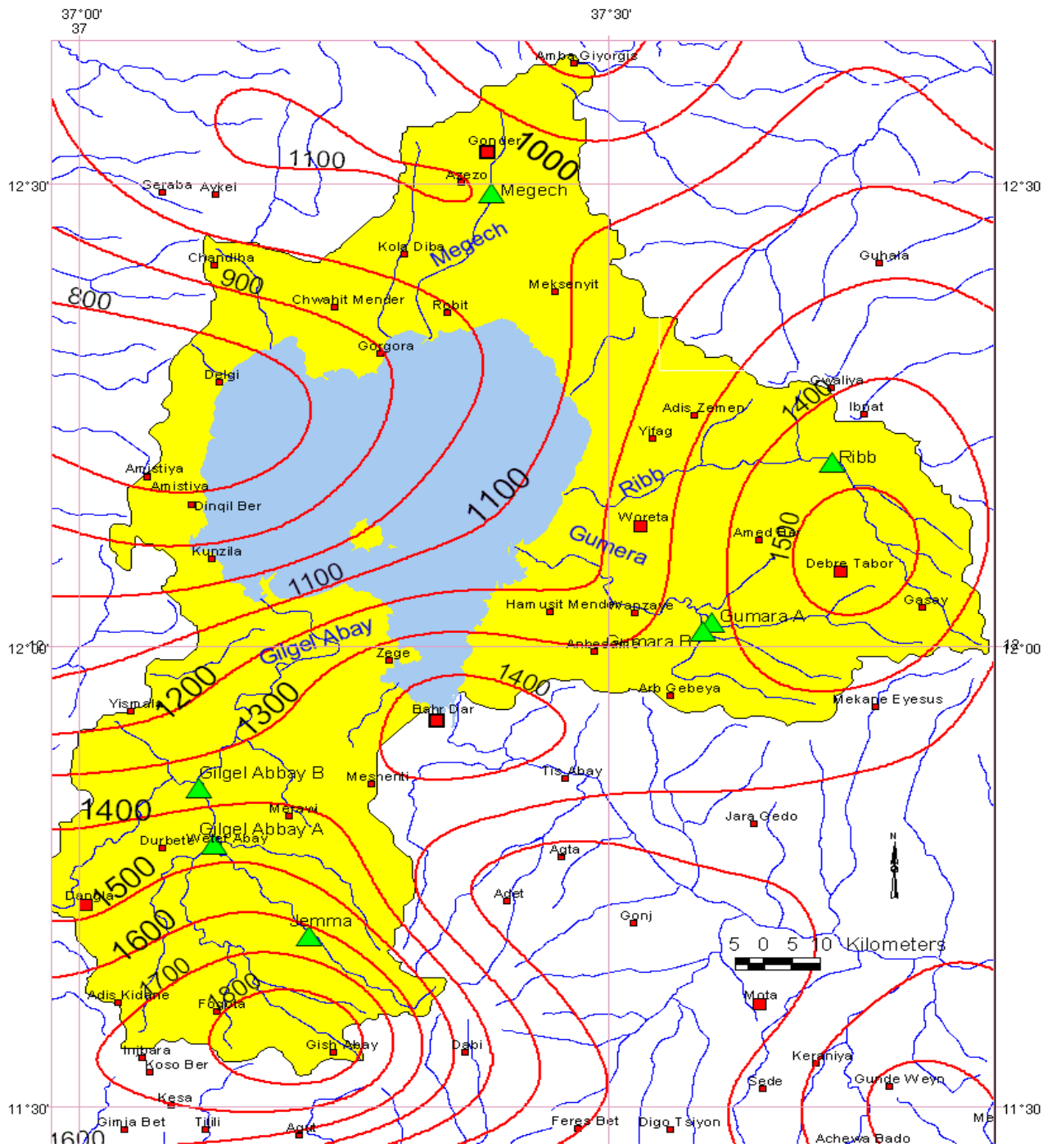


Figure 3.2 Mean Annual Isohyets (mm) over Tana subbasin
 (Source :WWDSE,2007)

In the rainy month's maximum temperature (22°C), wind speed (1.2m/s) and sunshine hours (4.2hr) are low as compared to the dry month's values. However, relative humidity is high (reaching about 80%) in the rainy months.

3.1.2 Land Use and Cover

Farming practices that can maintain soil, such as crop rotation and fallowing have almost vanished, mainly due to diminishing land-holding sizes. Most parts of the study area are intensively cultivated for centuries. The natural vegetation cover has been ruined, except of some remnants of vegetation, such as scattered trees left in the farm fields, churchyards, and open forest along the streams. As a result, the landscape over wide areas of the watershed is virtually bare, with very scant vegetation cover.

In the past natural forests covered most of the areas. Furthermore, they explained that the proportion of cultivated lands increases with time on account of grazing and forest lands because of high population growth and increased demand for food. Most of the steep slopes are used for cultivation beyond their capability and suitability.

The sources of information for the present study for the interpretation of land use and land cover data were previous studies and field observations. It was important to re-assess the existing conditions to determine the actual land use and land cover types.

At present, cultivated lands cover most of the watershed area, and even very steep slopes are cultivated for annual crops. In particular, the upper part of Gondar Town are highly degraded due to old-age and traditional agriculture practices. During field visits, it was observed that most of the land, including steep slope, is being used for cultivation beyond its capability.

Large shrub land areas are found in and around the watershed. The shrub lands are used for livestock grazing and for production of wood for different purposes. The so-called grassland comprises very scattered shrubs, bush and weeds, used or grazing of livestock, including cattle, small ruminants and equines. Very limited grazing land is also found around settlement areas, swamps, hills and other spots.

Cultivated lands cover most of the watershed, which accounts for 79% of the study area. The grasslands in the watershed accounts for about 9% of the study area; shrub lands constitute about 9% of the total, and bare land - about 2%.

3.1.3 Megech River Flows

The hydrometric station No. 1007-Megech River near Azezo (12.48⁰ North, 37.45⁰ East) having a watershed area of 462 km² has been operational since 1959. The gauging site has no low flow control. The high flows usually are overtopping the river banks and usually are hard to be correctly estimated.

BCEOM (1999) gave a number of rating equations for the Megech gauging site applied for specific years (Table 3.2), indicating of changes in the Q-H relationships. Very few high flow measurements were included when these rating curves were determined.

Period	Q = a (H-Ho) ^b Where: Q = Discharge in (m ³ /s) H = River stage (m)			
	a	b	Ho	R ²
Nov 1959 – Jan 1962	0.037	8.342	-0.50	0.92
Feb 1962 – May 1964	0.048	8.704	-0.25	0.94
Jun 1964 – Oct 1969	21.24	2.404	-0.05	0.97
Nov 1969 – Oct 1970	23.40	1.960	0.10	0.98
Feb 1971 – Nov 1973	100.80	3.205	0.25	0.87
Mar 1974 – Nov 1974	18.00	3.939	-0.05	0.93
Jan 1975 – Oct 1976	27.96	2.998	0.25	0.89
Nov 1976 – Sep 1978	45.42	2.157	0.50	0.95
Feb 1979 – Oct 1982	33.88	2.371	0.55	0.91
Nov 1982 – Oct 1983	13.60	3.873	0.40	0.96
Nov 1983 – Dec 1986	19.90	6.368	0.40	0.86
Mar 1983 – Mar 1994	22.97	4.181	0.50	0.91

Table 3.2 Megech River hydrometric station near Azezo (No. 1007) rating curves (BCEOM, 1999)

Table 3.2 present the daily variation of river stream flow at Megech gauging station during the rainy season (July-September). Flows vary considerably in the rainy months, which characterize a mountainous river, with high peak values and a little delayed runoff, such as the Megech River.

3.2 Approach and Methodology

The methodology of this study has the following components, data collection, data processing, running the model, calibration and validation and model interpretation.

The conceptual frame work (Figure 3.3) serves to describe the overall research steps describing the methodology applied to carry out the research .In general the necessary hydro-metrological data, daily rainfall, daily maximum and minimum tempratures temperatures, daily humidity, sunshine hours, wind speed and observed river discharge and suspended sediment load/concentration at different stations in the basins are collected and processed to make the data ready for use in the models. Once the model is parameterized by converting the results of data analysis into model parameters, then model sensitivity analysis, calibration, validation and simulation for different parameter changing are conducted ending up on some conclusions and recommendations.

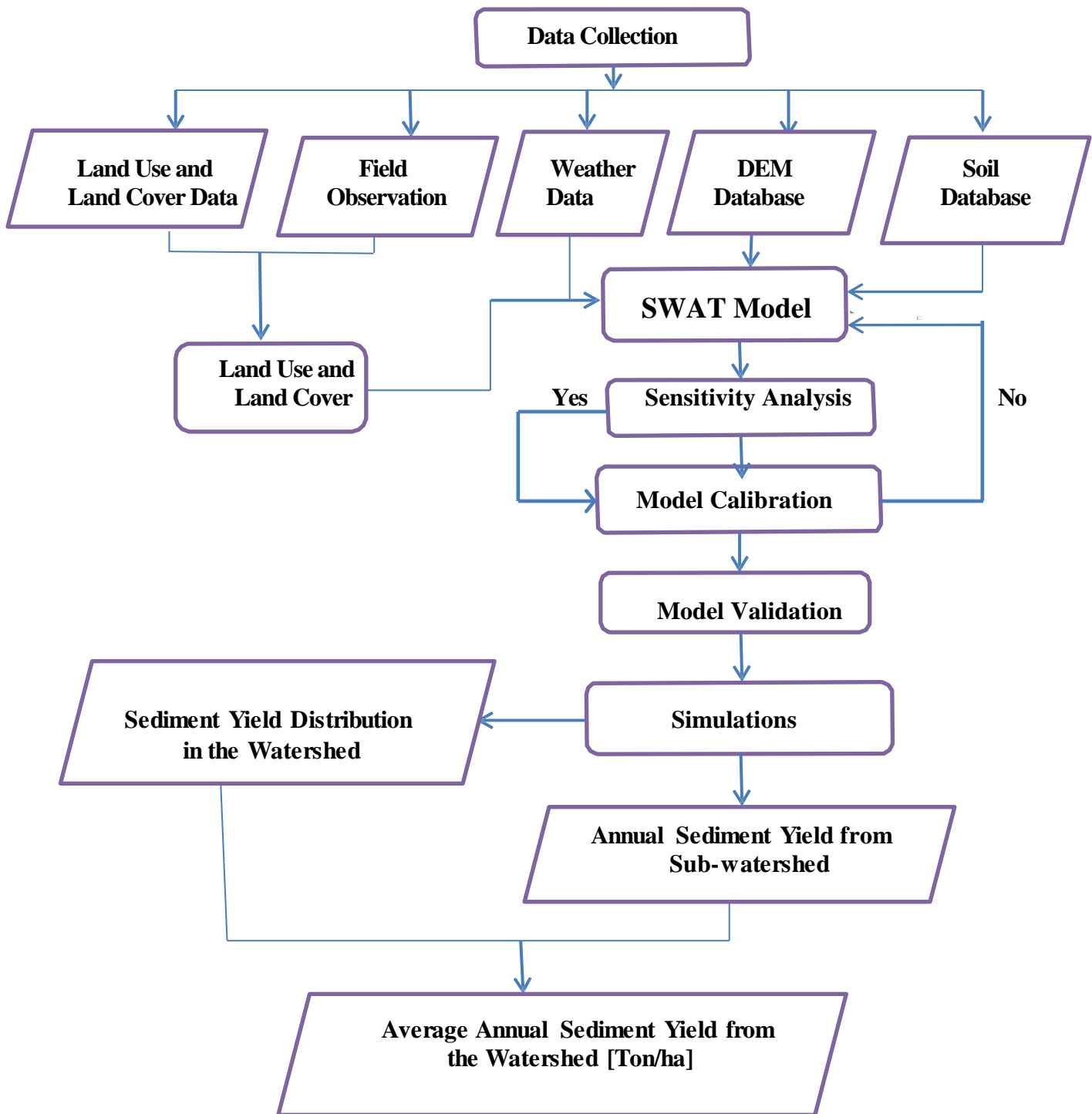


Figure 3. 3 Conceptual Fram Work of the research

3.2.1 Data collection

The necessary data that was collected and used for this study can be classified into spatial and time series data. Spatial data used are DEM, land use/cover and soil map of the study area and collected from MoWIE. The time series data are Metrological and hydrological data and these data are collected from Ethiopian National Metrological Agency and MoWIE respectively.

Models and software"s used for estimation of sediment yield in the study area was Arc GIS 10.2 extension of SWAT model that is Arc SWAT 2012.

3.2.2 Metrological Data

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

- Precipitation: the daily precipitation and temperature of all gauging stations (Gonder, Amba Giorgis, Maksegit, Chewahit, Bahirdar, and Gorgora) were prepared in text format.
- Temperature: the daily temperature of all gauging stations (Gonder, Bahirdar, Amba Giorgis) were prepared in text format
- Solar radiation, relative humidity, and wind speed data were available only for principal station (Gonder and Bahirdar), these data for the rest of the stations were generated by SWAT. More over these data were required when Penman Montheith equation is used to evaluate potential evapotranspiration.
- Weather simulation data: these data consists of monthly average values of all the values required by the SWAT model in order to generate daily values.
- All the above data were collected from Ethiopian National metrological agency for the period from (1988-2015 G.C).

3.2.3 Hydrological Data

Daily flow data is required for SWAT simulated result calibration and validation. This data was obtained from ministry of Water, Irrigation and Energy, hydrological department from 1980-2009 G.C. Depending on the extent of calibration and validation, flow data was collected and arranged as per the requirement of SWAT model. The selected site was Megech flow station (12:29N, 37:27E). This site was selected as it this station has long term and reliable stream flow data.

