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Runoff and Sediment Yield Modeling in Laga Dadi Reservoir and its Watersheds

By

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Runoff and Sediment Yield Modeling in Laga Dadi Reservoir and its Watersheds

A thesis *proposal* submitted in partial fulfillment of the requirement for the degree of Masters of Science in Hydraulic Engineering

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APPROVAL PAGE

This thesis is entitled with "Runoff and Sediment Yield Modeling, A case study of Lege Dadi Dam Watershed, Upper Awash, Ethiopia" has been approved by the following advisor, examiners, and department head in the partial fulfillment of the Master of Science in Hydraulics Engineering.

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ABSTRACT

Reservoir sedimentation is a serious moment of surface runoff and soil erosion with large environmental and economic implications. Deposition of sediment in reservoirs reduces the storage capacity of the reservoirs and affects the operation and stability of the dams. The main objective of this study is to assess runoff & sediment yield at Laga Dadi reservoir and its catchment and identify hotspot areas of the watershed in runoff & sediment yield.

The outlined objective is attained by a physical based hydrological model Soil and Water Assessment Tool (SWAT). Daily runoff and sediment data from 1994-2009 were used in this study. Data from 1994-2003 were used for calibration and 2004-2009 for validation. Following the successful calibration and validation of the model on the study area, runoff and sediment yield have been estimated.

The annual runoff volume generated on the watershed was estimated to be 654.5 mm as it is known that SWAT Generate Runoff in mm. The total simulated mean annual Sediment yield loading from Laga Dadi watershed simulated is 6.73 ton/ha/yr. The total mean annual sediment yield that is drawn from Laga Dadi watershed predicted by SWAT model is found to be 138146.71 tons. The model prediction verified that about 17% of the watershed around the dam site has erosion potential area contributing very high sediment yield exceeding the tolerance limit.

Hence, the researcher recommends conservation and environmental protection in upper catchments, tributary rivers site and on the spot, area shall be done continuously.

Key Words:

Sedimentation, Stream Flow; Sediment Yield; Laga Dadi Catchment

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List of Abbreviations

AAWSA	Addis Ababa Water and Sewerage Authority
CN	Curve Number
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
HRU	Hydrologic Response Unit
MoWIE	Ministry of Water, Irrigation and Energy
PBIAS	Percent Bias
PE	Processing Element
NSE	Nash Sutcliffe Efficiency
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Education, Science and Culture Organization
WXGEN	Weather Generator

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CHAPTER ONE

1.0. INTRODUCTION

1.1. GENERAL

Ethiopia has been experiencing persistent land, water, and environmental degradation due to localized and global climatic inconsistencies and it's been increasing at an alarming rate and therefore the effect of worldwide warming has been viewed in Ethiopia climatic change throughout the country regardless of the character of the topography (Zemenfes, 1995).

The poor land-use practices, inappropriate and lack of management systems of conservation measures are major reasons for erosion and land degradation problems within the country (Zemenfes, 1995). The rates of erosion and land degradation in Ethiopia are high due to the topography and high rate of deforestation, because of these 34% of the land in Ethiopia soil depth is already but 35 cm (Zemenfes, 1999) (SCRP, 1999). This therefore degradation of land through erosion is increasing at a high rate. Hence, it will be forced to request for fast measures to save lots of the soil and water resources before collapse of the country (Amare, 2005).

River is not only conveying water but it also carries erosion products like clay, sand, boulders gravel, and silt from its catchment Getnet (2012). If we build reservoir, deposition of sediment can occur (Luis, Estimation of Sediment Transport and Dominant Flow during a Hyper Concentrated Flow, 2006). Some revolution in land might be, harmful if they're not properly taken care and many reservoirs including Laga Dadi are affected by excessive sedimentation because either the upstream sediment supply was never considered or the significance of this process is underestimated mainly due to lack of sufficient data (Gesese, 2008). (Addis Ababa Water and Sewerage Authority, 1999)

Change in sediment yield due to changed land use within the upstream catchments causes harmful sedimentation (Wischmeier & Smith, 1978). Therefore, an all-inclusive understanding of hydrological processes within the watershed may be a requirement for successful water management and environmental restoration. So, analyzing the sediment yield of Laga Dada dam watershed concerning quantity and quality of runoff is important for the right and sustainable utilization of Laga Dadi dam water system Project to extend its life and minimalize the value of removing sedimentation ((Gesese, 2008); (Getnet, 2012) (Tahal & Metaferia Consulting Engineers, 2002)).

This research is showing run off and sedimentation yield of Lag Dadi Dam and its Watershed and also give a basis for future scenario to analysis water resource management of Laga Dadi dam catchment and also to guage the SWAT model capability to predict the sediment yield of Upper Laga Dadi River catchment to the Laga Dadi dam reservoir

1.2. Statement of the Problem

Like many other parts of the planet, erosion affects the equilibrium of the ecosystems in Ethiopia due to on-site and off-site impacts, repeatedly causing permanent land degradation and sedimentation of the reservoirs (Zemenfes, 1995). Sedimentation may be a major problem for all the reservoirs in Ethiopia (Gesese, 2008). Several reservoirs that are established for hydroelectric power, urban water system, and irrigation accumulate an alarmingly higher level of sediment than expected, Ribb, Koka, Angereb, Laga Dadi, Gilgel Gibe I, and other reservoirs are endangered by this accelerated sedimentation (Kebede, 2012), (Gesese, 2008). This is often mainly due to lack of adequate database and lack of appropriate methodologies and methods to plan for erosion, sedimentation, and watershed management within the landscapes combined with the high potential erosion rate (Neitsch, Arnold, Kiniry, &Williams, 2005).

Arnold, Williams & Maidment (1995) describe that there is no full understanding concerning the interdependence between the sediment yield and watershed on different spatial and temporal heterogeneity in soil properties, vegetation, and land-use practices during a river catchment. As results of this, there aren't any thorough studies that considered the complex hydrologic system for study catchments during a special area to identify the extent of sediment (Arnold, Williams & Maidment, 1995). Both mathematical and parametric methods require plenty of data, which can be a serious constraint in many developing countries (Yanda, 1995). Less developing countries have a scarcity of accurate erosion prediction models although universal soil loss equation (USLE) is used in several tropical countries (Mulengera, 1999). Meanwhile, kind of a way less developing nation, Ethiopia experiences the challenge. Particularly, the magnitude of sediment transported by the upper Laga Dadi catchment has become a big concern for existing dam and future planning, design, and expansion through a very near study didn't exist with the upper predicting model (Gesese, 2008).

During study of plan review creation of Geffersa, Lagadadi and Dra Catchments, the Laga Dadi reservoir has lost 2.1 Mcm of volume between 1979 and 1998 (Dar-Al Oran, 2011). Hence, this research will study rune off and sedimentation in Laga Dadi Dam and its watershed by using the SWAT model hoping it's a really important tool. Hence, the present study will use the tactic for the Modeling of runoff and sedimentation within the Laga Dadi dam and its watershed.

1.3. Research Question

The current research intended to answer the following research question presented below here

- ☆ What the sediment inflow to the Laga Dadi dam reservoir in per annum?
- ☆ What Area in the catchment contribute More intense sediment load?
- ☆ How Mach yield released from each catchment sub catchment?

1.4. objective of the Research

The main objective of the present study is to predict runoff and sedimentation in Laga Dadi dam and its watershed using SWAT model

1.4.1. Specific Objective

- ☆ Predicting Run off and sediment yield at Laga Dadi reservoir.
- ☆ To forecast the sediment yield of every sub-catchment
- ☆ To identify the foremost erodible sub-catchment

1.5. Significance of the Study

Effective watershed planning requires understanding of runoff and sediment yield at the plot, hill slopes, and at small catchments scales and the way these vary across the landscape. Identification of areas that have high runoff and sediment yield risks is vital for the design and implementation of management options. Hence, this study will put a rock base for reconsideration of the reservoir area seriously by identifying the hotspot area of runoff and sedimentation and can also initiates others researches to research the varied aspect of sedimentation problem controlling methods and supported the prediction to be not increase from current estimation. Besides, it'll show what the ministry of water, and irrigation minster to think about when consider filling water demand and provide issues to the capital city. Also, it benefits researcher to conduct similar area by replicating the model utilized in this study.

Scope And Limitation of Thesis

The study is to focus on modeling of Runoff and sediment yield in Laga dadi Reservoirs and its watersheds using SWAT. The aims of the study are to gate answer for estimation of run off and sediment yield at Laga Dadi reservoir, estimation of sediment yield and runoff of every sub-catchment and identify the foremost erodible sub-catchment of Laga Dadi Watershed and also all necessary Data were collected for the success of the research. During data Collection there is a limitation of little long term sediment data and I use rating Curve to fill the gap on the research and the rating curve is one of reasons to create uncertainty on comparing of measured data with simulated sediment data So it needs to give attention on measuring of sediment Data By the concerning Government Body so as to minimize uncertainty in rating curve resalt and to gate Better resalt

Thesis structure

The first chapter introduces the overall context of the research presented in dissertation and introduces the overall background information related with the study, problem justification, objectives and supportive structure of the dissertation. Chapter two will contain supportive literature on runoff and sedimentation. Chapter three will give detail description of the study area (Laga Dadi) including climate of the basin, topography, Hydrology, soil and land use sort of the watershed were well described and will deals with the source and analysis of the info and model setup and general guidelines are going to be set to which the target is going to be met. Chapter Four will provide result & discussion where all findings are summarized to the dissertation consistent with the objectives. Chapter five wills address conclusions and proposals for future work

CHAPTER TWO
2LITERATURE REVIEW

2.1 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 and Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998; Hurni, 1989.). Universal Soil Loss Equation (USLE) was suggested and supported the concept of the separation and transport of particles from rainfall by Wischmeier and Smith (1965) to calculate the quantity of erosion in agricultural areas. The USLE has been enhanced during the past 30 years by several researchers. In 1996, when the U.S. Department of Agriculture (USDA) developed a way for calculating the quantity of erosion under soil conditions the revision of the weather factor, the event of the erosion factor counting on seasonal changes besides pilot sites like pastures or forests, RUSLE was announced to feature many factors like, the event of a replacement calculation procedure to calculate the duvet vegetation factor, and therefore the revision of the length and gradient of the slope.

The use of USLE and its derivatives is restricted to the estimation of gross erosion and can't compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the very fact that erosion can occur only along a flow line without the influence of the water flow itself restricts the direct application of the USLE to complex terrain within GIS. USDA developed the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995) to exchange the USLE family of models and expand the capabilities for erosion prediction during a sort of landscapes and settings. This model may be 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 within the channel via a transport equation.

At the catchment scale, spatial and temporal organization emerges from an outsized number of physical and biological processes operating at lower levels (Wallingford, 2004). The long-standing method of understanding and modeling these lower-level processes, from which it's claimed higher level organization are often simulated, has so far not produced the anticipated results (Sloff, 2005). Many landscape modelers remain stuck at lower levels, and therefore the catchment scale models required for management and scientific understanding are either not available or are too complex for meaningful use (Eckhardt, K., & J.G. Arnold, 2001). Emphasis should now tend to either directly modeling the high level, or emergent, properties of catchments, or producing models which will reproduce these high-level properties.

Sediment budgets are wont to explore these ideas (Ahmed, 2008). There are two reasons for questioning the idea that bottom-up process-based modeling is that the best and only due to produce useful models: the primary one may be a practical objection where models of the natural variability of rainfall infiltration, run off, erodibility, cover, channel characteristics, and sediment storage demand enormous data inputs. Such data are rarely if ever available for areas much larger than a couple of tens of square kilometers, and therefore the cost of knowledge collection is prohibitive in most countries (Ahmed, 2008). Highly parameterized models of the type needed to take advantage of such data are essentially un testable, and while the accurate simulation of measured runoff and/or sediment yield could also be obtained, it's impossible to understand if it's due to correct model configuration or due to the tuning that's nearly always needed to successfully simulate outputs (Ahmed, 2008).

The second reason was philosophical objection where catchments are complex systems during which the dynamics are likely to be best understood by examining across - system organization instead of concentrating on the parts from which an entire system view is made (Conway, 2000). The interaction of components produces results that generally can't be simulated from the components; that's, the entire is emergent from a good range of processes and interactions that are neither predictable from, deducible from, nor reducible to the parts alone (Anderson, 1972). In what follows, the top-down approach is adopted, whereby emergent properties of catchment are identified as a start line for modeling, instead of the normal approach of continuum mechanics during which processes are modeled and combined, usually during a spatial setting, using GIS, to breed an emergent property like runoff or sediment yield. (Ahmed, 2008).

2.2 ESTIMATION OF RUNOFF &SEDIMENT YIELD

Estimation of future runoff and sediment yield has been used for several decades to size the sediment storage pool and estimate reservoir life (Conway, 2000). However, these estimates are often erroneous, and lots of reservoirs have stored sediment sooner than originally planned

(Amare, 2005). Most sediment is exported from watersheds during relatively short period of flood discharge and these events must be accurately monitored to supply information on the future yield also because the time wise variation in load needed to guage sediment routing strategies (Cunderlik, 2003). Knowledge of the spatial variation in yield is required to focus yield reduction efforts on the landscape units that deliver most sediment to the reservoir (Arnold, JG & Soil, Grassland, 1995). Future trends in sediment yield occurring over a period of decades can also influence sediment management in reservoirs (Arnold, JG & Soil, Grassland, 1995).

2.3 SEDIMENT TRANSPORT AND RESERVOIR SEDIMENTATION

2.3.1 SEDIMENT PROPERTIES

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth’s crust. Such particles home in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in relative density and mineral composition, the predominant material being quartz. Once the sediment particles are detached, they'll either be transported by gravity, wind or/and water. When the transporting agent is water, it's called fluvial or marine sediment transport. The method of moving and removing from their source or resting place is named erosion. During a channel, the water flow erodes the available material within the banks and/ or the stream bed until the flow is “loaded” with the maximum amount sediment particles because the energy of the stream will allow it to hold. Usually, three modes of particle motion are distinguished: Rolling and/ or sliding particle motion, Saltating or hopping particle motion, and Suspended particle motion.

2.3.2 RESERVOIR SEDIMENTATION

Most natural rivers are approximately balanced with reference to sediment inflow and outflow. Dam construction dramatically alters this balance due decreased flow velocity of reservoirs, which reduces the sediment transport capacity and causes settling (Gesese, 2008). Sediment carried into a reservoir may deposit through its full length, thus gradually raising the bed elevation and causing aggradations (Ahmed, 2008). The pattern of deposition generally begins with a deltaic formation, mainly composed of coarser sediments within the reservoir head water area. (Awulachew, McCartney, Steenhuis, & Ahmed, 2008). Reservoir sedimentation may be a complex process that varies with watershed sediment production, rate of transportation, and mode of deposition (Wallingford, 2004).

Sumi (n.d) delineated that reservoir sedimentation depends on the frequency of flood at the river regime, geometry of reservoir, operation, fluctuation, sediment consolidation, density currents, and therefore the possible land use changes over the anticipation of the reservoir. The author also shows, sedimentation reduces reservoir storage capacity for the flow regulation and with it all water system and control benefits (Hirose, n.d.). Also, hydropower, navigation and recreation and its environmental benefits depend upon releases from storage (Neitsch, 2002). Additionally, to storage loss, many sorts of sediment related problems also can occur both upstream and downstream of dams, and sediment entrainment also can interfere with the beneficial use of diverted water (Conway, 2000).

Sediment can enter and thwart intakes and significantly hasten abrasion of hydraulic machinery, thus decreasing its efficiency and increasing repairs costs. (Cunderlik, 2003) Aggradations within the upstream channel may arise over long distances above the reservoirs, consequently increasing flood risks on these areas. (Hirose, n.d) the mixture of sediment trapping and flow regulation also has dramatic impacts on the ecology, water transparency, sediment balance, nutrient budget and river morphology (Wallingford, 2004).

Surface escape and Reservoir sedimentation is serious off-site consequence of erosion with large environmental and economic implications (Haile., 2010). On the opposite hand runoff and reservoir sedimentation also provides valuable information on erosion problems and sediment transport with during a catchment area (Ahmed, 2008). Erosion by water is one among the foremost important land degradation problems and a critical environmental hazard in worldwide (Awulachew, McCartney, Steenhuis, & Ahmed, 2008). Specially, accelerated erosion dueto human-induced environmental alterations at global scale is causing extravagant increase of geomorphic process activity and sediment fluxes in many parts of the planet.

Arturo Escobar (1996) delineated that it's necessary to be ready to predict its erythrocyte sedimentation rate with reasonable accuracy to form an eloquent economic prediction for a planned dam. However, it's extremely difficult to assess what proportion sediment are going to be trapped by a reservoir (Haile., 2010). Collecting data on sediment discharge is even costlier and difficult than gathering stream flow data, then there's little reliable information available on the sediment carried by the world's rivers (Flanagan, 1995). Sediment flows vary widely both annually and seasonally over time much more than water flows – then calculating an annual average needs an extended run of knowledge (Hirose, n.d.).

2.3.3 Sediment Transport Modes

According to the mechanisms of transport, the entire sediment loads are often subdivided by source or by mode of transport from source; the entire load is split between the bed material load and wash load. The bed material load springs from the river-bed and is usually sand-sized or gravel-sized. The wash load consists of sediment that has been flushed into the river from the upload source and is sufficiently fine-grained that the river is usually ready to carry it in suspension. For the mode of transport, the entire sediment transport is split into suspended load transport and bed load transport. The suspended load transport is dispersed within the flow by turbulence and is carried for a substantial distance without touching the bed. The bed load transport is usually coarse sediment occupation almost continuous contact with the bed by rolling, sliding, or saltating under the tractive force exerted by the water flow (Campos, 2001).

2.4 HYDROLOGICAL Models

Hydrological models are characterizations of the real-world system. Modeling of the rainfall-runoff processes of hydrology is required for several different reasons; the most reasons being the limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 2000). Therefore, it's necessary to develop a way of extrapolating from those available measurements in space and time to ungauged catchments and into the longer term to assess the likely impact of future hydrological changes. a good range of hydrological models are employed by researchers; however, the applications of these models are highly hooked in to the needs that the modeling is formed.

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water. Universal Soil Loss Equation (USLE) model was suggested first supported the concept of the separation and transport of particles from rainfall by (Wischmeier, W.H., & D.D. Smith., 1978) in order to calculate the quantity of erosion in agricultural areas. The USLE has been enhanced during the past 30 years by variety of researchers. In 1996, when the U.S. Department of Agriculture (USDA) developed a way for calculating the quantity of erosion under soil conditions besides pilot sites like pastures or forests, RUSLE was announced to feature many factors like the revision of the weather factor, the event of the erosion factor counting on seasonal changes, the event of a replacement calculation procedure to calculate the duvet vegetation factor, and therefore the revision of the length and gradient of slope.

As discussed in Tesfaye G. (2012), he uses USLE and its derivatives is restricted to the estimation of gross erosion, and lacks the potential to compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the very 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) mode (Flanagan, 1995) to replace the USLE family of models and expand the capabilities for erosion prediction during a sort of landscapes and settings. This model may be 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 (Tesfaye, 2012).

Tesfaye (2012) Hydrological models are characterizations of the important world system. Modeling of the rainfall-runoff processes of hydrology is required for several different reasons the most reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Ahmed, 2008) Therefore, it's necessary to develop a way of extrapolating from those available measurements in space and time to ungauged catchments and into the longer term to assess the likely impact of future hydrological changes (Ahmed, 2008). a good range of hydrological models are employed by the researchers; however, the applications of these models are highly hooked in to the needs that the modeling is formed. (Hailu, 2016).

2.4.1 Types of Hydrological Models

Lumped models: Parameters of lumped hydrologic models don't 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 (Arnold, JG and Soil, Grassland, 1995). Parameters of lumped models often don't represent physical features of hydrologic processes and typically involve certain degree of empiricism (Ahmed, 2008). The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the whole basin. the foremost commonly employed procedure is an area-weighted average (Amare, 2005) Lumped models aren't usually applicable to event scale processes. If the interest is primarily within the discharge prediction only, then these models can provide even as good simulations as complex physically based models (Awulachew, McCartney, Steenhuis, & Ahmed, 2008)

Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into variety of smaller sub basins. There are two main sorts of semi-distributed models: 1) kinematic undulatory theory models (KW models, like HEC-HMS), and 2) probability distributed models (PD models, like Top model). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Awulachew, McCartney, Steenhuis, & Ahmed, 2008) 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 include data concerning the spatial distribution of parameter variations alongside computational algorithms to guage 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 intimately, and if properly applied, they will provide the very best degree of accuracy (Tesfaye G., 2012).

2.4.2 Selection of Hydrological Model

Each model types use certain application, and therefore the choice of an appropriate model structure relies heavily on the function that the model must serve (Addis Ababa Water and Sewerage Authority, 1999). There are various criteria which may be used for selecting the right hydrological model for a selected problem. These criteria are always project dependent, since every project has its own specific requirements and wishes.

Further, some criteria also are user-depended (and therefore subjective). Among the varied project-dependent selection criteria, there are four common, fundamental ones that has got to be always answered (Cunderlik, 2003): - this are, does the model predict the variables required by the project? (Required model outputs important to the project and thus to be estimated by the model; is that the model capable of simulating single-event or continuous processes? (Hydrological processes that require to be modeled to estimate the specified outputs adequately; can all the inputs required by the model be provided within the time and price constraints of the project? (Availability of input data); Does the investment appear to be worthwhile for the objectives of the project? (Price)

The selection of model was by considering the above criteria with inclusive of availability of knowledge, level of application, purpose, required accuracy, space and duration, catchment basin, simplicity, previous trends (studies) within the surrounding area and Ethiopia as an entire. Considering all the criteria's set above, physically based models (SWAT) were adopted for this study. SWAT model was selected dueto its nature of physically based, spatially distributed and belongs to the general public domain (Arnold, JG and Soil, Grassland, 1995). instead of incorporating regression equations to explain the connection between inputs and output variables, SWAT requires specific information about weather, soil properties, and topography, vegetation, and land management practices occurring within the watershed (Awulachew, McCartney, Steenhuis, & Ahmed, 2008); it's been tested that the model has obvious advantages as a hydrological modeling tool that has modularity, computational efficiency, ability to predict long-term impacts as endless model, and skill to use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance together of the foremost widely adopted and applied hydrological models worldwide (Amare, 2005). It’s computationally efficient. Simulation of very large basins or a spread of management strategies are often performed without excessive investment of your time or money (Addis Ababa Water and Sewerage Authority, 1999) and specifically the model was tested for prediction of runoff and sediment in Abbay with satisfying results and good performance (Awulachew, McCartney, Steenhuis, & Ahmed, 2008).

2.4.3 SWAT Model Development And Its Interface

According to Arnold et al. (1998), SWAT may be a semi-distributed, time-continuous watershed simulator operating on a daily time step. It's developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and bigger river basins. The model is semi-physically based and allows simulation of a high level of spatial detail by dividing the watershed into sub-watersheds (Anderson, 1972). The main components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The program is given an interface in Arc GIS (Arc SWAT 2005, Winchell et al., 2008) for the definition of watershed hydrologic features and storage, also because the organization and manipulation of the related spatial and tabular data.

The simulation of the hydrology of a watershed is completed in two separate components. One is that the land phase of the hydrologic cycle that controls the water movement within the land and determines the water, sediment, nutrient and pesticide amount which will be loaded into the mainstream. Hydrological components simulated within the 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 that the routing phase of the hydrological cycle during which the water is routed within the channels network of the watershed, carrying the sediment, nutrients, and pesticides to the outlet.

2.4.4 Model Description:

SWAT is the acronym for Soil and Water Assessment Tool, a basin, or watershed scale model developed by the USDA Agricultural Research Service (ARS) (Arnold, JG and Soil, Grassland, 1995). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of your time (Dar-Al Omran, 2011).

The SWAT watershed model is one among the foremost recent models developed by the USDA-ARS to predict the impacts of land management practices on water, sediment and agricultural chemicals yields in watersheds with varying soils, land use and management practices over long periods of your time (Neitsch, S, Arnold, J, Kiniry, J & Williams, J, 2005).

