JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Prediction of Sediment Inflow into Dire Reservoir and Assessing Sediment Reduction Methods Using SWAT model

A thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

Prepared by: Abito Negeo Goshu

November, 2017

Jimma, Ethiopia.

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Advisor: Dr. Ankit Chakravarti

Co-advisor: Mr. Fayera Gudu (MSc)

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CERTIFICATION

As Master research Advisors, we hereby certify that we have read and evaluated this MSc. research prepared under our guidance, by ABITO NEGEO entitled: “**Prediction of sediment inflow into Dire reservoir and assessing sediment reduction methods**” We recommend that it can be submitted as fulfilling the M.Sc thesis requirements.

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By: Abito Negeo Goshu

APPROVED BY BOARD OF EXAMINERS

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DEDICATION

DEDICATED TO MY FAMILY!!!

DECLARATION

I, Abito Negeo Goshu, declare that this dissertation is my own original work and it has not been presented and will not be presented by me to any other university for the similar or any other degree award.

Signature ___________________________

ABSTRACT

Sediment inflow and sedimentation of the inflow sediment study is most important practices in the design and management of reservoirs and in water resources development. Sediment transport is a worldwide environmental problem that degrades soil productivity, water quality, causes sedimentation to the reservoirs and increases the probability of floods. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of reservoir storage capacity.

Dire reservoir has a problem of sedimentation and erosion and Dire catchment which contribute sediment to this reservoir has a drainage area of 78 km^2*. To develop effective erosion control plans and to achieve reductions in sedimentation it is important to predict the sediment yield and identify areas that are vulnerable to erosion. Soil and Water Assessment Tool (SWAT), which is computationally efficient model has been used to predict sediment yield and to test the potential of different sediment management interventions in reducing sediment yield.*

The model was calibrated and validated against measured flow and sediment data. Both, calibration and validation results, showed a good match between measured and simulated flow and sediment. Flow calibration gives coefficient of determination (R^2*) and Nash-Sutcliffe simulation efficiency (*E_{NS}*) of 0.78 and 0.72 respectively. Flow validation gives coefficient of determination (*R^2*) and Nash-Sutcliffe simulation efficiency (*E_{NS}*) of 0.75 and 0.64 respectively. Sediment calibration gives (*R^2*) and (*E_{NS}*) of 0.9 and 0.82 respectively. Sediment validation gives (*R^2*) and (*E_{NS}*) of 0.66 and, 0.64 respectively. The model prediction results indicated that the total amount of sediment yield in baseline time in the Dire catchment was 48,991.8 ton/year.*

The model was also applied to evaluate the potential of different sediment management interventions to reduce sediment production. The investigation showed that implementing contour farming, filter strips, strip cropping on contour can reduce sediment yield by 79%, 75% and 64% respectively. Contour farming has high sediment reduction potential than other practices, so it is the best management practice that should be applied in the catchment

Key words: Calibration, Dire Dam, Sediment yield, SWAT model, Validation.

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ACRONYMS

A.A	Addis Ababa
AAWSA	Addis Ababa Water and Sewerage Authority
AESL	Associate Engineers Service Lane
AVSWAT	Arc View Soil Water Assessment Tool
CN	Curve Number
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
HDMWIR	Hydrological division of ministry of water, irrigation and energy
HRU	Hydrologic Response Unit
ITCZ	Inter-Tropical Convergence Zone
LULC	Land Use Land Cover
m.a.m.s.l	meter above mean sea level
MoWIE	Ministry of Water, Irrigation and Electrify
MRS	Mean Relative Sensitivity
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Service Agency
PcpSTAT	Precipitation statics calculator
SUFI-2	Sequential Uncertainty Fitting algorithm version-2
SWAT	Soil Water Assessment Tool
SWAT-CUP	Soil and Water Assessment tool-Calibration and Uncertainty Program
USA	United States of America
USDA	US Department of Agriculture
USDA-ARS	US Department of Agriculture –Agriculture Research Service
USLE	Universal Soil Loss Equation
UTM	Universal Transvers Mercator

1. INTRODUCTION

1.1. Background

Sediment yield is the net result of soil erosion and processes of sediment accumulation, so it depends on variables that control water and sediment discharge to reservoirs. Typically, sediment yield reflects the influences of climate (precipitation), catchment properties (soil type, topography), land use/cover, and drainage properties (stream network form and density) (Walling, 1994). Erosion is a natural process causing soil loss and generating sediment yield from catchment areas even in the absence of human alterations of land cover. Sediment yields vary from low values in humid, low-relief catchments to very high values in arid, mountainous areas (Lavinge and Suwa, 2004). Due to human modifications, erosion rates have been raised above natural levels, a phenomenon known as accelerated erosion.

The processes of erosion, entrainment, transportation and deposition in a river catchment are complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the forces generated by flowing water. Once a particle has been detached, it must be entrained before it can be transported away. Both entrainment and transport depend on the shape, size and weight of the particle and the forces exerted on the particle by the flow. When these forces are diminished to the extent that the transport rate is reduced or transport is no longer possible, deposition occurs. Sediment is transported in suspension, as bed load rolling or sliding along the bed and interchangeably by suspension and bed load. The nature of movement depends on the particle size, shape, and specific gravity in respect to the associated velocity and turbulence. Under some conditions of high velocity and turbulence, e.g. high flows in steep-gradient mountain streams; cobbles are carried intermittently in suspension. Conversely, silt size particles may move as bed load in low-gradient, low-velocity channels, e.g. drainage ditches. Even in transport, whether as bed load or in suspension, sediment may cause problems.

The products of erosion may be deposited immediately below their sources, or may be transported considerable distances to be deposited in channels, on flood plains, or in lakes, reservoirs, estuaries, and oceans. When stream flow enters a natural lake or reservoir, its velocity and transport capacity is reduced and its sediment load is deposited. In natural lakes that have no outlets the total incoming sediment load is deposited.

All reservoirs formed by dams on natural rivers are subject to some degree of sediment inflow and deposition. Because of the very low velocities in reservoirs, they tend to be very efficient sediment traps. Therefore, the amount of reservoir sedimentation over the life of the project needs to be predicted before the project is built. If the sediment inflow is large relative to the reservoir storage capacity, then the useful life of the reservoir may be very short. Since reservoirs are beneficial for the provision of storage of water that is required for drinking, irrigation, recreation, hydropower production and flood control, sedimentation has resulted in serious economic losses, and environmental and aesthetic problems. It has therefore become not only important but very necessary to consider erosion and sedimentation issues in the planning and detailed design of proposed dams, reservoirs and water resource projects (Villiers, 2006)

In artificial lakes with outlets, e.g. reservoirs, the amount deposited depends on the detention storage time, the shape of the reservoir, operation procedures, and other factors. Generally, reservoir sedimentation and the consequent loss of storage capacity is affect water availability and operation schedules. (Morris *et al.*, 2010).

Man-made reservoirs usually satisfy multiple objectives including flood control, irrigation, hydropower generation, water supply, boating, fishing and recreation. The reservoir sedimentation is a serious offsite consequence of soil erosion that threatens the sustainability of dams built for various purposes in many parts of the world as well as throughout Ethiopia with different climatic conditions. It depends on the river regime, flood frequencies, reservoir geometry and operation, sediment consolidation, density current, and possible land use change over the life expectancy of reservoir. The magnitude of changes on the stream flow due to land use changes varies with catchments and other factors such as climate change and human activities. (Bruk, 1985)

The process of sedimentation usually happens in the following stages: Erosion, Entrainment (drawing of particles into fluid), transportation and compaction (deposition). The processes are highly complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by flowing water. Once a particle has been eroded it must entrain before it can be transported away. Both entrainment and transport depend heavily upon the weight, shape, size and forces exerted on the particles by the flow. (Ahmed, 2004)

Deposition occurs when the forces are diminished enough leading to a reduction or cessation of transport. Therefore, deposition is the counterpart of erosion, for example, when river flow enters a reservoir, its velocity and transport capacity are reduced and its sediment load is eventually deposited. The amount and rate of deposit are determined mainly by: detention storage time ,the shape of the reservoirs and operating procedure of the reservoir. The depositional pattern usually starts with the coarser material depositing towards the reservoir headwater. The aggradations continue more and more until a delta is formed (Ahmed, 2004).

Sediment may cause severe damages depending on the amount, character, and place of deposition. Deposits that occur on flood plains create numerous types of damages to crops and developments. The deposition of sediment in drainage ditches, irrigation canals, and in navigation and natural stream channels creates serious problems in loss of services and cleanout costs. The deposition of sediment in natural stream channels has greatly aggravated flood water damages. The deposition of sediment in channels decreases the channel capacity and the flood-carrying capacity. This results in higher and more frequent overflows. Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre- requisite for successful water management and environmental restoration.

A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource.

The present investigation intended to provide a basis for future analysis of water resource management of Dire catchment also to evaluate the SWAT model capability to predict the sediment yield of Dire catchment to the Dire dam reservoir and assess sediment reduction methods that will be applied in the catchment.

1.2. Statement of the problem

Reservoir sedimentation is one of the most important factors in the planning of a storage-dam, because uncontrolled soil erosion and land degradation resulting in heavy sediment transport in streams and rivers has caused significant reduction of the capacity of reservoirs and studies have shown that in Ethiopia billions of tons of soil are lost annually (Dereje , 2010) .