3.2.3.1 Sediment Data

There are few sediment data which have measured suspended sediment data in the Megech River for limited years. However the sediment data was taken from the Ministry of Water, Irrigation and Energy, hydrological department for year 1990, 1992,1993,1994,2005,2007,2010,2011 and 2013 G.C. (see annex 2). Depending on the observed suspended sediment data the remaining values were generated from sediment rating curve for calibration and sensitivity analysis.

3.2.4 Digital Elevation Model (DEM) Data

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input of SWAT hydrological model. The Megech River watershed was delineated and River networks were generated from DEM. The DEM obtained has a resolution of 30m x 30m. Elevation of the study area ranges from 1871m amsl to 2982m amsl.

Map 2 Masked DEM of Megech Watershade

3.2.5 Soil Map Data

The soil textural and physicochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. These data were obtained from FAO (1998; 2002; 2005) and the Ministry of Water Resources and energy of Ethiopia. The shape file which describes the distribution of soil in the study area was obtained from the base line maps available at MOWIE. It was observed that Eutric Vertisols, Haplic Nitisols, Chromic Luvisols and Eutric Leptosols are the most dominant soils in the catchment. The value of different soil parameters (properties) for each soil which were collected from the above soil data sources are listed in Appendix 3

Map 3 SWAT SOIL Map of Megech Watershade

3.2.6 Land use /land Cover Map

Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Agricultural land use is the dominant land use in the Megech River catchment. The land use map was obtained from ministry of water irrigation and electricity from Abbay River basin Integrated Development master plan project, 1998.

Map 4 SWAT Land Use Classes of Megech Watershade

Landuse/cover	Area (Ha)	% Area (Ha)
AGRICULTURE	29055	70
URBN	796	2
Shereb Land	8599	21
Grass Land	3307	7.5
WATR	0.06	0.11
	41334.985	100

Table 3.3 Landuse/cover of the study area

3.3 Data Analysis

Engineering studies of water resources development and management depend heavily on meteorological and hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, we need a simple but efficient screening procedure. A time series of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the choice of time origin. (By „unaffected“, we mean that estimates of these properties agree within the range of expected statistical variability). The basic data-screening procedure presented here is based upon split- record tests for stability of the variance and mean of such a time series.

3.3.1 Meteorological data analysis

Daily precipitation, daily temperature (maximum and minimum), sunshine hours, relative humidity and wind speed were collected from meteorological stations within and around the watershed. The six stations which are used for the model are presented in Table 3.4 which are within and around the Megech watershed.

S.No	Station Name	Latitude	Longitude	Elevation (m)
1	Gonder	12.33	37.83	1967
2	Amba Gorgies	12.46	37.77	2885
3	Makisegit	12.22	37.75	1935
4	Chewahit	12.32	37.32	2000
5	Bahir Dar	11.36	38.07	1770
6	Gorgora	12.15	37.65	1830

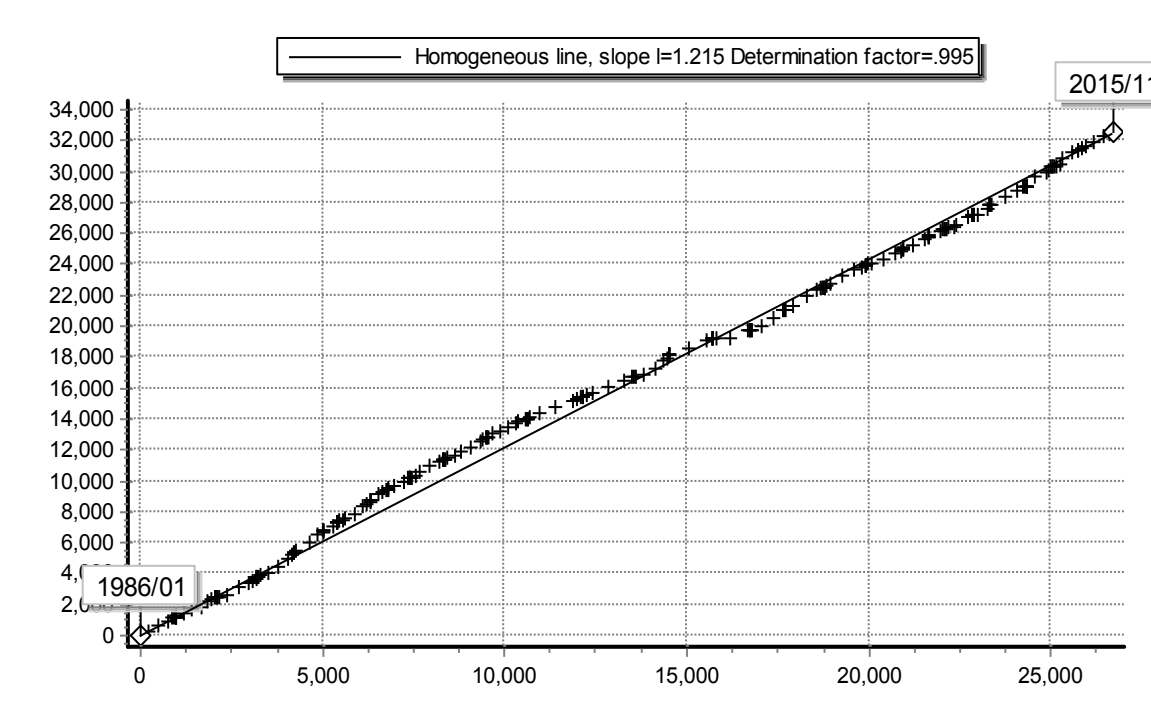
Table 3. 4 Location of metrological stations within and around the watershed

3.3.2 Checking Homogeneity of Selected Rainfall station

One of the methods to check homogeneity of the selected stations in the watershed is the non- dimensional rainfall records and plotted to compare the stations with each other. Using Hydrogronum software, the homoginity of each stations are checked with the principal stations.

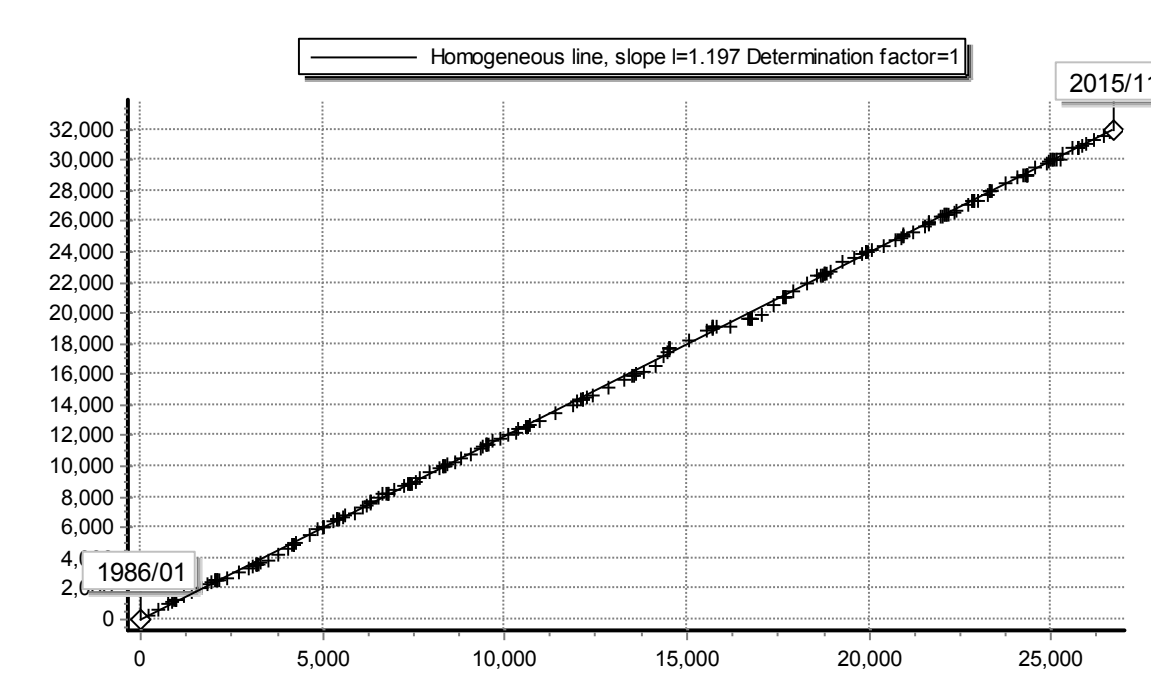
3.3.3 Checking Consistency and Adjustment of rainfall stations

A consistent record is the one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. The consistency of rainfall records on selected stations commonly checked by Hydrogronum software, the software uses the alogarithem of the concupt of double mass curve analysis. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time the significant change took place. If significant change in the regime of the curve is observed, it should be corrected.



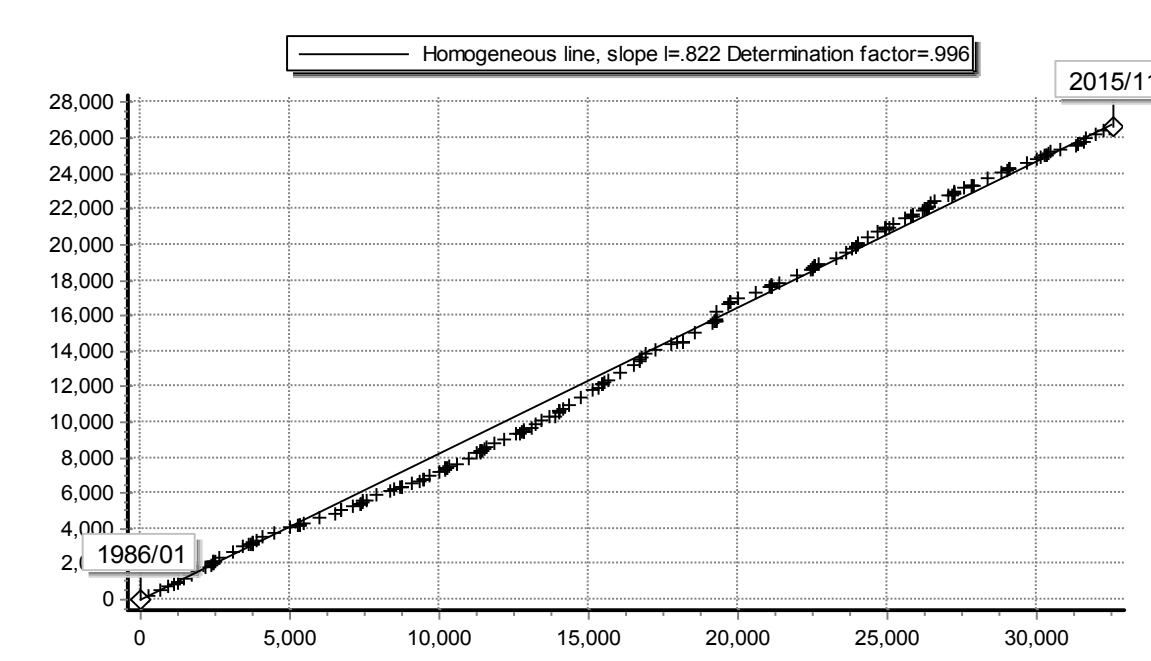
Double mass curve of Bahirdar station with Gondar, Gorgora, Chewahit and Maksegnit

(Before Correction of outliers)

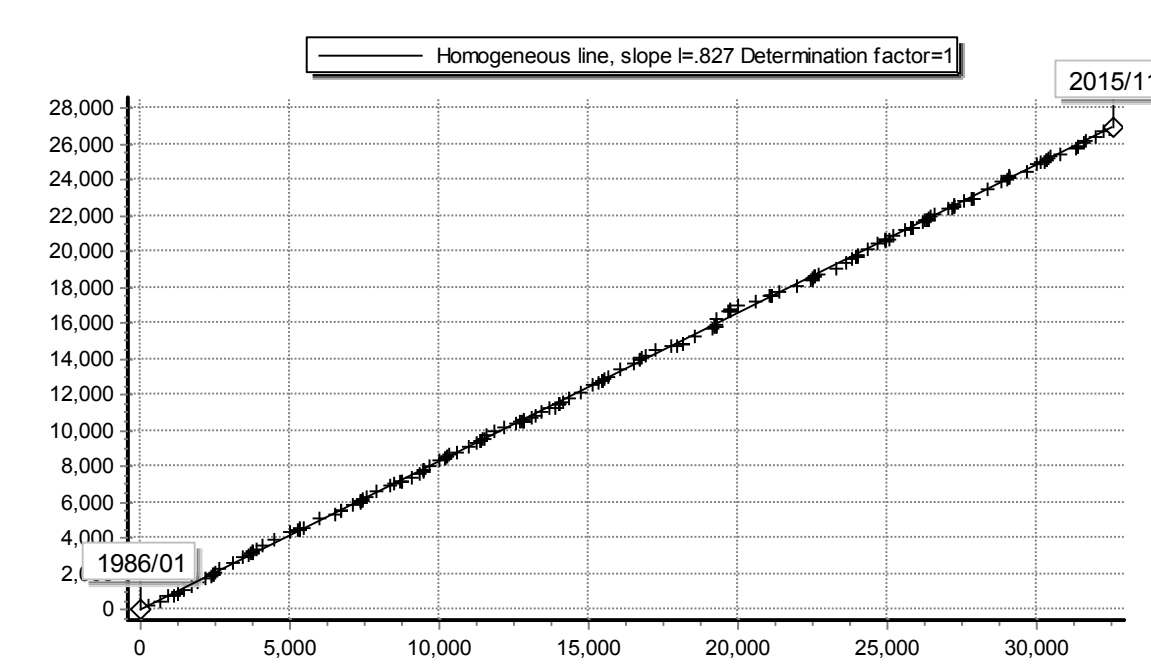


Double mass curve of Bahirdar station with Gondar, Gorgora, Chewahit and Maksegnit

(After Correction of outliers)



Double mass curve of Gondar station with Bahirdar, Gorgora, Chewahit and Maksegnit
 (Before correction of outliers)



Double mass curve of Gondar station with Bahirdar, Gorgora, Chewahit and Maksegnit
 (After correction of Outlier)

Figure 3. 4 Corrected Double Mass Curve

3.3.4 Filling Missing Rainfall Data

The weather generator model included in SWAT was used to fill missing values in measured records and also to simulate the data if simulation option is selected. The WXGEN was provided with all the necessary statistical information from the meteorological records of the watershed to fill the missing portion properly. These statistical values were calculated from the meteorological data available within and around the Megech watershed metrological stations. After loading this WXGEN parameter and location table, the daily meteorological data (daily precipitation, daily minimum and maximum air temperature) with the missing data filled with a missing data identifier of -99 and including the corresponding location table prepared according to the SWAT format were loaded to the model.