The model may be a physical based, semi-distributed, continuous time, and operating on daily time step. As a physical based model, SWAT uses Hydrological Response Units (HRUs) to explain spatial heterogeneity in terms of land use, soil types and slope with during a watershed (Neitsch, S, Arnold, J, Kiniry, J & Williams, J, 2005). In order to simulate hydrological processes during a watershed, SWAT divides the watershed in to sub watersheds based upon drainage areas of the tributaries (Tesfaye, 2007). The sub watersheds are further divided into smaller spatial modeling units referred to as HRUs, counting on land use and land cover, soil and slope characteristics (Neitsch, S, Arnold, J, Kiniry, J & Williams, J, 2005)

The SWAT model uses two phases of hydrologic cycle; one for the land processes and therefore the other for the channel processes: (Michael, 2004)

A. Land Phase Hydrologic Cycle

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{sur} - E_a - w_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots. equation\ 3.1$$

Where: - **SW_t** is that the final soil water content (mm), **SW_0** is that the initial soil water content on day i (mm), **t** is that the time (days), **R_{day}** is that the amount of precipitation on day i (mm), **Q_{surf}** is that the amount of surface runoff on day i (mm), **E_a** is that the amount of evapotranspiration on day i (mm), **w_{seep}** is that the amount of water entering the void zone from the profile on day **i** (mm), and **Q_{gw}** is that the amount of return flow on day i (mm). Thirty

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for every HRU and routed to get the entire runoff for the watershed (Sloff, 2005). This increases accuracy and provides a way better physical description of the water balance.

B. Channel Phase Hydrological Cycle

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the most channels, the loadings are routed through the stream network of the watershed employing a command structure almost like that of HYMO (Williams, JR and Hann, RW, 1978). Additionally, to keeping track of mass flow within the channel, SWAT models the transformation of chemicals within the stream and stream bed (Luis, 2006).

C. Erosion

Erosion and sediment yield are estimated for every HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, JR, 1975). While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the quantity of runoff to simulate erosion and sediment yield (Luis, 2006). The substitution leads to variety of benefits: the prediction accuracy of the model is increased, the necessity for a delivery ratio is eliminated, and single storm estimates of sediment yields are often calculated. The hydrology model supplies estimate of runoff volume and peak runoff rate which, with the sub basin area, are wont to calculate the runoff erosive energy variable. The crop management factor is recalculated a day that runoff occurs. it's a function of above-ground biomass, residue on the soil surface, and therefore the minimum C factor for the plant. Other factors of the erosion equation are evaluated as described by Wischmeier, W.H., & D.D. Smith (1978).

D. Surface Runoff USASCSM

Surface runoff occurs whenever the speed of water application to the bottom surface exceeds the speed of infiltration. (Arnold, JG & Soil, Grassland, 1995) When water is initially applied to a dry soil, the appliance rate and infiltration rates could also be similar. However, the infiltration rate will decrease because the soil becomes wetter. When the appliance rate is above the infiltration rate, surface depressions begin to fill. If the appliance rate continues to be above the infiltration rate once all surface depressions have filled, surface runoff will commence. SWAT provides two methods for estimating surface runoff the SCS curve number procedure (Heber A. & GA, 1911).

The SCS runoff equation is an empirical equation that came into common use within the 1950s. it had been the merchandise of quite 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The model was developed to supply a uniform basis for estimating the amounts of runoff under varying land use and soil types (Rallison, Robert E & Miller, Norman, 1982).

The SCS curve number equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \dots\dots\dots\dots\dots\dots\dots\dots equation\ 3.2$$

Where: $\mathbf{Q_{surf}}$ is that the accumulated runoff or rainfall excess (mm), $\mathbf{R_{day}}$ is that the rainfall depth for the day (mm), $\mathbf{I_a}$ is that the initial abstractions which incorporates surface storage, interception and infiltration before runoff (mm), and **S** is that the retention parameter (mm). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4\left(\frac{100}{CN} - 10\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.3$$

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

$$\mathrm{Q_{sur}} = \frac{(\mathrm{R_{day}}_{-}0.2S)^2}{R + 0.8S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . equation\ 3.4$$

Peak runoff rate

The peak runoff rate is an indicator of the erosive power of a storm and is employed to predict sediment loss. SWAT calculates the height runoff rate with a modified rational method for every HRU as follow:

$$Q_{peak} = 3.6\frac{\alpha_{tc} * Q_{sur} * A}{t_{conc}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.5$$

Where $\mathbf{Q_{peak}}$ is peak runoff rate (m^3/s), α_{tc} is that the fraction of daily rainfall that happens during the time of concentration, $\mathbf{Q_{surf}}$ is that the surface runoff (mm); A is that the sub-basin area (km2), $\mathbf{t_{conc}}$ is time of concentration (hr.) and 3.6 is factor.

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

$$\alpha_{tc} = 1 - \exp\left[2 * t_{conc} * \ln(1 - \alpha_{0.5})\right. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . equation\ 3.6$$

Where $\alpha_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall?

Time of Concentration

The time of concentration, $\mathbf{t_{conc}}$, is that the time within which the whole sub basin area is discharging at the outlet point. it's calculated by summation both the overland flow time of the furthest point within the sub basin to succeed in a stream channel (tov) and therefore the upstream channel flow time needed to succeed in the outlet point (t_{ch})and calculated by ...

$$t_{conc} = t_{ov} + t_{ch} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. equation\ 3.7$$

Overland flow time is defined as the time it takes for water to travel from the furthest point in the sub-basin to a stream channel. The overland flow time (**t_{ov}**) is computed by: -

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \dots\dots\dots\dots\dots\dots\dots\dots\dots \; equation\ 3.8$$

Where: L_{slp} is the average sub basin slope length (m), **V_{ov}** is the overland flow velocity (m/s), and 3600 is a unit conversion factor.

The overland flow velocity for a unit width along the slope is calculated by using the Manning's equation:

$$V_{ov} = \frac{q_{ov} * 0.4 * slp}{n^{0.6}} \dots\dots\dots\dots\dots\dots\dots\dots . equation\ 3.9$$

Where: **q_{ov}** is the average overland flow rate (m^3/s), **Slp** is the average slope of the sub basin (m/m), and **n** is Manning's roughness coefficient of the sub basin

Channel flow time is computed as:

$$t_{ch} = \frac{L_c}{3.6 * V_c} \dots\dots\dots\dots\dots\dots\dots\dots . equation\ 3.10$$

Where: **L_c** is the average flow channel length (km), **V_c** is the average flow velocity (m/s), and 3.6 is a unit conversion factor.

The average flow channel length is calculated as:

$$L_c = \sqrt{L * L_{cem}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . equation\ 3.11$$

Where: L is the channel length from the furthest point to the sub basin outlet (km), and **L_{cem}** is the distance along the channel to the sub basin centroid (km).

E. Soil Water Percolation, Bypass Flow and Lateral Flow

Soil water may follow different paths of movement: vertically upward (plant uptake), vertically downward (percolation), or laterally - contributing to stream flow. The vertical movement. as plant uptake. Removes the most important portion of water that enters the profile.

Percolation is that the downward movement of water within the soil. SWAT calculates percolation for every soil layer within the profile. Water is allowed to percolate if only the water content exceeds the sector capacity of that layer (Neitsch, Arnold, J, Kiniry, J & Williams, J, 2005).

Bypass flow is that the vertical movement of free water along macro pores through unsaturated soil horizons. While simulating the bypass flow, SWAT calculates the crack volume of the soil matrix for every day of simulation by layer. On days during which precipitation events occur, infiltration and surface runoff are first calculated for the soil. a part of the surface runoff like the cracks volume enters the profile as bypass flow and therefore the rest remains as overland flow. Cracks are filled in accordance with their presence within the consecutive layers: those at rock bottom layers are filled first (Neitsch, S, Arnold, J and Kiniry, J & Williams, J, 2005).

Lateral flow is common in areas with high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturated zone stored above this layer. this is often called a perched water table; which is that the source of water for lateral subsurface flow. Lateral flow occurs when water stored within the shallow aquifer exceeds a threshold value.

2.4.5 SEDIMENT COMPONENT OF SWAT

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

$$Sed = 118 * (Q_{Surf} * q_{peak} * A_{hru})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \ldots\ldots.. equation\ 3.12$$

Where Sed is that the sediment yield on a given day in metric tons, Qsurf is that the surface runoff from the watershed in mm/ha, qpeak is that the peak runoff rate in kiloliter per second, Ahru is that the area of HRU, KUSLE is that the USLE soil erodability factor, CUSLE is that the USLE land cover and management factor, PUSLE is that the USLE support practice factor, LSUSLE is that the USLE topographic factor, and CFRG is that the coarse fragment factor. In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

Sediment transport: Sediment transport within the channel network may be a function of two processes, deposition and degradation; SWAT computes both of them by using an equivalent channel dimension for the whole simulation. the quantity of sediment degradation within the channel are often calculated by the model by using

$$Sed_{deg} = Conc_{sed.ch.i} * V_{ch} * K_{ch} * C_{ch} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 3.13$$

And the net amount of sediment deposited in the reach segment is calculated by:

$$Sed_{dep} = \left(Conc_{sed,sh,i} - ConCed\ chmx\right) * V_{ch} \dots\dots\dots\dots\dots\dots\dots equation\ 3.14$$

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

Once the quantity of degradation and deposition are calculated, then the ultimate amount of sediment within the reach is: venerable children

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \dots\dots\dots\dots\dots\dots\dots.\ equation\ 3.15$$

The amount of sediment transported out of the reach is then calculated as: -

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V} \dots\dots\dots\dots\dots\dots\dots\dots\dots..\ equation\ 3.16$$

Where Sedch is that the amount of suspended sediment within the reach (metric tons), Sedch,i is that the amount of suspended sediment within the reach at the start of the period of time (metric tons), Seddeg is that the amount of sediment re-entrained within the reach segment (metric tons), Sedout is that the amount of sediment transported out of the reach (metric tons), Vout is that the volume of outflow during the time step (m^3) and Vch is that the volume of water within the reach segment (m^3).

Surface Runoff and Sediment lag

In large sub basins with a time of concentration greater than 1 day, only some of the surface runoff will reach the most channels on the day it's generated and also sediment within the surface runoff is lagged also. SWAT incorporates a surface runoff storage feature to lag a part of the surface runoff release to the most channel. Once surface runoff is calculated, the quantity of surface runoff released to the most channel is estimated as:

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1})(1 - \exp\left[\frac{-surlag}{t_{conc}}\right] \dots\dots\dots\dots\dots\dots\dots..\ equation\ 3.17$$

And after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using

$$Sed = (sed' + Sed_{stor,i-1})(1 - \exp[\frac{-Surlag}{t_{conc}} \ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.18$$

Where: $\mathbf{Q_{surf}}$ is amount of surface runoff discharged to main channel during a day (mm), $\mathbf{Q'_{surf}}$ is amount of surface runoff generated during a sub basin during a day (mm), $\mathbf{Q_{stor,\ i-1}}$ is that the surface runoff stored or lagged from the previous day (mm), **Surlag** is that the surface runoff lag coefficient, $\mathbf{t_{conc}}$ is that the time of concentration for the sub basin (hrs.) and in Equation 3.15. **Sed** is that the amount of sediment discharged to the most channels on a given day (metric tons), **Sed'** is that the amount of sediment load generated within the HRU on a given day (metric tons), $\mathbf{Sed_{stor,\ i-1}}$ is sediment stored or lagged from the previous day (metric tons)

F. **Routing phase of the hydrologic cycle**

The SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g., nutrients, pesticides) within the stream network. The change in channel dimensions with time due to down cutting and widening is additionally included. Almost like the overland flow case, the speed and velocity of flow is calculated by using the Manning's equation. the most channels or reaches are assumed to possess a trapezoidal shape by the model. Two options are available to route the flow within the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. The variable storage method uses an easy continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume during a channel length as a mixture of wedge and prism storages. While calculating the water balance within the channel flow, the transmission and evaporation also are well considered by the model. For this study, the variable storage method will adopt. The tactic was developed by (Williams, JR, 1975) and recommended by (Arnold, JG and Soil, Grassland, 1995). The Storage routing is predicated on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. equation\ 3.19$$

where: V_{in} is volume of inflow during the time step (m3), 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).

2.4.5.1 Limitation of SWAT Model

The model has enormous popularity in multi-disciplinary coverage of processes representing the hydrology but it's also limitation on its low capacity to capture the spatial variability related to precipitation within an outsized watershed and it doesn't simulate detailed event-based flood and sediment routing. Another criticism on SWAT model is that the tactic of estimating runoff is by means of curve number method that applies universal soil loss equation (infiltration excess method) which considers runoff caused when rainfall intensity rate is above infiltration capacity of the soil and therefore the other method is by changing the algorithm of previous SWAT (CN method) to water balance method of estimating runoff (saturated excess) that entails runoff is caused by when infiltration is above overland flow (Neitsch, S and Arnold, J and Kiniry, J and Williams, J, 2005).

2.5 PREVIOUS WORKS ON THE STUDY AREA

Gesese (2008) has studied "Prediction of Sediment Inflow to Laga Dadi Reservoir Using SWAT Watershed and CCHE1D Sediment Transport Models". He generates runoff and sediment inflow for the Laga Dadi Reservoir by hydrological calculations supported the hydrology similarity method. Since the hydrological stations are situated during a nearby catchment area with similarly physic geographical, soil and geological conditions, also as other hydrological parameters, then the un-gauged unknown discharges are often estimated supported known discharges within the nearby basin consistent with their catchment areas, mean annual rainfall and elevations. He concluded that SWAT and CCHE1D models performed well in predicting the Laga Dadi Reservoir sedimentation.

Aside from the intensive effort in preparing the info for the models, the models were very friendly to figure with hence they ought to be incorporated within the prediction of sedimentation for other cases. In other words, the models proved to be worthwhile in capturing the one-dimensional processes of flow and sediment transport in Laga Dadi Reservoir. It was found that the computed values agreed well with the measured and bed profiles. The study conducted by plan Review, Catchment Rehabilitation and Awareness Plan Review Creation for Geffersa, Laga Dadi, and Dire Catchment Areas.

The bathymetric survey of 1998 was conducted using similar methodology and equipment as for Geffersa dam. The soundings were appropriated a period of 4 days, during which the reservoir was at about 0.6 m below FSL. to enrich the bathymetric survey, a land survey of several cross-sections was performed at the top of the season with the reservoir water level withdrawn by some 14 m below FSL.

The methodology and equipment employed during the 2010 survey is analogous to the one followed by the plan. Again, a ship fitted with single-beam sonar and a differential GPS was wont to cover the reservoir in parallel traverse lines spaced out about 30 m apart. The main difference between this latest and therefore the previous survey is that it had been conducted with the reservoir about 3 m less than its maximum level. to enrich the bathymetric survey a land survey was conducted during this zone. (Dar-Al Oran, 2011)

There is some confusion over the precise value of the Laga Dadi FSL consistent with the plan the FSL is 2,452.915 m.a.s.l. However, the older 1979 survey and therefore the water level gauges at the dam are fixed on a datum of 2,466.0 m.a.s.l. the newest Seureca & others (2010) survey uses this FSL value to enable comparison with previous surveys.

The 1998 survey indicated a reservoir volume at FSL of 43.8 Mcm. This compares with the results of the 1979 survey which found a complete volume at FSL of 45.9 Mcm. Therefore, Laga Dadi reservoir has lost 2.1 Mcm of volume between 1979 and 1998, indicating a mean annual siltation rate of 110,500 m 3/yr.

Between the years 1979 and 1998 this figure was 0.24%/yr. It appears therefore that in later years the speed of siltation of the Laga Dadi reservoir has increased, something which is according to the overall context of developments within the catchment to what concerns factors affecting erosion and sedimentation. The resulting sediment yield of the catchment consistent with the results of the 1998 survey is 762 t/km2/yr. The 2010 survey report (Seureca & others, 2010) didn't include calculations of the sediment yield, but from the results reported a worth of 845 t/km2/yr. is quickly obtained (assuming a sediment mix density of 1.3 t/m 3) (Dar-Al Oran, 2011). Similarly, a study done in Kessim reservoir by (Hailu, 2016) shows there a gap on the area. Besides, he used similar tool as of early researches done on the area.

CHAPTER THREE

3.0. MATERIAL AND METHODS

3.1 MATERIALS

3.1.1 DESCRIPTION OF THE STUDY AREA

The study area is found about 25 km from Addis Ababa within the east direction. The catchment is bounded by latitude 9º01' N – 9º13' N and longitude 38º60' E - 39º07' E. The Laga Dadi catchment covers a neighborhood of 207.3 km^2. It had been one of the sub-catchments of the Akaki basin, which flows toward a northeast direction and is a component of the system that forms the northwest corner of the Awash basin. The Laga Dadi catchment basin is the largest of the three main water system sources of Addis Ababa city.

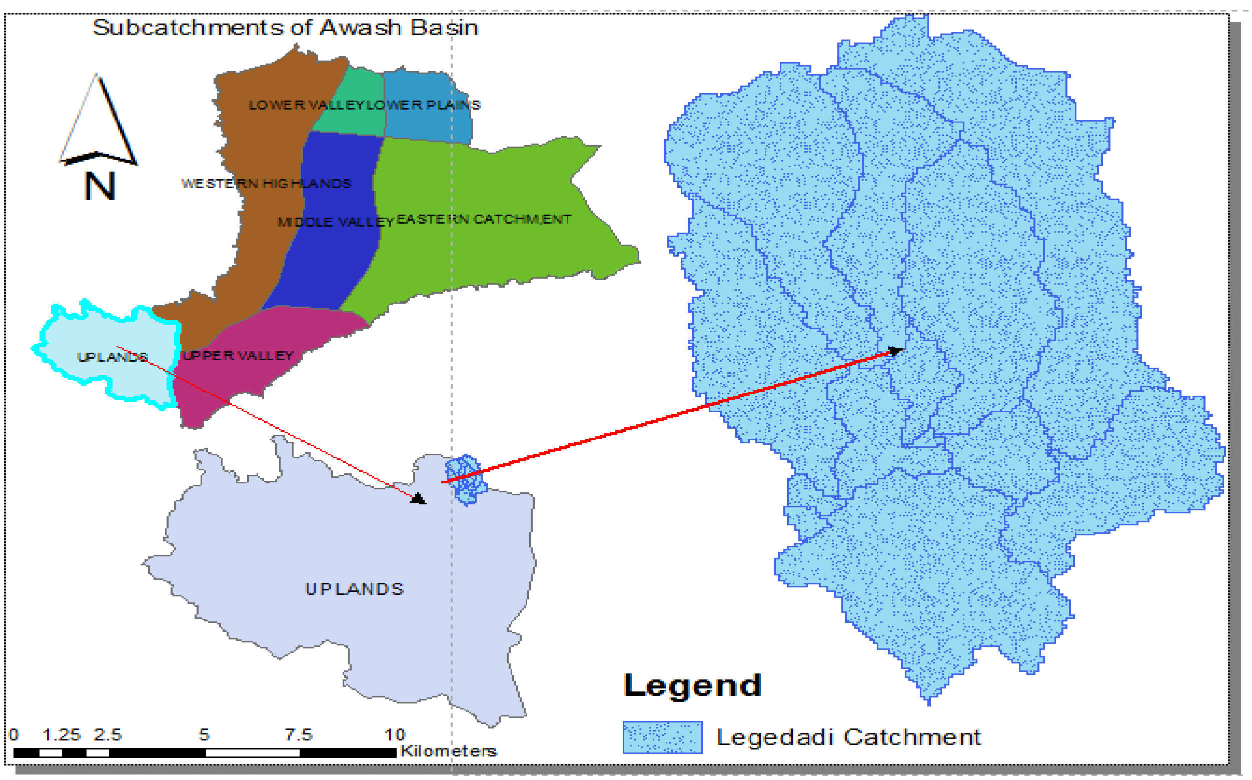

Figure 3.1.1-1: Location of the study Area

Laga Dadi dam reservoir exists in Oromia Regional State under the administration of North Western Shoa Zone in Aleltu Bereh district administration, Sendafa town. The dam is run by the

Addis Ababa Water and Sewerage Authority. Except the eastern part, which is mountainous, the-remainder of the reservoir area is accessible by four-wheel drive vehicles (Gesese, 2008).

A. Topography

The elevation home in the watershed varies between 2438 and 3226 above mean water level with a maximum slope of 64.6 m/m. the main physiographic units found within the catchment basin are: mountains, dissected side slopes of mountains, hills, steep to undulating foot-slopes, gullies, valleys, and undulating plains and flat to almost flat plain (Impact of Land use/cover change on catchment hydrology and water quality in Lege_dire catchments, (Amare, 2005). Above 70% of the watershed has gentle slope ranging between 0 & 3.0m/m.

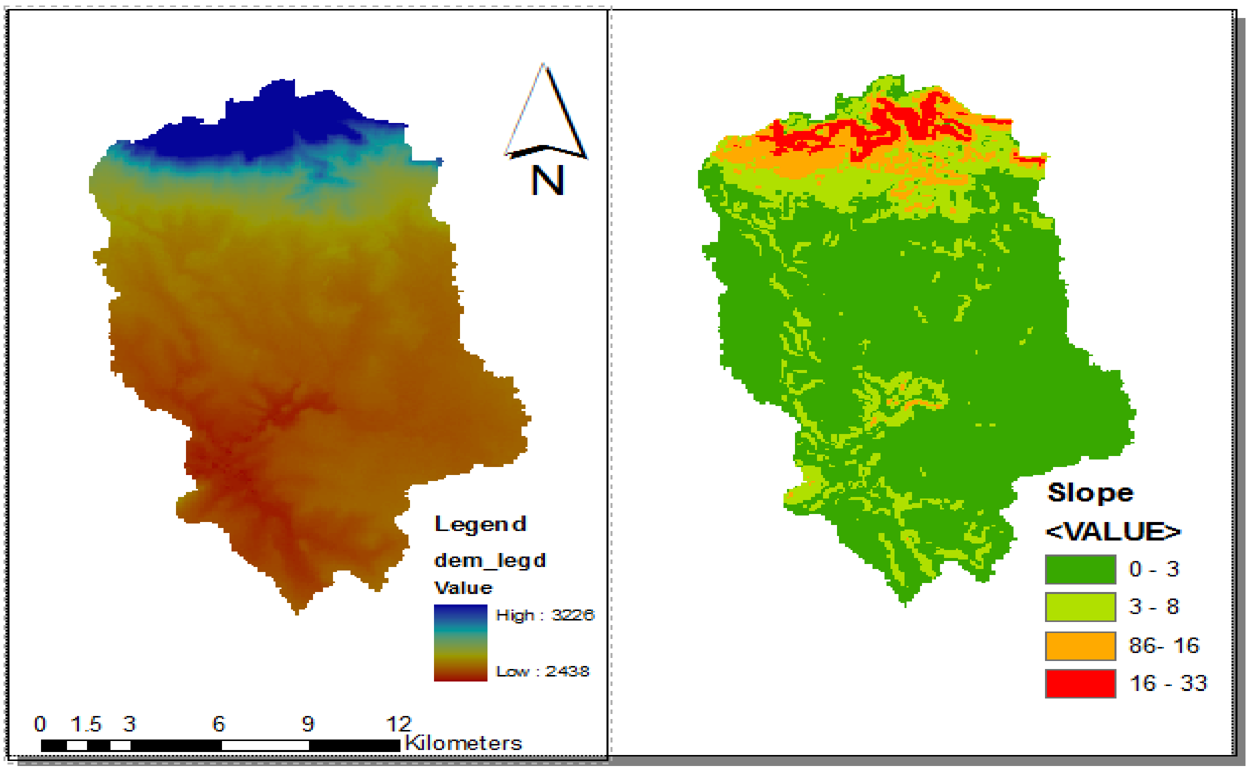

Figure 3.1.1-2: Elevation and slope map of Laga Dadi catchment

B. Climate

The climate of Ethiopia is particularly controlled by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) and associated atmospheric circulation also as by the complex topography of the country. It's a diversified climate ranging from semi-arid desert type to humid and temperate type.

The rainfall pattern within the study area is distinctively uni-modal with peak rainfall located between June and August month. The mean annual rainfall ranges between 1216 and 1088 mm at the Addis Ababa Observatory and Sendafa stations which is found at far west direction and top boundary of the catchment, respectively. The longer term mean maximum and minimum temperature is around 21.6 & 10.33^{0}C within the Addis Ababa Observatory station.