In Ethiopia the construction of dams has caused social, environmental and economic problems by increasing the relocation of communities against their will and inducing watershed land degradation (Bezuayehu, 2006). Many farmers in Ethiopian highlands cultivate sloped or hilly land, causing topsoil to be washed away during the heavy rains of the rainy season. In addition, the projected increase in the intensity of rainfall has a significant impact on soil erosion rates (Nearing *et al*., 2004). High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation & maintenance and shortening life span of water resources infrastructure (Tamene *et al.*, 2005). Reservoirs around the world are losing on average about one percent of their storage capacity annually causing serious problems for water supply, hydropower, irrigation, and flood control due to sedimentation (WCD, 2000).Even though there has been watershed management in the Awash Basin, one of critical water resource development constraint is soil erosion and reservoir sedimentation (Dilnesaw A., 2006).

The problem of land degradation is a threat and devastating challenge to Dire dam reservoir and downstream areas due to generating high runoff discharges and imposing huge sediment yield, which may result in reducing water storage capacity of the dam With the fast growing population and the density of livestock in the catchment, there is pressure on the land resources, resulting in even forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation. High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation & maintenance and shortening lifespan of water resources infrastructure. (AAWSA, 2014)

The above things result in sedimentation of reservoirs and short life time. Therefore analyzing the impacts of different variables which cause/accelerate the problem is essential. Specifically, the problems and constraints in the study area lack of sediment data, difficulty of gathering this data, parameters of land management due to highly increasing deforestation for search of agricultural land and climate change makes the things difficult A proper investigation of the sediment yield of the catchment is essential for management of sedimentation and utilization of water resource. If these are not investigated the life of Dire reservoir is shortened by sedimentation. Therefore, assessing the possible impact of high sediment yield on reservoir is essential for future development as well as for managing the current reservoir condition in adaptive way. The continuous inflow of sediment from the catchment into the reservoir has been decreasing the life span of Dire reservoir unless appropriate sediment management interventions and strategies are undertaken.

1.3. Objectives

1.3.1. General objective

The general objective of this study is to predict amount of sediment inflow into Dire reservoir from the Dire catchment and assess sediment reduction methods by using SWAT model.

1.3.2. Specific objectives

The specific objectives are:

- To Calibrate, validate and undertake sensitivity analysis of SWAT model for predicting amount of sediment inflow into Dire reservoir.
- To predict the amount of sediment inflow into Dire reservoir using SWAT model
- To assess and recommend appropriate management practices to reduce the amount of sediment inflow into Dire reservoir using SWAT model.

1.4. Research questions

In order to meet the research objectives of the study, the research questions of the study are:

1. How to calibrate and validate the SWAT model based on stream flow and sediment data?
2. How to predict amount of sediment inflow to reservoir?
3. What are the adaptation options to be taken to mitigate the adverse impacts of sedimentation on the reservoir?

1.5. Significance of the study

Availability of large amount of water resource and adequacy of topography enables our country to be the most beneficiary from water resource development projects such as dams and reservoirs. On the contrary poor land management makes our dams to be in serious problem of sedimentation even beyond their dead storage capacity.

Any types of Dam design includes dead storage part of the reservoir where deposited sediment that comes from the watershed. Dead storage is the volume that is below the invert of the lowest level outlet and which cannot be drained by gravity. Sediment deposited in place of inactive storage where the amount of water is reduce that passes through the outlet or may close the outlet gate. Then, quantifying the amount of sediment that inflow from watershed is the main part of the dead storage design and also for operation of the reservoir.

Predicting the amount of sediment inflow to Dire reservoir and assessing sediment reduction methods is useful for designer and policy maker of the AAWSA to take appropriate measures or implement effective land and water management interventions to reduce on site and off site impact of erosion (engineering conservation measures, silt retention micro dams and design of water harvesting structures in the catchment). Besides this identifying the spatial variability of sediment yield and prediction of mean annual sediment inflow have a great significance for designers and decision makers in designing storage capacity and expected to help concerned sectors in planning, developing and managing water resource projects of AAWSA and as an input for those who are interested to further research in related area and field of study.

1.6. Scope of the study

This research attempts to present a prediction of sediment inflow into dire reservoir from catchment of the study area and assess sediment reduction methods. The scope of this research work is broad and attempts to address the method of prediction of sediment yield and reduction, when observed the reduction of storage capacity of reservoir and increased the amount of sediment yield from the catchment, is entered in the reservoir per annum, how can prevent the catchment from erosion as well as the reduction of storage capacity of the reservoir.

The research indicates the method to know the amount and the problem of the sediment transport by using soil and water assessment tool (SWAT) and additional supporting tools. Finally this research gives the solutions and how to prevent the catchment from erosion and loss of storage capacity of the reservoir from suspended and bed load materials by using different conservation practical measures and management planning.

1.7. Thesis organization

The thesis contains five chapters organized as: chapter one was an introduction section where the background, statement of the problem, objectives of the study, research significance and scope of the study were discussed. In chapter two, review of related literatures where the definition and concepts of reservoir sedimentation, problem of sediment yield, methods of sediment reduction, hydrological models, an introduction to SWAT model, application of SWAT model were reviewed. In the third chapter, methodology section in which description of the study area, materials used and methods followed, collection of input data and analysis, input data preparation, model setup, sensitivity analysis, model calibration and validation, model performance evaluation and sediment management scenarios were elaborated.

The fourth chapter describes with the result and discussions which were stream flow, sediment yield modeling and evaluation of sediment yield due to different sediment management scenario analysis. The stream flow and sediment yield modeling includes sensitivity analysis, calibration and validation of stream flow simulation and sediment yield and the performance evaluation of the model. Finally, in chapter five, conclusions and recommendations of the study were explained.

2. REVIEW OF LITERATURE

2.1. Sediment yield from watershed

Sediment yield refers to the amount of sediment exported by a watershed over a period of time, which is also the amount which will enter a reservoir located at the downstream limit of its tributary watershed. Sediment yield is the end product of erosion or wearing away of the land surface by the action of water, wind, ice, and gravity. The total amount of onsite sheet, rill, and gully erosion in a watershed is known as the gross erosion. However, not all of this eroded material enters the stream system. Some of the material is deposited as alluvial fans, along river channels, and across flood plains. The portion of the eroded material that is transported through the stream network to some point of interest is referred to as the sediment yield. Therefore, the amount of sediment inflow to a reservoir depends on the sediment yield produced by the upstream watershed (Morris *et al.*, 2010).

Estimates of long-term sediment yield have been used for many decades to size the sediment storage pool and estimate reservoir life. However, these estimates are often inaccurate, and many reservoirs have accumulated sediment more rapidly than originally planned. Most sediment is exported from watersheds during relatively short periods of flood discharge, and these events must be accurately monitored to provide information on the long-term yield as well as the time wise variation in load needed to evaluate sediment routing strategies.

Sediment yields may fluctuate greatly because of natural or man-induced accidents. Collecting sediment flow data over a decade and periodic reservoir survey information are some resources demanding methods for estimating sediment yield rates at a catchment level *(silva et al.*, 2007) .Others have also cautioned that long term sediment monitoring of suspended sediment loads does not necessarily give better results (summer *et al.*, 1992).

Some workers have suggested that an excellent sediment-rating curve could be constructed from detailed sediment flow data of short period of sampling programs (summer *et al.*, 1992).However, (Foster , 1982) indicated that most of the sediment-rating curves underestimate the actual loads. Besides, other researchers such as (Boge , 2003) have cautioned that such relationships should be used on catchment where no significant landforms, land use and sediment supply source changes are expected.

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

Sediment is fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Sediment yield refers to the amount of sediment exported by a basin over a period of time and also it is the amount of eroded sediment discharged by a stream at any given point; it is the total amount of fluvial sediment exported by the watershed tributary to a measurement point and is the parameter of primary concern in reservoir studies. They ranges in size also vary in specific gravity and mineral composition. Once the sediment particles are detached, they may either be transported by gravity, wind or/and water. Sediment is a critical pollutant in surface water that adversely affect water quality and contains other important contaminants (including nutrients, pesticides and heavy metals) (Amare, 2005). Sediment yield is dependent on factors of soil erosion (mainly rainfall, soil condition, land use, topography) and the capacity of transportation.

Sediment export is also a function of land use, since the sediment transport capacity is different for different types of land cover. The incoming sediment load is usually measured at gauging stations. Flow and sediment measurements define the sediment-rating curve. The sediment rating- curve is typically highly scattered and daily sediment discharge covers several orders of magnitude. It is important to realize that a single point on the upper part of the sediment-rating curve can correspond to a daily sediment load in excess of the daily sediment load at a low discharge. The rate at which sediment is carried by natural streams is much lower than the gross erosion on its upstream watershed. Sediment is deposited between the source and the stream cross section whenever the transport capacity of runoff water is insufficient to sustain transport (Megersa , 2015)

Estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. The sediment transportation monitoring requires a good sample techniques which is very lengthy and costly (Pavaneli and Palgliarani , 2002). Therefore, it is important to develop a model that can estimate accurately the suspended sediment yield from the basin. If the input layer contains variable(s) different from those of the output layer then the term estimation is preferred than the term forecasting. Forecasting is used as in the case of having the same variable in both input and output layers (Cigizoglu, 2002).