The metrological stations used for both daily precipitation and temperature data were Amba Gorgies, Baher dar, Chewahit, Maksegit, Gonder and Gorgora stations was included and the Gonder Station selected to be principal station for the weather generator. For the missing data filling all stations were added to the WXGEN with their statistical values. Due to data shortage, for the relative humidity, wind speed and solar radiation parts simulation option were selected. SWAT takes data of each climatic variable for each sub-basin from the nearest weather station measured from the centroid of the sub-basin.

Sediment rating curve preparation

Sediment measurement in the Megech River was taken by MoWIE at Megech gauge station was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step, the relationship known as sediment rating curve. The measured suspended sediment concentration data of Megech River is presented in appendix 2. It used for sediment rating curve preparation.

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

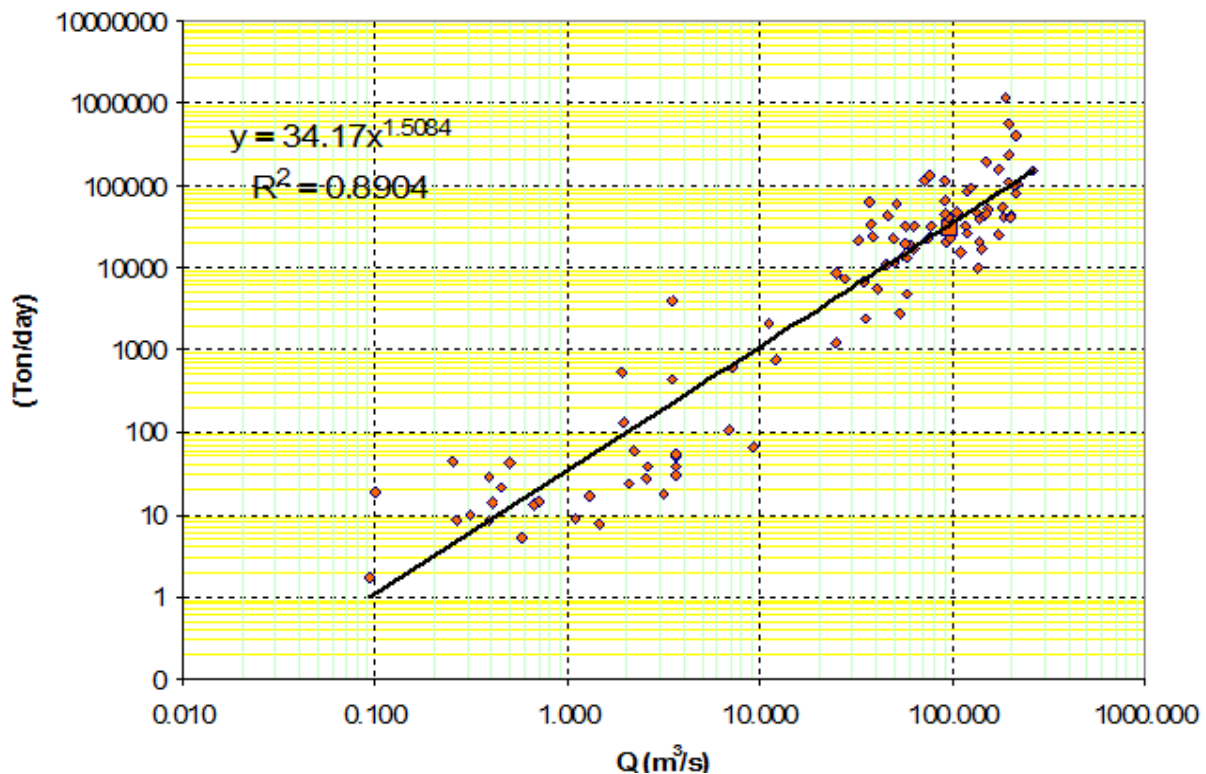


Figure 3.5 Composite Sediment Rating Curve, Megech River, 1994 - 2005

(Source: WWDSE Megech Project Final Hydrology Report)

3.4 SWAT Model Setup and Input of the model

3.4.1 Model Parameterization

a) Watershed and Channel Delineation

The DEM is used to derive the watershed boundary, channel network, and sub basin size and distribution. The Megech River watershed was delineated with an outlet point

at the outlet of the watershed. The overall watershed was further broken down into sub-basins based on the algorithms provided by the SWAT model. As a consequence these sub-basins influence the level of spatial complexity that is represented in the SWAT model. A sub-basin in SWAT is defined as the hydrologic area contributing to only one stream channel. Stream channels were defined as DEM cells having at least a 500 ha hectare contributing area. The contributing area resulted in 29 sub-basins being delineated.

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

The watershed delineation tool uses and expands the Arc GIS, spatial analyst functions to perform watershed delineation (Neitsch et al, 2005) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub- basins and details of stream network depends on this threshold area (Winchell et al, 2007). The watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates a watershed area 420 km² with 29 sub-basins (map 5).

Map 5 The delineated watershed and sub-basins by SWAT model

b) Hydrologic Response Unit Analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land use and the soil data in a projected shape file format were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The second step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 10 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to

consideration, 15%, and 20% threshold levels for the land use, and soil were applied, respectively so as to encompass most of spatial details.

The third step in HRU definition is selection of slope classification option (single or multiple) and if multiple slope option is select then defines the range of the slope. For this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified to five and the range was 0-3%, 3-8%, 8-15%,15-25%, and above 25%.

Finally defining the HRUs within a sub-basin complete the HRU setup. For this study the option of multiple HRU was selected and 20%, 10% and 20% were the threshold area of land use, soil and slope in each HRU from the sub-basin values respectively. The reason for taking these threshold values was in order to keep the HRUs to a reasonable and manageable number and also considering computer processing time required. Even though, application of these thresholds eliminates the land uses and soils that covered relatively small areas in the sub-basins it creates a total of 77 HRUs for 29 sub-basins.

Map 6 SWAT Land Slope of Megech Watershade

3.4.2 SWAT Model Input

Inputs including basin area and main channel length were determined by ARC SWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland Manning's n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics.

An ArcView GIS interface (ARCSWAT) is available to generate model inputs from GIS data (Di Luzio et al, 2002). ARC SWAT processes mapped land use and soils data as well as a Digital Elevation Model (DEM) to create a set of default model input files.

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

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

I. Spatial data Digital Elevation Model

Topography is defined by a DEM that describe the elevation of any point in a given area at a specific spatial resolution. A 30 m by 30 m resolution DEM was taken from the Ministry of Water and Energy (MoWIE). The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain, and the stream

network characteristics such as channel slope, length, and width were derived from the DEM.

Soil Data

SWAT model requires different soil textural and physio-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content or different layers of each soil type. These data were obtained mainly from the following sources: MOWIE (master plan Nile BASIN), Major Soils of the world CD-ROM (FAO, 2002), and Abbay River basin Integrated Development Master Plan Project. Major soil types in the watershed are Chromic Luvisols, Eurotic Leptosols, Eurotic Vertisols and Haplic Nitisols. The value of different soil parameters (properties) for each soil are listed in Appendix 3.

Land Use

Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from ministry of water and energy. I have reclassified the land use map of the area based on the available topographic map (1:50,000), aerial photographs and satellite images. The reclassification of the land use map was done to represent the land use according to the specific land cover types such as type of crop, pasture and forest.

Land use / Land cover	Land use according to SWAT database	SWAT code
Cultivated land	Agricultural land close to grown	AGR
Shrub land	Forest deciduous	RNG
Grass land	Pasture land	PAST
Water & marshy land	Water	WATR

Table 3. 5 Land use/cover classification of Megech watershed as per SWAT Model

II. Weather Generator

The weather generator model included in SWAT was used to fill missing values in measured records and also to simulate the data if simulation option is selected.

The metrological stations used for both daily precipitation and temperature data were Amba Gorgies, Baher dar, Chewahit, Maksegit, Gonder and Gorgora stations was included and the Gonder Station selected to be principal station for the weather generator. For the missing data filling all stations were added to the WXGEN with their statistical values. Due to data shortage, for the relative humidity, wind speed and solar radiation parts simulation option were selected. SWAT takes data of each climatic variable for each sub-basin from the nearest weather station measured from the centroid of the sub-basin. Average Daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity. Moreover, daily solar radiation was calculated from the daily available sunshine hour's data.

III. River Discharge and Sediment yield Data

Daily river discharge values and sediment concentration for Megech River were obtained from the Hydrology Department of the MOWIE, Ethiopia. These daily river discharges and sediment concentrations at Megech River were used for model calibration and validation.

3.5 SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation

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

3.5.1 Sensitivity Analysis

There are several parameters which affect a complex hydrological modeling. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in description of both the elements and processes present in the system are some of the reasons (Holvoet et al., 2004). Therefore, optimizing internal parameters of a model is an important task in order to achieve a well representative hydrological model. This kind of task is called model calibration which is usually supported by sensitivity analysis. Sensitivity analysis helps to determine the sensitivity of parameters by comparing the output variance due to input variability. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability. Therefore, the number of parameters that can be involved for calibration will be less in number and influential. It also evaluates the model capacity and helps to understand the behavior of the system being modeled.

Sensitivity analysis was performed to determine the influence a set of parameters had on predicting total flow. The analysis was carried out to identify the SWAT's hydrologic sensitive parameters by comparing their relative sensitiveness. It was performed on Twenty- six different SWAT parameters. An observed stream flow data of 27 years from 01 January 1980 to 31 December 2007, of Megech gauge station was used. Using ArcSWAT interface, the position of the subbasin that contains the gauge station was identified. Then the model parameters used in the sensitivity analysis of stream flow were selected and the method algorithm for analysis was defined. In the project the Latin Hypercube One factor At a Time (LH-OAT) sensitivity analysis method was used. It is combination of the One-factor- At-a-Time (OAT) design for simulation and Latin Hypercube (LH) sampling. It basically has the same concept as that of Monte Carlo simulation except the sampling method which is used by LH-OAT is stratified sampling rather than random sampling (McKay et al., 1979; McKay, 1988).

By applying default lower and upper boundary parameters values, the parameters were tested for sensitivity analysis for the simulation of the streamflow. Average criteria options have been selected for sensitivity analysis output. Finally the sensitivity analysis were run for gauge station. In the analysis, the sensitive parameters of the stream flow of the basin were identified. Up on the completion of sensitivity analysis, the mean relative sensitivity (MRS) values of the parameters were used to rank the parameters, and their category of classification. Out of the twenty-six stream flow parameters the nine most sensitive ones were chosen for calibration processes. The category of sensitivity was defined based on the (Lenhart et al., 2002) classification presented below (Table 3.6).

Class	MRS	Sensitivity category
I	$0.00 \leq \text{MRS} < 0.05$	Low to negligible
II	$0.05 \leq \text{MRS} < 0.20$	Medium
III	$0.2 \leq \text{MRS} < 1$	High
IV	$\text{MRS} >$	Very high

Table 3. 6 SWAT parameters sensitivity class (Lenhart et al., 2002)

Based on the above classification, parameters producing MRS values of medium, high and very high were selected for calibration process.

Model Calibration

Model inputs and values of parameters are associated with a number of uncertainties. Therefore model calibration is an important task to improve the result of model simulation. It is a process in which parameter adjustment are made in order to simulate as closely as possible the hydrological behavior of the watershed. A proper model calibration is necessary to consider a good fit between simulated and observed watershed runoff volume (water balance), the shape of the hydrograph, the peak flow, and the base flow. All these objectives are considered during model calibration because a single objective function cannot establish a reasonable match

between simulated and observed data. Most calibrations are supported by sensitivity analysis which avoids performing calibration on non-effective parameters.

Calibration can be performed in two ways: either manually or automated. In ArcSWAT2012 Manual Calibration Helper used for making adjustment to parameters across a user defined group of HRUs or subbasins. Auto calibration and Uncertainty of ArcSWAT 2012 is used for automated calibration. It has two dialogue boxes namely Auto-Calibration Input and Auto- Calibration Output. The earlier allows performing the automatic model calibration by selecting a simulated model and a subbasin which a discharge outlet located at. The latter provides option to refine to the out parameters for an analysis.

The parameters which had been selected by sensitivity analysis were optimized by both auto and manual calibration. In auto calibration, an Objective Function such as Sum of the Squared of the Residuals (SSQ) works at matching a simulated series to a measured time series.

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch et al, 2005) at different spatial and temporal scales.