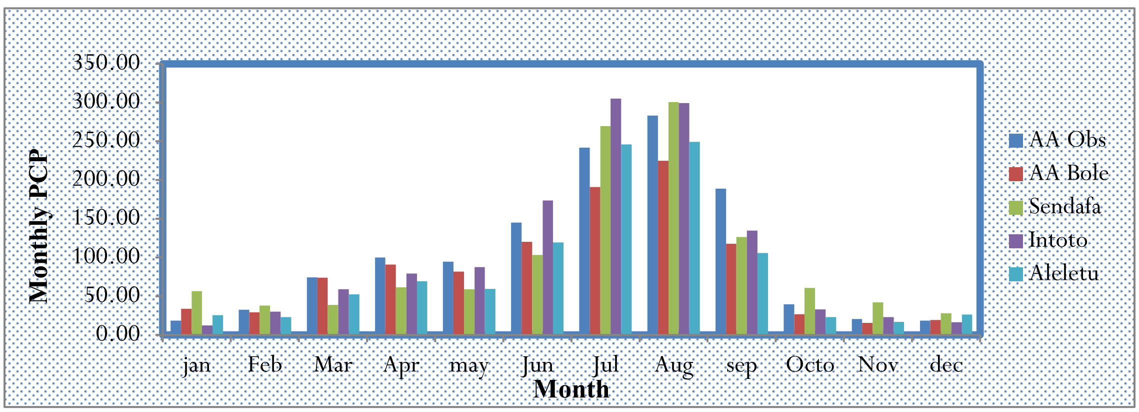

Figure 3.1.1-3: Long term monthly rainfall in and around Laga Dadi (1994 – 2019)

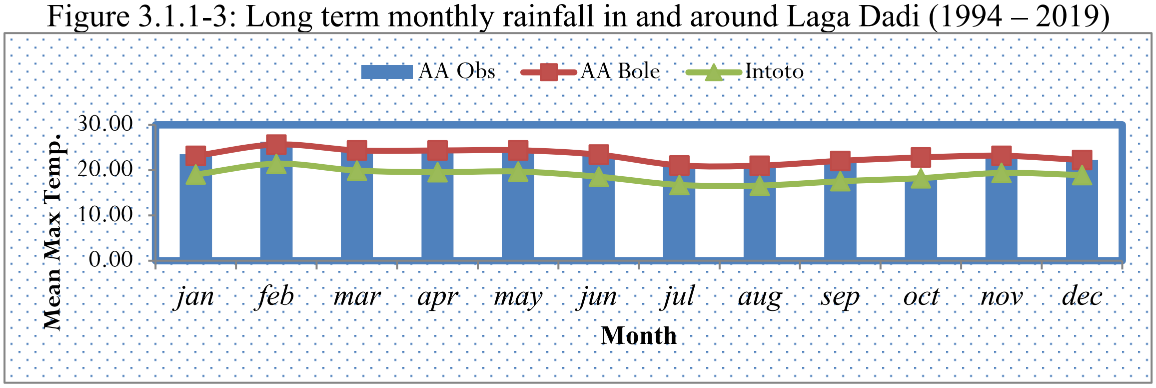

Figure 3.1.1-4: Long term mean monthly maximum temperature in and around Laga Dadi Watershed (1994 –2019)

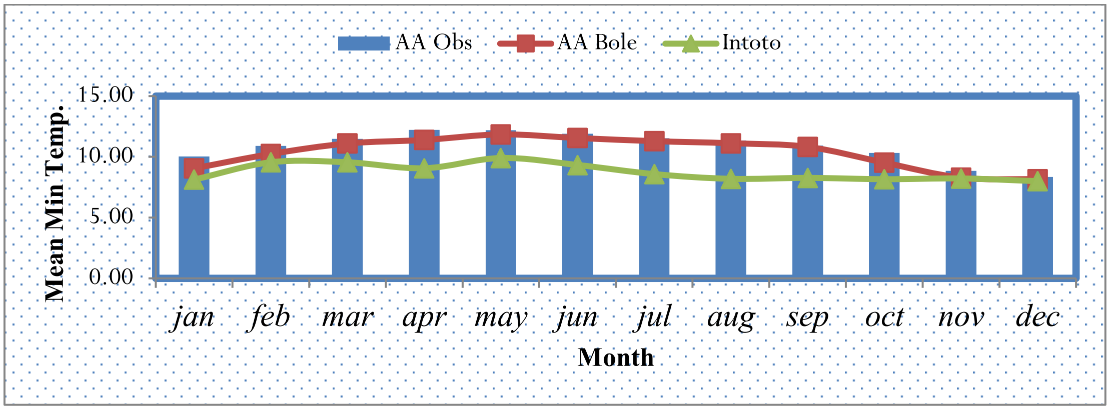

Figure 3.1.1-5: Long term mean monthly minimum temperature in and around Laga Dadi Watershed (1994 –2019)

C. HYDROLOGY AND DRAINAGE AREA

The Laga Dadi catchment basin, constructed in 1970 to reap run-off water during the rainy seasons for urban water system and it's the principal source of water for the Addis Ababa Metropolitan Area. Laga Dadi catchment has no gauging stations inside. Legeberi, Sekoru_fule River, Lege bolo and Sendafa River were the sub-catchments found within the catchment. LegeSekoru and LegeFule enter Laga Dadi reservoir via a standard course. Lege Bolo and Lege Sendafa also merge several hundred meters before entering Laga Dadi reservoir (Dar-AL Omran, 2011).

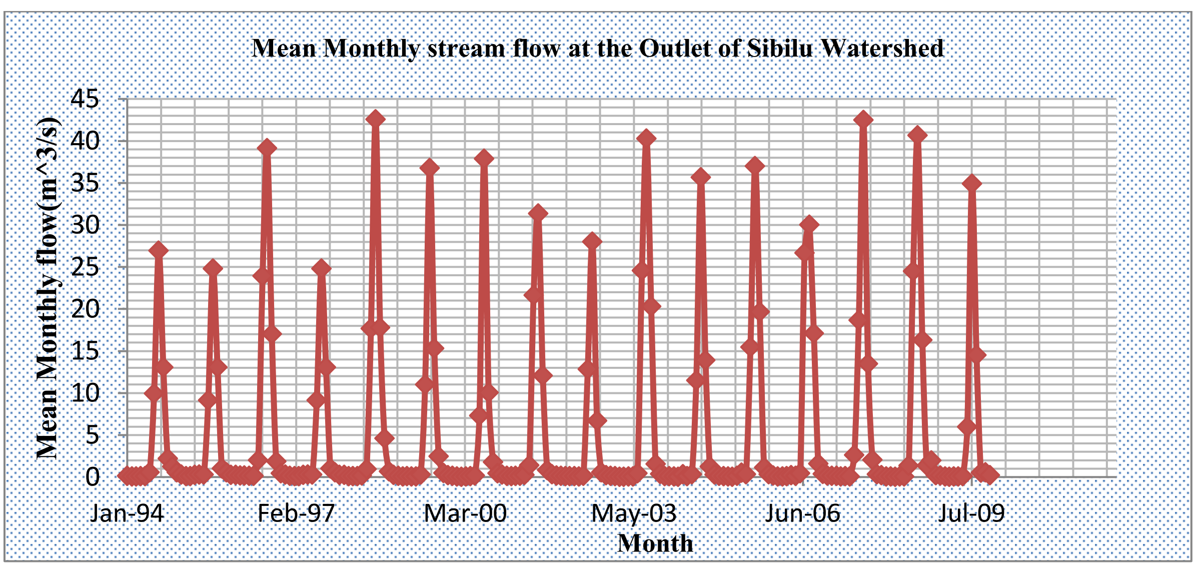

Figure 3.1.1-6: Mean monthly stream flow at Sibilu gauging Station (1994 – 2009)

D. SOIL

According to the farmers of the worda, there are four sorts of soils within the catchment basin on which crops are grown annually. These soils are as follows: Koticha afer (Black vertisols soil), Dalecha afer (Grey soil), Gembore afer (Light soil) and Key Afer (Red soil).

The Koticha afer (Black soil) is found on flat to almost flat areas and valley bottoms and isn't sensitive to erosion. It gives good yield of crops when fertilizers are applied; teff, wheat, barely, lentil, chickpea and singletary pea are grown on these soils. These crops occupy 45%, 30%, 5%, 10%, 5% and 5%, respectively, of the cropped areas situated on the black vertisol soils. The Dalecha afer (Grey soil) occupies a number of the undulating plains and valley sides. Consistent with the farmers, this soil has low fertility. Half the world of those soils has got to be left fallow every other year and therefore the residues burned to offer good crop yields. These soils are vulnerable to erosion. The Gembore afer (Light soil) and therefore the Key afer (Red soil) occupy the hills, mountainsides and therefore the foot slopes. They're vulnerable to erosion when ploughed due to their steep slopes (Dar-Al Omran, 2011). Consistent with FAO soil classification obtained from MoWIE the catchment has major soils as shown within the table 3.1-1.

Table 3.1.1-1: Distribution and Area Coverage of Soils in Laga Dadi watershed

Soil Type	Area [ha]	(%) of coverage over the watershed
Calcic Xerosols	841	4.1
Leptosols	15768	76.82
Orthic Solonchanks	1890	9.21
Pelic Vertisols	2026	9.87

Sources: - MoWIE, 2016.

E. LAND USE /LAND COVER

The terms land use and land covers are often used interchangeably albeit the excellence between the 2 is vital. (Arnold, JG & Soil, Grassland, 1995). Land use refers to the particular economic activity that the land is employed whereas land cover refers to hide of the earth's surface (Gesese, 2008). The land use and land cover types within the Laga Dadi catchment basin are distributed by the govt, local authorities through "Peasant Association" consistent with the farmers' needs but without there being any regional plan that's necessary to take care of the ecological balance of the reservoir.

The cultivated fields are located within the mid and lower slopes of the mountains and hills, foot-slopes, undulating plains, flat to almost flat plain valley sides, and at part the sting of the perimeter of the reservoir (Wischmeier, W.H., & D.D. Smith., 1978). The cultivated fields situated on the steep and undulating slopes aren't shielded from water erosion by any soil and conservation measures (Dar-Al Omran, 2011). Within the study area cultivable land and grass land takes the most important coverage. The foremost dominant soils within the watershed are Leptosols (Gesese, 2008; Sloff, 2005). The distribution and areal coverage of land use/cover in Laga Dadi watershed is shown within the Table 3.1-2.

Table 3.1.1-2: Distribution and Area Coverage of land use/cover in Laga Dadi watershed

Land use/cover	Area [ha]	(%) of coverage over the watershed
Cultivation	12127.5	59.09
Woodland	855.5	4.17
Natural (indigenous plants	752.2	3.66
Grassland	6781.5	33.04
Residential	8	0.04

Sources: Gesesse, 2008

3.2 METHODOLOGY

Before dealing out of this research, it's vital to form a strong look for the information and identifying clear and efficient methodology. Then describe the experimental design that provide enough detail in order to undergo a competent worker will done simply. Data is that the crucial input in hydrological modeling so preparation, analysis and formatting to suit the specified model input is vital and has influences on the model output. The relevant statistic data used for this study includes daily rainfall data, stream flows, suspended sediment yield, temperature (minimum and maximum), wind speed, solar radiation and Spatial data (DEM, soil map, land use map). Data are going to be collected from the Ministry of Water, Irrigation & Energy (MoWIE) and Ethiopian Meteorological Agency

3.2.1 CONCEPTUAL FRAME WORK OF THE STUDY

The general methodology of this study is counting on the information which can be collected from different organization and also field observation. This system follows collection of various secondary data's (such as Hydro-meteorological & spatial data's); Filling of missed data's; Checking data quality; Model setup, Simulation, Calibration and Validation and Result analysis for all the outlined objective are incorporated based ("maxwell.J.(2009))

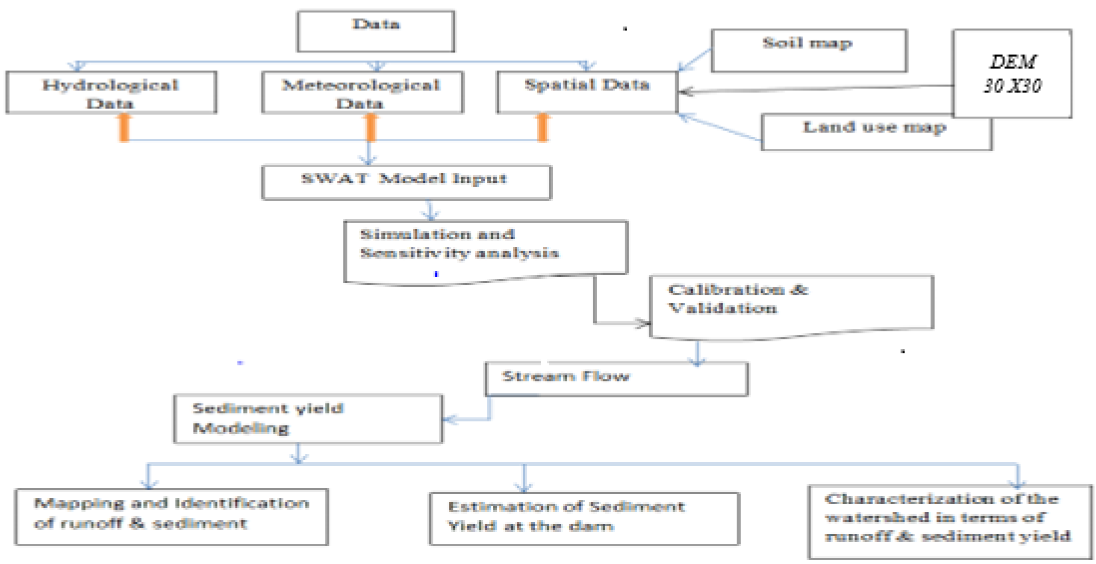

Figure 3.2-1: Conceptual Frame work of this study

3.2.2 DATA COLLECTION AND ANALYSIS

This a part of the research works involves both desk and field investigation for the gathering of important data so as to realize the research objectives. The deskwork is going to be administered to gather the essential literature review on modeling and former work done by other researchers regarding sedimentation modeling. It involves the gathering of a detail topographic map, soil data, land use/land cover data, Digital model (DEM), Meteorological data, hydrological data and make ready code that help for modeling like SWAT, Arc GIS (View), Global Mapper 8, and so on.

3.2.2.1 METROLOGICAL DATA ANALYSIS

Meteorological data sets are the key inputs for hydrological modeling purpose, but the choice of representative meteorological gauging station depends on the information availability (including existence of enough length of record and distance from the world of interest).

The daily precipitation and temperature of all gauging stations were prepared in text format. Solar radiation, relative humidity, and wind speed data were available only for the principal station (Addis Ababa observed). These data for the remains of the stations that are not available like solar radiation, relative humidity and wind speed were generated by SWAT using Weather Generator (Neitsch, Arnold, Kiniry, J & Williams, J, 2005). Weather simulation data consists of monthly average values of all the values required by the SWAT model so as to get daily values. All the above data were collected for the amount from (1994 – 2018 G.C) and are ready as per the model requirement.

Table 3.2-1: List of Meteorological stations in and around Laga Dadi Watershed

Station Name	X- Coordinate	Y- Coordinate	ELEVATION
AA Observatory	476590.00	993272.00	2354
AA Bole	472710.00	996727.00	2408
Intoto	473907.00	1004831.00	2964
Sendafa	502651.00	1011388.00	2560
Aleltu	516418.00	1017570.00	2648

Filling Missing Weather Data

A well measured precipitation data is important to many problems in hydrologic investigation and style. But, due to failure of the observer to form the obligatory visit to the gage, Vandalism of recording gages or instrument failure (by mechanical or electrical malfunctioning) may end in missing data. There are varieties of methods to undertake appraisal of those missing values within the given stations. For this particular study missing values are going to be projected from other stations adjacent to the missed record station by considering the assumptions of a minimum of three as on the brink of and evenly spaced round the station with the missing record station as possible.

Station average method (SAM), normal ratio method (NRM), quadrant method (QM), inverse-distance weighting method (IDWM) and regression methods (RM) are the common methods. From those methods Normal ratio (NR) and Distance power method (DPM) are used for this study. within the normal ratio method, the rainfall PA at station "A" is estimated as a function of the traditional monthly or annual rainfall of the station under question and people of the neighboring stations for the amount of missing data at the station under question. Normal ratio method (NRM) is going to be used when the mean monthly or annual rainfall of all selected index stations differs from that of the interpolation station into account (station X) by more than 10% and calculated the missing data by equation 4.1.

$$P_X = \frac{1}{N}(P_A + P_B + P_C + \cdots \dots + P_N) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. \text{equation 3.1]}.$$

Distance Power Method (DPM): it's easy method to use for filling the missing precipitation data (Hubbard, K.G, 1994). it's consistent if only the weather stations are placed inside 100 Km radius (Tronci N, Molteni F, & Bozzini, M, 1986).

The rainfall at a station is projected as a weighted average of the observed rainfall at the neighboring stations. The weights are adequate to the reciprocal of the space or some power of the reciprocal of the space of the estimator stations from the estimated stations. Let Di be the space of the estimator station from the estimated station. If the weights are an inverse square of distance, the estimated rainfall at point of interest (missed) is:

$$P_A = \frac{\sum_{i=1}^{n} P_i / {D_i}^2}{\sum_{i=1}^{n} 1 / {D_i}^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \, equation \; 3.2$$

Where P_i and P_A are precipitation at neighboring stations and at the target station respectively

D_i is the distance between the target station and the neighboring stations, estimated as:

$${D_i}^2 = [(X - X_i)^2 + (Y - Y_i)^2] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \, equation \; 3.3$$

3.2.2.2 HYDROLOGICAL DATA ANALYSIS

The Laga Dadi watershed after overlaying of soil, land use and slop in HRU processing, it covers 205.27 km2 and there's no river flow gauging station within the watershed to collect stream flow Data. Laga Dadi is represented by Sibilu river flow having gauged area of 375 Km^2 and it is found vary close to northern west boundary of Awash basin like Lega Dadi watershed, so almost all behaver of the watershed is influenced by upper Awash basin. These reference sites are selected in each case by comparison of the geology like the volcanic rocks of the upper awash sub-basin and sibilu are hydro geologically heterogeneous, studies on the hydrogeological framework in the area revealed the occurrence of two basaltic systems (upper and lower) separated by thick impermeable acidic volcanic (trachytic and rhyolitic volcanic centres and ridges) (Yitbarek et al., 2012), soils between catchments description According to FAO soil classification obtained from MoWIE the most dominant soil types of both watershed is Leptosols soils, their main annual rainfall is between June to September ranges between 1216 and 1088 mm at Addis Ababa Observatory and Sendafa stations which founds on far west direction and top boundary of the both catchment respectively (Gamachu,1977) and mean elevations of Lega Dadi and Sibilu watershed range with in 3226 to 2353 above mean water level, the dry and wet period monthly flow distribution are the same and therefore Areal Ratio method is used to transfer stream flow data by considering the above similarity (Dar-Al Omran , 2011).

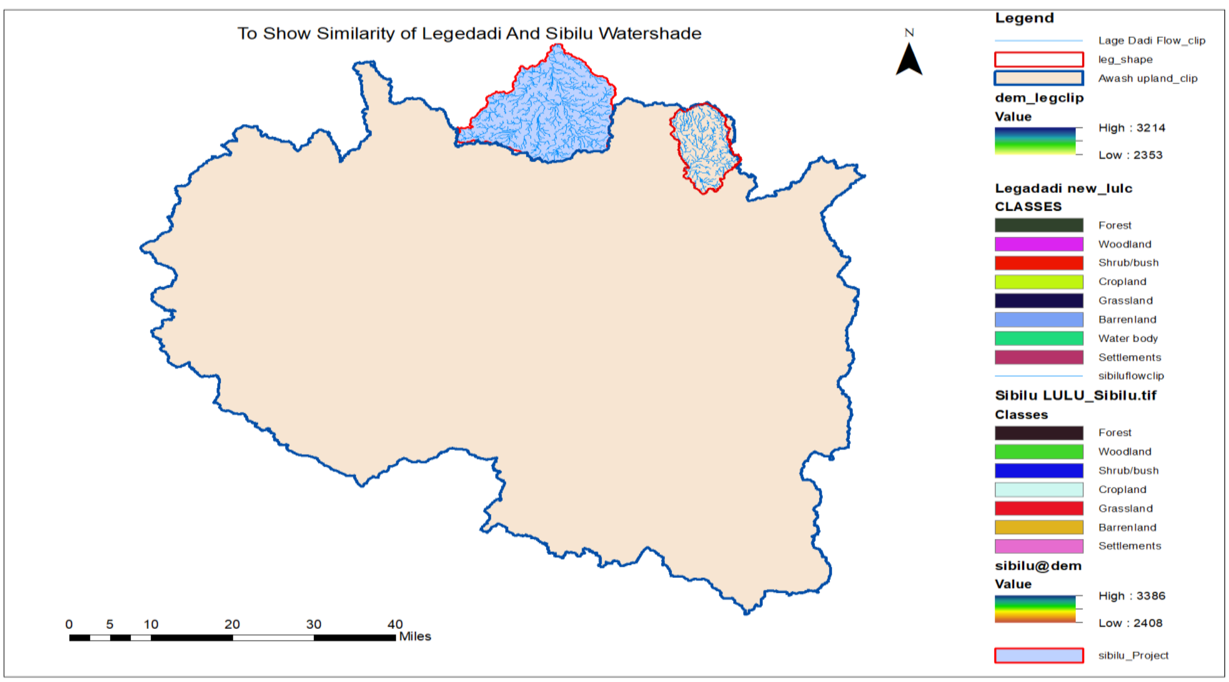

Figure 3.2-2: comparisons of Sibilu Watershed with Lag Dadi Watershed

Transfer of Gauged Data Using Area Ratio Method to Laga Dadi Watershed

Transferring from Gauged Station Data Using Area Ratio Method to Laga Dadi Watershed Since there's no gauging station available within the study area and it had been vital to calibrate and validate a hydrological model at the outlet of the watershed. Therefore, hydrological calculations supported similarity method were performed so as to get stream flow and sediment flow for calibration and validation from a close-by gauging station. the foremost recommended guideline to transfer stream flow data to the purpose of interest is to use area ratio methods described by equation below (Turkey. J. Environ. Manag. 2016). This method uses the drainage areas to interpolate flow values between or near gauged sites on an equivalent stream. Flow values are transferred from a gauged site, either upstream or downstream to the ungauged site.

$$Q_{unguaged} = [Q_{guaged} \frac{Area_{unguaged}}{Area_{guaged}}]^n$$

Where: - $Q_{ungauged}$= discharge at site of interest

Qgauge= discharge of the gauge site

n = a parameter typically varies between 0.6 and 1.2. If the $Q_{ungauge}$ is within 20% of the Qgauge ($0.8 \leq Q_{unguaged}/Q_{guaged} \leq 1.2$), then n=1 to be used and I use n=1 for my research

Thus, discharge at the outlet of Laga Dadi watershed is calculated with the above equation from Sibilu gauging station (Chancho)stream flow data and also suspended Sediment data were determined from suspended sediment rating curve developed for Laga Dadi watershed (at the outlet) from Sibilu available sediment concentration data.

Infilling of hydrological data (Stream flow): Complete River flow statistics are vital to the sustainable management of water resources and even very short gaps can severely compromise data utility. There are variety of methods applied for infilling missed flow data, from which the choice of an appropriate method depends on the prevailing gauging stations (existence of neighbouring stations and availability of data’s). Regression method, interpolation method and application of hydrological models are among the foremost widely used and customary methods for infilling purpose of stream flow.

The infilling of missing flow data during this study is accomplished by using regression method by taking the correlation between Sibilu and Aleltu gauging stations (dry and wet season data periods for all stations were conducted independently for various time periods.

In similar way with the meteorological data's the assessment of knowledge quality test for hydrological data (stream flow) of the used gauging stations of Sibilu flow data for absence of trend, instability (stationery-test), absence of inconsistency and absence of inhomogeneity has been checked.