Traditional approaches to sediment management have not considered the need for sustained use. Large initial storage volumes and erosion control have traditionally been recommended to reduce sediment inflow and delay the eventual "death" of reservoirs, but erosion control alone cannot achieve the sediment balance required to stabilize reservoir storage capacity and achieve sustainable use. Furthermore, many erosion control programs are poorly conceived and implemented, and fail to achieve the desired reductions in sediment yield. As a result, reservoirs worldwide are losing storage capacity rapidly, possibly as fast as 1 percent per year (Haan *et al*., 1994).

Sediment transported from rivers to the oceans is largely dominated by forest conversion to cropland. The major sources of sediments may be from other human activities such as road construction, poorly constructed and maintained terraces, and runoff from cultivated land or bank erosion. Erosion is a consequence of complex interactions among climate (precipitation, temperature, wind speed and direction), geology (volcanic and tectonic activities), soils, topography (slope, catchment orientation, drainage basin area), and land use/land cover *(Sidle et al.*, 2006).

Soil erosion is largely determined by the absence of protective land cover, whereas sediment export to rivers is determined by on site sediment production and connectivity of sediment sources and rivers also Soil erosion is controlled by many factors, including soil properties, land use, climatic characteristics and topography. Although there is a significant relationship between land use and stream water quality the relative impacts of different types of land use on the amount of surface water are yet to be ascertained and quantified. (Vandorn *et al.*, 2008).

2.2. Sediment management

2.2.1. Watershed management and soil conservation

The intent of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system. The distribution of erosion over the watershed is investigated, and the areas contributing excessive sediment to the streams draining into the reservoir are demarcated. Conservation measures applied to these areas result in a significant reduction in sediment input to the reservoir. These measures include practices such as contour farming and terracing, strip cropping, crop rotation, no-till farming, grassed drainage ways, gully erosion control, and stabilization of critical areas by their return to grasslands or forests. Conservation measures take years to implement. Among the problems involved in instituting such measures are the relative costs of various measures to farmers, and the need for farmers to make significant changes in their usual style of farming. The efficiency of watershed management in reducing sediment inflow to the reservoir varies from a low of 5% to a high of 40% (Bruk, 1985).

Soil and water conservation planning requires knowledge of the relationship between factors that cause loss of soil, water and those that help to reduce such losses. Soil and water conservation is major part of watershed management intervention that involves the development of systems for the management and utilization of land, water and vegetation resources that are economic, productive and sustained in the long run. Agronomic or vegetative measures and Physical (engineering measures) are the two commonly used soil and water conservation practices (Devlin *et al*., 2003)

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

2.2.1.1 Contour farming

Contour farming is the practice of performing tilling, planting and other farming operations on or near the contour of the field slope to reduce sheet and rill erosion. Contour farming reduces the size and cost of drainage practices since less runoff will occur than with sloped furrows. Table provided with recommendations for curve number in fields with different land use and soil characteristics under various hydrologic conditions. The recommendations also include impacts of contour farming, strip-cropping and filter strip on curve number. (Neitsch *et al*., 2005).

2.2.1.2 Filter strip

A filter strip is a narrow band of grass or other permanent vegetation used to reduce sediment, nutrients, pesticides, and other contaminants. Filter strips are located on cropland or degraded pastures immediately adjacent and parallel to streams, lakes, ponds, ditches, sinkholes, wetlands, or groundwater recharge areas. Filter strips intercept undesirable contaminates from runoff before they enter a water body and slow the velocity of water, allowing the settling out of suspended soil particles, the infiltration of runoff and soluble pollutants, the adsorption of pollutants on soil and plant surfaces, and the uptake of soluble pollutants by plants. It also disrupts the wind erosion process and trap air borne sediments before they reach the water body. In addition filter strips provide valuable wildlife habitat including excellent winter cover, nest sites for ground nesting birds, nectar and pollen for pollinating insects and forage for grazing wild animals. To be eligible for this conservation practice the land must be within the approved watershed, be needed to reduce the negative impacts on water quality and the area must be adjacent to a permanent water body such as a lake; or adjacent to a perennial or seasonal water course such as a stream or river; or adjacent to a permanently or seasonally flooded wetland. (Neitsch *et al*., 2009).

2.2.1.3 Strip cropping on contour

Implementation of strip-cropping practices in a field will result in: (1) reduction of surface runoff by impounding water in small depressions; (2) reduction of peak runoff rate by increasing surface roughness and slowing surface runoff; and (3) reduction of sheet and rill erosion by preventing development of rills (Neitsch *et al*., 2009).

2.2.2. Bypassing of heavily sediment-laden flows

A great amount of sediment is carried by a stream or river during flood flows. A large part of such flow can be bypassed through a channel, tunnel or pipes, significantly reducing silting in the reservoir. The bypass may consist of a barrage for diversion of floods and a bypass canal joining the main stream or river some distance downstream of the dam; or it may be a bypass tunnel instead of a bypass canal. Pipelines can be anchored in a low submerged weir near the stream/lake junction, can be placed along the lake bed or partially embedded in it, and can discharge downstream of the dam.. This technique has been successfully applied in Italy (Ralison R.E *et al*., 1981).

2.3. Methods of maximizing sediment removal through flow

2.3.1. Density current flushing

Density current is defined as a gravity flow of turbid water through, under or over water of different density (Fuat , 1994). The density difference being a function of the differences in temperature, salt content or silt content of the two fluids. The venting of density currents has long been considered an effective means of reducing the rate of reservoir silting, especially in impounding reservoirs. Following the recognition of the phenomenon of density currents, the method of density current flushing has been adopted in many reservoirs to reduce sedimentation (UNESCO, 1985).

2.4. Reservoirs and sedimentation

All reservoirs formed by dams on natural water courses are subject to some degree of sediment inflow and deposition. Sedimentation reduces reservoir storage worldwide (Palmeiri *et al*., 2001). Reservoir sedimentation is a complex process that varies with watershed sediment production, rate of transportation and mode of deposition. The deposition of sediment which takes place progressively in time reduces the active capacity of the reservoir which in turn affects the regulating capability of the reservoir to provide the out flows through the passage of time. Sediment deposition in reservoirs for irrigation schemes, hydroelectric power supply and urban water supply reduces their capacity, shorten lifespan, reduce water quality and requires costly operations for removal and treatment.

In order to increase the life of the reservoir and to best achieve the purpose for which it has been constructed, reducing sediment inflow and removing sediment from the reservoir are substantial activities. The development of effective strategies to reduce sedimentation rates requires distinguishing between background erosion rates in undisturbed settings and human-accelerated erosion in disturbed settings. The rate of sediment varies dramatically as the differences of river basin and impoundment characteristics control the rate and pattern of the sedimentation deposition in the reservoir. The reservoirs of many countries are adversely affected by high rate of sedimentation. In Ethiopia accelerated sedimentation in reservoirs providing hydroelectric power and irrigation water has resulted in loss of these intended services. (Small, *et al*., 2003).

The frequent power cuts and rationing based electric power distribution recently experienced in the country are also partially attributed to the loss of storage capacity of hydroelectric power reservoirs, a consequence of sedimentation Reservoir sedimentation is a phenomenon that also has a positive impacts to water usage systems particularly to the downstream river. Reservoir sediment deposition is a reflection of watershed erosion and deposition processes which are controlled by terrain form, soil type, surface cover, drainage networks and rainfall-related environmental attributes. Sediment inflow can be reduced either by implementing land management methods, particularly integrated watershed management, that reduce sediment yield (Tamene *et al.*, 2005).

2.5. Recovering reservoir storage capacity

2.5.1. Dredging of sediments

Dredging is an expensive means of restoring the storage capacity of a reservoir unless a large part of the cost can be recovered by beneficial use of the dredged material. Dredging is used if other methods (such as flushing, bypass construction, and drawdown flushing) are not successful or feasible, and the dam cannot be raised or replaced. The nature of the dredged materials namely liquid mud is such that it cannot be spilled freely and should be impounded in settling basins/reservoirs where the sediments will settle, while excess water flows back to the reservoirs. This would also prevent sediments from being washed back to the reservoirs during the wet season. The spillway and the excess water canal would be protected to allow conveyance of the original reservoir without erosion. The cost of dredging, including impoundment of the sediments in settling reservoirs is estimated at 65-75 Birr/m3 (Tahal and Metaferia Engineering, 1999)

2.5.2. Excavation

A large amount of sediments from incoming floods when reservoirs water levels are high settle in the flooded areas at the upstream end of the reservoirs. During the dry season, when water levels drop to supply and to losses, the sediments using heavy earthmoving and it is then possible to remove the sediments using heavy earthmoving equipment working in a downstream direction. The excavated material would be disposed of or spread in areas nearby (in order to lower the cost of disposal) .Spreading the material on agricultural and other lands would contribute to soil fertility. The sediment would be spread in such a way that most of them would be prevented from being washed back to the reservoirs in the subsequent wet seasons. However, excavations during the wet season at high levels would be more costly, while it would also increase the turbidity of the water. The cost of sediment excavation and disposal /spreading at locations near the excavation site and away from the flooded area is estimated at about 24 Birr/m^3 (Tahal and Metaferia Engineering, 1999).

2.6. Hydrological models

Modeling is defined by (Walling *et al.*, 1988) as the process of organizing, synthesizing, and integrating component parts into a realistic representation of the prototype. (USDA, 1988) lists the following benefits of modeling: Models help sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiments instead of conducting the experiments on the watershed itself. Hydrological Models can be categorized into three classes: Empirical models, Conceptual models, and Physical models (Beven, 2003).