Parameter estimation for calibration is various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. The process of adjustment can be done manually or computer-based automatic methods. The manual method is the most common, and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite. In sediment transporting modelling

two-step calibration procedures has been suggested by (Neitsch et al, 2005), the first is to check water balance contribution, then calibrate stream flow and followed by sediment calibration.

In this study the calibration process was divided into two steps: first stream flow and followed by Sediment calibration. Before starting the calibration of these components the measured total stream flow from the watershed should be sub-divided into base flow and surface flow for the purpose of comparison of these components in the observed to the model simulated. After annual and monthly time step calibration and checking the R², NSE and PBIAS values and calibrate at least until the minimum recommended values were embraced by the model that is R² > 0.6, NSE > 0.5 and PBIAS < ±15 (Santhi et al, 2001).

Calibration of stream flow and sediment carried out at outlet of sub basin 29 (near Megech gaging station). This site was selected due to the availability of measured flow and sediment data. The stream flow and sediment calibration was on annual and monthly average time steps. The procedure for calibrating the model for flow and sediment yields.

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Model Validation

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and

validation phase, the model can be used with some confidence for future predictions under some different management scenarios. Flow and sediment validation was carried out at a station similar to the calibration. The statistical criteria (the R², NSE and PBIAS) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits. R² > 0.6, NSE > 0.5, and PBIAS < ±15 (Santhi et al, 2001)

After calibration of flow with the given time step the next step was calibration of sediment yield of the watershed. Like flow calibration, it was calibrated based on sensitive parameters that observed at sensitivity analysis of sediment flow.

Based on the available model input data parameters the time periods of modeling are:

- ✚ Flow Calibration period (1994-2002)
- ✚ Flow Validation period (2003-2008)
- ✚ Sediment calibration period (1994-2002)
- ✚ Sediment validation period (2003-2008)

The first three year of each period used is used as a model warm up period and is not used for model evaluation.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

A SWAT model was calibrated and validated on a monthly basis to estimate the flow and sediment yields from the Megech watershed using a time series dataset of 22 years from 1994 to 2015. The first three years of the modeling period were used for „model warm-up“. Data for the period 1996 to 2002 were used for calibration and the remaining part of the dataset was reserved for validation. The watershed was subdivided into 29 sub basins based on a chosen threshold area of 413 km². The overlay of land use, soil and slope maps resulted in the definition of 77 HRUs. The simulated flow and sediment yields at the outlet of the watershed gauging station were compared with the observed flow and sediment yields.

4.1 Flow Simulation

About 250, iteration has been done by SWAT sensitivity analysis at the watershed of sub-basin no. 29 where the outlet of the watershed found for flow calibration with the output of 20 parameters were reported as sensitive in different degree of sensitivity for flow. Among these 20 parameters, only 9 of them have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to medium of sensitivity class as shown in Appendix 4.

4.1.1 Flow Calibration

Before calibration proceeds, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this the monthly simulation Coefficient of determination (R^2) of 0.56, Nash Sutcliffe model efficiency (ENS) of 0.54, and mean deviation of -17.6 % were obtained from the initial model run. The result shows the performance indicator was with the acceptable limits, i.e. $R^2 > 0.6$, $NSE > 0.5$ and $PBIAS < \pm 15\%$ (Santhi et al, 2001). But, some the model flow parameters were required adjustment and this adjustment was based on the sensitivity analysis result of flow parameters see Appendix 4.

Model parameters were calibrated manually. The calibration processes considered the sensitive parameters and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The initial /default and finally calibrated values are shown in Table 4.1. The CNs used in this study ranged from 41 to 87.8 with area averaged values of 78.23 and 50.62 for forested and agricultural lands, respectively.

<u>Parameters</u>	<u>Range</u>	<u>Initial (De fault) value</u>	<u>Adjusted Parameter Value</u>
Alpha_Bf	0-1	0.04	0.056
CN2	±25%	(36 – 77)	(41 – 87.8)
Esco	0-1	0.95	0.84
Revapmn	0-500	1	0
Sol_Awc	±25%	**(0.09 - 0.2)	(0.1071 – 0.238)
Gw_Revap	0.02-0.2	0.02	0.15
Gwqmn	0-5000	0	1500

**indicate that the values are in appendix 3 soil database of the watershed

Table 4. 1 Default and final calibrated flow parameter values of the watershed

The model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters. Calibration resulted after simulation found to be Coefficient of determination (R²) of 0.85, Nash–Sutcliffe efficiency (ENS) of 0.72, and mean deviation of -8.45% showing a good agreement between measured and simulated monthly flows (Table 4.2). The result also indicated that model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates SWAT's ability to predict realistic flow.

Monthly time step	Mean Annual Stream Flow (m ³ /sec)				
Simulation	Observed	Simulation	R ²	ENS	D
Calibration					
(1990-1999)	12.49	16.82	0.85	0.72	-8.25%

Table 4. 2 Calibration result statistic for monthly measured and simulated

Stream flow

During the calibration period (1990 to 1999), the simulated monthly flows matched well with the measured monthly flows (R²= 0.8 and ENS= 0.74) as shown in Figures 4.1 and 4.2. The trends of seasonal variability and monthly average discharge were generally well captured. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes (as for example in August 1994). However, the model slightly over estimates the peak monthly flow in most of the simulation periods of July and August months.

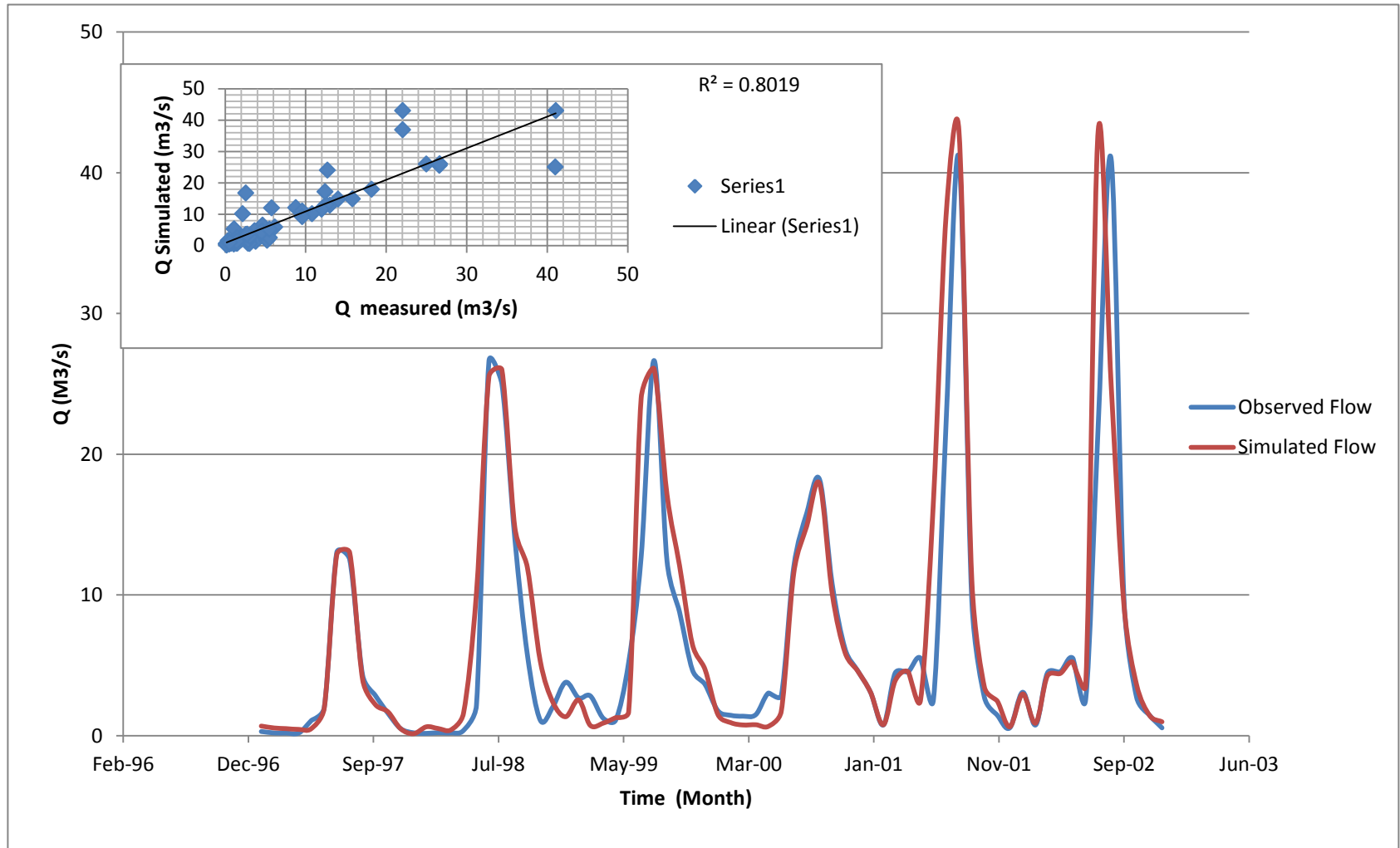


Figure 4. 1 Calibration results of average monthly Observed and simulated flow hydrograph (1996 – 2002)

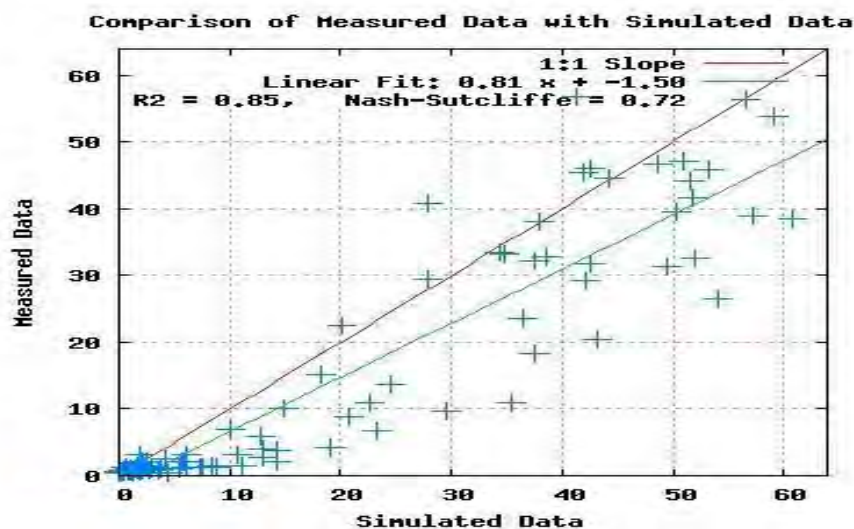


Figure 4. 2 Regression analysis line and 1:1 fit line of Simulated versus observed monthly flow during calibration period using webased hydrograph analyst tool

4.1.2 Flow Validation

The model with calibrated parameters was validated by using an independent set of measured flow data which were not used during model calibration. The model performance in validation was carried out from 2003 to 2008, without further adjustment of the parameters of flows. Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.87, Nash-Sutcliffe simulation efficiency (ENS) of 0.86 and a mean deviation of measured and simulated flows for the monthly flow was found to be 11.03% (Table 4.3).

Parameters	Default Value	Calibrated (1990-1999)	validated (2000-2008)
R^2	0.56	0.85	0.87
ENS	0.54	0.74	0.86
D %	-17.6%	-13.28%	11.03%

Table 4. 3 Default, Calibration and validation statistic for monthly observed and simulated Stream flow

The hydrograph of the validation period of the observed and simulated flow in monthly estimation, the model slightly over estimates some of the peak flows of the months, like in the year 2003 and 2004 and also July of the year 2005, respectively; and some of the months peak flows were also under estimated by the model in the year 2008 in period of validation period. (Figure 4.3 and 4.4) .This may be resulted from the quality of weather or flow data used as an input to the model. Some of the stations have many missing weather data which were left to be estimated and filled by the model's weather generator. Using estimated data may influence the simulation output. Additionally, mistake in measurement of flow and weather data may be another reason for the slight variation between measured and simulated flows at peak and under discharges.