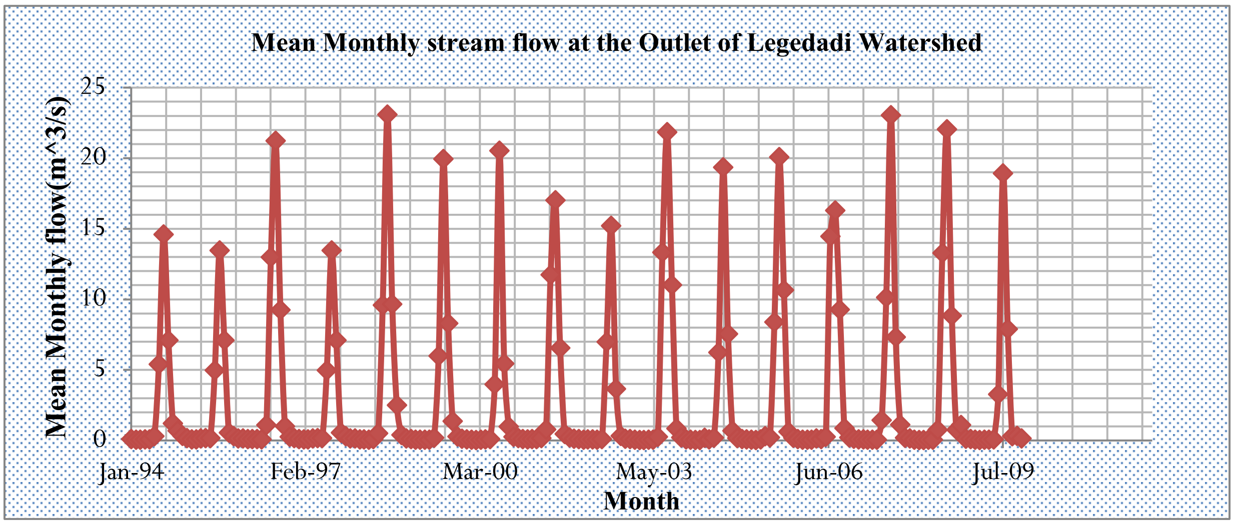

Figure 3.2-3: Transferred Mean monthly stream flow at the– outlet of Laga Dadi Catchment (1994 2009)

Sediment Data Analysis and preparation of Sediment Rating Curve

Sediment rating curve preparation

Sediment yield data of the basin is required to advert and undertake management scenario changes to reduce reservoir sedimentation. Lack of sediment data is experienced and it had been quite difficult to assess the watershed modelling with the scarce data. Optimal solution to solve this type of scarcity is by generation of sediment rating curve (developing exponential relationship between river discharge and sediment concentration for the prevailing data (USGS,1988)), but it'd increase uncertainty which isn't as equal because the real observed values.

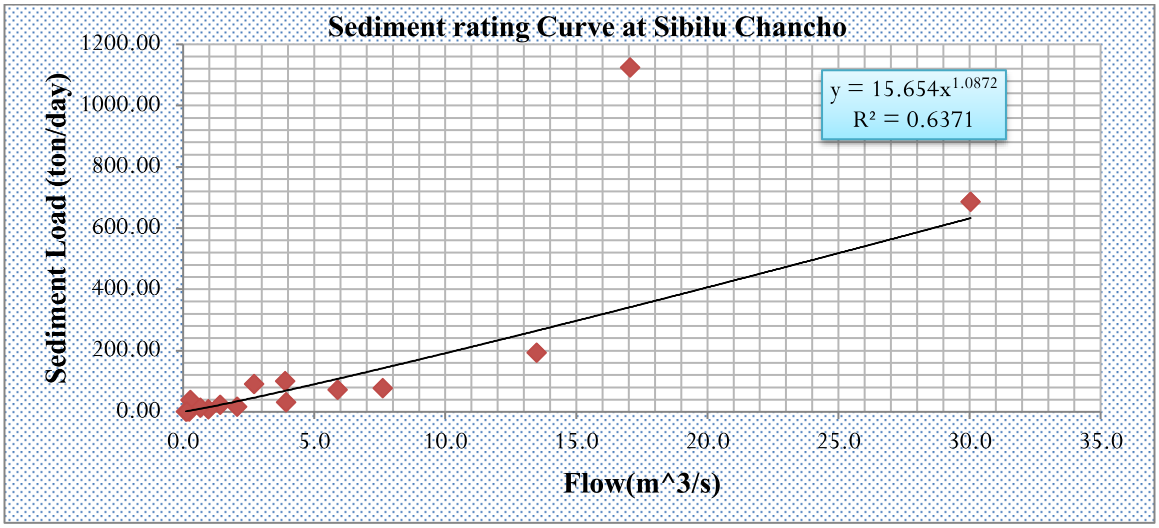

Figure 3.2-4: Sediment rating curve of Sibilu (Chancho) gauging station develop for this Thesis.

Exist uncertainty from the developed rating curve due to non-existence of accessible data for overall months of the year will also create uncertainty arrived during calibration and validation on the woreda of interest for the significant representation. The statistic sediment data generated by the equation within the graph at the outlet of the Sibilu gauging station and transferred stream flow data from Sibilu station to Lage Dadi out late were employed for calibrating and validating SWAT model.

3.2.3 Data Quality Analysis

Engineering studies of water resources development and management are determined by using hydrological and meteorological data. These data should be fixed, consistent, and identical once they are used for frequency analyses or to simulate a hydrological system. to work out whether the info meet these conditions, we'd like an easy but efficient screening technique to understand and explain the statistical variability. A statistic of hydrological data is strictly stationary if its statistical properties (e.g., its mean, variance, and higher-order moments) are unaffected by the selection of your time origin. (By unaffected‟, we mean that estimates of these properties agree within the range of expected statistical variability). The essential data-screening procedure presented here is predicated upon split-record tests for stability of the variance and mean of such a statistic. Hydrological data for water-management studies should be stationary, consistent, and homogeneous once they are utilized in frequency analyses or system simulations. an easy but efficient procedure for screening these data is to check annual or seasonal statistic for absence of trend and stability of variance and mean.

The data quality screening procedure consists of 5 principal steps. These are:

I. Rough screening of the info and compute or verify the totals for the hydrological year
II. Plotting the data
III. Test the statistic for absence of trend with Spearman's rank-correlation method
IV. Apply the F-test for stability of variance and therefore the t-test for stability of mean to separate non-overlapping, sub-sets of the statistic.
V. Test the statistic for relative consistency and homogeneity with double-mass analysis.

I. Rough Screening of the Data

The basic procedure begins with an initial, rough screening of the information. For rainfall totals, we advise tabulating daily observations by region (but observations from several collection stations should be available). This may allow visual detection of whether the observations are consistently or accidentally credited to the incorrect day, whether or not they show gross errors (e.g., from weekly readings rather than daily ones), or whether or not they contain misplaced decimal points. Verifying the completeness of the info and checking the observer's arithmetic when computing totals may be a useful exercise. In most cases, it's convenient and perfectly acceptable to use yearly totals as long as by 'year' one means 'water year' (hydrological year). This definition removes any risk of the seasons' being split over two years. Nevertheless, it can sometimes be better to research a selected period of a year (e.g. the wet or season, or maybe a specific month) if that period may be a critical one within the envisaged water project scheme.

II. Plotting the Data

After doing a rough screening of the info, one plots them on arithmetic or semi-logarithmic paper. Figure 3.2-3 shows a statistic of the yearly rainfall totals from 1994-2019.

III. Test for Absence of Trend

Test for Absence of Trend After plotting a statistic, one must make certain that there's no correlation between the order during which the info are collected and therefore the increase (or decrease) in magnitude of these data. Accordingly, to see absence of trend, we recommend using Spearman's rank-correlation method. The tactic is predicated on the Spear-man rank coefficient of correlation**,** $\mathbf{R_{sp}}$, which is defined as: -

$$R_{sp} = 1 - \frac{6 * \sum_{i=1}^{n} D_i^2}{n^2(n-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 3.4$$

Where n is the total number of sample data D is the difference and i is the chronological order number. The difference between rankings is computed with

$$D_i = K_{xi} - K_{yi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots equation\ 3.5$$

Where K_{xi} is the rank of the variable xi and K_{yi} is chronological transformed series for observationyi. The Null hypothesis is finally checked for the acceptance with t-test statics which is described by:

$$t_t = R_{sp}(\frac{n-2)}{1-R_{sp}})^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.6$$

With t as student t distribution having degree of freedom (v) as n-2 and bounded at two tailed 5% level of significance in between:

$$\left(-\infty, t(v, 2.5\%)\right) U \left(t(v, 97.5\%)\right), +\infty) \ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.7$$

With the bounded region of the null hypothesis, the time series the statistic has got to be said "No Trend" if it satisfies and fall for t_t in between:

$$\left(t(v, 2.5\%)\right) < t_t < \left(t(v, 97.5\%)\right)$$

Stations having Rainfall and stream flow was tested for the absence of trend.

IV. Tests for Stability of Variance and Mean

Stations having Rainfall and stream flow was tested for the absence of trend. Tests for Stability of Variance and Mean A statistic of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the selection of your time origin. (By 'unaffected', we mean that estimates of those properties agree within the range of expected.

Stationery of your time series was checked based upon split-record tests for stability of the variance (F-test) and stability of mean (t-test) during this study. The tests for stability of variance and mean verify not only the stationary of a statistic, but also its consistency and homogeneity. Within the basic data-screening procedure, these two tests are reinforced by a 3rd one, for absence of trend. Although stability of those two properties indicates only a weak sort of stationary, this is often enough to spot a non-stationary statistic or to pick those parts of a statistic that are acceptable to be used.

A statistic is first divided in to subsets and computation of ordinary deviation for every subset are going to be attained first, then variance of the 2 subsets is checked for the suitable range for stability of variance.

$$F_t = \frac{{\sigma_1}^2}{{\sigma_2}^2} = \frac{S_1^2}{S_2^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equtaion\ 3.8$$

$$S = [\frac{\sum_{i=1}^{n}(X_i^2) - (\sum_{i=1}^{n}(X_i))^{\frac{2}{n}}}{n-1}]^{0.5} \ldots\ldots\ldots\ldots equation\ 3.9$$

The t-test for stability of mean involves computing for the 2 subsets then comparing the means of two or three non-overlapping sub-sets of the time series (the same subsets from the F-test for stability of variance) appropriate statistic for testing the null hypothesis, Ho:XI = X, against the alternate hypothesis, HI: XI <> X, is:

$$t_t = \frac{\bar{X}_1 - \bar{X}_2}{[\frac{n_1-1)*{S_1}^2+n_2-1)*{S_2}^2}{n_1+n_2-2} * \left(\frac{1}{n_1} * \frac{1}{n_2}\right)]^{0.5}} \ldots\ldots equation\ 3.10$$

Where n is the amount of data in the sub-set, X the mean of the sub-set, and s^2its variance

V. Tests for Relative Consistency and Homogeneity

Test For Consistency

A statistic of hydro meteorological data is comparatively consistent if the periodic data are proportional to an appropriate simultaneous statistic (Chang, Mingteh, Lee & Richard, 1974).

Double mass curve may be a simple, visual and practical method, and it's widely utilized in the study of the consistency hydro-meteorological data and it had been a commonly used data analysis approach for investigating the behavior of records made from hydrological or meteorological data at variety of locations. It’s wont to determine whether there's a requirement for corrections to the info to account for changes in data collection procedures or other local conditions. Such changes may result from a spread of things including changes in instrumentation, changes in observation procedures, or changes in gauge location or surrounding conditions. Double mass analysis for checking consistency of a hydrological or meteorological record is taken into account to be an important tool before taking it for analysis purpose.

This method is predicated on the hypothesis that every item of the recorded data of a population is consistent. In this study double mass curve method is adopted for checking consistency of both meteorological and hydrological data.

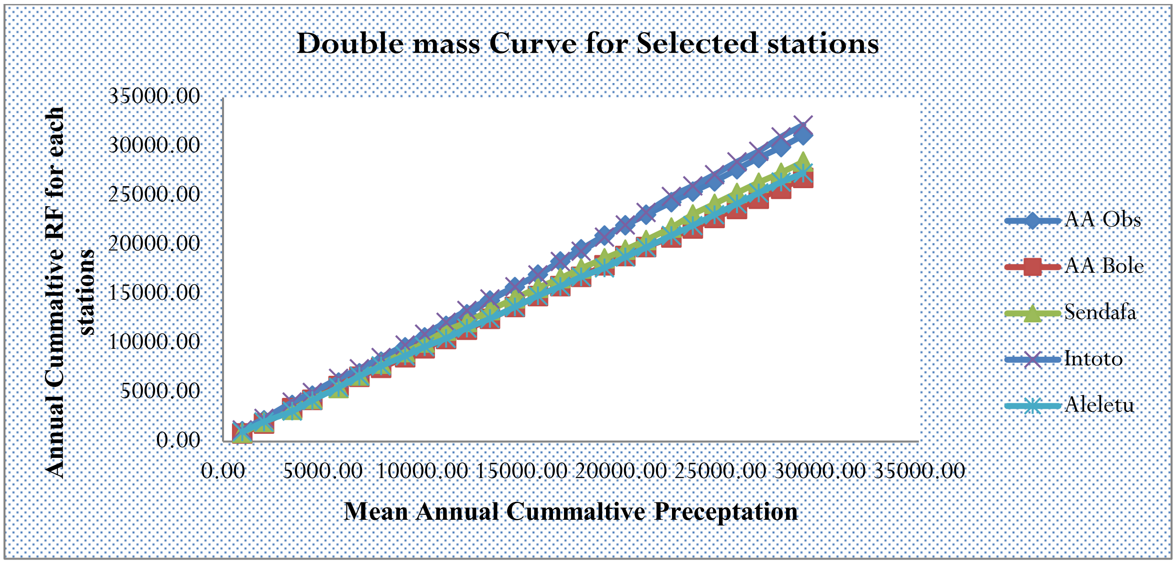

Figure 3.2-5: Double mass curve graph for consistency test

Test for Homogeneity

The data qualities with reference to possible temporal and spatial variations or errors should need to be investigated by checking homogeneity and consistency of selected stations. Non-homogeneity may be a change within the statistical properties of the statistic. Its causes can be either natural or man-made. These include alterations to land use, relocation of the station, and implementation of flow diversions. Rainbow and non-dimensional plot are the widely used methods for checking homogeneity of your time series data of rainfall. During this study Absolute homogeneity is checked by rainbow software and relative homogeneity is checked by non-dimensional plot.

In RAINBOW the test for absolute homogeneity is predicated on the cumulative deviation from the mean and clearly shows the probability of rejecting homogeneity. There exist two sorts of homogeneity called absolute homogeneity and relative homogeneity; once absolutely the homogeneity of every station alone is checked (by using Rainbow test) their relative homogeneity is then checked (by using Non-Dimensional Plot) during this study.

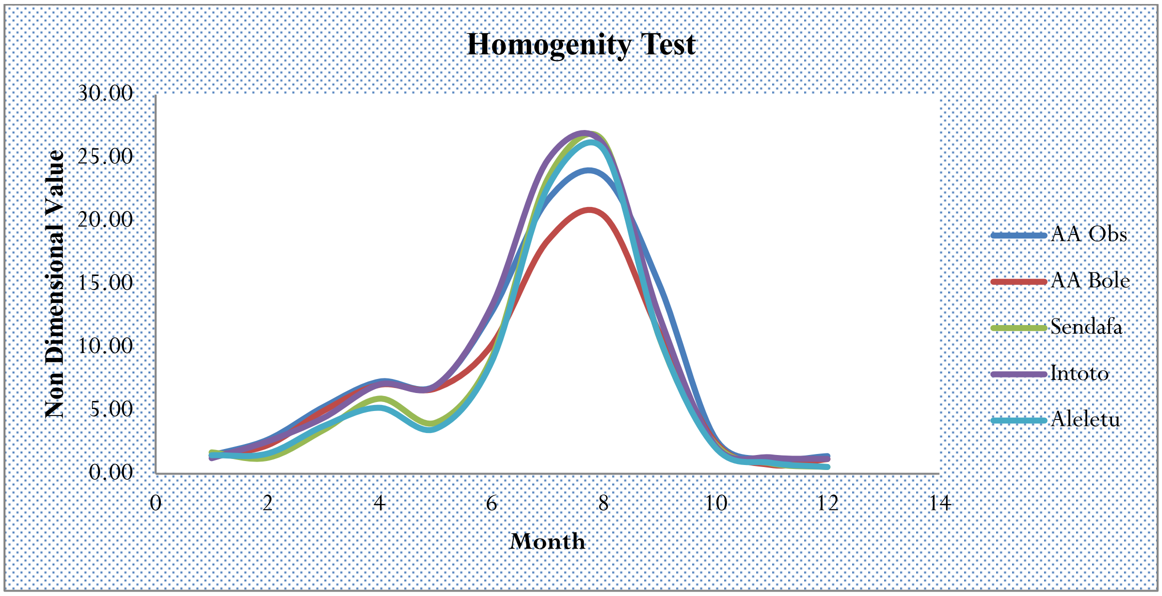

Figure 3.2-6: Non-Dimensional Plot for homogeneity test of RF stations

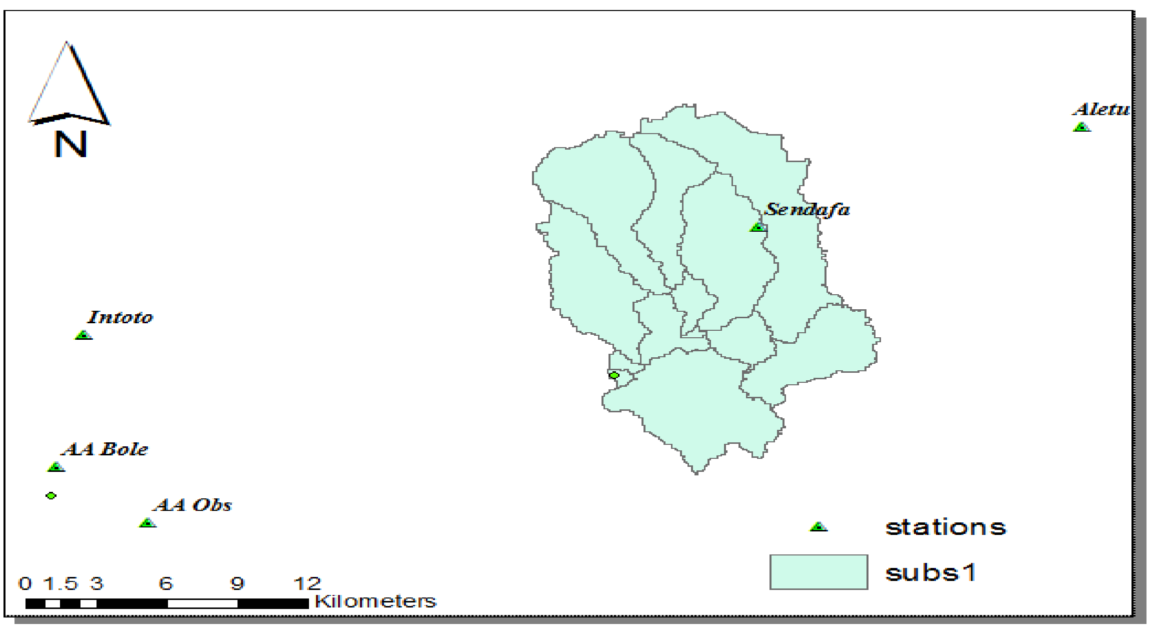

Figure 3.2-7: Spatial Distribution of Meteorological stations in and around Laga Dadi catchment

3.3 SWAT Model

3.3.1 Reason For selection of SWAT

SWAT is chosen for the present research because the model predictions are semi distributed spatially (models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins) unlike other model i.e., lumped model (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) (Arnold, JG and Soil, Grassland, 1995). To inform more unlike SWAT model, lumped models predict a definite (single) estimate that only applies at the watershed outlet and thus provide no extra spatial information concerning the upstream sources of the modeled quantities (Gesese, 2008).

The other core motive for the selection of SWAT model is sediment erosion from each hydrologic response unit (HRU) are stimulated using the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt 1977). Hence, this equation substitutes the normal Universal Soil Loss Equation's (USLE) rainfall factor with a runoff think about order to estimate event-based sediment yield estimates (Neitsch, S, Arnold, J and Kiniry, J & Williams, J, 2005). MUSLE predicts sediment erosion when there's surface water runoff and it reduces the erosion estimates when there's snow cover (Dar-Al Omran, 2011).

3.3.2 MODEL SET UP

The model setup involved data preparation, sub basin discretization, HRU definition, parameter sensitivity analysis, calibration and uncertainty analysis. SWAT allows variety of various physical processes to be simulated during a watershed. So as to adequately simulate hydrologic processes during a basin, the basin is split into sub basins through which streams are routed. The subunits of the sub basins are mentioned as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous. The model calculations are performed on a HRU basis and flow and water quality variables are routed from HRU to sub basin and subsequently to the watershed outlet.

3.3.3 MODEL INPUTS

3.3.3.1 Watershed Delineation and HRU

The first step in creating SWAT model input is watershed delineation from digital elevation model. Inputs entered into the SWAT model are organized to possess spatial characteristics. The SWAT model provides three spatial levels: the watershed, the sub basins, and therefore the hydrologic response units (HRUs). Each level is characterized by a parameter set and input file. the most important spatial level, the watershed, refers to the whole area being represented by the model. For modelling purposes, a watershed could also be partitioned into variety of sub watersheds or sub basins.

The utilization of sub basins during a simulation is especially beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub basins, the user is in a position to reference different areas of the watershed to at least one another spatially. Moreover, the choice and implementation of appropriate conservation measure are often aided by reliable predictions of watershed response under different land use scenarios.

The watershed delineation is supported an automatic delineation procedure employing 30m x30 m digital elevation model (DEM) setup, Stream definition, outlet and inlet definition, watershed outlet selection and calculation of sub basin parameters. Hence, definition of watershed, sub-basin boundaries and streams is set by selecting a threshold area or the minimum catchment area to define streams. During this study the default threshold area was taken and therefore the watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates the watershed with 13 sub watersheds for simulations.

HRU

After watershed delineation, the watershed was partitioned in to hydrologic response units (HRU), which are unique occurrence of soil type, land cove and slope class combinations within within the watershed to be modelled. Any parcels of lands within one sub basin that share an equivalent combination of those three features are going to be considered one HRU. HRUs are utilized in most SWAT runs since they simplify a travel by lumping all similar soil and land use areas into one response unit.

SWAT has predefined land use classes in its crop database. So, it's necessary to organize search table, which refers land use land cover classes found in hand with SWAT land use land cover codes. Since in HRU definition the model refers the land use classes found within the SWAT model. So, well preparation of the lookup-table of the land use /cover types within the SWAT compatible way is basic for the loading of the land use/cover of the study area. After adding the land use map into the model, subsequent is that the soil map of the watershed. so as to integrate the soil map within the SWAT model, it's necessary to form a user soil database lookup-table that contains physical and chemical properties of each soil of the study area. to organize this user database of the soils, the properties of soils that required within the SWAT model are extracted from FAO-UNESCO soil data base because the soils of the study area is ready supported FAO-UNESCO classification. After loading and projecting the soil map and reclassifying, the third step of HRU definition. During this step of HRU definition SWAT allows to classify the slope of the sub basins. Hence, multiple slope option (an option for considering different slope classes for HRU definition) was selected and therefore the slope class was classified to 5 and therefore the range was 0-5%, 5-10%, 10-18%, 18-38% and above 38%.

Table 3.3-1: Slope classes in the watershed

No.	Slope Classes	Area Coverage (km^2)	% Watershed area
1	0-5	161.587219	78.73
2	5-10	22.746969	11.08
3	10-18	10.89236	5.31
4	18-38	8.775505	4.28
5	above 38	3.297311	0.61

In multiple HRU definition, an intensity was wont to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover but the edge level are eliminated. The land use, soil and slope map of Laga Dadi catchment were overlaid to supply a hydrologic response group by setting a threshold value of 10, 10, and 20% for land use, soil and slope domination to which land use percentage over the sub basin, soil over the land use and slope class percentage over the land use respectively were adopted in this study during HRU definition. Those thresholds were selected by considering the effect on the formulation of hydrologic response and for creating the HRU formation during a manageable amount. Accordingly, the study area is split into 13 sub basin and 55 HRU were generated with an equivalent hydrological response for the ultimate water balance analysis.