2.6.1. The SWAT model

The Soil and Water Assessment Tool (SWAT) model was developed by US Department of Agriculture –Agriculture Research Service (USDA-ARS). It is a model that functions on a continuous time step. Model components include weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, channel routing, and pond/reservoir routing.

The SWAT model predicts the influence of land management practices on constituent yields from a watershed. SWAT is the continuation of over 30 years of model development within the US Department of Agriculture's Agricultural Research Service. The CREAMS, GLEAMS, and EPIC models (Leonard *et al.*, 1987) have each contributed to the scaling up of past field-scale models to one which includes large river basins. SWAT is a public domain model which is actively supported by the USDA Agricultural Research Service at the Grassland, Soil, and Water Research Laboratory in Temple, Texas, USA.

The Arc SWAT extension of Arc GIS is a graphical user interface for the SWAT model (Arnold J.et al, 2012). To create a SWAT dataset, the interface will need to access Arc GIS compatible raster (GRIDs) and vector datasets (shape files or feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the model.

In the SWAT model, the modeling or estimation of flow, sediment or nutrient transport of the watershed is done by dividing the watershed into sub basins and the land areas in the sub basins are also sub-divided again into one or more land units, possessing similar land use, soil type and applied management strategies. These similar land units in land use, management and soil attributes are called Hydrologic Response Units (HRUs). The HRUs are helpful for a better estimation of the loadings (flow, sediment, pollutants) from the sub basins.

The SWAT watershed model also contains algorithms for simulating erosion from the watershed. Erosion is estimated using the Modified Universal Soil Loss Equation (MUSLE). MUSLE estimates sediment yield from the surface runoff volume, the peak runoff rate, the area of the HRU, the Universal Soil Loss Equation (USLE) soil edibility factor, the USLE cover and management factor, the USLE support practice factor, the USLE topographic factor, and a coarse fragment factor.

After the sediment yield is evaluated using the MUSLE equation, the SWAT model further corrects this value considering snow cover effect and sediment lag in surface runoff. The SWAT model also calculates the contribution of sediment to channel flow from lateral and groundwater sources. Eroded sediment that enters channel flow is simulated in the SWAT model to move downstream by deposition and degradation (Neistch *et al.*, 2002).

2.6.2. SWAT-CUP

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

The recently developed SWAT-CUP interfaced program for calibration and uncertainty analysis procedures (Abbaspour et al., 2007) also made the SWAT model more attractive for this study. SWAT-CUP is linked to five different algorithms such as: Sequential Uncertainty Fitting (SUFI-2) (Abbaspour et al., 2007). Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992), Parameter Solution (ParaSol) (Van Griensven and Meixner, 2006), Particle swarm optimization (PSO) (Eberhart and Kennedy, 1995) and Markov Chain Monte Carlo (MCMC) (Kuczera and Parent, 1998) procedures to SWAT.

SUFI2 (Abbaspour et al., 2007): Sequential Uncertainty Fitting Ver. 2, the parameter uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data.

GLUE (Beven and Binley, 1992): Generalized Likelihood Uncertainty Estimation is based on the estimation of the weights or probabilities associated with different Parameter sets, based on the use of a subjective likelihood measure to derive a posterior probability function, which is subsequently used to derive the predictive probability of the output variables.

Parasol (Van Griensven and Meixner, 2006): Parameter Solution method aggregates objective functions into a global optimization criterion and then minimizes these objective functions or a global optimization criterion using the SCE-UA (Shuffled Complex Evolution, (Duan *et al*., 1992) algorithm, which is a global search algorithm for minimization of a single function, were utilized in the calibration process.

MCMC: Markov Chain Monte Carlo generates samples from a random walk which adapts to the posterior distribution (Kuczera and Parent, 1998). This simple technique from this class is the Metropolis Hasting algorithm.

Various SWAT parameters for estimation discharge were estimated using the SUFI-2 program (Abbaspour *et al.*, 2007) . In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. Uncertainty is defined as discrepancy between observed and simulated variables in SUFI-2 where it is counted by variation between them. SUFI-2 combines calibration and uncertainty analysis to find parameter uncertainties while calculating smallest possible prediction uncertainty band. It is automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files.

The SUFI-2 was the most suitable way to find the SWAT Uncertainty under the condition that the parameter range. The Goodness of fit in SUFI-2 is expressed by the 95PPU band; it cannot be compared with observation signals using the traditional indices such as R^2, Nash Sutcliffe (NS). For this reason two measures referred to as the P-factor and the R-factor (Abbaspour, *et al.*, 2004, 2007), the P-factor is the percentage of the measured data bracketed by the 95PPU. The R-factor, on the other hand, is a measure of the quality of calibration and indicates the thickness of the 95PPU. As all forms of uncertainties are reflected in the measurements (e.g., discharge and sediment), the parameter uncertainties generating the 95PPUaccount for all uncertainties.

2.7 Studies in the catchment

The impact of land use/ land cover change on soil erosion potential in legedadi watershed were carried out by Sisay Habtegebreal Mogesie on impact of land use/ land cover change on catchment hydrology and water quality of legedadi-dire catchments were carried out by Taye Aduna. The reports of AAWSA water and sanitation development and rehabilitation project office indicated that Dire catchment is one of the watershed affected by severe soil erosion in the basin. According to the study, total volume lost due to sedimentation from year (2000-2015) is 3,816,703 m^3**,** mean annual sediment load of 33,927 ton/yr, and design study foreseen sediment accumulation of 848,156.7m^3 in 25 years, finally these study concluded that actual sedimentation rate of Dire reservoir during the last 15 years was more than three times larger than what was foreseen during the design phase.

3. METHODOLOGY

3.1. Description of the study area

3.1.1. Geographical location

Dire catchment and Dire reservoir is located about 25 km far from east of Addis Ababa North Western Shoa Zone in Aleltu Bereh district (Figure 3.1), but Dire reservoir is administrated by Addis Ababa Water and Sewerage Authority. .

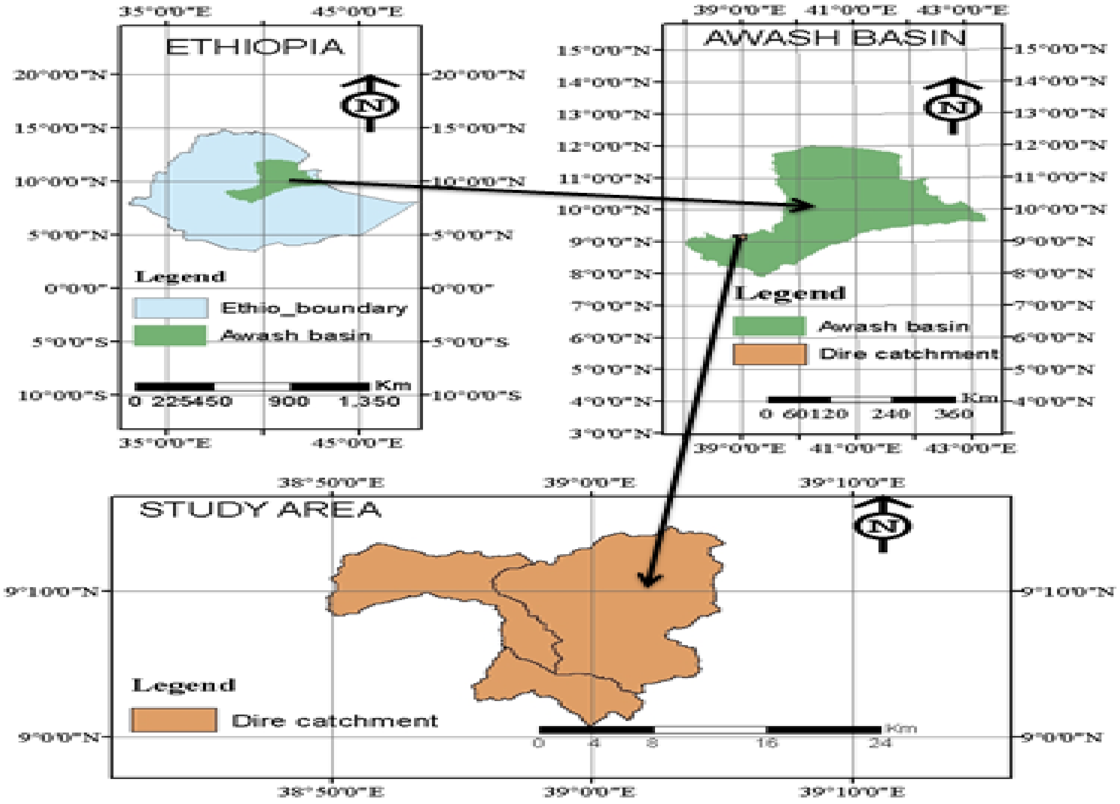

Figure 3.1 Location of study area

The region is characterized by a range of volcanic mountains rising to elevations range from 2398 to 3220 m.a.s.l.

The catchment is bounded by latitude 9^{0}01'N – 9^{0}13'N and longitude 38^{o}60' E - 39^{o}07' E. In general, this study area has a total area of 78km^2. The Addis Ababa–Dessie main asphalt road runs west to East direction across the central part of the reservoir catchment and dry weather road cross the catchment area from South to North. Dire Reservoir was constructed in 1999 and one of the three dams contributing as a surface water source for Addis Ababa city which others includes, Legedadi Dam constructed in 1979 and Geffersa Dam constructed in 1943.