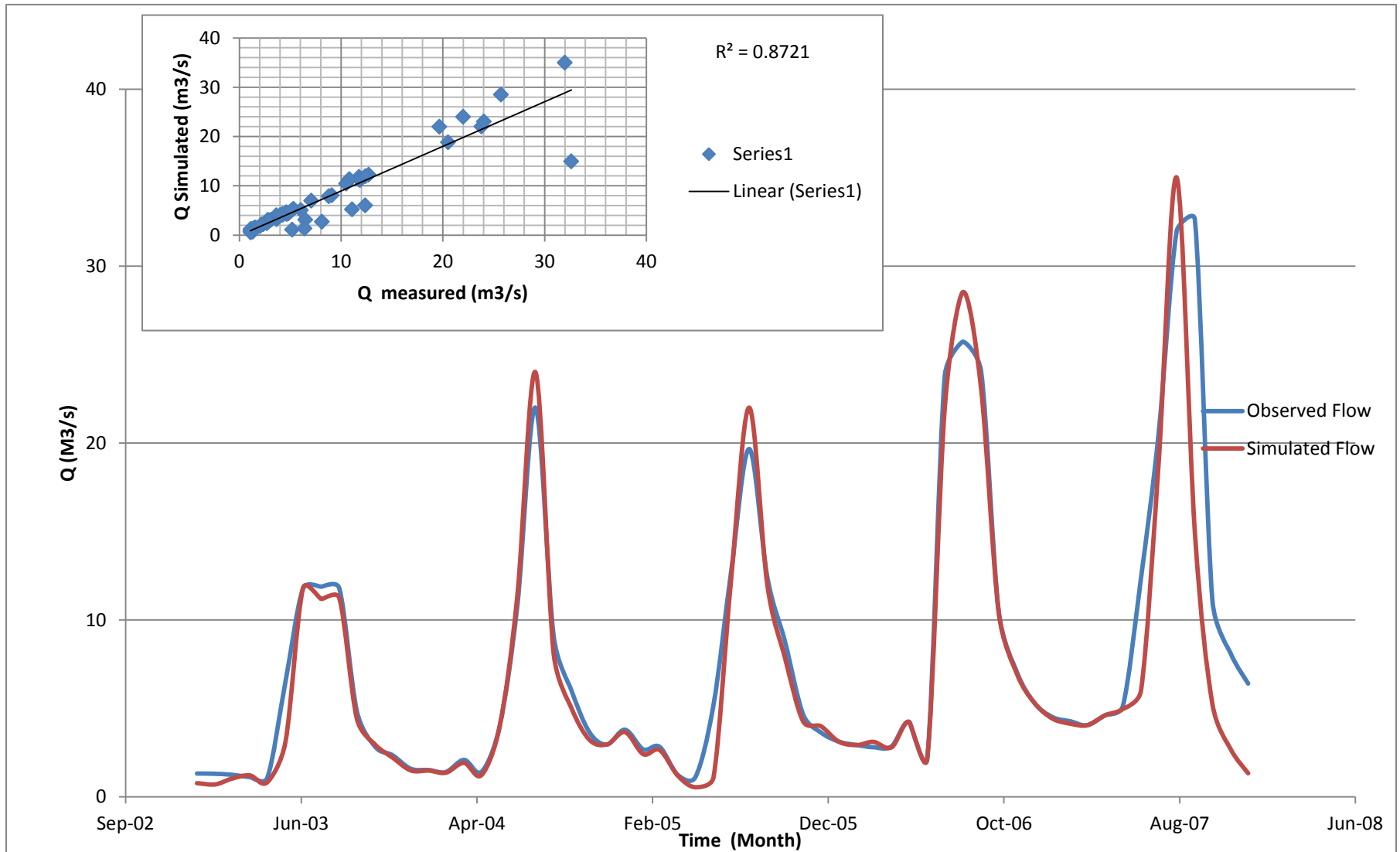


Figure 4. 3 Validation results of average monthly Observed and simulated flow hydrograph (2003- 2008)

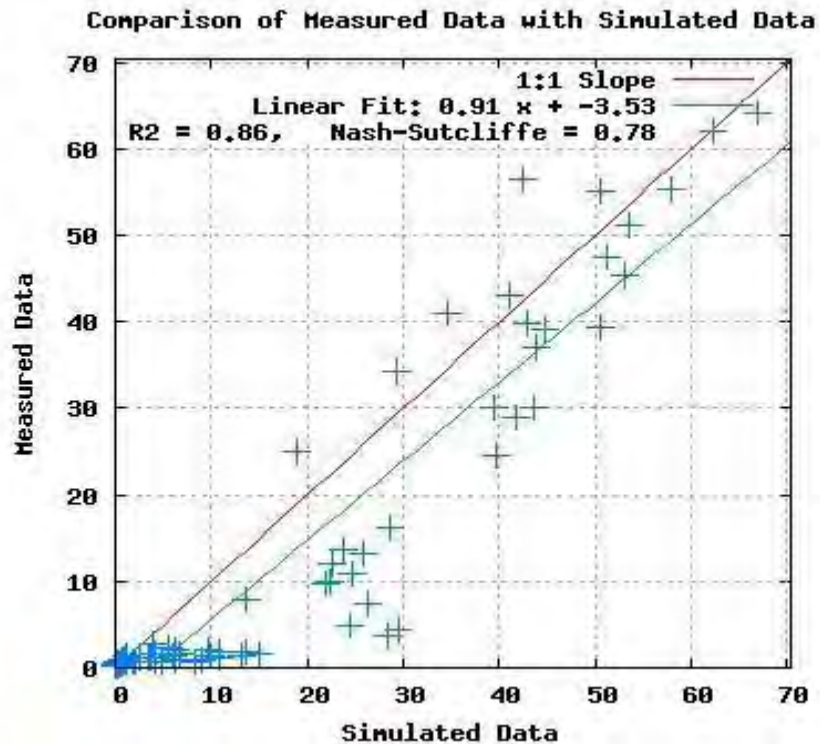


Figure 4. 4 Regression analysis line and 1:1 fit line of Simulated versus observed monthly flow during validation period using web based hydrograph analyst tool

4.1.3 Sediment Yield Simulation

Sediment yield is the amount of sediment transported out of a watershed or sub watershed. This value is used for model calibration and validation because it can be compared against available data sets.

4.1.4 Sediment Yield Sensitivity Analysis

Once it is shown that the flow was accurately represented by the model the focus is shifted to the calibration of the model for sediments. Sensitivity analysis was carried out for sediment to identify parameters that affect sediment yield. About 130 iteration have been done by SWAT sensitivity analysis at the Megech out let sub basin for

sediment calibration with the output of eight parameters out of twelve parameters were reported as sensitive in different degree of sensitivity for sediment. Among these eleven parameters, seven of them have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to high of sensitivity class as shown in Appendix 5.

4.1.5 Sediment Yield Calibration

After sensitivity analysis, the next step was calibrating sediment yield of the watershed. For the years (1994 - 1999) Two year, (1990 -1991) was used for model warm up. So that model was calibrated from 1996 to 2002. The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis that has identified sensitive parameters and has effect on the simulated result when changed for sediment yield of the watershed (see Appendix 5), and by varying iteratively within the allowable ranges of the parameters.

Parameters	Range	Initial (Default) values	Adjusted Parameter
Usle_P	0-1	1	0.9
Sol_Awc	±50%	(0.1071 – 0.238)	+4% =(0.1114 – 0.2475)
Slope	±50%	(0.00345 – 0.4653)	+13% = (0.003903 –
Biomix	0-1	0.2	0.1
Spcon	0.0001-0.01	0.0001	0.0015
Spexp	1-2	1	0.4

Table 4. 4 Default and final calibrated Sediment Parameter values of the watershed

After adjustment of all the above parameters, the model is run again with the calibrated parameters. The model was calibrated for sediment by comparing monthly model simulated sediment load against monthly measured sediment load from Megech station for the period 1990 to 1999.

The SWAT model was found to simulate well on monthly basis of sediment load. Coefficient of determination (R^2) value and Nash-Sutcliffe model efficiency (ENS) statistic computed between the simulated and observed monthly sediment loads for the calibration periods are 0.97 and 0.98 respectively (Table 4.6). The sediment calibration results displayed a -6 % difference between the simulated and average observed monthly load. Calibration results show that model performance is good with simulation of monthly sediment load.

Annual mean sediment yield					
Monthly time step			(Ton/ha/year)		
Simulation	Observed	Simulation	R^2	ENS	D Calibration
(1990 – 1999)	7.92	8.295	0.97	0.98	-6.97%

Table 4. 5 Calibration statistics of observed and simulated sediment load

The hydrograph of the calibration period of the observed and simulated sediment load in monthly basis shows the model slightly over-estimated some of monthly sediment yields of the watershed and slightly under estimate the sediment yield of March of 1994 and in the years 1998. (Figure 4.5 and 4.6).

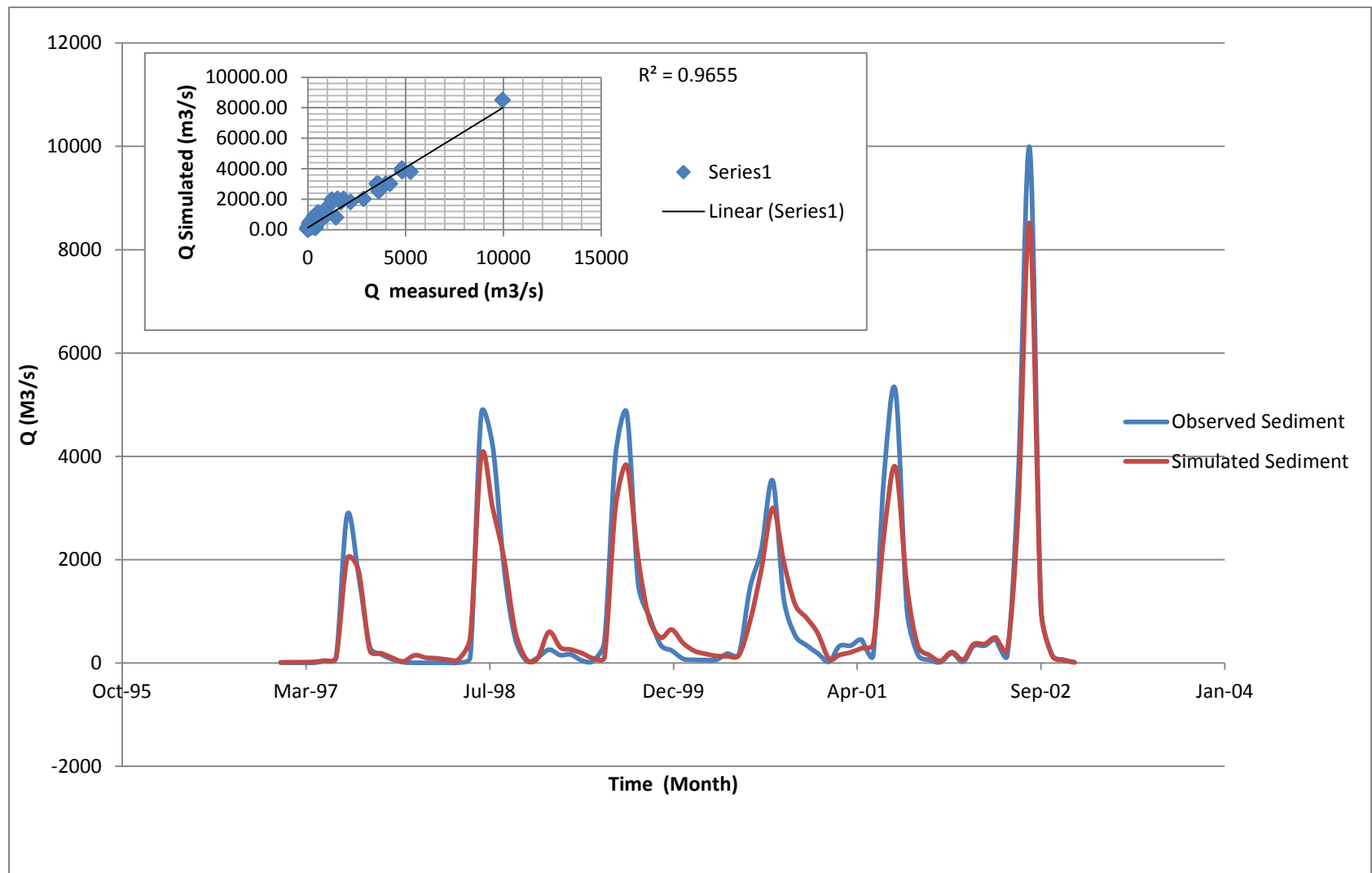


Figure 4. 5 Observed and simulated monthly sediment yield in the calibration period (1996 - 2002)

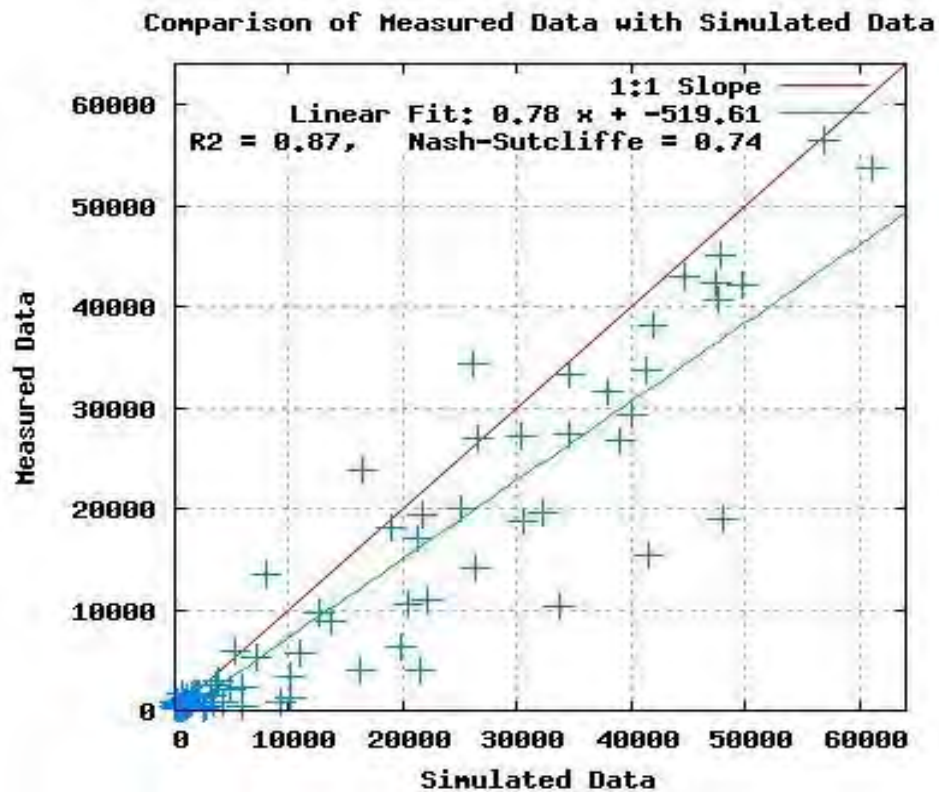


Figure 4. 6 Regression analysis line and 1:1 fit line of observed and simulated monthly sediment yield during calibration period (1992–1999)

4.1.6 Sediment Yield Validation

After calibration then SWAT model was validated to sediment for the period 2001 to 2008 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

The model over estimated high sediment loads in most of calibration and validation periods. Similar to flow, this is may be resulted from limited weather or sediment data used as an input to the model. However, as indicated in the model's performance statistics (Table 4.5) the mean deviation between observed and simulated sediment is only 4.9 % for the calibration and validation period respectively which are within the

acceptable range of +15. The overall time series trend of the measured sediment load is well explained by the simulated sediment in both calibration and validation periods.