3.3.3.2 Digital Elevation Model (DEM)

The digital elevation model (DEM) is any digital representation of a topographic surface and it's specifically made available within the sort of raster or regular grid of spot heights. it's the essential input of SWAT hydrological model. The DEM obtained for this study was obtained from ministry of water and energy and it's a horizontal resolution of 30m. All the specified spatial datasets were projected to an equivalent projection called UTM Zone 37N, which is that the transverse Mercator projection parameters for Ethiopia, using ArcGIS 9.1. The DEM was wont to delineate the watershed and analyze the drainage patterns of the land surface terrain. A predefined digital stream network layer was imported and superimposed onto the DEM to accurately delineate the situation of the streams.

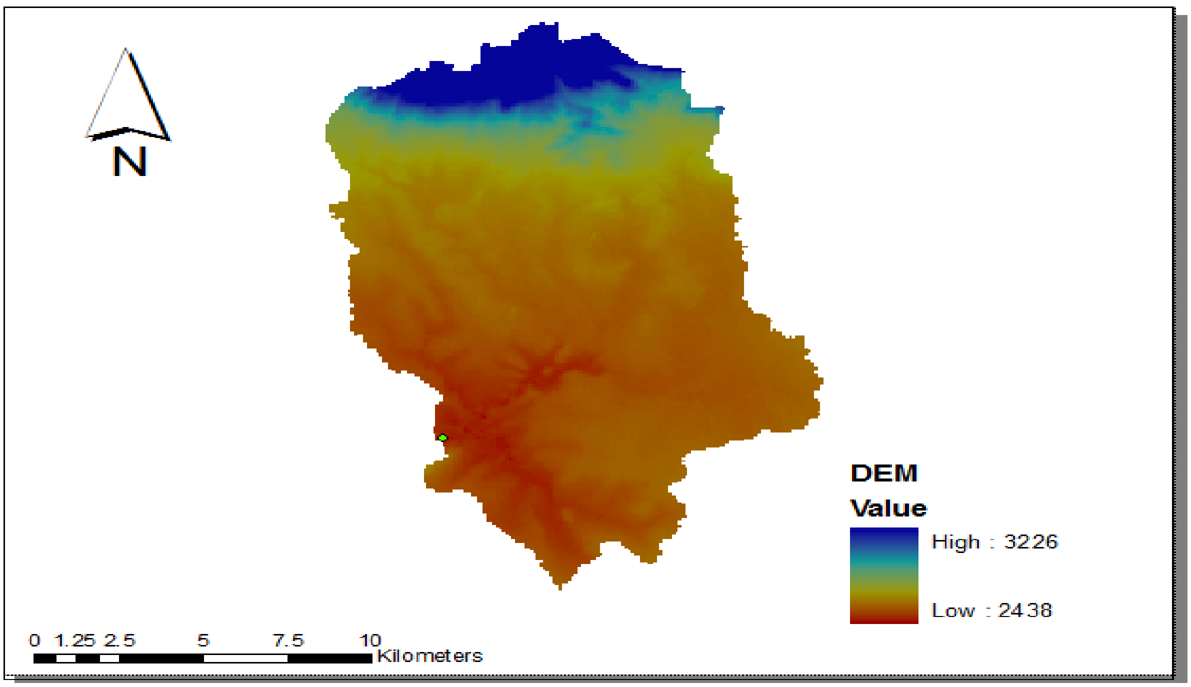

Figure 3.3-1: DEM of the Laga Dadi catchment

3.3.3.3 Soil Map

The soil data are going to be required for SWAT model to supply both the distribution of the soil type within the catchments and therefore the various parameters describing the soils hydrological and textural properties soil data is one among the main input file for the SWAT model with inclusive of physical and chemical properties (number of soil layers, soil maximum depth, available water capacity, content of clay, silt & sand, bulk density, soil hydrologic group, soil erodiblity factor, saturated hydraulic conductivity and moist soil albedo) which were obtained from different literature and plan study of Abay basin and Awash basin developed by FAO mapping classification, are require for the model and obtained as needed. The soil map of the study area was also obtained from Ministry of Irrigation and Water Resources of Ethiopia.

According to FAO/UNESCO classification (FAO, 2002), four major soil groups were identified within the watershed. Leptosols, Orthic Solonchanks, Pelic vertisols and calcic Xerosols are the dominant soil types in Laga Dadi watershed with different areal coverage. The distribution of all soils within the watershed is described in appendix with their respective physical and chemical properties. A soil search table including the soils within the watershed was prepared in text form and therefore the grid values within the map were loaded which exists within the SWAT database.

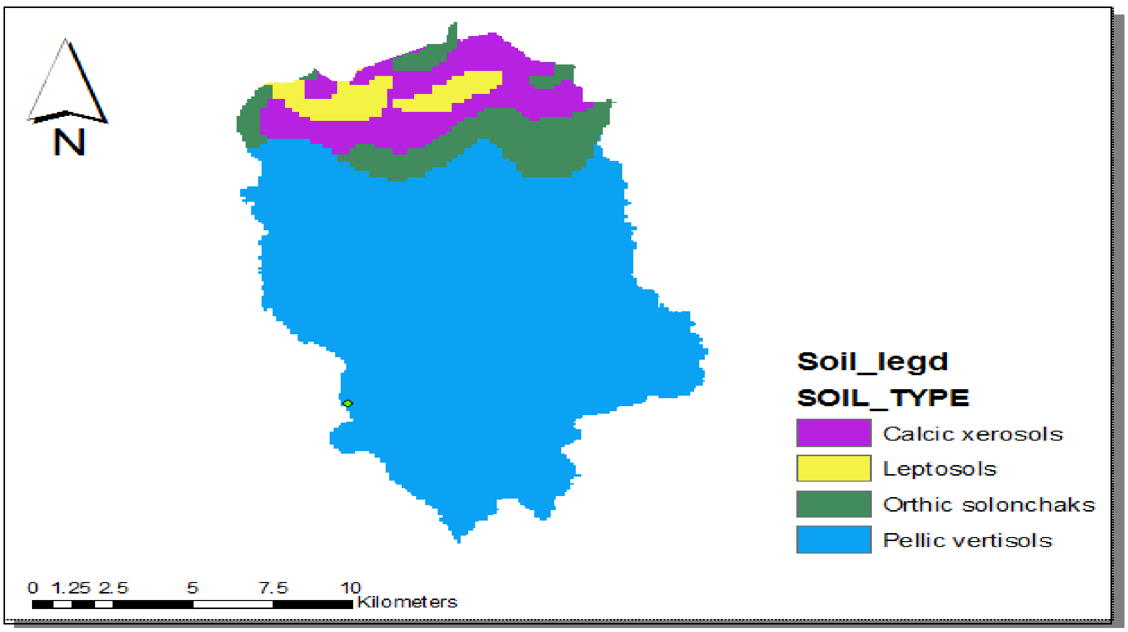

Figure 3.3-2: Soil map of Laga Dadi Catchment (source: - FAO, 2002)

3.3.3.4 **Land use /land Cover Map**

Spatial distribution and specific land use parameters are going to be 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 within the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Weather Data Definition and Weather Generator Weather data are amongst the indispensable inputs for SWAT model.

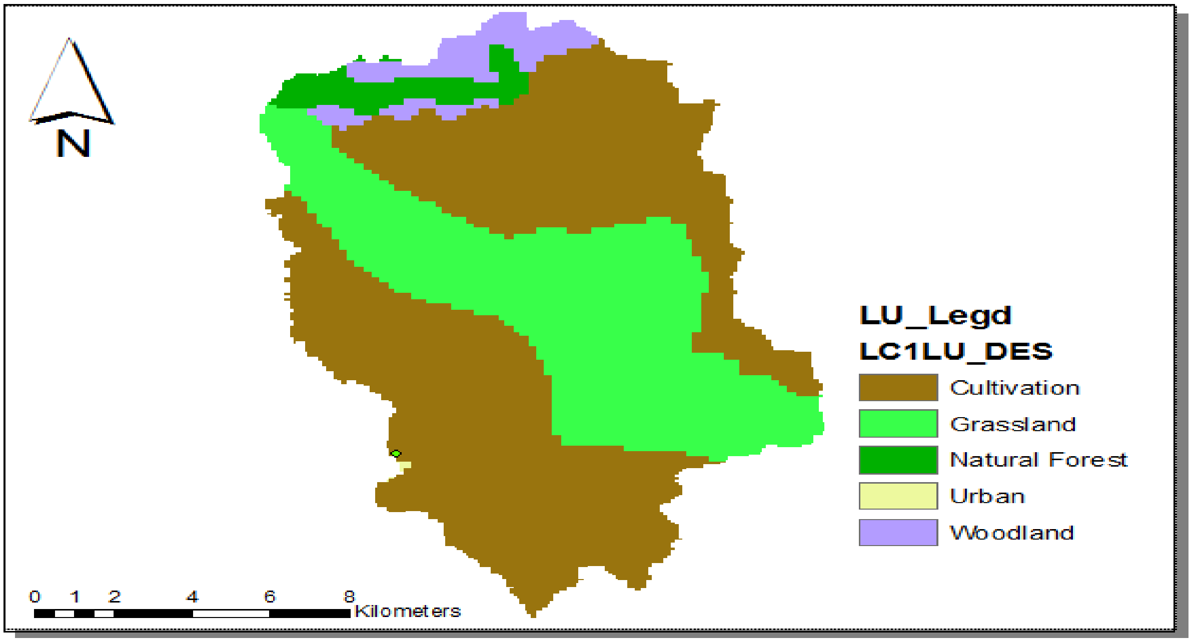

Figure 3.3-3: land use/cover map of Laga Dadi catchment (source; - MoWIE 2005)

3.3.3.5Weather Data Definition and Weather generator

Accordingly, weather data like daily data's of rainfall, temperature (minimum and maximum), Wind Speed, ratio and radiation were analyzed and ready consistent with the model requirement. The weather data used were represented from the five selected stations (Addis Ababa Observed, Addis Ababa Bole, Sendafa, Aleltu and Intoto stations).

There exists lack of full and realistic long period of meteorological data in our country, which may be solved by the help of Weather generator that solves the matter by generating data from the prevailing observed data. The weather generator requires the daily values of all climatic variables from measured data or generated from values using monthly average data over variety of years. to get the info, weather parameters values were developed by using WGN maker (Excel Macro Solver) and temperature calculator DEW02 are used (obtained from SWAT website: http://www.brc.tamus.edu/swat/arcswat.html).

The weather generator parameters from the stations of Addis Ababa Observatory are first loaded to the user database and therefore the batch file containing the situation and elevation of weather gauge stations are loaded sequentially. The missing Values which is common within the existing data sets were crammed with no dataset identifier (-99) and generated by the Programmed embedded within the model.

3.3.4 SIMULATION, SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION

3.3.4.1SIMULATION

Before deleing the above scenarios there is SWAT running steps in this process and it is a place that used to select paired of running and there is a place to select warm-up time (1 to 5 year) depend on your metrological data and stream flow data.

Model Simulation is that the process of making and analyzing prototype of a physical model to predict its performance within the world. Simulation modeling is employed to assist designers and engineers understand whether, under what conditions, and during which ways a neighborhood could please and what loads it can withstand (Addis Ababa Water and Sewerage Authority, 1999).

After the model was found out subsequent step was run the model and therefore the result from the simulation can't be directly used for further analysis. Instead, the power of the model to sufficiently predict the constituent flow and sediment yield should be evaluated through sensitivity analysis, model calibration and model validation (White, K.L. & I. Chaubey, 2005).

3.3.4.2 SENSITIVITY ANALYSIS

Sensitivity analysis may be a method of reducing the number of parameters to be utilized in calibration step and using the foremost sensitive parameter largely controlling the behavior of the simulation processes which finally eases calibration and validation processes also because the time required for it. It's important for understanding which model inputs are most vital or sensitive and to know potential limitations of the model. The tactic of identifying the foremost sensitive parameters that significantly effect on model calibration or on model prediction. It describes how model output varies over a variety of a given input variable (Dilnesaw A, 2006). After running sensitivity analysis, the sensitive parameters were categorized in to four classes supported their mean relative sensitivity (MRS).

Small to negligible	$(0 \leq MRS < 0.05)$,
Medium	$(0.05 \leq MRS < 0.2)$,
High	$(0.20 \leq MRS < 1.0)$
Very high	$(MRS \geq 1.0)$ (Lenhart et al. 2002)

Parameters Description	**Parameter Code**	**Mean Sensitivity**	**Category of Sensitivity**
Base Flow alpha factor(day)	Alpha_Bf	0.384	high
Maximum canopy Index(mm)	Canmx	0.0786	high
Available Water capacity pf the soil layer(mm)	Sol_Awc	0.0907	high
SCS_CN for moisture condition II (unitless)	Cn2	0.292	high
Maximum potential leaf Area Index(unitless)	Biomix	0.00154	Negligble
Thresh hold depth of water in the shallow aquifer required for evaporation to occur(mm)	Revapmn	0.094	high
Soil Albedo (unit less)	Sol_Alb	0.00604	Negligble
Soil conductivity(mm/h)	Sol_K	0.00396	Negligble
Manning coefficient for channel (unit less)	Ch_N2	0.00756	negligible
Surface runoff lag coefficient(day)	Surlag	0.00594	Negligble
Average slope length(m)	Slsubbsn	0.0014	Negligble
Thresh fold depth of water in the shallow aquifer required for return flow to occur(mm)	Gwqmn	0.194	high
Ground Water delay(day)	Gw_Delay	0.0104	Negligble
Effective Channel Hydraulic conductivity(mm/h)	Ch_K2	0.0152	Negligble
Soil evaporation compensation factor (unit less)	Esco	0.0821	high
Plant evaporation compensation factor (unit less)	Epco	0.0191	Negligble
Average slope steepness(m/m)	slope	0.00361	Negligble
Soil depth(mm)	Sol_Z	0.201	high
Ground water evaporation coefficient (unit less)	GW_Revap	0.0337	medium
maximum potential leaf area index (unit less)	Blai	0.154	high

Table 3.3-2: parameters that used for sensitivity analyses in the watershed

Based on this classification, sensitive parameters with mean relative sensitivity value of medium to very high were selected for calibration. The upper the worth of mean relative sensitivity, the upper are going to be the influence on the escape and sediment yield generation.

3.3.4.3 Model calibration

Calibration is that the process whereby model parameters are adjusted to form the model output match with observed data. It's also a way of adjusting or fine-tuning model parameters to match with the observed data the maximum amount as possible, with limited range of deviation accepted. There are three calibration approaches widely used manual calibration, automatic calibration and a mixture of the two. Manual calibration is that the most generally used approach. However, it's tedious, time consuming, and success of it depends on the experience of the modeler and knowledge of the watershed being modeled (Eckhardt, K., & J.G. Arnold, 2001).

Automatic calibration involves the utilization of an enquiry algorithm to work out best-fit parameters. it's *desirable* because it is a smaller amount subjective and due to extensive search of parameter possibilities can give results better than if done manually. SWAT has two built-in calibration tools. The manual calibration approach helps to match the measured and simulated values, then to use the expert judgment to work out which variable to regulate, what proportion to regulate them, and ultimately assess when reasonable results are obtained. In sediment transporting modelling two-step calibration procedures has been suggested by (Neitsch, S Arnold, J, Kiniry, J & Williams, J, 2005) the primary is to see water balance contribution, then calibrate stream flow and followed by sediment calibration.

The calibration period for both flow and sediment were from 01/01/1994 to 30/12/2003 including the warm-up period. During this process, model parameters varied until recorded flow patterns are accurately simulated. For this study, the manual calibration was applied due to its simplicity. Where a trial-and-error process of parameter adjustment; after each parameter adjustment is formed, the simulated and observed hydrographs are visually compared to ascertain if the match is improved.

3.3.4.4 Model Validation

Model validation is testing of calibrated model results with independent data set with none further adjustment at different spatial and temporal scales. It's comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. so as 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 will 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 usually mentioned as model validation. Accordingly, the model validation period adopted during this study is from 01/01/2004 to 30/12/2009.

3.3.5 MODEL PERFORMANCE EVALUATION

The evaluation of hydrologic model behaviour and performance is usually made and reported through comparisons of simulated and observed variables. the rationale to gauge model performance is to supply a quantitative estimate of the model's ability to breed historic and future watershed behaviour, to supply a way for evaluating improvements to the modelling approach through adjustment of model parameter values and representation of important spatial and temporal characteristics of the watershed and to match current modelling efforts with previous study results. Graphical and statistical methods with some sort of objective statistical criteria are wont to evaluate the performance of models. Coefficient of determination, Nash-Sutcliffe simulation efficiency and Percept Bias where the goodness of fit measures won't to evaluate model prediction during this study.

Coefficient of determination (R^2): - Estimates the combined dispersion against the only dispersion of the observed and predicted series and shows the interdependence (correlation) in between the observed and simulated statistic values which is described as: -

$$R^2 = \frac{\sum_{i=1}^{n}[S_i - \bar{S}_i)(O_i - \bar{O}_i)]^2}{\sum_{i=1}^{n}[\,[O_i - \bar{O}_i]^2) * \sum_{i=1}^{n}[S_i - \bar{S}_i]^2)} \dots\dots\dots\dots\dots\dots\dots\dots\dots.\ equation\ 3.14$$

Nash-Sutcliffe simulation efficiency: The efficiency NSE proposed by (Nash, J Ea and Sutcliffe, JV) is defined together minus the sum of absolutely the squared differences between the anticipated and observed values normalized by the variance of the observed values during the amount un-der investigation.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\ equation\ 3.15.$$

CHAPTER FOUR
RESULT AND DISCUSSION

SWAT model was calibrated and validated on a monthly basis to check its capability to model flow and sediment yield of Laga Dadi watershed using a time series dataset of 16 years from 1994 to 2009. The first two years of the modeling period were used for 'model warm- up (used for flashing of precipitation in the watershed). Data for the period from 1996 to 2003 were used for calibration and therefore the remaining a part of the dataset was used for validation (2004-2009). The watershed was subdivided into 13 sub basins based on a defined (1400) threshold area. The simulated flow and sediment yield was calibrated and validated at the outlet of the Lage Dadi watershed by transferring stream flow data from Sibilu river gauging station

4.1 STREAM FLOW MODELING

4.1.1 FLOW SIMULATION AND SENSITIVITY ANALYSIS

The model was run a period of eight years (from 01/01/1994 to 31/12/2003) excluding the validation period, is taken for sensitivity analysis as. Sensitivity analysis was conducted to work out the influence of a group of parameters had on predicting total flow excluding warm-up period. And initially I use 20 parameters to make the prototypes of the watershed that described on table 3.3-2, from those parameters Table 4.1-1 shows the foremost sensitive parameters for stream flow drawn by SWAT model based on mean relative sensitivity (MRS).

Table 4.1-1: Sensitivity analysis result for stream flow in Laga Dadi Watershed

No	Flow parameters	Mean sensitivity	Rank	Category of Sensitivity	Unit	Process
1	Alpha_Bf	0.384	1	high	Day	Ground water
2	Blai	0.154	5	high	unit less	Plant (land use)
3	Canmx	0.0786	9	high	mm	Hydraulic response
4	Cn2	0.292	2	high	unit less	Surface runoff
5	Esco	0.0821	8	high	unit less	Evapotranspiration
6	Gwqmn	0.194	4	high	mm	Ground Water
7	Revapmn	0.094	6	high	mm	Ground Water, evaporation
8	Sol_Awc	0.0907	7	high	mm	Ground Water, evaporation
9	Sol_Z	0.201	3	high	mm	Ground Water

To check the influencing parameters, I start from Ground (spring water) parameter, the result denotes that threshold depth of water within the shallow aquifer required for return flow to occur (Gwqmn), base flow alpha factor (Alpha_Bf), and thresh hold depth of water within the shallow aquifer required for evaporation to occur (Revapmn) are found the influencing flow parameters .Secondly I am going to check hydraulic response unit parameters and like maximum potential index (Canmx) , soil evaporation compensation factor (Esco) had influence and spatially Esco increase PET And ET will also increase and (Esco) decrease PET And ET also decrease. Thirdly from management date base the SCS_CN for moisture condition II (Cn2) was found sensitive which indicates that the parameters had a governing effect on simulated surface flow in respective with the observed flow. Finally, the soil parameters inclusive of soil depth (Sol_Z) and soil available water capacity (Sol_Awc) had also contributing effect on stream flow and were taken as a suggestion for the calibration.

4.1.2. STREAM FLOW CALIBRATION AND VALIDATION

Before calibration proceeds, the performance of the model was evaluated from the initial simulation by making prototype of the Laga Dadi watershed with model default values of initial 20 parameters. The monthly simulations were resulted Coefficient of determination (R2). After each simulation, the model goodness-of-fit was evaluated and therefore the model performance after adjusting all the above parameters that used to make prototype of the watershed shows the R^2, Nash Sutcliffe Coefficients (NSE) of 0.56 & 0.54 respectively. The result shows the performance indicator was below the suitable limits, i.e., $R^2 > 0.6$ & NSE > 0.5 (Sloff, C. (2005)). So that, the model flow parameters were required adjustment and this adjustment was supported the sensitivity analysis results of flow parameters. From all 20 parameters that used for making prototype of the watershed Nine of the foremost sensitive parameters were utilized in calibration having small to high class of sensitivity.

Flow calibration for the watershed was conducted for the entire of eight years (from January 1, 1996 to New Year's Eve, 2003) which incorporates two years, 1994 & 1995, for model initialization (warm up). Therefore, for the model performance in calibration was considered from 1996 to 2003. Thus, the parameters (Table 4.1-1) were adjusted further by varied iteratively in their allowable range until satisfactory agreement between measured and simulated stream flow was obtained.

Manual calibration was utilized in this study. Adjustment was done till observed and simulated values were correlated well by changing the parameters in their allowable range manually. The SWAT default parameters values were adjusted as follows. First, the surface flow components of average annual water balance by adjusting the CN2 (used to increase surface rune off by increasing CN2 or decrease surface rune off by decreasing CN2). an attempt was also made to stay the curve numbers on the brink of standard table values. Next, parameters that control the watershed (Gwqmn, Esco, SOL_AWC, Sol_Z, REVAPMN) were adjusted till the deviation between simulated and observed values get minimized and therefore the performance indicators dwell the suitable range. Accordingly, the ultimate calibrated parameters were presented as shown Table 4.1-2 for flow in Laga Dadi watershed.