3.1.2 Accessibility

Wide part of the study area is accessible by four-wheel drive vehicle; however, the western part of the watershed is mountainous and steep terrain, and also in different part of the catchment gulley shape eroded lands are considered as inaccessible. The Addis Ababa-Dessie main asphalt road runs west to east direction across the central part of the Dire reservoir catchment area. Besides these, there are many walkways from different villages that join Addis Ababa-Dessie main asphalt road on the catchment area boundary. In addition to these, the newly introduced construction activity and quarry areas create road access for four-wheel drive vehicle inside the catchment area. The partial view of the study area in Northeast, South east direction of the study watershed is presented in the following picture. (Figure3.2)

3.1.3. Climate

The area is located in the upper northwestern part of the awash basin. There are two major seasonal patterns in the region of Addis Ababa. The weather is relatively cool in the wet season of June to September when the main rain falls, while less rainy season of October to May has warmer temperatures with easterly winds. Rainfall usually occurs in the form of localized thunderstorms due to convective heating of the air masses during the day and rapid cooling at night.

Figure 3.2: Partial view of study area (photo taken May, 2017)

I) Temperature

The mean monthly temperature is between 16^{o}C and 26^{o}C throughout the year. Temperature data is unavailable in some stations (Chefedonsa and Aleltu) but, based on the other stations (Addis Ababa Bole, Shola Gebeya, and Sendafa) the minimum monthly average temperature registered is 16.1^{o}C in the month of August and the maximum monthly average temperature is 25.5^{o}C in the month of February. In the study area the hottest season extends from December to late March.

II) Rainfall

Dire Reservoir catchment characterized by Moist Dega agro-climatic Zones and the rainfall is bimodal type, which is distributed into minimum rainy season occurring in the months between October and May, and longer rainy season occurring between June and September. Climatic Stations with in and in the Proximity to the study area, there are six meteorological stations, these are Aleltu, Addis Ababa Bole, Addis Ababa observatory, Sendafa and Shola Gebeya. From the rainfall data of the stations high rainy seasons are observed in July and August. The main cause of the rainfall in this region is the southward migrating Inter Tropical Convergence Zone (ITCZ) and westward propagating disturbance from the Indian Ocean. The rainfall patterns in the catchment areas have a bimodal profile with strong peaks in the summer months and minimum rainfalls in the winter season (Figure 3.3).

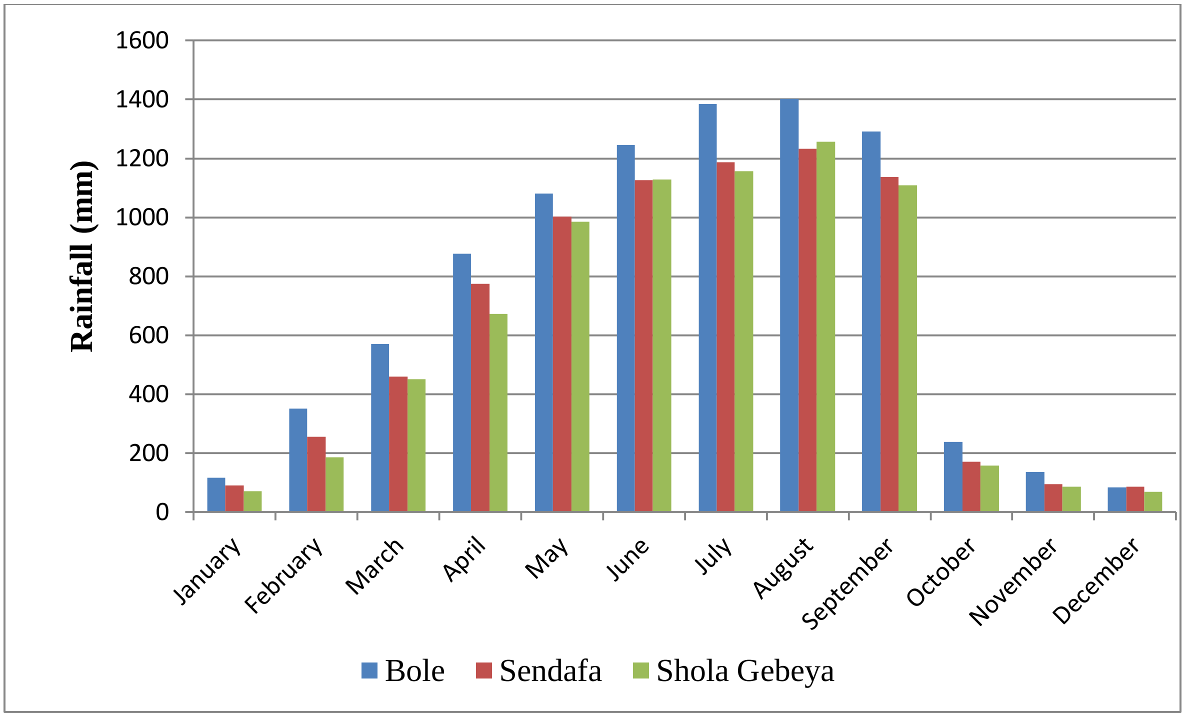

Figure 3.3: Mean Monthly rainfall (mm) of Dire catchment.

3.1.4. Land use/ land cover and socio-economic situation

Land in the Dire catchment area distributed by the government and local authorities based on the farmers needs and recently land certification try to secure ownership right of the land but, historical nature of land ownership of farmers creates some complication to proceed according to government plan. Agriculture is the major source of income for the community and recently various infrastructures development of Sendafa town create population migration in to the town. Industrial and infrastructure expansions create employment opportunity for the people however; following this situation massive encroachments in the catchments have seriously affected the vegetation and other natural resources in Dire catchment. As it is well understood, Vegetation in a watershed plays significant role in intercepting raindrops, reducing surface runoff, and there by control erosion, maintain soil fertility and regulate the micro climates.

In the contrary in this catchment the natural vegetation has been destroyed or altered by extensive cultivation and human settlements.

The major land use types of the catchment are: Forest decidecious, Urban, Mixed-forest, agricultural generic land, Agricultural -close grown and Pasture/Grazing land (Table 3.2).The dominant land use type is Agricultural-close grown which is located in 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 edge of the perimeter of the reservoir. This cultivated field and other land use categories are not well protected from water erosion by any soil and water conservation measures. The farming system of the catchment is mixed farming with dominantly oxen plough cereal crop production and livestock rearing. According to Aleltu-Bereh district Agriculture and Rural Development Office, almost all cultivated land of the catchment is used for annual crops cultivation. The major crops grown in the catchment includes Wheat, Barley, Oat, Teff and Beans, and Common Livestock species raised cattle, horse, donkey, sheep and goat.

3.1.5. Geology and soil types

According to the Ethiopian physiographic region division, the study area is situated in the upper Awash part of the rift valley system and adjoining the plateau lands of the central high lands. The overall geomorphologic relief of the Dire catchment area is characterized by plateau areas, escarpments with steep slope sections and infill zones where sedimentary and colluvial sediments are deposited. The dominant landscapes of Dire catchment area are flat, gently undulating plains and mountainous which elevation range from 2398 to 3220 m.a.s l.

According to the model soil classification, major soil types of the study area are three types of soils in the catchment. These soils are Pellic Vertisols, Eutric Nitosols and water is the dominant soil types (Figure 3.3), which is found in almost all parts of the catchment.

3.2. Study design

Some of the Models and software's used for estimation of sediment yield in the study area were: Arc GIS 10.1, Arc SWAT 2012 version and SWAT-CUP.

Arc GIS: it was used for input preparation of SWAT model.

Arc SWAT: it was used for prediction of sediment inflow to study area and their spatial variability and simulate the input data to have the required outputs.

SWAT-CUP: it was used for sensitivity analysis, model calibration and model validation.

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

The methodology of this study has the following components.

1. Data collection
2. Data analysis/ processing
3. Running model
4. Sensitivity Analysis
4. Model calibration
6. Model validation
5. Model result interpretation and
6. Assess and recommend best sediment management interventions.

The overall methodology was analyzed using the Geographical Information System (GIS) based version of Soil and Water Assessment Tool (SWAT).Calibration, validation and evaluation by appropriate systems to check the performance of the model with observed data has been done. Finally, selection of appropriate management practices and evaluation of those practices and selection of best management practices has been done The overall methodology of the study was presented in the following figure.