The statistical values in the monthly basis of sediment yield estimation in the validation period results the R², ENS and mean deviation (D) of 0.89, 0.79 and 4.91% respectively (Table 4.8). The observed and simulated sediment yield in monthly time step of the validation period shows that model slightly over estimate the sediment yields of highly flow time periods, and in low and medium flow periods the model simulation and the observed sediment yield were good fit but there was also in some months under estimation (Figure 4.7 and 4.8).

	Default)	Calibrated(1990-1999)	validated (2000-2008)
R ²	0.82	0.97	0.97
ENS	0.34	0.98	0.97
D %	-13.1%	6.96%	-11.23%

Table 4. 6 Default, Calibration and validation statistic for monthly observed and simulated Sediment Yield

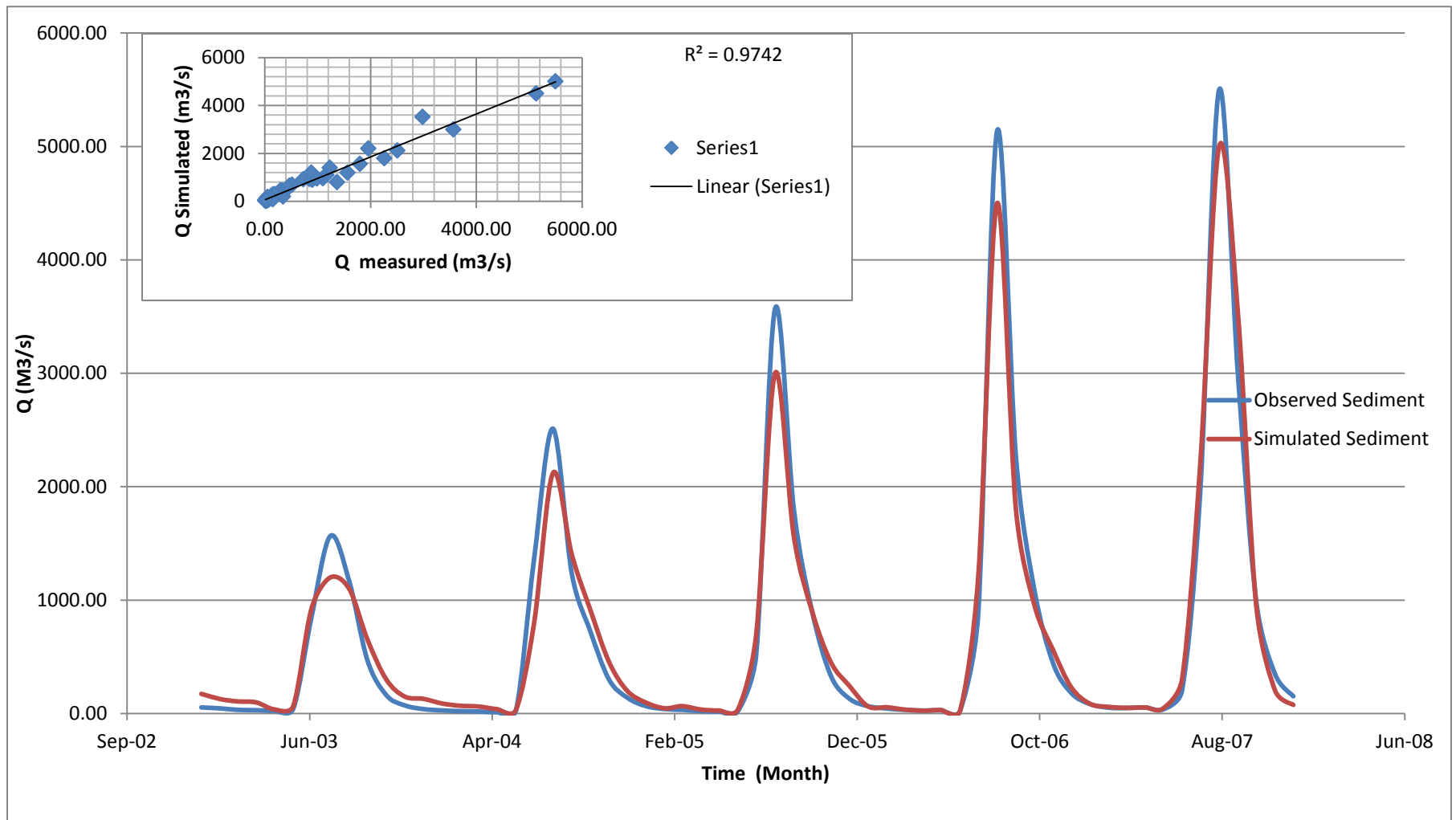


Figure 4. 7 Validation results of average monthly Observed and simulated Sediment yield hydrograph (2003- 2008)

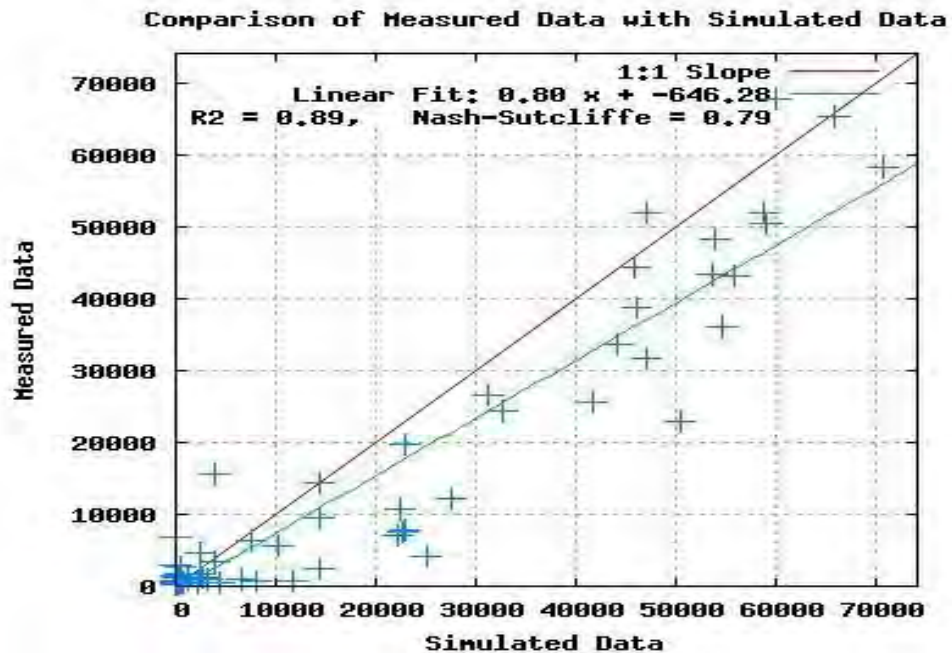


Figure 4. 8 Regression analysis line and 1:1 fit line of Simulated versus observed monthly Sediment yield during validation period using web based hydrograph analysis

4.2 Spatial pattern of Sediment source areas

After Calibration and validation, the model was run for a period 22 years from 1994 to 2015. From the model simulation output, sediment source areas were identified in the Megech Watershed.

The annual average measured suspended sediment generated from the sediment rating curve was 11.70 ton/ha/yr. and the simulated annual average sediment yield by SWAT model was 13.486 t/ha/yr. (See Appendix 6 and 7)

SWAT calculates the soil erosion and sediment yield within each hydrological response units (HRU"s) within each sub basins. The GIS tool combines the slope, Land cover, soil and river layers as a major factor which contributes to soil erosion. The output of the SWAT model has shown that 8.9% of the watershed area has severely eroded and about 30.6% of the watershed area has high potential for soil erosion (Table 4.9) which produces an average annual sediment yield of 8 to 35

tons per hectare which is above the tolerable limit of soil loss rate. Based on the classes assigned to the annual sediment yield, the map was reclassified into four major categories of soil erosion hazards region i.e. low, moderate, high and severe erosion conditions (Map 7 and Table 4.9)

Class	Area (%)	Sediment yield (tons/ha/year)	Remarks
1	5	0 - 6	low
2	30	6 - 12	moderate
3	18	12 - 17	high
4	47	18 - 35	severe

Table 4. 7 Sub basin areas and sediment yield in percent

The output of the SWAT model has shown that 47 % of the watershed area has sever potential for soil erosion (Annex 5) which produces above an average annual sediment yield of 8 to 35 tons per hectare. Based on the classes assigned to the annual sediment yield, the map was reclassified into four major categories of soil erosion hazards region i.e., very low, low, moderate and severe erosion conditions (Map 7).

Based on the model's prediction, sediment yield in the watershed varies from HRU to HRU depending on the type of soil, slope and land use in each HRU. In this study Sub-watersheds 4, 5, 8, 17, 22, 24, 25, and 29 produced the highest sediment yield and more exposed for erosion (Map 7).These watersheds are located in agricultural land, with soil property of Eutric Vertisoil with slope of greater than 25 percent.As discussed above, in the landuse section, Megech water shade is experienced landuse and landcover change from 1998 to 2015.

4.3 Soil Formation and Soil Loss Tolerance

Soil formation rates are vital for evaluation of soil loss rate (the extent to which soil loss can be tolerated) and the potential of soil regeneration once soil erosion can be stopped completely. A study of soil formation rates in different agro ecological zone of Ethiopia indicates that the range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia were 2 to 18 t/ha/yr (Hurni H.)

Map 7 Distribution of SWAT Simulated Annual Sediment yield in Megech watershed sub basins

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this thesis is to predict the amount of Sediment Yield from Megech Dam watershed. In addition to this, to assess and evaluate the spatial variability of sediment yield and identify vulnerable sub-watersheds for erosion and sediment yield in the watershed.

Even though the problem of soil erosion is recognized from gross erosion estimates and field observations, quantitative information and data are required at micro watershed level to develop alternative watershed management plans and for decision making. In this study, attempts were made to characterize the Megech watershed in terms of sediment yield, identification of potential sediment source areas and evaluation of alternative management interventions to reduce the onsite and offsite impact of soil erosion in the watershed.

2008 on a monthly basis to examine its applicability for simulating flows and sediment yields from the Megech watershed. The average monthly simulated flows and sediment yields were compared with the average monthly observed values using graphical and statistical methods. The results showed reliable estimates of average monthly flow and sediment yields with a high coefficient of determination (R^2) and Nash-Sutcliffe model efficiencies (ENS) during both the calibration and validation periods.

As it is looked from the model performance efficiency indicators, coefficient of determination (R^2) and the Nash-Sutcliffe (ENS) are found to be 0.8 and 0.74 in calibration and 0.87 and 0.86 in validation for flow analysis. Similarly, sediment model efficiency indicators R^2 and ENS 0.97 and 0.98 for calibration and 0.97 and 0.97 in validation respectively. Considering, the acceptable limit of the statistical model evaluation criteria; the result indicates a good much between measured and simulated sediment yield.

A good performance of the model in the Validation period indicates that the fitted parameters during calibration period can be taken as a representative set of parameters for Megech watershed.

Therefore, the calibrated model can be used for further simulation and evaluation of alternative scenario analysis can be carried out for other periods using the SWAT model in the watershed

The twenty two year sediment yield simulation result indicates that the simulated annual average sediment yield by SWAT model was 13.48 ton/ha/yr. The result shows annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y at some sub basins. But the average annual sediment yield of the whole Megech watershed is around 13.48 t/ha/yr.

When we compare the result of this study with other studies conducted in this area, the mean annual sediment load estimates by USBR (1964) and BCEOM (1999) for the Megech dam site were 70,000 ton (151 ton/km²/year) and 240,000 ton (576 ton/km²/year), respectively, which are apparently too low for mountainous watersheds with no or little forest cover such as the Megech watershed. Bathymetric survey conducted on Legedadi and Gefersa reservoirs in 1979 and 1989 showed mean annual sediment deposition of 760 ton/km²/year and 1,200 ton/km²/year, respectively with Hydrology Department of the MoWIE conducted bathymetric survey on Angerb reservoir (a tributary of Megech River with watershed area 48 km²) found that a mean annual sediment deposition of 0.14 Mm³ estimated over ten years (1995-2004), taking the density of sediment as 1.2 gm/cc, the sediment yield is 3500 ton/km²/year, which is very high. Studio Pietrangeli (2005) gave a comparison of total sediment load estimate for five hydropower reservoirs table below. The recent study conducted by WWDSE estimate of Megech reservoir sediment yield was 1,170 ton/km²/year. So, the result of this study is within the sediment yield estimate given in Table below.

Hydropower reservoirs	Tons/km ² /year
Gibe 1	1,300
Gojeb	218
Halele-Weabesa	1,200
Chemoga Yeda	1,600
Tekeze	1,283

Table 5 1 Sediment yield estimate for hydropower reservoirs in Ethiopia

The model prediction verified that about 47% of the watershed is erosion potential area contributing very high sediment yield exceeding the tolerance limit (soil formation rate) in the study area and about 18% of the watershed area has high potential for soil erosion which produces above an average annual sediment yield of the watershed.