Table 4.1-2: Result of final calibrated flow parameters for Laga Dadi Watershed

Parametres	Default Values	Allowble Range To change	Adjusted Parametre value	Unit	Process
Gwqmn	0	0 - 5000	100	mm	Ground Water
Canmx	0	1 _ 2	1.4	mm	Hydraulic response
Alpha_Bf	0.048	0 - 1	0.061	Day	Ground Water
Sol_Awc	**	±25%	10% (Added)	mm	Ground Water, evaporation
Cn2	**	±25%	17% (Added)	unit less	Surface runoff
Revapmn	1	0 - 500	250	mm	Ground Water
Esco	0	0 - 1	0.9	unit less	Evapotranspiration
Sol_Z	**	±25%	30 % (Subtracted)	mm	Ground Water

default* shows the default
SWAT model values
** indicates the input soil properties of the watershed (varies for each soil

The hydrograph of the calibration period of the observed and simulated flow in monthly basis shows (Figure 4.1-1), the model slightly overestimates a number of monthly peak flows of the years; like September 1997, July 1998, July 2001 and April and also slightly underestimate the height flows, like August 1999 & 2000 and September of 2002 of the year's monthly mean flows. Low flows (especially flows < 8m3/s) were slightly underestimated; whereas medium flows were relatively estimated well by the model. This fluctuation might exist due to the model's low capability to capture peak rainfall event, the information qualities occurred during filling missed data and error during measurement records

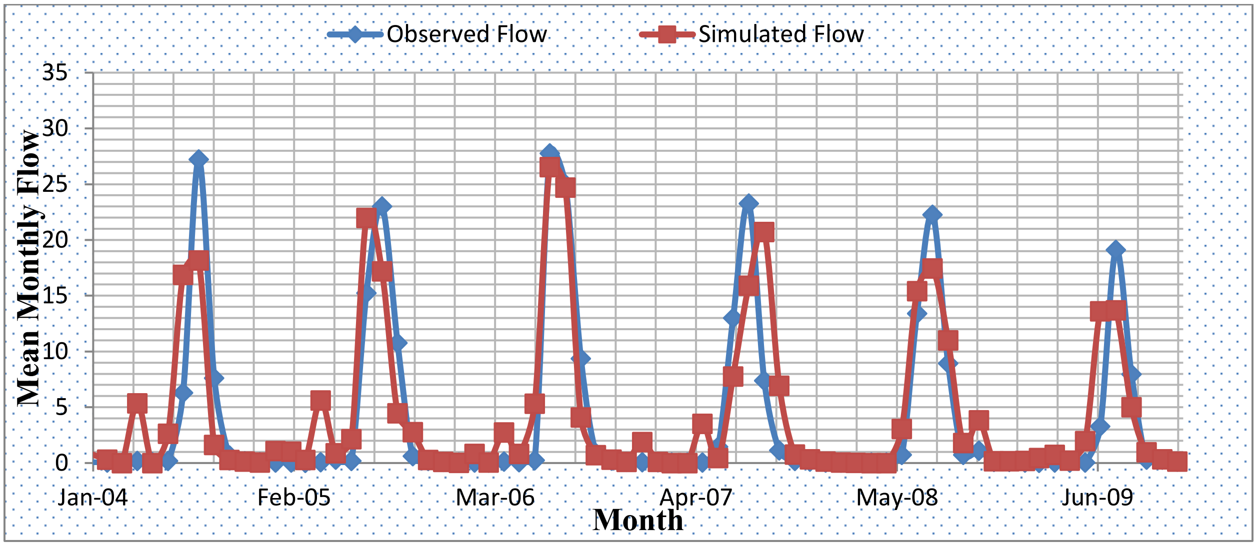

Figure 4.1-1: Observed and simulated stream flow hydrograph on mean Monthly time step during the calibration period

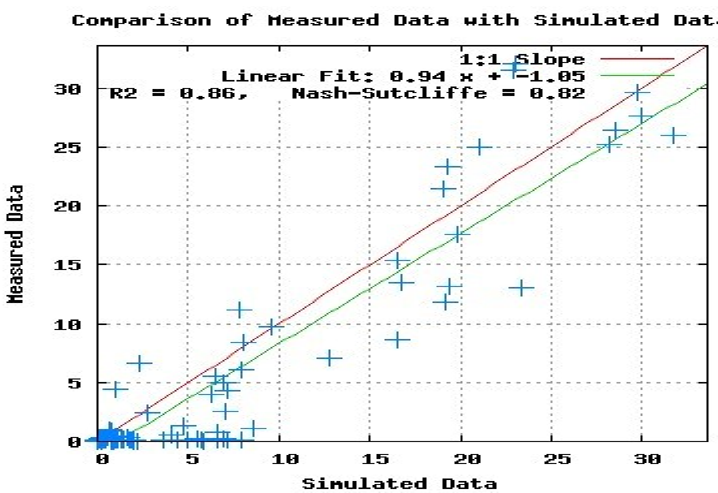

Figure 4.1-2: Regression and 1:1 line fit of observed and simulated monthly Stream flow during the calibration period.

After flow is calibrated, subsequent step was validation with independent data sets which aren't utilized in the calibration period without changing the fitted parameters. The validation was undertaken for a period of six years (01/01/2004 to 12/31/2009). The hydrograph of validation period was as presented in figure 4.1-3.

The hydrograph of the validation period of the observed and simulated flow in monthly estimation, the model under estimates a number of the height flows of the months, like August of the year 2004, 2005, 2007,2008 & 2009. a number of the medium and low flows were underestimated and over estimated by the model with within the years b/c of the model's low capability to capture peak rainfall event, the information qualities occurred during filling missed data and error during measurement records.

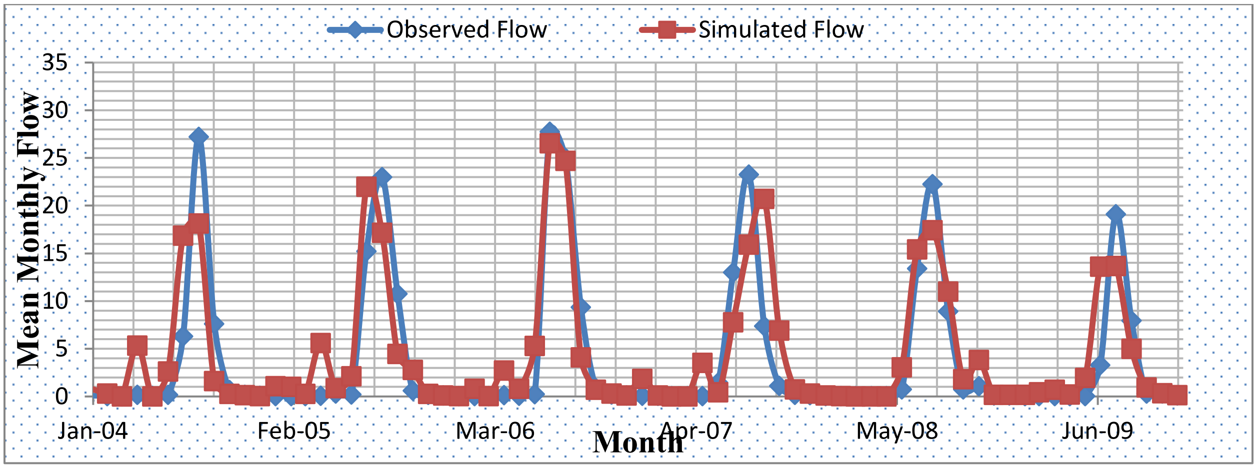

Figure 4.1-3: Observed and simulated stream flow hydrograph on mean Monthly time step during the validation period.

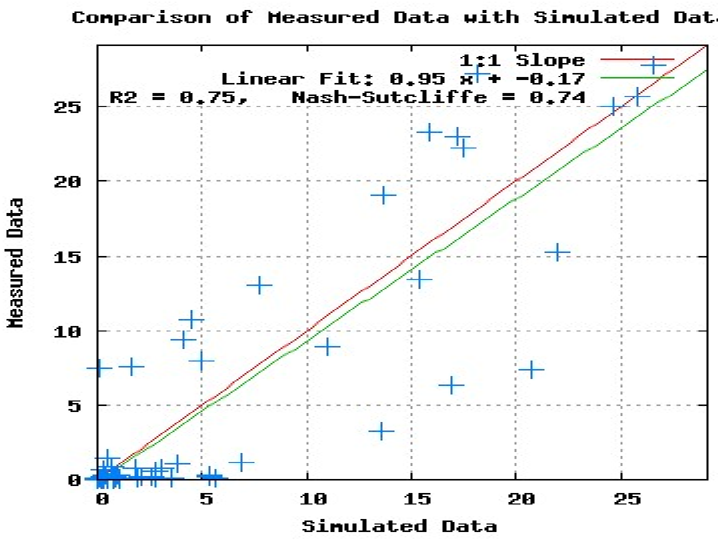

Figure 4.1-4: Regression and 1:1 line fit of observed and simulated monthly Stream flow during the validation period.

Table 4.1-3: Calibration and validation statistics of observed and simulated stream flow

Monthly time step	Over Year mean Monthly stream flow(m^3/s) Observed	Simulated	NSE	R^2
Calibration (1995 - 2003)	4.4	5.9	0.82	0.85
Validation (2004- 2009)	3.9	4.43	0.75	0.76

4.2. SEDIMENT YIELD MODELING

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

4.2.1. SEDIMENT YIELD SENSITIVITY ANALYSIS

Once it's shown that the flow was accurately represented by the model the main target is shifted to the calibration of the model for sediments. Sensitivity analysis was administered for sediment to spot parameters that affect sediment yield. From six parameters that I use to make the proto type of the watershed for sedimentation the most Sensitive parameters for sediment within the watershed include USLE support practice factor (USLE_ P), linear factor for channel sediment routing (SPCON) and exponential factor for channel sediment routing (SPEXP) were found very sensitive to sediment flow. From those sensitive parameters USLE support practice factor (USLE_P) was the foremost sensitive of all (Table 4.2-1).

Table 4.2-1: Result of sensitivity analysis for sediment parameters.

Parameter Description	Parameter Code	rank	mean Sensitivity	Category Of Sensitivity	Unit	process
Channel Cover factor	Ch_Cov	4	0.00E+00	Negligible	Unit less	Erosion
Channel Erodibility factor	Ch_Erod	4	0.00E+00	Negligible	Unit less	Erosion
Channel sediment routing	Spcon	3	5.55E-01	Medium	Unit less	sediment
Sediment re entrained in channel routing	Spexp	2	1.68E-02	Medium	Unit less	Sediment
USLE-Cover and management factor	Usle_C	4	0.00E+00	Negligible	Unit less	Land cover
USLE-Support practice factor	Usle_P	1	2.78E+00	Very High	Unit less	USLE equation support practice

4.2.2 Sediment yield Calibration & Validation

After calibration and validation of flow, the next step is calibrating sediment yield of the watershed. Like Flow, sediment calibration for the Laga Dadi watershed by comparing monthly model simulated sediment load against monthly measured sediment at the outlet of the watershed for the period of January 1, 1996 to December 31, 2003. Also, two years January 1, 1994 to December 31, 1995) was skipped for model initialization (warm-up period). The calibration of sediment yield of the watershed was done supported sediment sensitivity analysis that has identified sensitive parameters for sediment yield of the watershed (Table 4.2-1) and by varying iteratively within the allowable ranges of the parameters.

USLE support practice factor (USLE_P) that's the ratio of soil loss with a selected support practice to the corresponding loss with up and down slope culture adjusted to 0.16 From the channel properties, the linear parameter for calculating the utmost amount of sediment which will be re-entrained during channel sediment routing (SPCON) adjusted to 0.0002 and therefore the exponent parameter for calculating sediment re-entrained in channel sediment routing (SPEXP) adjusted to 1.8(Table 4.2-2).

Table 4.2-2: Final calibrated sediment parameters for Laga Dadi watershed

Parameters	Default Values	Allowable Range To change	Adjusted Parameter value
Spcon	0.0001	0.0001 to 0.01	0.0002
Spexp	1	1 to 2	1.8
Usle_P	1	0 to 1	0.16

After adjustment of all the above parameters, the monthly simulations were results Coefficient of determination (R2) and Nash Sutcliffe Coefficients (NSE) of 0.84&0.76 respectively (Table 4.2-3). The observed and simulated sediment load in monthly basis within the calibration period shows the model slightly overestimated a number of monthly sediments yields of the watershed like August 1999 & 2002 and slightly below estimates the sediment yield of march of 1998 and August of the years 2001 and 2002 this because of uncertainty that occur during developing rating curve and malfunctioning of measurement instrument (Figure 4.2-1).

Table 4.2-3: Calibration statistics of observed and simulated Sediment load

Monthly Time step Simulation	Mean Monthly Sediment Yield(t/month)		NSE	R^2
	Observed	Simulated		
Calibration (1996 - 2003)	3163.5494	4392.628	0.76	0.84

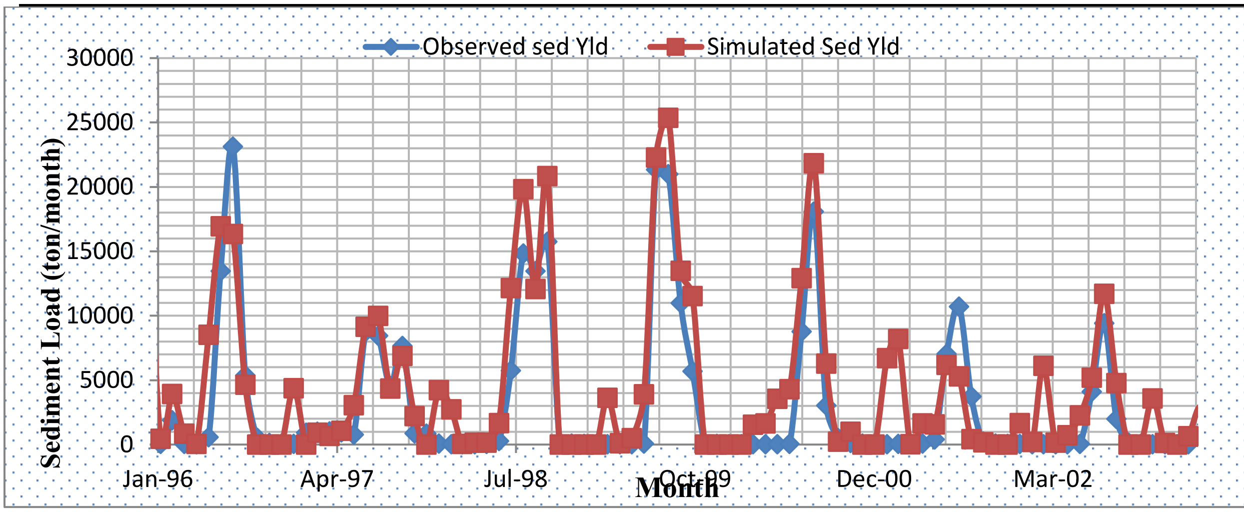

Figure 4.2-1: Calibration results of monthly Observed and simulated sediment yield hydrograph

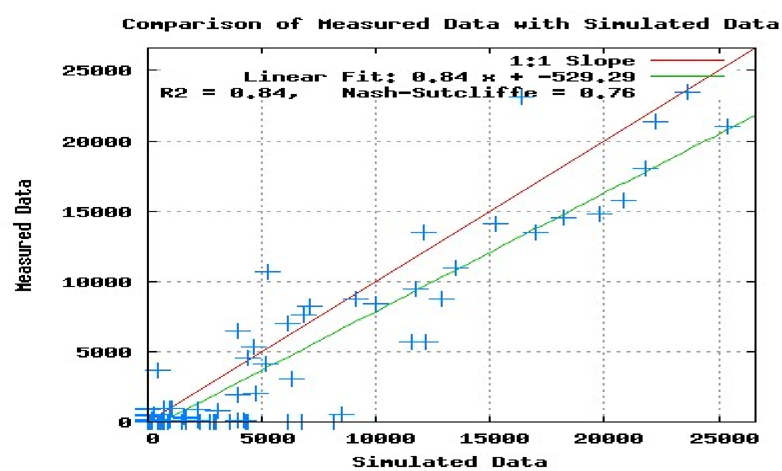

Figure 4.2-2: Regression analysis and 1:1 line fit of observed and simulated monthly Sediment Yield during the Calibration period.

Like flow validation, validation of sediment yield of the watershed was administered for the years January 1, 2004 to December 31, 2009. Therefore, for the model performance in validation was considered from 2004 to 2009 without further adjustment of the parameters. The statistical values within the monthly basis of sediment yield estimation within the validation period results the R2, and NSE were 0.76 &0.7 respectively (Table 4.2-4)

Table 4.2-4: Validation statistics of observed and simulated Sediment load.

Monthly Time step Simulation	Mean Monthly Sediment Yield(t/month)		NSE	R^2
	Observed	Simulated		
Validation (2004-2009)	2558	3190	0.7	0.76

The observed and simulated sediment yield in monthly time step of the validation period was shows the model slightly underestimate the sediment yields of highly flow time periods like August of the years 2006, 2008 & 2009 b/c of crop management factor of the area in land use land cover map is good than reality, and in low and medium flow periods the model simulation highly overestimates in most the years b/c of the uncertainty error during developing of rating curve (Figure 4.2-3).

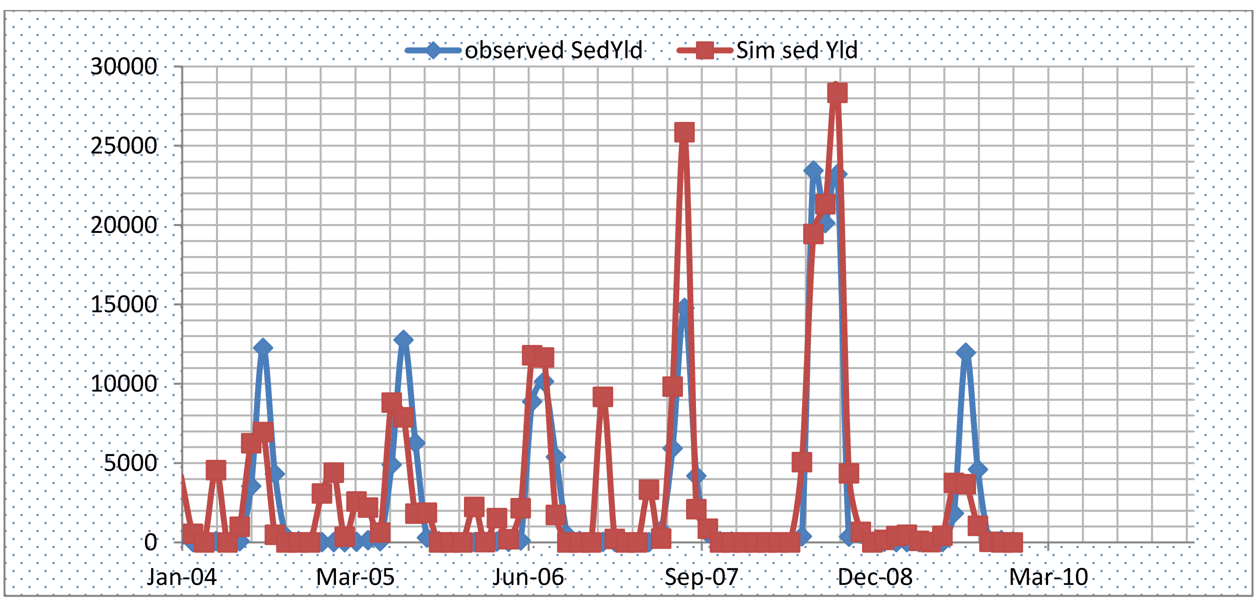

Figure 4.2-3: Validation results of monthly Observed and simulated sediment yield hydrograph

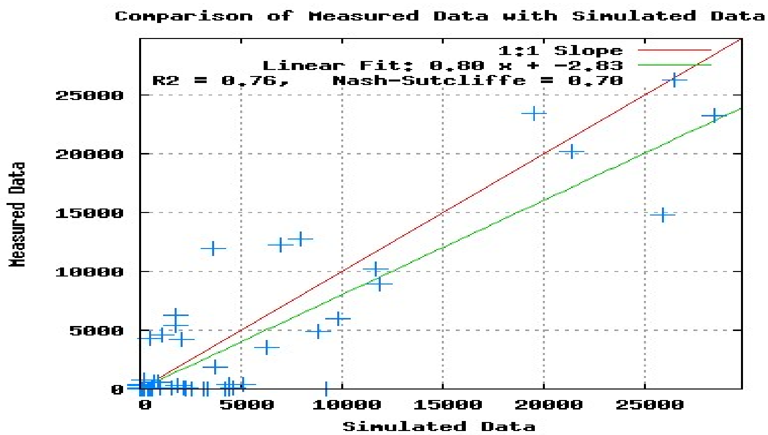

Figure 4.2-4: Regression analysis and 1:1 line fit of observed and simulated monthly Sediment Yield during the validation period.

4.3. Identification and Mapping of Runoff & Sediment source areas

Once the model (SWAT) was calibrated and validated, it had been run a period 16 years (1994 to 2009), then the general simulated output is often used for further and sediment source areas were identified within the Watershed.

13 sub basins are classified as per the model (Figure 4.3-1). 1400 m2 cell area was taken when streams are defined, these could be the rationale that a number of the sub basins have a really small areal coverage and areal coverage of the sub basins vary from 1 to 19%. The most important coverage was occupied by sub basins 6, 13, 3 and 9.

Table 4.3-1: Sub basins Areal coverage, HRU distribution in the Watershed

Sub basins	Area(km2)	% Of coverage	Dominate land use	Dominant Soil	Dominant Slope
1	27.93	0.14	RNGE	Leptosols	0 - 5
2	15.9	0.08	AGRC		
3	26.1	0.13	RNGE		
4	3.95	0.02			
5	0.40	0.002	AGRC		5 to 10
6	39.8	0.19			0 - 5
7	18.40	0.09	RNGE		
8	6.4	0.03			
9	23.9	0.12	AGRC		
10	7.41	0.04			
11	1.14	0.01			
12	0.82	0.00			
13	32.8	0.16			

The model simulation of sediment yield varies from HRU to HRU. As the study conducted by [Arnold, JG and Soil, Grassland. (1995)] soil formation rates for erosion in several Agro ecological zone like Ethiopia have range of 2 to 16 ton/ha/year tolerable soil loss levels. Sub basins having sediment yield above 5 ton/ha/year were selected as high to medium range sediment source areas of the watershed and their dominant HRU distribution (slope, soil and land use) were presented as shown in Table 4.3-1 above. The identification of dominant HRU distribution of high sediment source areas of the watershed is vital for simplifying add undertaking management options.

The spatial variability of runoff and sedimentation rate was identified and based on which the potential area of intervention is often identified. SWAT calculates the 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 serious factor which contributes to erosion.

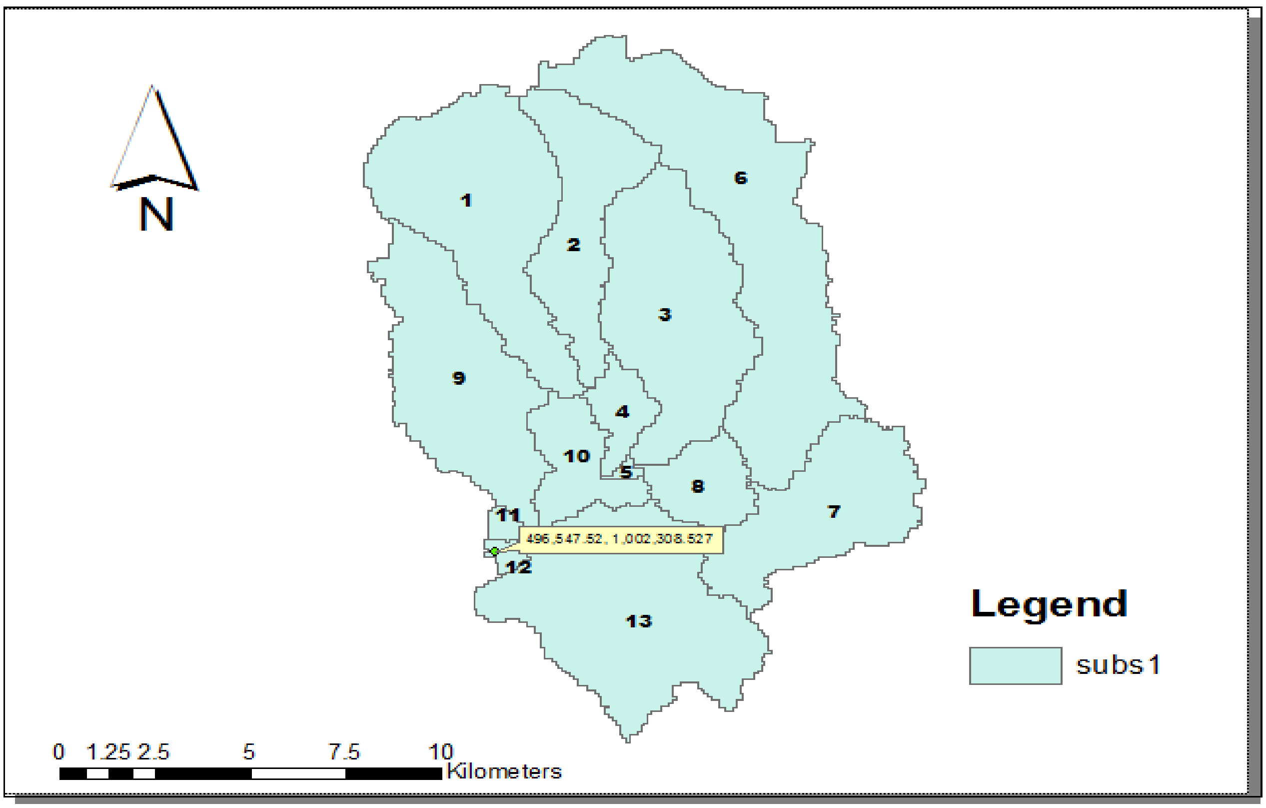

Figure 4.3-1: SWAT Sub basins of Laga Dadi Watershed.