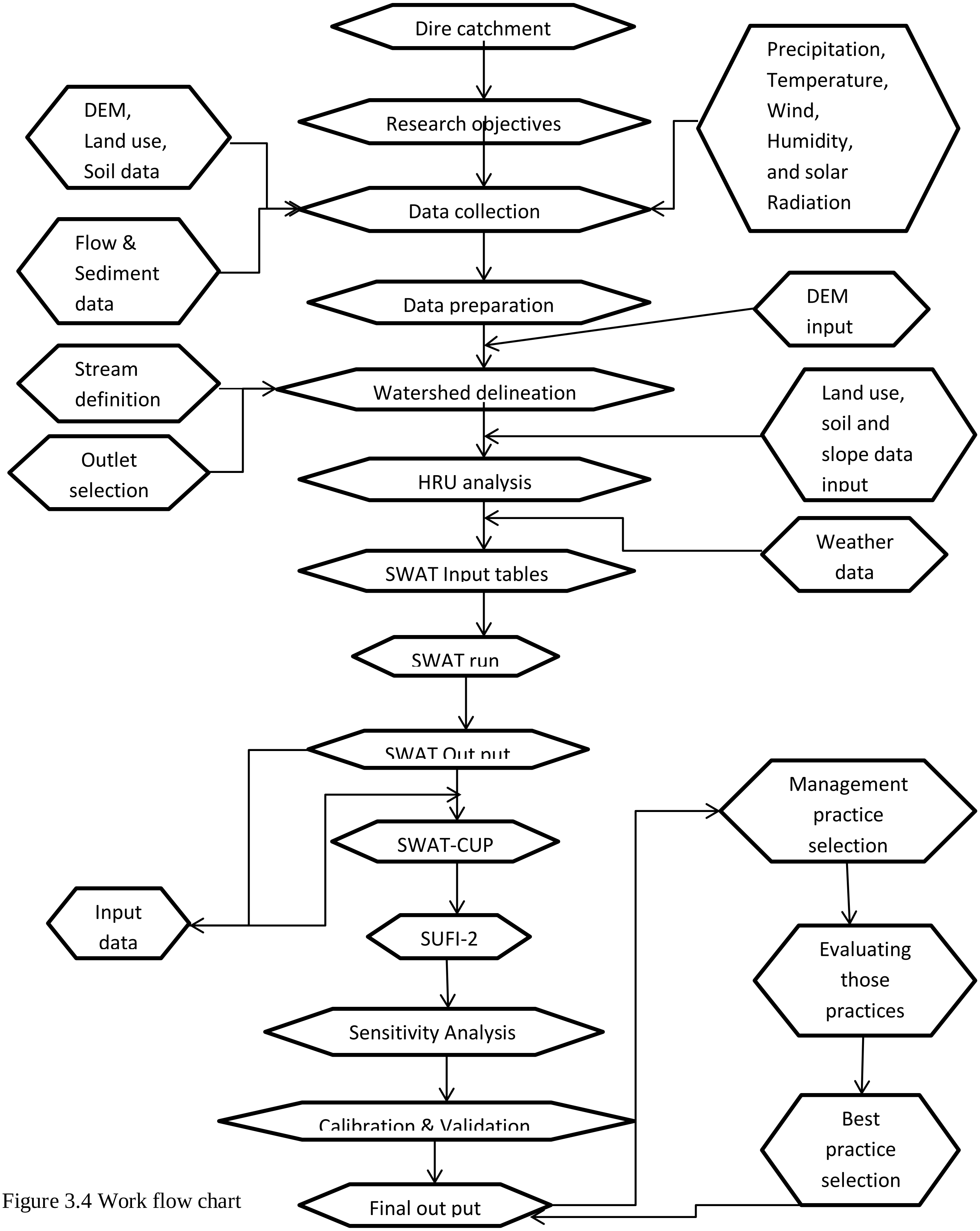

Figure 3.4 Work flow chart

3.2.1 Data collection

3.2.1.1 DEM, Land use/ Land cover and Soil Map

The Digital Elevation Model of 30m by 30m resolution, Land use/Land cover and Soil data have been taken from Ministry of Water, Irrigation and Electricity, Data Base and GIS Directorate. Land use/Land cover and soil map obtained in the format of shape file.

(i) Land use/land cover map

The land use/ land cover map gives the spatial extent and classification of the various land use/ land cover classes of the study area. The land use/land cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and the storage in the soil layers. LULC is one of the most important factors affecting different processes in the watershed, such as surface runoff, erosion, recharge and evapotranspiration. The LULC data for this study area was obtained from Ethiopian Ministry of water, Irrigation and Electricity, GIS department.

(ii) Soil map and data

SWAT requires soil properties and land cover information to simulate loads in the hydrological components. The importance of soil properties stems from the important role they play in hydrological modeling. Hydrological soil type classification considers the physical properties of soils including texture, infiltration capacity, and particle size and soil structure. The soil data as required by SWAT to predict the stream flow and sediment yield should include the relevant hydraulic conductivity properties: the soil bulk density, the saturated hydraulic conductivity and the soil available water capacity (SOL_AWC). The parameters of the soil such as the Soil Bulk Density (g/cc), Saturated Hydraulic Conductivity, Ks (mm/hr.), soil group and Soil map. They were obtained from Ethiopian Ministry of water, Irrigation and Electricity, GIS Department.

3.2.1.2 Meteorological and Hydrological Data

Metrological data

The climate data is among the most prerequisite parameter of SWAT model. This data was collected from National Metrological Service Agency. The collected data were

Rainfall, Maximum and Minimum air Temperature, Wind speed, Sunshine and Relative Humidity of three stations in and around the catchment.

The Sendafa meteorological station (502651 E and 1011388 N) is located adjacent to the study area; at an altitude of about 2569 m. From this station Available data is limited to the period from 2000 to 2009, covering daily precipitation, and daily air temperatures. The station does not operated since the beginning of 2010 to 2012 and again from 2013 to 2015, it starts operation. Even within the period of record there are a number of missed data. The mean annual rainfall for sendafa station is 1,662 mm.

The shola station (516383 E and 1016947 N) is the nearest station which is found in the catchment, it has the same problem as Sendafa station, from 2000 – 2009 has a numerous data gaps. From 2010 to 2012 the station does not operated, and again 2013 the station has started operation, generally within the period of 2000 – 2009 there are a numerous missing data or gaps.

The Bole station is the only synoptic station which is located 476590 E and 993272 N, records continuous rainfall, minimum and maximum temperatures, wind speed, sunshine hours, and relative humidity.

Table 3.1: Location of Metrological Stations within and around the catchment

Station name	Latitude	Longitude	Elevation	Mean annual rainfall(mm)
Addis Ababa (Bole)	476590	993272	2354	1100
Sendafa	516383	101697	2648	1050
Shola Gebeya	502651	101138	2569	950

Hydrological data

(a) Stream Flow data

SWAT simulates stream flow, sediment yield, nutrient and pesticide transport at catchment scale, on a continuous, daily time step (Neitsch *et al.*, 2011). SWAT does not use this data values in calculations but instead they are used for comparing observed and simulated values in calibration and validation periods. Stream flow in a main channel is determined by three sources: surface runoff, lateral flow and base flow from the shallow aquifers. Daily stream flow was obtained from Ethiopian Ministry of water, Irrigation and Electricity, hydrology Department.

(b) Sediment yield data

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

$$S = a\,Q^{b} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: S is sediment load in ton/day, Q is the discharge in m^3/s and, b & a regression constants. Hence the measured value that was collected from the MoWIE, hydrology and water quality directorate was sediment concentration in (mg/l), so that the first work was convert this value into sediment load by the following formula:

$$S = 0.0864 \times Q \times C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: S is sediment load in (ton/day), Q is flow of the stream (m^3/s), C is sediment concentration (mg/l) and 0.0864 is conversion factor.

After calculating the sediment load the next step was making the relation between measured flow in m^3/s and the measured sediment load (ton/day). The relation between the flow and sediment load with R^2 of 89.23 % was

$$S = 12.193Q^{0.9235} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

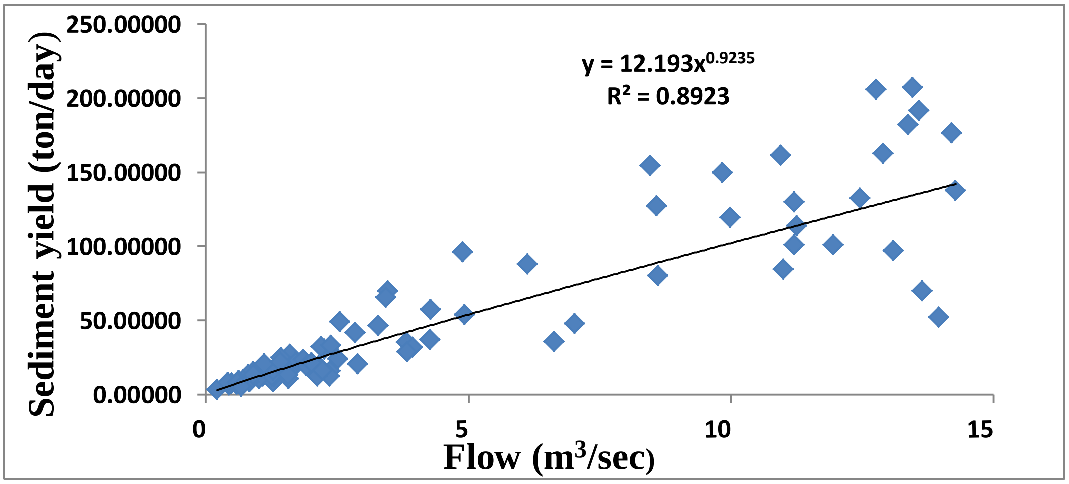

Figure 3.5 Sediment rating curve

3.2.1.3 Model Selection

SWAT is computationally efficient hydrological model, which uses readily available inputs. It 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 time (Neitsch *et al*., 2005).

Additional reasons for the selection of SWAT model to be used in prediction of sediment yield modeling includes, the model has also been tested in different watersheds in Ethiopia and reported to be able to simulate well watershed hydrological processes: (Dilnesaw , 2006) in Upper Awash River Basin, (Lijalem, 2006) in Lake Ziway watershed and (Degefie , 2007) Keleta watershed in Awash River Basin can be mentioned as examples, which additionally justify the possible use of this model in the study area.