In general, the SWAT model performed well in predicting both the flow and sediment yields from the study watershed and the results were acceptable. It is a capable tool for further analysis of the hydrological responses in the watershed. The study can be further extended to similar watersheds in the country, particularly in the Blue Nile Basin of Ethiopia, where quantifying the total volume of runoff and sediment yields is urgently required for better land and water resources planning and management purposes.

5.2 Recommendations

The result of this study could help different stakeholders to plan and implement appropriate soil and water conservation strategies in the watershed. The model developed could be used in prediction mode to take appropriate measures in advance. The calibrated model can be used for further analysis of the effect of

climate and land use change as well as to investigate the effect of different management scenarios on stream-flows and sediment yields in the watershed.

As a mitigation measure for prevention of severe erosion and conservation mechanism, it is recommended to cover the mountainous and hilly area with plantation and control further degradation by erosion. Further study is required in different scenarios to decide a type of coverage and extent of application on different sub basins. And also the high sediment yielding areas should be verified by field measurements.

The Model prediction output depends on the quality of input data. One of the constraints in conducting this research work was lack of continuous measured suspended sediment data. The sediment data used for this study were generated from sediment rating curves developed from limited sediment measurement data. There is therefore, possible discrepancy of actual sediment and sediment data derived based on rating curves. However, superior results can be obtained if detail suspended sediment data are used. Hence, responsible bodies should give due attention to the time and frequency of sampling, method of sampling and recording of reliable sediment data together with flow measurement.

Finally, Lots of researchers in the world suggest that SWAT is efficient in predicting suspended sediment yield from a watershed and sediment concentration in streams. Therefore, Ethiopians researchers are beneficial if they use the model for quantifying the total volume of runoff and sediment yields for better land and water resources planning and management purposes.

Appendix 1 Mean Monthly Annual Stream Flow data of Megech River at gaging site

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Year
1960	1.553	1.185	1.205	0.674	0.750	1.685	34.792	334.666	39.191	9.214	2.748	1.607	429.3
1961	0.750	0.677	0.321	0.337	0.295	2.255	14.838	83.673	36.081	6.616	4.147	4.178	154.2
1962	1.446	1.306	2.089	1.115	1.339	1.866	5.437	58.925	44.582	14.999	3.110	1.178	137.4
1963	0.589	0.532	0.375	0.441	0.804	1.529	9.428	85.012	21.747	6.696	2.281	1.795	131.2
1964	1.259	1.452	1.178	1.037	1.393	6.610	54.639	95.458	44.790	11.678	4.588	2.652	226.7
1965	1.527	0.895	1.259	6.739	0.589	1.296	21.293	54.934	12.701	9.749	4.406	1.821	117.2
1966	0.937	0.605	0.375	0.337	0.830	2.281	7.473	83.352	25.168	6.080	3.214	1.473	132.1
1967	0.911	0.363	0.562	0.648	0.857	2.955	55.068	73.067	20.710	9.535	2.903	1.446	169.0
1968	0.670	0.266	0.134	0.104	0.482	6.065	30.132	40.390	9.876	5.169	1.529	0.991	95.8
1969	0.482	0.169	0.321	0.156	0.402	0.881	16.767	77.406	12.442	4.232	1.115	0.482	114.9
1970	0.295	0.121	0.134	0.181	0.295	1.322	6.026	47.247	32.141	3.616	1.218	0.723	93.3
1971	0.429	0.266	0.134	0.104	0.589	1.685	28.230	151.356	27.864	2.277	1.555	0.937	215.4
1972	0.750	0.387	0.295	0.492	0.750	0.985	3.161	58.014	15.241	2.732	2.203	1.286	86.3
1973	0.804	0.726	0.830	1.089	2.625	3.966	10.446	87.637	11.301	3.375	0.829	0.107	123.7
1974	0.616	0.363	0.214	0.130	4.634	20.088	30.668	82.615	21.280	4.928	2.981	2.518	171.0
1975	0.295	0.339	0.268	0.467	0.723	5.702	33.409	83.820	125.479	2.625	2.981	1.420	257.5
1976	0.589	0.266	0.402	0.622	1.071	30.197	36.855	83.820	50.674	5.009	6.065	2.518	218.1
1977	1.232	0.726	0.589	0.233	1.795	4.329	23.275	144.339	45.775	5.491	2.048	1.071	230.9
1978	0.804	0.460	0.375	0.518	0.964	2.540	42.479	68.728	37.869	8.866	2.903	1.527	168.0
1979	0.268	0.145	0.295	0.441	4.232	1.970	18.133	31.337	3.007	1.178	0.415	0.187	61.6
1980	0.107	0.121	0.080	0.337	0.268	3.007	76.522	119.430	84.084	8.946	2.773	1.848	297.5
1981	1.045	0.556	0.589	0.907	1.714	1.555	20.624	151.705	25.168	4.393	3.084	1.795	213.1
1982	1.286	0.798	0.830	0.492	1.018	1.218	4.848	45.613	15.526	3.134	1.659	1.071	77.5
1983	0.268	0.266	0.187	0.285	0.643	1.607	11.678	75.370	31.519	1.286	0.648	0.429	124.2
1984	0.295	0.145	0.107	0.130	0.402	97.874	116.135	72.397	34.422	1.607	0.674	0.348	324.5
1985	0.214	0.169	0.134	0.259	0.723	1.633	39.131	57.992	98.755	4.098	1.711	0.562	205.4
1986	0.375	0.314	0.295	0.311	0.295	11.431	30.752	106.507	73.198	4.741	0.959	0.482	229.7
1987	0.562	0.266	0.214	0.181	2.062	5.858	12.937	111.100	11.120	2.759	1.374	0.562	149.0
1988	0.348	0.363	0.214	0.181	0.295	0.855	26.727	142.450	45.179	10.794	3.784	1.420	232.6
1989	0.964	0.605	0.750	0.778	1.928	7.776	18.026	160.865	12.571	1.205	0.674	0.509	206.7
1990	0.295	0.169	0.134	0.130	0.295	1.918	79.897	72.478	28.071	2.464	0.804	0.536	187.2
1991	0.321	0.218	0.295	0.518	0.268	17.444	14.383	169.944	13.141	3.482	0.829	0.402	221.2
1992	0.268	0.169	0.268	0.959	0.562	0.907	46.149	131.992	118.584	6.214	2.540	1.473	310.1
1993	0.827	0.674	0.673	0.763	2.150	2.878	23.632	64.831	35.909	11.768	3.201	0.811	148.1
1994	0.801	0.371	0.247	0.220	1.024	6.535	31.392	106.969	32.423	4.088	2.268	1.249	187.6
1995	0.669	0.410	0.413	0.378	2.468	11.973	32.157	117.380	16.999	1.247	0.402	0.242	184.7
1996	0.074	0.035	0.031	0.500	3.995	29.872	40.925	89.013	20.271	5.505	2.554	1.289	194.1
1997	0.796	0.473	0.512	0.498	2.887	15.576	61.058	51.784	11.137	7.719	4.099	1.363	157.9
1998	0.547	0.403	0.579	0.520	1.006	5.606	66.625	122.698	41.527	15.476	2.867	5.457	263.3
1999	4.747	3.506	3.715	3.889	8.116	7.390	32.124	95.901	47.155	28.910	15.983	12.410	263.8
2000	10.167	6.725	7.576	10.405	10.158	13.481	34.032	71.411	32.154	23.543	12.086	9.771	241.5
2001	8.273	7.858	11.911	11.780	14.756	6.695	59.095	115.347	24.788	7.327	3.779	1.489	273.1
2002	0.996	0.526	0.594	0.368	0.760	3.389	47.963	50.685	18.970	7.123	5.414	4.445	141.2
2003	3.539	3.162	3.350	2.911	2.887	16.835	44.898	104.139	30.539	12.971	7.368	6.304	238.9
2004	4.263	3.805	3.77	5.43	3.81	10.44	55.75	90.86	23.58	16.20	9.48	7.935	235.3
Mean	1.3	1.0	1.1	1.3	2.0	8.5	33.6	96.1	34.8	7.1	3.2	2.1	192.0
Max	10.2	7.9	11.9	11.8	14.8	97.9	116.1	334.7	125.5	28.9	16.0	12.4	429.3
Min	0.1	0.0	0.0	0.1	0.3	0.9	3.2	31.3	3.0	1.2	0.4	0.1	61.6
STDEV	2.0	1.6	2.1	2.5	2.8	15.4	23.1	49.8	27.0	5.8	3.0	2.6	73.4
75%	0.0	0.0	0.0	0.0	0.1	0.0	18.0	62.5	16.6	3.2	1.2	0.4	101.9
85%	0.0	0.0	0.0	0.0	0.0	0.0	9.6	44.5	6.8	1.2	0.1	0.0	62.1

Appendix 2 Ministry of Water, Irrigation and Electric / Hydrology and Water Quality Directorate Laboratory Result of

Sediment

Suspension Analysis

Sampled by _____ Hydrology Technicians
 Conducted by _____ Lab technician
 Checked by _____

No.	Field Sam. No.	Lab. Lab.No.	River / Stream	Station	Basin	Region	Date & Time of Sampling	Time Taken (Sec)	G/height (m)	Flow (m ³ /s)	Depth (m)	Width (m)	Sediment Conc. (mg/l)
1	1		Megech	Azezo	Abbay	Bahir Dar	21-Feb-90	59	0.74	0.044	0.10	0.700	186.76
2	2		Megech	Azezo	Abbay	Bahir Dar	21-Feb-90	61	0.74	0.044	0.09	1.700	177.06
3	3		Megech	Azezo	Abbay	Bahir Dar	21-Feb-90	60	0.74	0.044	0.04	2.500	229.99
4	1		Megech	Azezo	Abbay	Bahir Dar	10-Aug-90	30	1.29	8.960	0.62	6.000	8307.19
5	2		Megech	Azezo	Abbay	Bahir Dar	10-Aug-90	25	1.29	8.960	0.660	12.000	594.06
6	3		Megech	Azezo	Abbay	Bahir Dar	10-Aug-90	25	1.29	8.960	0.35	18.000	451.56
7	1		Megech	Azezo	Abbay	Bahir Dar	27-May-92	35	0.75	0.046	0.03	0.400	368.00
8	2		Megech	Azezo	Abbay	Bahir Dar	27-May-92	31	0.75	0.046	0.10	0.800	368.00
9	3		Megech	Azezo	Abbay	Bahir Dar	27-May-92	27	0.75	0.046	0.17	1.200	315.00
10	1		Megech	Azezo	Abbay	Bahir Dar	14-May-93	68	0.83	0.192	0.33	1.100	454.52
11	2		Megech	Azezo	Abbay	Bahir Dar	14-May-93	20	0.83	0.192	0.36	2.300	628.70
12	3		Megech	Azezo	Abbay	Bahir Dar	14-May-93	6	0.83	0.192	0.21	2.500	528.90
13	1		Megech	Azezo	Abbay	Bahir Dar	6-Oct-94	37	1.00	2.610	0.57	2.200	253.24
14	2		Megech	Azezo	Abbay	Bahir Dar	6-Oct-94	38	1.00	2.610	0.58	4.200	188.67
15	3		Megech	Azezo	Abbay	Bahir Dar	6-Oct-94	40	1.00	2.610	0.36	6.200	245.37
16	1	444/05	Megech	Azezo	Abbay	Bahir Dar	11-Mar-05	70	1.09	0.108	0.30	1.00	300.00
17	2		Megech	Azezo	Abbay	Bahir Dar	11-Mar-05	45	1.09	0.108	0.35	2.00	289.43

No.	Field Sam. No.	Lab. Lab.No.	River / Stream	Station	Basin	Region	Date & Time of Sampling	Time Taken (Sec)	G/height (m)	Flow (m ³ /s)	Depth (m)	Width (m)	Sediment Conc. (mg/l)
18	3		Megech	Azezo	Abbay	Bahir Dar	11-Mar-05	92	1.09	0.108	0.34	2.60	
19	1	171/05	Megech	Azezo	Abbay	Bahir Dar	2-Sep-05	11	1.60	9.614	0.74	6.00	277.68
20	2		Megech	Azezo	Abbay	Bahir Dar	2-Sep-05	13	1.60	9.614	0.54	12.00	280.75
21	3		Megech	Azezo	Abbay	Bahir Dar	2-Sep-05	22	1.60	9.614	0.32	18.00	204.87
22	1	172/05	Megech	Azezo	Abbay	Bahir Dar	3-Sep-05	11	1.57	9.782	0.74	6.00	191.58
23	2		Megech	Azezo	Abbay	Bahir Dar	3-Sep-05	10	1.57	9.782	0.52	12.00	210.99
24	3		Megech	Azezo	Abbay	Bahir Dar	3-Sep-05	12	1.57	9.782	0.24	18.00	213.42
25	1	173/05	Megech	Azezo	Abbay	Bahir Dar	4-Sep-05	10	1.54	8.665	0.70	6.00	189.43
26	2		Megech	Azezo	Abbay	Bahir Dar	4-Sep-05	9	1.54	8.665	0.49	12.00	223.06
27	3		Megech	Azezo	Abbay	Bahir Dar	4-Sep-05	9	1.54	8.665	0.34	18.00	204.35
28	1	112/00	Megech	Azezo	Abbay	Bahir Dar	15-Aug-07	8	1.86	17.236	1.95	3.00	564.06
29	2		Megech	Azezo	Abbay	Bahir Dar	15-Aug-07	9	1.86	17.236	1.46	6.00	650.00
30	3		Megech	Azezo	Abbay	Bahir Dar	15-Aug-07	15	1.86	17.236	0.91	9.00	529.19
31	1	113/00	Megech	Azezo	Abbay	Bahir Dar	16-Aug-07	9	2.22	45.996	2.44	4.00	2361.52
32	2		Megech	Azezo	Abbay	Bahir Dar	16-Aug-07	9	2.22	45.996	1.49	8.00	2070.91
33	3		Megech	Azezo	Abbay	Bahir Dar	16-Aug-07	14	2.22	45.996	0.85	12.00	1681.16
34	1	114/00	Megech	Azezo	Abbay	Bahir Dar	18-Aug-07	7	2.25	49.332	2.50	4.00	2441.94
35	2		Megech	Azezo	Abbay	Bahir Dar	18-Aug-07	8	2.25	49.332	1.52	7.50	2671.01
36	3		Megech	Azezo	Abbay	Bahir Dar	18-Aug-07	13	2.25	49.332	0.91	11.50	2310.27
37	1	115/00	Megech	Azezo	Abbay	Bahir Dar	19-Aug-07	18	1.90	21.405	0.85	3.00	628.62
38	2		Megech	Azezo	Abbay	Bahir Dar	19-Aug-07	10	1.90	21.405	1.46	6.00	504.74
39	3		Megech	Azezo	Abbay	Bahir Dar	19-Aug-07	7	1.90	21.405	0.88	9.00	382.29
40	1	116/00	Megech	Azezo	Abbay	Bahir Dar	20-Aug-07	10	1.90	23.985	6.60	4.00	581.00