The total surface runoff and average annual yield of sedimentation for every sub-basin was used to generate sediment source map. The annual average simulated surface runoff was found

654.5mm. some of the sub basin like sub basin 4 are high runoff with small area coverage this is because for a fixed return interval, as watershed size increases, the runoff per unit area decreases. This occurs primarily because average rainfall amount decreases with increasing area; secondarily, increased travel time for runoff allows more infiltration and other losses like evaporation depreciation and lateral flow in addition to the above reasons land use that use for grazing in the area and slope of the area are highly affect the runoff.

Table 4.3-2: Sub basins Runoff in Laga Dadi catchment

Sub Basins	Surface Runoff (mm)	Sub Basins	Surface Runoff(mm)
1	442	7	775
2	380	8	766
3	712	9	777
4	774	10	783
5	785	11	791
6	511	12	791
		13	25

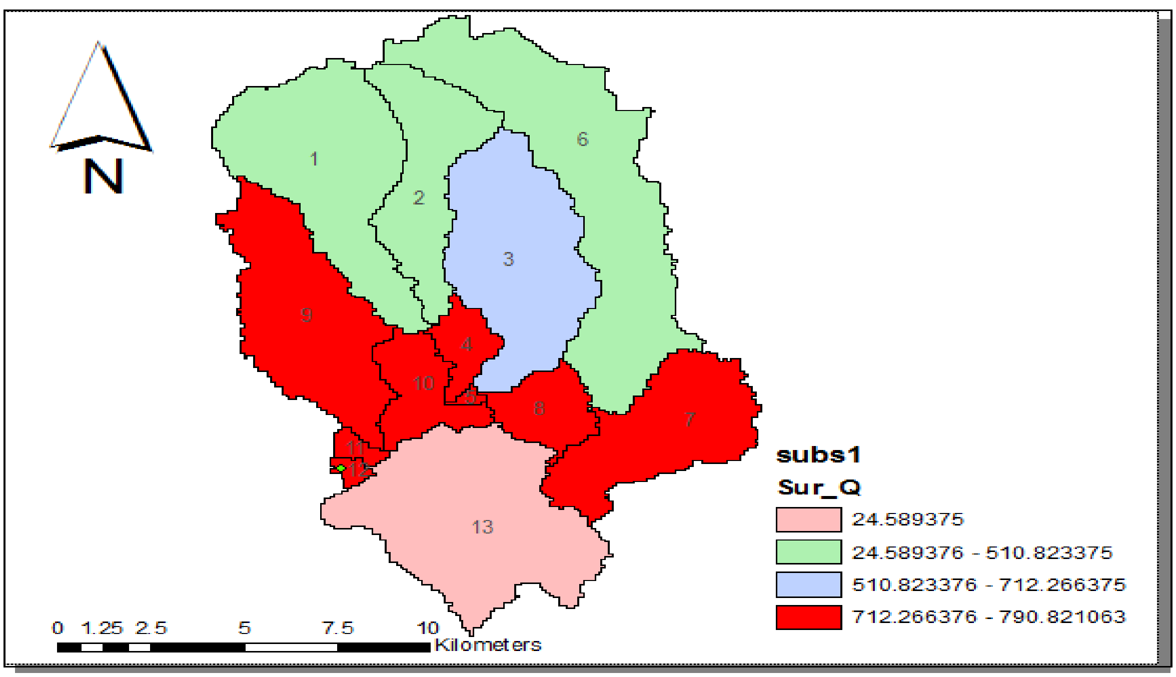

Figure 4.3-2.: Spatial Distribution SWAT simulated annual surface runoff in Laga Dadi watershed.

As the study conducted by [Arnold, JG and Soil, Grassland. (1995)] soil formation rates for erosion in several Agro ecological zone like Ethiopia have range of 2 to 16 ton/ha/year tolerable soil loss levels. Out of the 13-sub basin created by the model, five of the sub basins have sediment yield above 5 ton/ha/year and therefore the others sub basins are in tolerable range. a number of the sub basins having high areal coverage have contributed low runoff & sediment yield and the other way around, this might arise due to the prevailing HRU in each sub basins has revealed different surface runoff contribution in respective with the soil properties and land use effect that wear surface runoff generation.

The highest sediment yield sub basin areas of then watershed (sub basins 5, 12, 13 & 11) are those which are covered with farmland cover, Grazing land and Leptosols soils. The yellow and red highlighted areas of the watershed are potential areas which are susceptible for erosion and sediment yield. The HRU distribution for the chosen sub basins clearly indicates the land cover (cultivated area and Grazing) is that the major controlling factor for sediment potential areas.

Sediment yield of a watershed is that the summation of suspended and bed load. The analysis described above is suspended sediment load. Suspended load is that the portion of the sediment that's carried by a fluid flow which settles slowly enough such it almost never touches the bed. Whereas Bed load consists of sediments that are moving along during a riverbed, or simply above rock bottom, essentially by either rolling or "saltation," where particles bounce along rock bottom. These heavier particles are usually sands and gravels. From the entire sediment contribution bed load contributes 10 to 15 % of suspended load.

Table 4.3-3: Sub basins sediment yield in Laga Dadi catchment.

Sub Basins	Sed yield (t/ha/yr.)	Sub Basins	Sed yield (t/ha/yr.)
1	0.9869	7	2.7878
2	1.1751	8	0.2146
3	3.0874	9	5.2214
4	2.8908	10	9.1832
5	18.4827	11	21.0736
6	1.6203	12	23.8588
		13	24.5894

The entire mean annual measured sediment yield obtained from the sediment rating curve was 4.923 ton/ha/ yr. and the simulated annual average sediment yield by SWAT model was 6.73 t/ha/yr.

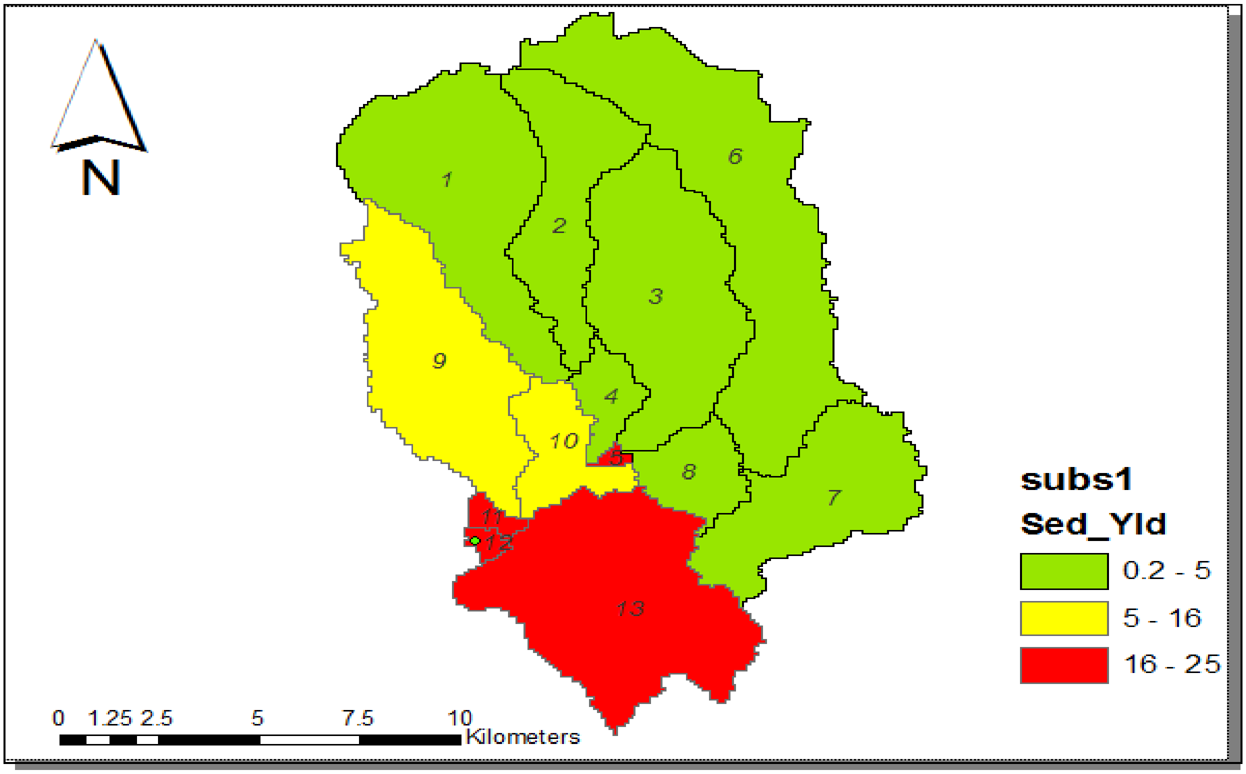

Figure 4.3-3: Spatial Distribution SWAT simulated annual Sediment Yield in Laga Dadi watershed

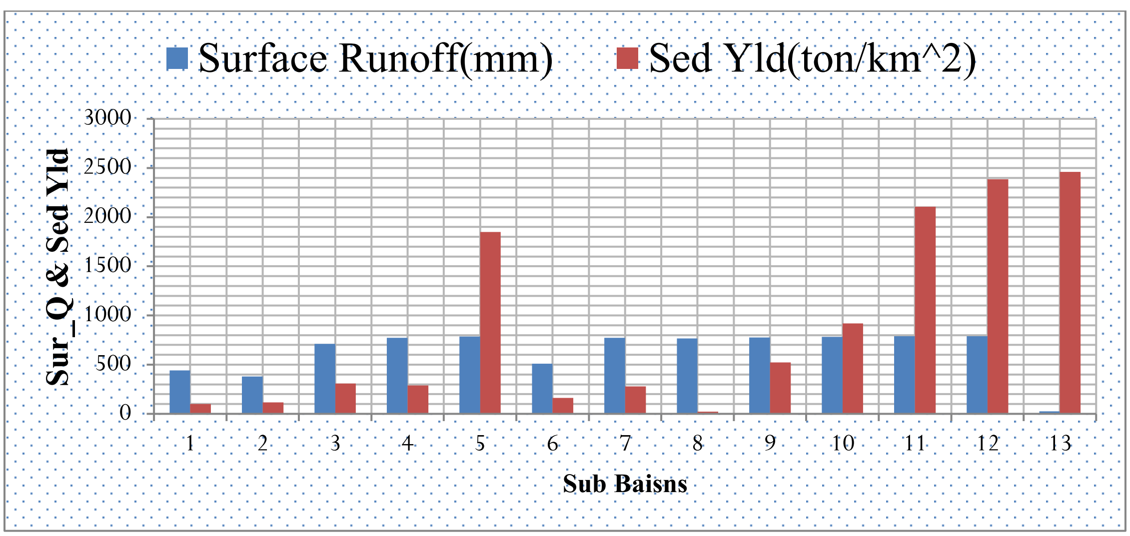

Figure 4.3-4: Comparisons of surface runoff and sediment yield in each sub basins

As observed from the (Figure: 4.3.4) sediment yield don't have absolute relation with surface runoff lonely, rather combination surface runoff and other factors have great effect on the sediment yield like soil type, land use, area etc. This shows surface runoff alone has no direct impact on the sediment yield. it's due to the land use/land cover factor; slope length and steepness, and soil characteristics are the main factors for low sediment yield in each sub watershed and are expected to highly influential for sediment yield.

Sediment Loading Laga Dadi Dam Site

Sedimentation of reservoirs occur on different purposes like, erosion of agricultural soil, degradation of cultivable and potential areas, etc. This problem may be a big challenge in Ethiopia and it can continue within the future except appropriate mitigation measures are taken. To control & manage such quite problems it had been vital to understand & estimate the trend of sediment loading at the precise site. By using the chosen SWAT model it's tried to estimate the quantity of sediment at Laga Dadi reservoir as this reservoir is that the main water system source of Addis Ababa City that's losing its capacity due to sedimentation.

The results of bathymetric survey study obtained from the plan view study conducted by [Dar-AL Omran. (2011)] at Laga Dadi reservoir in 2010 calculated the remaining volume capacity to be approximately 42.18 Mcm and 1.62 Mcm less when compared to the quantity estimated by the 1998 survey(43.8Mcm) and less by 3.72 Mcm estimated by the 1979(45.9Mcm) survey. supported the results of the three bathymetric surveys the typical annual siltation rates are 1979 to 1998 (110,000 m 3/year), 1979 to 2010 (120,000 m 3/year) and 1998 to 2010 (135,000 m 3/year).The level of accuracy of the three bathymetric surveys can't be an equivalent, especially of these that the reservoir wasn't at FSL when the survey was conducted, but the very fact that there are strong indications that sedimentation is increasing, taking catchment measures to regulate erosion and capture sediment load before entering the reservoirs should be considered.

The simulated sediment loading at the dam site found within the outlet of the watershed (sub basin 12) by SWAT model was 716.34 ton/km2/year but the sediment yield of the catchment consistent with the results of the 1998 survey is 762 t/km2/yr. and sediment loading by 2010 survey reported a worth of 845 t/km2/yr. is quickly obtained (assuming a sediment mix density of 1.3 t/m3). Such discrepancy of annual sediment loading arises during this research was due to the uncertainties from the generated sediment rating curve at dam site.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Modeling of flow and sediment in the watersheds, understanding the biophysical, hydrological and hydraulic problems and proposing relevant intervention measures to regulate degradation, improving land and water productivity, enhancing ecological and environmental functions in developing countries are serious challenges due to absence of relevant information and data ((Gesese, 2008); (Getnet, 2012) (Tahal & Metaferia Consulting Engineers, 2002)). During this study, attempts were made to model the Laga Dadi watershed in terms of sediment yield, surface runoff and identification of potential sediment source.

The main objective of this thesis is to model runoff-sediment yield for Laga Dadi reservoir and its Catchment. Before completing the simulation of flow and sediment yield, the suitability and performance of the SWAT model was evaluated using Standard calibration and validation statistics. Agreement between measured and simulated monthly flow at the outlet of Laga Dadi Watershed was demonstrated by coefficient of correlation (R^2= 0.85) and Nash-Sutcliffe model efficiency (ENS = 0.82) for calibration period and R2= 0.76, ENS = 0.75 for validation periods.

The result indicates matching between measured and simulated flow, by considering the suitable limits of statistical model evaluation criteria. As the same procedure of stream flows the simulation of sediment yield, coefficient of correlation (R2=0.84) &Nash-Sutcliffe model efficiency (ENS= 0.76) in calibration period and R2=0.76, and ENS =0.70for validation periods were achieved.

The result indicates matching between measured and simulated sediment yield, by considering the suitable limits of statistical model evaluation criteria for calibration (1996 -2003) and validation periods (2004-2009) respectively. The 16 years' simulation result indicates that the simulated annual average suspended sediment yield by SWAT model was 6.73 t/ha/yr. and therefore the annual average measured suspended sediment develop with rating curve was 4.93 ton/ha/yr.

The sub watersheds that produce high sediment load because of the area are used for agriculture and cultivation are 13,12and 11 in their order of importance contributing sediment yield exceeding the soil loss tolerable rate. The model prediction verified that about 17% of the watershed area has high erosion potential contributing very high sediment yield exceeding the tolerance limit (soil formation rate) within the study area and therefore the rest parts of the watershed area have moderate to low range potential for erosion which produces below a mean annual sediment yield of the watershed and this resalt is depends on combination of land, soil and slop overlaying.

In general, the SWAT model performed well in predicting both the flow and sediment yields from the study watershed and therefore the results are acceptable. It's a Suitable tool for further analysis of the hydrological responses within the watershed.

5.2. RECOMMENDATIONS

The study can be further extended to similar watersheds within the country, particularly within the Awash Basin of Ethiopia, where quantifying the entire volume of runoff and sediment yields is urgently required for better land and water resources planning and management purpose

The uncertainties regarding the spatial representativeness of meteorological and hydrological gauging stations end in uncertainties in estimates of areal rainfall estimation which is to be accounted so as to enhance the standard of selections made. The Model prediction output depends on the standard of input file. One among the constraints in conducting this research work was lack of continuous measured suspended sediment and stream flow data inside the catchment. The sediment and stream flow data used for this study were generated by transferring data from Sibilu flow gauging station and sediment rating curves was developed from limited sediment measurement data. It had been quite clear that use of more accurate data will improve the modeling approach so responsible bodies should give due attention to possess enough hydrological data within the study area. Generally, the subsequent points are recommended: -

- ✓ It is suggested to put in hydro-meteorological gauging stations in and round the catchment in respective with accurate measurement, so responsible bodies should have exposed their contribution in additional installation and measurement accuracy.
- ✓ There is not any measurement of sediment concentration within the dam; better results are going to be obtained if reliable future measurement exists. [The performance of the model is often improved by increasing the amount of rainfall and discharge gauging stations within the catchment].

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APPENDICES

Appendix A: Weather generator statics for Addis Ababa Observatory Station.

Parameters	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TMPMX	24.26	25.70	25.59	25.13	25.42	23.61	21.29	21.10	22.03	23.17	23.42	23.35
TMPMN	9.76	9.85	11.36	12.30	12.48	11.61	11.45	11.52	11.28	10.42	8.82	8.15
TMPSTMX	1.42	1.57	1.94	2.00	1.94	2.11	1.71	1.59	1.66	1.35	1.26	1.38
TMPSTDMN	3.70	1.90	1.79	1.25	1.25	1.06	0.89	0.98	1.37	1.75	1.95	1.93
PCPMM	14.15	23.72	58.31	81.42	81.95	151.46	282.38	286.6	175.01	34.83	13.74	13.09
PCPSTD	2.48	4.50	6.22	6.81	6.59	6.72	9.34	10.17	9.41	5.22	3.33	3.20
PCPSKW	7.86	9.50	7.57	4.34	3.75	2.09	1.54	2.11	2.44	8.63	10.55	11.57
PR_W(1)	0.05	0.07	0.16	0.24	0.21	0.51	0.85	0.93	0.41	0.09	0.05	0.03
PR_W(2)	0.41	0.46	0.55	0.67	0.63	0.83	0.92	0.91	0.75	0.50	0.37	0.39
PCPD	2.45	3.15	8.30	12.10	11.30	21.80	28.35	28.20	19.50	5.35	1.90	1.65
RAINHHMX	0	0	0	0	0	0	0	0	0	0	0	0
SOLARAV	19.5	22.2	21.04	19.9	19.93	15.85125	13.78	14.29	17.19	21.52	20.95	20.07642
DEWPT	7.92	7.54	8.95	10.2	9.41	11.09	11.78	11.91	10.94	7.45	6.45	7.23
WINDAV	0.58	0.66	0.649	0.59	0.60	0.4	0.30	0.28	0.403	0.63	0.65	0.616531

Appendix B: Definition of weather generator parameters

parameter	*Definition*
TMPMX	Average or Mean maximum air temperature for month(^{0}C
TMPMN	Average or Mean minimum air temperature for month(^{0}C
TMPSTMX	Standard deviation for daily maximum temperature for month(^{0}C
TMPSTDMN	Standard deviation for daily maximum temperature for month(^{0}C
PCPMM	Average or Mean total monthly precipitation(mm H_2o)
PCPSTD	Standard Deviation for daily precipitation in month (mm H_2o)
PCPSKW	Skew Coeffiecnt For daily Precipitation in month
PR_W(1)	PR_W1 Probability of a wet following a dry day in the month
PR_W(2)	PR_W2 Probability of a wet following a wet day in the month
PCPD	Average number of days of precipitation in month
SOLARAV	Average daily solar radiation for month (MJ/m^2/day)
RAINHHMX	Average maximum half hour rainfall(mm)
DEWPT	Average daily dew point temperature in month(^{0}c)
WINDAV	Average daily Wind Speed in month(m/s)

Appendix C: Definition of soil parameters

Code	Description
SNAM	Soil Name
NLAYERS	No of layers
HYDGRP	Soil Hydrologic Group(A,B,C,D)
SOL_ZMX	Maximum Rooting Depth of the soil profile
TEXTURE	Soil texture
SOL_Z	Depth from soil surface to bottom layer
SOL_BD	Moist bulk density for soil
SOL_AWC	Available Water Capacity Of soil Layer
SOL_K	saturated Hydraulic conductivity
SOL_CBN	Organic Carbon Content
CLAY	Clay Content
SILT	Silt Content
SAND	Sand Content
ROCK	Rock Fragment Content
SOL_ALB	Moist Soil Albedo
USLE_K	Soil Erodiblity(K factor)

Appendix D. Soil parameters of the study area (According to FAO(soil classification(FAO, 2002)& literatures)

SNAM	NLAYERS	HYDGRP	SOL_ZMX	Texture	Sol_Z	Sol BD	Sol_AWC	SOL_K	SOL-CBN	CLAY	SILT	SAND	ROCK	SOL-ALB	USLE-K
orthic solonchaks	3	B	1800	SCL-CL	600	1.25	0.19	26	3.49	64.5	9	25.4	1.1	0.01	0.32
					1200	1.35	0.14	15	0.29	72	8	20	0	0.13	0.28
						1.83	0.09	6.8	0.29	75	7	18	0	0.13	0.2
pellic vertisols	1	A	500	SCL	500	1.44	0.19	287	1.8	35	38	27	0	0.13	0.21
calcic xerosols	1	B	1500	SICL-CL	1000	1.43	0.2	307	1.8	33	35	12	0	0.13	0.21
leptosols	3	D	1800	CL-SCL	600	1.35	0.2	7.9	5.81	76	8	16	0	0.01	0.49
					1200	1.35	0.15	0.23	1.94	70	11	19	0	0.01	0.49
					1800	1.35	0.13	0.12	0.65	79	7	14	0	0.07	0.49
Chromic luvisols	3	B	1800	SIL	210	1.45	0.22	38.4	1.2	11	67	22	0	0.13	0.3
					260	1.46	0.21	37.2	0.3	14	66	20	0	0.13	0.3
					460	1.45	0.2	34.8	0.21	19	59	22	0	0.13	0.3

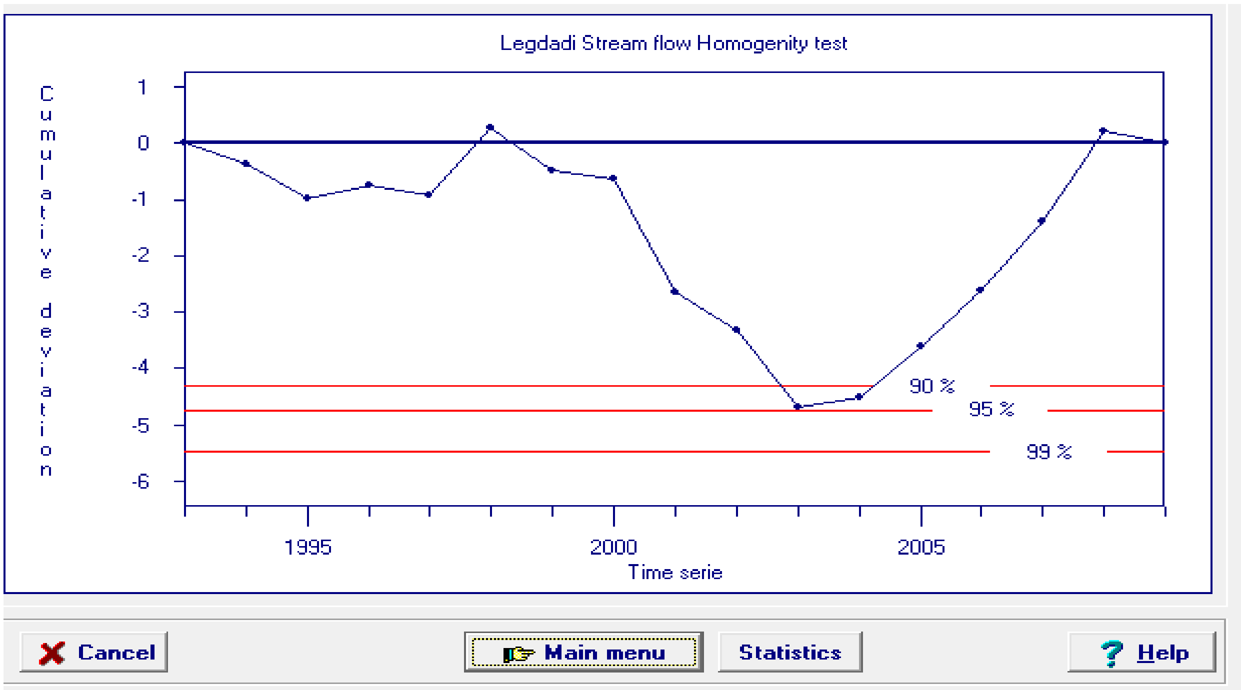
Appendix E. Transferred Measured Mean Monthly stream flow (m^3/s) at the outlet of Laga Dadi Watershed