(b) Modeling Approach

SWAT allows a number of different physical processes to be simulated in a watershed. In order to adequately simulate hydrologic processes in a basin, the basin is divided into sub basins through which streams are routed. The subunits of the sub basins are referred to as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrological homogeneous.

Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE). The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and floodplain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stoke's law (Chow *et al.*, 1988) and is calculated as a function of particle diameter squared. The depth of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold's stream power concept (Chow *et al.*, 1988).

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. The model splits hydrological simulations of a watershed into two major phases: the land phase and the routing phase.

(A) Land phase

The land phase of the hydrologic cycle controls the amount of water, sediment loadings to the main channel in each sub basin. The land phase of the hydrologic cycle was simulated based on the following water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), $E_{a.}$ is the amount of evapo-transpiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), Q_{gw} is the amount of return flow on day i (mm H_2O).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

(B) Routing phase

The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. The method was developed by Williams, (1969) and recommended Williams and Haan, (1973) and Arnold *et al*., (1995). The Storage routing is based on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: V_{in} is volume of inflow during the time step (m^3), V_{out} is volume of outflow during the time step (m^3), and ΔV_{stored} is change in volume of storage during the time step (m^3).

SWAT can also be applied at the river basin, or watershed scale. It was developed for the purpose of simulation and to predict the impact of land management practices on water, sediment and agrochemical yields in large, complex watersheds with varying soils, land use and agricultural conditions over extended time periods (Neitsch *et al*., 2005). A great number of SWAT applications have been used to study hydrology and sediment yield in small or large catchments in different regions of the world.

SWAT model calculates the surface erosion and sediment yield within each HRU with the Modified Universal Soil Loss Equation (MUSCLE (Williams, 1975). The sediment routing in the channel consists of channel degradation using stream power and deposition in channel using fall velocity. MUSLE predicts sediment yield as a function of surface runoff volume, peak runoff rate, area, soil erodibility, land cover, land support practices, topography, and percent coarse fragments in top soil layer. The estimated sediment yield is a function of the surface runoff and peak rate of runoff. The sediment yield has direct relation with the rainfall and stream flow. Channel sediment routing in SWAT is based on the maximum amount of sediment that can be transported from a reach segment, which is a function of peak channel velocity (Neitsch *et al.*, 2011). The MUSCLE is:

$$Sed = 11.8\,(Q_{surf} * q_{peak}.\, A_{hru})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * C_{FRG} \ldots\ldots\ldots\ldots\ldots .(6)$$

Where: sed: sediment yield on a given day (tons), Q_{surf}: is the surface runoff volume (mm water/ha), q_{peak}: is the peak runoff rate (m^3/s), A_{hru}: is the area of the HRU (ha), K_{USLE}: is the USLE soil erodibility factor (0.013 metric ton m^{2}hr/ (m3.metric ton cm)), C_{USLE}: is the USLE cover and management factor, P_{USLE}: is the USLE support practice factor, LS_{USLE}: is the USLE topographic factor and , C_{FRG}: is the coarse fragment factor.

Conceptual basis of the SUFI-2 Uncertainty Analysis

SWAT-CUP is a public domain program linking the SUFI-2 procedure to SWAT. SWATCUP provides a decision making frame work that incorporates a semi-distributed approach using both manual and automated calibration incorporating sensitivity and uncertainty analysis. The Sequential Uncertainty Fitting, version 2 (SUFI-2) is one of the uncertainty analysis programs that is incorporated in an independent program called SWAT calibration and Uncertainty Program (SWAT-CUP) (Abbaspour *et al.*, 2007), that perform uncertainty analysis due to both parameter and model uncertainties. Its main function is to calibrate SWAT and perform validation, sensitivity and uncertainty analysis for a watershed model created by SWAT.

SUFI-2 is developed for a combined calibration and uncertainty analysis to find parameter uncertainties while calculating smallest possible prediction uncertainty band. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), parameters, conceptual model, and measured data (e.g., observed flow, sediment). Source of uncertainties in distributed models are due to inputs such as rain fall and temperature. Therefore, carrying out uncertainty analysis for the prediction of the hydrological model is crucial to decide the calibrated parameters to transfer to other homogenous catchments and also using for further predictions.

3.2.2. Data analysis

After the data was collected, an analysis of all the collected data was made. One of the problems in hydrology especially in developing countries is hydrological data both in quantity (length of record) and quality (standard of scientific approach). The output of any research depends highly on data input. The acquired data were checked for any outliers and missing values. The missing meteorological and stream flow data were filled using linear regression method. The Advances in scientific hydrology and in the practice of engineering hydrology are dependent on good, reliable and continuous measurements of the hydrological variables.

The data were then arranged into daily series and saved as Text files as an input into the SWAT model. For weather generator the necessary average Precipitation value, maximum and minimum temperature, relative humidity, dew point, average Solar radiation, average wind speed, maximum half hour, probability of wet and dry days, skewness coefficients were determined by using PCP STAT, Dew02.exe and pivot table. The weather generator is used to either generate daily weather data or fill in missing values in the input data. The generator generates daily weather data based on monthly averages.

3.2.2.1 Filling missing data

Missing data is a common problem in hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data is very important. A number of methods have been proposed to estimate missing rainfall data. The missing data can be completed by using meteorological and hydrological stations located in the nearby stations, provided that the stations are located in the hydrologically homogenous region. The missing values were filled using the values from the nearby values of recording stations.

A regression analysis is the application of a statistical procedure for determining a relationship between variables (Haan *et al.*, 1994). In this procedure one variable was expressed as a function of other variables. The variable to be determined is termed as the dependent variable while others are called the independent variables. Application of regression analysis made possible completing short and long period breaks in data series for given meteorological station.

The Shola and Sendafa stations were found within the watershed are the third class stations; then, they have not relative humidity, sunshine hours and wind speed data. The missing metrological data from these weather stations were filled by a weather generator model embedded in SWAT model which requires daily rainfall data and arranged vertically parallel to time series. For generating of evaporation and evapotranspiration, temperature data is required for SWAT model simulation in this study. The maximum and minimum daily temperature values are arranged downward parallel to corresponding date of record.

(i) Checking consistency and adjustment of rainfall stations

A consistent record is the one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. The consistency of rainfall records on selected stations commonly checked by double mass curve analysis. Double mass curve is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time the significant change took place. If significant change in the regime of the curve is observed, it should be corrected by using equation 4. The stations used in this study have not undergone a significant change during the base line period of the study.

$$P_{cx} = P_X * \frac{Mc}{Mo} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where: P_{cx} is corrected precipitation at any time period, P_x is original recorded precipitation at time period, M_c is corrected slope of the double mass curve and M_o is original slope of the double mass curve.

The accumulated totals of the gauge are compared with the corresponding totals for a representative group of nearby gauge. If greater than 10% change in the regime of the curve is observed it should be corrected, otherwise we can ignore the change.

However, as all the selected stations in this study were consistent, there was no need of further correction. The graphs below shows all points set on or from almost the straight lines, which was plotted for checking of consistency of rainfall, all stations were consistence to each other.

Therefore, the stations did not need further adjustment

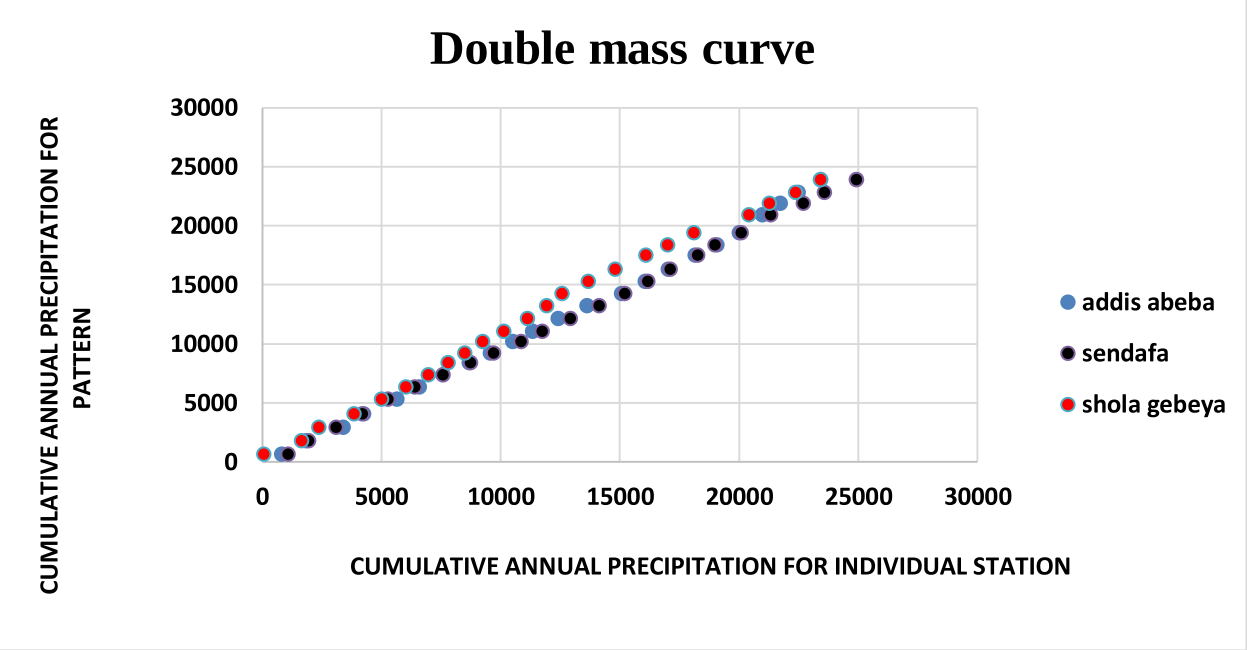

Figure 3.6: Double mass curve of all stations used for the study

3.2.3 Model Setup

3.2.3.1 Watershed delineation

At first, setup for new SWAT project has been created. The required spatial data sets were projected to the same projection called Adindan UTM Zone 37 N, which is the transverse Mercator projection parameters for Ethiopia, using ArcGIS 10.1. The geographic information system interface-Arc SWAT was used for the setup and parameterization of the model. A DEM had a Geographic coordinate system so it was converted into the projected coordinate system by using Arc tool box data management tool. After sub-setting the DEM data, it has been imported in the SWAT project to start watershed delineation.