No.	Field Sam. No.	Lab. Lab.No.	River / Stream	Station	Basin	Region	Date & Time of Sampling	Time Taken (Sec)	G/height (m)	Flow (m ³ /s)	Depth (m)	Width (m)	Sediment Conc. (mg/l)
41	2		Megech	Azezo	Abbay	Bahir Dar	20-Aug-07	17	1.90	23.985	3.80	8.00	852.05
42	3		Megech	Azezo	Abbay	Bahir Dar	20-Aug-07	29	1.90	23.985	2.00	12.00	709.87
43	1	117/00	Megech	Azezo	Abbay	Bahir Dar	21-Aug-07	7	2.16	41.816	7.40	4.00	1004.72
44	2		Megech	Azezo	Abbay	Bahir Dar	21-Aug-07	8	2.16	41.816	4.90	8.00	1261.43
45	3		Megech	Azezo	Abbay	Bahir Dar	21-Aug-07	7	2.16	41.816	2.80	12.00	1198.84
46	1	243/00	Megech	Azezo	Abbay	Bahir dar	22-Nov-07	35	1.32	0.701	0.30	3.00	301.43
47	2		Megech	Azezo	Abbay	Bahir dar	22-Nov-07	34	1.32	0.701	0.46	6.00	262.86
48	3		Megech	Azezo	Abbay	Bahir dar	22-Nov-07	45	1.32	0.701	0.42	9.00	255.00
49	1	031/03	Megech	Azezo	Abbay	Bahir Dar	17-Aug-10	15	2.060	21.991	2.16	4.000	609.75
50	2		Megech	Azezo	Abbay	Bahir Dar	17-Aug-10	20	2.060	21.991	1.25	8.000	930.00
51	3		Megech	Azezo	Abbay	Bahir Dar	17-Aug-10	23	2.060	21.991	0.79	12.000	978.00
52	1	032/03	Megech	Azezo	Abbay	Bahir Dar	18-Aug-10	14	2.000	20.277	2.01	3.500	983.21
53	2		Megech	Azezo	Abbay	Bahir Dar	18-Aug-10	18	2.000	20.277	1.40	7.000	776.10
54	3		Megech	Azezo	Abbay	Bahir Dar	18-Aug-10	37	2.000	20.277	0.73	10.500	886.25
55	1	075/11	Megech	Azezo	Abbay	Bahir Dar	14-Oct-11	57	1.600	1.559	0.32	2.400	133.01
56	2		Megech	Azezo	Abbay	Bahir Dar	14-Oct-11	42	1.600	1.559	0.52	4.950	148.68
57	3		Megech	Azezo	Abbay	Bahir Dar	14-Oct-11		1.600	1.559	0.54	7.450	113.08
58	1	076/11	Megech	Azezo	Abbay	Bahir Dar	15-Oct-11	60	1.580	1.480	0.34	2.400	258.29
59	2		Megech	Azezo	Abbay	Bahir Dar	15-Oct-11	38	1.580	1.480	0.60	5.400	130.37
60	3		Megech	Azezo	Abbay	Bahir Dar	15-Oct-11	48	1.580	1.480	0.54	7.900	183.49
61	1		Megech	Azezo	Abbay	Bahir Dar	6-Jun-13	27	1.480	1.770	0.36	3.000	63847.95
62	2		Megech	Azezo	Abbay	Bahir Dar	6-Jun-13	28	1.480	1.770	0.35	6.000	64356.75
63	3		Megech	Azezo	Abbay	Bahir Dar	6-Jun-13	30	1.480	1.770	0.35	12.500	60956.67

No.	Field Sam. No.	Lab. Lab.No.	River / Stream	Station	Basin	Region	Date & Time of Sampling	Time Taken (Sec)	G/height (m)	Flow (m ³ /s)	Depth (m)	Width (m)	Sediment Conc. (mg/l)
64	1		Megech	Azezo	Abbay	Bahir Dar	24-May-14	20	1.60	4.404	0.44	8.850	2115.44
65	2		Megech	Azezo	Abbay	Bahir Dar	24-May-14	25	1.60	4.404	0.34	16.850	2119.04
66	3		Megech	Azezo	Abbay	Bahir Dar	24-May-14	25	1.60	4.404	0.48	23.850	2073.58
67	1		Megech	Azezo	Abbay	Bahir Dar	26-Jun-14	40	1.32	0.782	0.28	6.000	3730.77
68	2		Megech	Azezo	Abbay	Bahir Dar	26-Jun-14	46	1.32	0.782	0.18	12.500	3597.21
69	3		Megech	Azezo	Abbay	Bahir Dar	26-Jun-14	32	1.32	0.782	0.25	17.500	3780.86

Appendix 3 Soil Parameters of the study area used in SWAT Model

VALUE	SNAM	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1
1	Chromic Luvisols	0.00000	3	D	1600.00	0.000	0.000	C-C-C	300.01	1.10	0.08	0.50	2.00	58.00	33.00	9.00
2	Eurotic Leptosols	0.00000	2	B	900.00	0.000	0.000	CL-C	200	1.41	0.08	0.50	2.00	39.00	35.00	26.00
3	Eurotic Vertisols	0.00000	3	C	1800.00	0.000	0.000	C-C-C	300.01	1.10	0.08	0.50	2.00	68.00	25.00	7.00
4	Habtic Nitisols	0.00000	3	D	1800.00	0.000	0.000	C-C-C	300.01	1.10	0.08	0.50	2.00	57.00	30.00	13.00
5	Rock Surface	5	1	D	1524	0.5	0.5	UWB	1524	2.5	0.01	180	0	5	25	70

VALUE	SNAM	ROCK1	SOL_ALB1	USLE_K1	SOL_EC1	SOL_Z2	SOL_BD2	SOL_AWC2	SOL_K2	SOL_CBN2	CLAY2	SILT2	SILT2	SAND2	SAND2	ROCK2
1	Chromic Luvisols	4.00	0.15	0.25	0.00	700.01	1.36	0.08	0.30	0.15	65.00	26.00	26.00	9.00	9.00	5.00
2	Eurotic Leptosols	4.00	0.15	0.25	0.00	900.02	1.36	0.08	0.30	0.15	56.00	25.00	25.00	19.00	19.00	5.00
3	Eurotic Vertisols	4.00	0.13	0.2	0.00	800.01	1.36	0.08	0.30	0.15	74.00	19.00	19.00	7.00	7.00	5.00
4	Habtic Nitisols	4.00	0.14	0.23	0.00	800.01	1.36	0.08	0.30	0.15	68.00	22.00	22.00	10.00	10.00	5.00
5	Rock Surface	98	0.23	0.01	0	0	0	0	0	0	0	0	0	0	0	0

VALUE	SNAM	SOL_ALB2	USLE_K2	SOL_EC2	SOL_Z3	SOL_BD3	SOL_AWC3	SOL_K3	SOL_CBN3	CLAY3	SILT3	SAND3	ROCK3	SOL_ALB3	USLE_K3	SOL_EC3
1	Chromic Luvisols	0.12	0.12	0.00	1600.02	1.36	0.08	0.30	0.05	68.00	22.00	10.00	7.00	0.12	0.12	0.00
2	Eurotic Leptosols	0.15	0.25	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Eurotic Vertisols	0.11	0.08	0.00	1800.02	1.36	0.08	0.30	1.00	74.00	17.00	9.00	7.00	0.11	0.08	0.00
4	Habtic Nitisols	0.14	0.23	0.00	1800.00	1.36	0.08	0.30	0.05	74.00	19.00	7.00	7.00	0.14	0.23	0.00
5	Rock Surface	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4 Result of sensitive analysis of flow parameters in Megech watershed

Rank	Parameter Description	SWAT Parameter Code	Mean Sensitivity	Category of Sensitivity
1	Base Flow alpha factor (days)	Alpha_Bf	0.0954	High
2	Soil evaporation compensation factor (unitless)	Esco	0.0922	High
3	Soil depth (mm)	Sol_Z	0.0606	High
4	SCS-CN for moisture condition II (unitless)	Cn2	0.0514	High
5	Maximum Potential Leaf Area Index (unitless)	Blai	0.0475	Medium
6	Threshold depth of water in the shallow aquifer required for reevaporation to occur (mm)	Revapmn	0.046	Medium
7	Maximum Canopy Index (mm)	Canmx	0.0443	Medium
8	Available water capacity of the soil layer (mm/mm)	Sol_Awc	0.0429	Medium
9	Groundwater reevaporation coefficient (unitless)	Gw_Revap	0.0252	Medium
10	Plant evaporation compensation factor (unitless)	Epco	0.00706	Low
11	Effective Channel Hydraulic Conductivity (mm/h)	Ch_K2	0.00676	Low
12	Average slope steepness (m/m)	Slope	0.00473	Low
13	Ground water delay (days)	Gw_Delay	0.00453	Low
14	Soil Albedo	Sol_Alb	0.0043	Low
15	Soil conductivity (mm/h)	Sol_K	0.00292	Low
16	Maximum Potential Leaf Area Index (unitless)	Biomix	0.00162	Low
17	Manning coefficient for channel (unitless)	Ch_N2	0.00152	Low
18	Surface runoff lag coefficient	Surlag	0.00101	Low
19	Average slope length (m)	Ssubbsn	0.000884	Low
20	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Gwqmn	0.000398	Low
21	Snowfall temperature (°C)	Sftmp	0	Negligible
22	Snowmelt base temperature (°C)	Smfmn	0	Negligible
23	Maximum snowmelt rate (mm/°C/day)	Smfmx	0	Negligible
24	Snowmelt base temperature (°C)	Smtmp	0	Negligible
25	Snowpack temperature lag factor	Timp	0	Negligible
26	Temperature lapse rate (°C/km)	Tlaps	0	Negligible

Appendix 5 Result of sensitive analysis of Sediment parameters in Megech watershed

Rank	Parameter Description	SWAT Parameter Code	Mean Sensitivity Index	Category of Sensitivity
1	USLE Support Practice factor	Usle_P	2.59	Very High
	Available water capacity of the			
3	Average slope steepness	Slope	0.903	High
	Maximum Potential Leaf Area			
	Linear factor for channel sediment			
6	Soil Albedo	Sol_Alb	0.0541	High
7	Soil conductivity (mm/h)	Sol_K	0.0307	High
	Exponential factor for channel			
9	Channel Cover factor	Ch_Cov	0.019	Medium
10	Channel Erodeability factor	Ch_Erod	0.015	Medium
11	USLE cover factor	Usle_C	0.012	Medium

Appendix 6 Average Monthly Megech Watershad Value Of SWAT Output

Month	SNOW				WATER		SED	
	RAIN	FALL	SURF Q	LAT Q	YIELD	ET	YIELD	PET
	(MM)	(MM)	(MM)	(MM)	(MM)	(MM)	(T/HA)	(MM)
1	3.53	0	0.04	9.67	12.25	8.08	0	91.22
2	3.23	0	0.02	7.52	8.66	7.05	0	94.29
3	16.94	0	0.2	7.24	8.31	35.13	0	110.27
4	39.31	0	0.32	6.15	7.22	52.71	0.01	108.17
5	92.64	0	4.83	5.96	11.63	65.44	0.24	116.99
6	178.73	0	17.63	6.37	28.24	68.76	1.23	95.02
7	318.81	0	61.52	10.29	96.58	75	5.6	96.81
8	295.53	0	65.37	15.5	149.23	66.5	6.22	90.9
9	107.16	0	8.5	16.23	89.18	59.68	0.89	98.15
10	68	0	6.84	15.28	57.91	48.17	1.08	98.56
11	19.47	0	0.24	12.94	29.81	30.04	0	87.12
12	7.87	0	0.09	11.46	18.85	19.33	0	84.88

Appendix 7 Annual Megech watershed values of SWAT Output

Parameters	Value
Precipitation	1151.3mm
Snow fall	0.00 mm
Snow melt	0.00mm
Surface Runoff Discharge	165.58mm
Lateral soil Discharge	124.67mm
Groundwater (shal. Aq.)	211.63mm
Deep aq. recharge	16.07mm
Total aq recharge	322.56mm
Total water Yield	517.94mm
Percolation out of soil	322.56mm
Actual evapotranspiration (ET)	535.9mm
Potential evapotranspiration (PET)	1173.1mm
<u>Total Sediment Loading</u>	<u>13.49 t/ha</u>

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