M/Y	Jan	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1994	0.17	0.09	0.08	0.11	0.12	0.56	9.95	26.93	13.09	2.21	1.27	0.59
1995	0.30	0.13	0.11	0.25	0.29	0.29	9.14	24.81	13.09	1.02	0.56	0.26
1996	0.14	0.10	0.10	0.09	0.08	1.10	13.10	21.44	27.60	1.01	0.26	0.16
1997	0.09	0.07	0.06	0.14	0.16	0.16	5.00	25.15	26.37	0.56	0.30	0.14
1998	0.15	0.07	0.06	0.06	0.10	17.60	26.00	23.30	9.74	2.52	0.38	0.14
1999	0.09	0.05	0.06	0.05	0.04	0.18	6.03	32.00	8.38	1.36	0.27	0.13
2000	0.08	0.04	0.02	0.05	0.07	0.10	4.00	31.54	5.50	16.30	0.26	0.16
2001	0.09	0.06	0.09	0.09	0.16	0.77	11.86	8.60	6.61	0.46	0.20	0.11
2002	0.09	0.06	2.43	0.06	0.05	0.09	7.04	15.34	25.00	0.32	0.12	0.08
2003	0.06	0.03	0.03	0.04	0.04	0.26	13.46	13.00	11.12	0.86	0.20	0.07
2004	0.10	0.06	0.04	0.35	0.12	0.34	11.51	35.68	13.92	1.25	0.31	0.16
2005	0.11	0.07	0.06	0.14	0.55	0.36	15.48	37.02	19.67	1.13	0.34	0.18
2006	0.08	0.08	0.10	0.24	0.16	0.45	26.67	30.04	17.10	1.59	0.38	0.20
2007	0.14	0.14	0.07	0.10	0.10	2.63	18.69	42.50	13.48	2.07	0.34	0.25
2008	0.10	0.06	0.05	0.07	0.07	1.36	24.50	40.69	16.30	1.36	2.00	0.21
2009	0.18	0.09	0.05	0.08	0.08	0.11	6.00	34.91	14.54	0.54	0.57	0.23

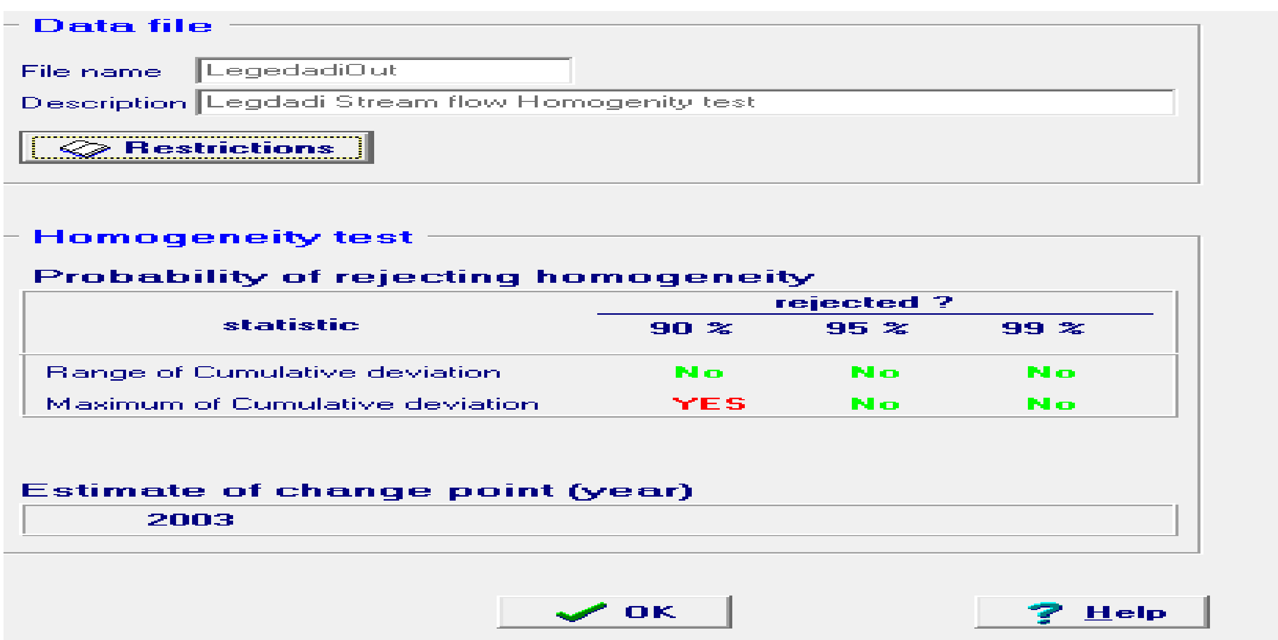
Appendix F. Test for Absence of trend for AA Observed Station (presented as a sample)

	AA Obs	Spear Man For Testing Absence Trend fr AA Obs				
i		Chro orde	Kxi	Kyi	Di	Di^2
1	1042.5	931.83	1	6	-5	25
2	1125.3	952.4	2	4	-2	4
3	1548.5	1016.1	3	9	-6	36
4	952.4	1042.5	4	1	3	9
5	1337.7	1052.4	5	18	-13	169
6	931.83	1074.1	6	19	-13	169
7	1191.1	1125.3	7	2	5	25
8	1452	1158.5	8	11	-3	9
9	1016.1	1173.3	9	10	-1	1
10	1173.3	1191.1	10	7	3	9
11	1158.5	1240.6	11	16	-5	25
12	1409.25	1264.1	12	20	-8	64
13	1385.53	1266.6	13	14	-1	1
14	1266.6	1330.7	14	15	-1	1
15	1330.7	1337.7	15	5	10	100
16	1240.6	1381.2	16	17	-1	1
17	1381.2	1385.53	17	13	4	16
18	1052.4	1409.25	18	12	6	36
19	1074.1	1452	19	8	11	121
20	1264.1	1548.5	20	3	17	289
n	20				SUM Di^2	1110
V	18					
				RSP	0.165414	
				T1	0.711593	
	From T distribution Table					
	$t\{v,2.5\%\} < t_t < t\{v,97.5\%\}$					
	t(18,2.5%)<t1<t(18,97.5%)					**No trend**
	-2.1	0.711593	2.1			

Appendix G. Homogeneity Test and probability of rejecting homogeneity plot for stream flow generated at Laga Dadi (by rainbow software).



Appendix H: Sensitivity analysis result for stream flow



Data file

File name: LegedadiOut

Description: Legdadi Stream flow Homogenity test

Restrictions

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	YES	No	No

Estimate of change point (year)

2003

OK Help

Appendix I: Sensitivity analysis result for stream flow

Parameters Description	**Parameter Code**	**Mean Sensitivity**	**Category of Sensitivity**
Base Flow alpha factor(day)	Alpha_Bf	0.384	high
Maximum canopy Index(mm)	Canmx	0.0786	high
Available Water capacity pf the soil layer(mm)	Sol_Awc	0.0907	high
SCS_CN for moisture condition II (unitless)	Cn2	0.292	high
Maximum potential leaf Area Index(unitless)	Biomix	0.00154	Negligble
Thresh hold depth of water in the shallow aquifer required for evaporation to occur(mm)	Revapmn	0.094	high
Soil Albedo (unit less)	Sol_Alb	0.00604	Negligble
Soil conductivity(mm/h)	Sol_K	0.00396	Negligble
Manning coefficient for channel (unit less)	Ch_N2	0.00756	negligible
Surface runoff lag coefficient(day)	Surlag	0.00594	Negligble
Average slope length(m)	Slsubbsn	0.0014	Negligble
Thresh fold depth of water in the shallow aquifer required for return flow to occur(mm)	Gwqmn	0.194	high
Ground Water delay(day)	Gw_Delay	0.0104	Negligble
Effective Channel Hydraulic conductivity(mm/h)	Ch_K2	0.0152	Negligble
Soil evaporation compensation factor (unit less)	Esco	0.0821	high
Plant evaporation compensation factor (unit less)	Epco	0.0191	Negligble
Average slope steepness(m/m)	slope	0.00361	Negligble
Soil depth(mm)	Sol_Z	0.201	high
Ground water evaporation coefficient (unit less)	GW_Revap	0.0337	medium
maximum potential leaf area index (unit less)	Blai	0.154	high

Appendix *I*. Simulated Hydrological balances for Laga Dadi Sub basins.

SUB	YEAR	PRECIP (mm)	PET (mm)	SURQ (mm)	GW_Q (mm)	SYLD (t_ha)	ETmm
1	1994	876.33	1006.314	134.259	20.796	2.305	605.029
2	1994	903.202	1035.696	100.775	31.765	1.137	588.645
3	1994	910.634	1042.466	162.551	9.574	3.553	815.048
4	1994	910.634	1041.845	215.741	0	2.693	811.823
5	1994	910.634	1039.551	213.578	0	7.639	787.266
6	1994	781.992	903.891	167.754	40.063	1.486	571.635
7	1994	838.765	1054.836	185.74	0	0.625	810.499
8	1994	910.634	1144.819	167.822	0	0.17	876.89
9	1994	910.634	1041.962	210.782	0	3.091	797.537
10	1994	910.634	1040.436	211.509	0	3.791	790.136
11	1994	910.634	1143.233	217.197	0	4.358	796.868
12	1994	891.463	1119.345	217.471	0	4.942	787.76
13	1994	910.634	1144.141	215.361	0	5.077	797.041
1	1995	1109.476	1043.765	146.801	56.347	1.447	693.012
2	1995	1143.498	1074.483	86.917	84.056	1.424	712.783
3	1995	1152.907	1081.796	218.09	23.953	3.918	860.355
4	1995	1152.907	1081.263	228.465	0	3.544	885.851
5	1995	1152.907	1079.259	236.625	0	20.869	880.271
6	1995	990.04	936.572	169.508	88.011	1.963	698.461
7	1995	1061.917	1095.168	220.25	0	1.184	863.448
8	1995	1152.907	1188.664	215.748	0	0.203	889.775
9	1995	1152.907	1081.361	229.903	0	6.043	885.263
10	1995	1152.907	1080.033	234.273	0	10.447	884.581
11	1995	1152.907	1187.32	228.168	0	8.82	890.198
12	1995	1128.635	1162.48	228.464	0	10.031	882.91
13	1995	1152.907	1188.105	225.985	0	10.321	890.402
1	1996	1265.308	1024.084	229.637	83.721	1.267	701.894
2	1996	1304.109	1054.239	162.163	118.336	1.461	722.911
3	1996	1314.839	1061.435	206.171	31.885	3.946	1013.712
4	1996	1314.839	1060.921	273.583	0	3.739	992.322
5	1996	1314.839	1058.98	282.69	0	23.536	980.05
6	1996	1129.097	918.85	281.232	116.383	2.001	690.258
7	1996	1211.069	1078.714	207.063	0	1.648	1035.921
8	1996	1314.839	1170.812	199.234	0	0.241	1077.695
9	1996	1314.839	1061.015	214.988	0	6.742	1047.085
10	1996	1314.839	1059.73	220.109	0	11.88	1044.053
11	1996	1314.839	1169.521	220.456	0	11.707	1050.354
12	1996	1287.158	1145.051	220.82	0	12.936	1041.994

13	1996	1314.839	1170.279	217.873	0	13.238	1050.542
1	1997	1099.95	1107.85	230.421	61.011	0.694	583.643
2	1997	1133.68	1140.54	171.589	84.402	0.759	611.43
3	1997	1143.008	1148.404	213.282	20.532	2.021	854.435
4	1997	1143.008	1147.87	196.747	0	1.805	906.081
5	1997	1143.008	1145.877	213.99	0	11.103	886.901
6	1997	981.539	993.727	190.879	80.527	1.072	664.153
7	1997	1052.799	1167.458	220.665	0	2.431	836.414
8	1997	1143.008	1267.156	215.867	0	0.221	851.678
9	1997	1143.008	1147.969	204.367	0	3.165	896.098
10	1997	1143.008	1146.646	211.688	0	5.539	890.738
11	1997	1143.008	1265.84	228.826	0	17.128	876.509
12	1997	1118.944	1239.343	229.128	0	19.151	869.516
13	1997	1143.008	1266.605	226.777	0	19.766	876.651
1	1998	1117.298	1020.184	167.184	72.791	1.044	660.378
2	1998	1151.56	1050.154	111.923	99.724	1.495	678.913
3	1998	1161.035	1057.236	153.447	23.334	3.544	931.436
4	1998	1161.035	1056.684	210.298	0	3.413	908.197
5	1998	1161.035	1054.641	235.542	0	23.524	879.512
6	1998	997.02	915.621	192.398	92.481	2.074	684.57
7	1998	1069.403	1064.881	203.318	0	4.15	891.025
8	1998	1161.035	1155.773	194.602	0	0.229	924.66
9	1998	1161.035	1056.787	202.938	0	6.252	911.501
10	1998	1161.035	1055.43	212.748	0	11.482	902.967
11	1998	1161.035	1154.379	218.355	0	29.425	899.947
12	1998	1136.592	1130.236	218.676	0	33.139	893.55
13	1998	1161.035	1155.181	216.309	0	34.021	900.101
1	1999	1277.241	1086.271	243.246	91.805	1.074	684.324
2	1999	1316.408	1118.047	170.687	123.762	1.462	708.252
3	1999	1327.24	1125.427	195.202	29.217	3.714	1037.892
4	1999	1327.239	1124.777	265.912	0	3.468	1011.229
5	1999	1327.239	1122.396	240.999	0	22.893	1033.714
6	1999	1139.745	975.46	135.842	114.282	2.043	850.375
7	1999	1222.49	1162.333	231.919	0	4.442	1015.938
8	1999	1327.24	1261.521	221.771	0	0.259	1045.98
9	1999	1327.24	1124.9	231.606	0	6.517	1041.894
10	1999	1327.24	1123.314	238.242	0	11.567	1037.018
11	1999	1327.24	1259.899	249.386	0	34.752	1030.232
12	1999	1299.297	1233.557	249.732	0	39.028	1023.812
13	1999	1327.24	1260.817	247.096	0	40.2	1030.371
1	2000	1210.957	1127.054	227.904	84.105	0.806	659.403

2	2000	1248.091	1160.309	154.818	113.998	1.015	687.519
3	2000	1258.361	1168.308	237.681	26.83	2.551	934.838
4	2000	1258.361	1167.777	307.532	0	2.313	904.792
5	2000	1258.361	1165.744	243.487	0	15.139	968.161
6	2000	1080.597	1010.979	136.104	105.12	1.429	805.393
7	2000	1159.048	1187.799	240.699	0	3.289	960.469
8	2000	1258.361	1289.229	233.509	0	0.265	997.636
9	2000	1258.361	1167.873	237.678	0	4.241	973.015
10	2000	1258.361	1166.53	241.085	0	7.525	971.819
11	2000	1258.361	1287.888	253.038	0	25.551	962.95
12	2000	1231.869	1260.934	253.351	0	29.152	956.674
13	2000	1258.361	1288.684	251.047	0	29.952	963.087
1	2001	1159.013	960.102	207.278	81.807	0.884	642.9
2	2001	1194.555	988.116	142.111	110.478	1.248	669.043
3	2001	1204.383	994.552	232.611	29.211	3.285	885.426
4	2001	1204.383	993.949	296.176	0	3.079	863
5	2001	1204.383	991.731	311.118	0	20.446	846.249
6	2001	1034.245	862.455	19.933	108.879	1.759	874.833
7	2001	1109.331	1005.214	289.895	0	1.721	853.087
8	2001	1204.383	1090.958	280.401	0	0.209	896.194
9	2001	1204.383	994.062	300.802	0	5.891	854.604
10	2001	1204.383	992.586	307.7	0	10.43	850.104
11	2001	1204.384	1089.42	306.412	0	12.747	854.952
12	2001	1179.028	1066.658	306.796	0	14.491	847.783
13	2001	1204.383	1090.297	303.712	0	14.574	855.149
1	2002	988.842	1003.274	245.885	57.626	0.649	484.294
2	2002	1019.165	1032.56	194.999	78.301	0.881	507.228
3	2002	1027.55	1039.301	213.065	18.769	2.342	742.544
4	2002	1027.55	1038.67	270.912	0	2.296	715.92
5	2002	1027.55	1036.374	305.001	0	15.275	687.675
6	2002	882.392	901.174	34.045	79.87	1.211	733.548
7	2002	946.453	1061.735	285.343	0	2.145	673.079
8	2002	1027.55	1152.312	275.274	0	0.202	697.275
9	2002	1027.55	1038.79	289.973	0	4.286	699.17
10	2002	1027.55	1037.26	302.804	0	7.537	690.645
11	2002	1027.551	1150.725	302.91	0	16.264	694.743
12	2002	1005.918	1126.677	303.188	0	18.369	688.438
13	2002	1027.55	1151.623	301.015	0	18.87	694.869
1	2003	1197.219	999.226	124.438	80.336	1.32	760.176
2	2003	1233.932	1028.402	156.885	110.061	1.912	683.725
3	2003	1244.085	1035.126	224.22	25.705	5.029	940.46

4	2003	1244.085	1034.507	289.162	0	5.02	914.034
5	2003	1244.085	1032.232	308.055	0	33.885	882.824
6	2003	1068.338	897.513	4.835	105.93	2.567	932.963
7	2003	1145.899	1038.482	304.892	0	3.774	862.855
8	2003	1244.085	1127.067	299.991	0	0.281	887.2
9	2003	1244.085	1034.624	298.266	3.829	9.298	895.815
10	2003	1244.085	1033.11	305.806	0	17.1	886.531
11	2003	1244.085	1125.488	313.205	0	29.329	881.399
12	2003	1217.894	1101.972	313.451	0	33.336	875.363
13	2003	1244.085	1126.388	311.433	0	33.877	881.534
1	2004	897.99	1002.317	241.405	60.938	0.76	428.794
2	2004	925.527	1031.616	188.489	82.815	1.079	454.256
3	2004	933.142	1038.4	292.671	19.555	2.738	582.761
4	2004	933.142	1037.794	345.829	0	2.722	555.438
5	2004	933.142	1035.562	353.238	0	18.701	551.314
6	2004	801.32	900.161	125.217	78.286	1.346	583.668
7	2004	859.496	1032.482	344.348	0	1.804	566.31
8	2004	933.142	1120.56	267.171	0	0.179	681.185
9	2004	933.142	1037.908	277.435	8.241	5.003	624.894
10	2004	933.142	1036.423	281.205	0	8.818	624.372
11	2004	933.142	1119.012	286.752	0	13.782	619.766
12	2004	913.497	1095.629	287.008	0	15.643	614.405
13	2004	933.142	1119.897	285.069	0	16.04	619.893
1	2005	1202.434	1017.764	191.371	87.594	0.801	679.542
2	2005	1239.307	1047.659	123.282	116.312	1.12	704.5
3	2005	1249.504	1054.721	268.304	37.268	2.981	890.723
4	2005	1249.504	1054.168	336.841	0	2.883	864.978
5	2005	1249.504	1052.126	352.007	0	19.664	844.195
6	2005	1072.991	913.455	271.827	112.539	1.625	652.634
7	2005	1150.89	1047.959	278.1	0	1.525	880.872
8	2005	1249.504	1137.403	271.169	0	0.238	899.441
9	2005	1249.504	1054.272	272.893	11.356	5.43	923.406
10	2005	1249.504	1052.914	279.814	0	9.537	917.405
11	2005	1249.504	1136.013	289.965	0	11.068	913.806
12	2005	1223.198	1112.255	290.276	0	12.503	907.101
13	2005	1249.504	1136.809	287.56	0	12.989	913.968
1	2006	1201.531	1116.386	218.577	94.922	0.723	655.977
2	2006	1238.376	1149.033	150.513	124.329	1.001	679.272
3	2006	1248.566	1156.605	211.346	35.896	2.298	952.367
4	2006	1248.566	1155.928	275.019	1.714	1.932	929.156
5	2006	1248.566	1153.464	279.027	0	12.722	924.926

6	2006	1072.186	1002.537	145.853	116.222	1.448	785.899
7	2006	1150.026	1158.89	275.747	0	1.556	922.83
8	2006	1248.566	1257.764	263.363	0	0.232	972.395
9	2006	1248.566	1156.057	274.165	9.643	3.598	929.086
10	2006	1248.566	1154.415	277.206	4.071	6.494	928.662
11	2006	1248.566	1256.063	297.188	0	11.487	911.137
12	2006	1222.28	1229.81	297.486	0	13.059	904.475
13	2006	1248.566	1257.024	295.101	0	13.533	911.278
1	2007	1096.641	1050.034	228.112	83.877	1.006	546.586
2	2007	1130.269	1081.138	165.316	113.162	1.455	564.721
3	2007	1139.569	1088.734	230.791	34.687	3.988	820.549
4	2007	1139.569	1088.282	296.532	7.13	4.025	798.048
5	2007	1139.569	1086.576	312.455	0	28.017	773.245
6	2007	978.586	941.399	198.826	110.151	2.02	623.243
7	2007	1049.631	1080.153	249.203	0	5.319	769.16
8	2007	1139.569	1172.417	242.523	0	0.201	766.272
9	2007	1139.569	1088.365	242.557	10.185	7.763	843.934
10	2007	1139.569	1087.236	249.417	8.016	13.648	836.672
11	2007	1139.569	1171.294	260.751	0	40.666	827.888
12	2007	1115.578	1146.766	261.095	0	46.182	821.723
13	2007	1139.569	1171.953	258.494	0	47.983	827.995
1	2008	970.19	1065.229	197.084	75.363	0.719	480.833
2	2008	999.941	1096.278	134.395	99.637	0.987	515.507
3	2008	1008.168	1103.382	206.352	29.783	2.448	704.3
4	2008	1008.168	1102.698	266.671	7.039	2.322	675.181
5	2008	1008.168	1100.19	261.198	0	15.635	707.489
6	2008	865.748	957.016	193.78	95.185	1.354	537.789
7	2008	928.601	1160.169	255.27	0	8.475	727.422
8	2008	1008.168	1259.147	244.628	0	0.193	780.446
9	2008	1008.168	1102.827	259.312	9.193	4.377	698.803
10	2008	1008.168	1101.157	258.975	7.105	7.84	710.211
11	2008	1008.169	1257.434	273.701	0	66.348	699.85
12	2008	986.944	1231.156	274.015	0	75.508	694.495
13	2008	1008.168	1258.411	271.656	0	78.616	699.964
1	2009	993.053	726.578		87.499	0.291	724.425
2	2009	1023.505	747.81	214.245	119.597	0.366	470.947
3	2009	1031.927	752.719	180.478	50.292	1.043	748.086
4	2009	1031.927	752.282	227.082	15.12	0.999	746.776
5	2009	1031.927	750.652	224.843	0	6.675	724.948
6	2009	886.15	652.56	165.141	129.159	0.527	548.174
7	2009	950.485	789.205	202.846	0	0.516	716.241

8	2009	1031.927	856.546	186.597	8.025	0.111	759.291
9	2009	1031.927	752.363	218.819	18.091	1.845	734.077
10	2009	1031.927	751.281	220.371	14.156	3.296	727.215
11	2009	1031.927	855.438	231.744	0	3.746	746.584
12	2009	1010.202	837.556	232.18	0	4.271	736.284
13	2009	1031.927	856.078	227.463	8.122	4.373	747.838