The procedures followed in the model setup were involved integrating the DEM, watershed delineation, land use/land cover map and soil characterization, weather data to create Sub-basins and hydrologic response Units and editing input information’s. This was followed by the creation of the watersheds. The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters.

(i) Stream definition

The stream definition and the size of sub-basins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of the streams *(Arnold et al.*, 2007). In this section, initial stream network and sub-basin outlets were defined. This was achieved by specifying a threshold area or critical source area , which is the minimum drainage area required to form a source of stream. Since the number of sub-basins does not affect the simulated stream flow significantly, the suggested threshold was used. It provides the option of defining streams based on DEM under which the flow direction and accumulation have been calculated or importing pre-defined watershed boundaries and streams watershed dataset and stream dataset have been determined. In this section, the method based threshold area was used. Stream definition defines both the stream network and sub-basin outlets. A minimum, maximum and suggested watershed area in hectares was shown in the drainage area box. The size of the sub-basin was changed within the specified range values. The threshold area defines the drainage area required to form the beginning of a stream. After that stream network create streams and outlets.

(ii) Outlet and inlet definition

In this section by defining the outlet point of discharge for the sub-basin and inlet of draining watershed and the definition of point source input or by adding manually point source to each sub-basin. The outlets of the sub-basin can represent the monitoring data points and the reservoir whereas the inlets of draining watershed represent point source discharge and watershed not modeled in SWAT. Drainage inlets and Sub-basin watershed outlets may be added, deleted or redefined. In this study the outlet and inlet definition was selected by using sub-basin outlet and manually adding the out let for the Dire reservoir particularly at the dam site.

(iii) Watershed outlet(s) selection and definition

Watershed delineation was more defined in this section by defining the outlet(s) point for the whole watershed. It is useful for comparison of measured and predicted flows and concentrations. It is convenient to select the most down-stream outlet of each target watershed to determine the whole basin. The area of the sub-basin was cut short from previous defined sub-basin area after defining the outlet and those are stored in the ‘‘Monitoring Points’’ layer. At the last delineation of watershed process has been run, and when completed a message indicating successful completion displayed.

(iv) Calculation of sub-basin parameter

Final step in the delineation of the watershed was calculation of Sub-basin parameters. The calculation of Sub-basin Parameters section contains functions for calculating geomorphic characteristics of the sub-basins and reaches, as well as defining the locations of reservoirs within the watershed, number of outlets and number of sub-basins were determined. Topographic report was created which contained the summary and distribution of discrete land surface elevations in the sub-basins. In addition, a new layer called longest path was added to the map which represents the longest flow path within each of the sub-basins.

The watershed delineation tool uses and expands the ArcGIS, spatial analyst functions to perform watershed delineation (Neitsch *et al.*, 2005) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub-basins and details of stream network depends on this threshold area. In this study the threshold area was taken 5000 ha and the watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineate a watershed area of 362.972km^2 with 3 sub-basins (Figure 3.7).

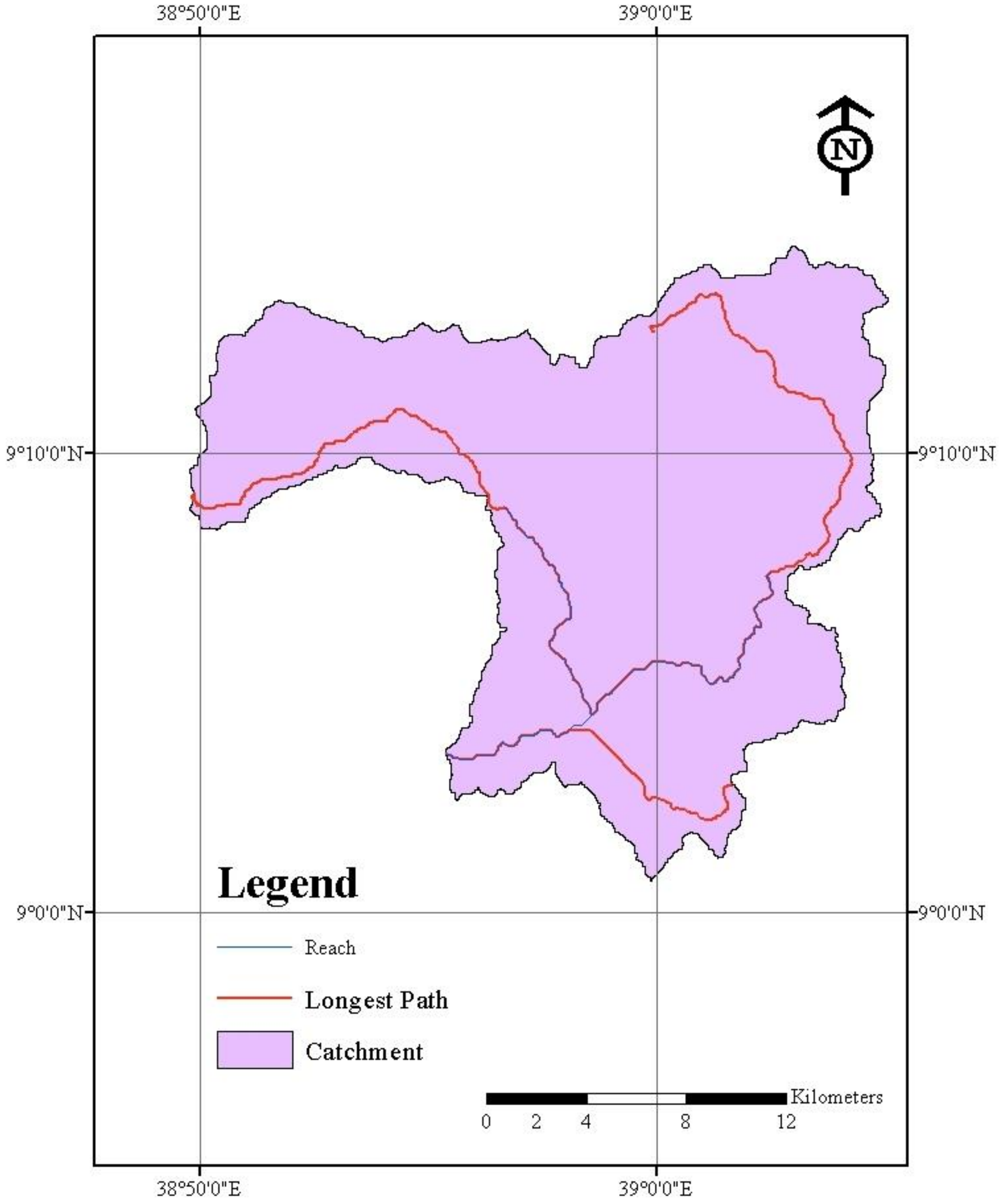

Figure3.7: The delineated watershed by SWAT model

3.2.3.2 Hydrologic response unit determination

The second part of the model setup is to define HRU. The Hydrologic Response Units (HRUs) analysis tool in Arc SWAT helps to load land use and soil maps to the project and also classify the slope of the sub-basins.

(a) Land use/ land cover

The land use/cover map that was collected from MoWIE was not directly used by the SWAT model. SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use map of the study area to SWAT land use databases in the GIS interface. So, well preparation of the lookup-table of the land use/cover types in the SWAT compatible way is basic for the loading of the land use/cover of the study area. Information collected from the digitalized land use/cover map shape file was used in renaming the land uses/cover or to prepare the look up table.

The dominant land uses/cover in the watershed are agricultural-close grown land covers about 58.13% of the catchment followed by Agricultural generic land that covers 19.28% of the catchment, Agricultural land covers 9.3% of the catchment, Forest decidecious land covers 7.18% of the catchment, Pasture land covers 4.15% of the catchment, Mixed-forest land covers 1.64% of the catchment and Urban land covers 0.32% of the catchment area (Table 3.2 and Figure 3.8).

Table 3.2: Original and the redefined (according to SWAT) land use/land cover database

Original land use/cover	Redefined land use/cover according to SWAT database	SWAT- CODE	AREA (ha)	% of Watershed area
Cultivable land	Agricultural land	AGRR	3376.6	9.3
Shrub land	Forest - decidecious	FRSD	2605.5	7.2
Low population settlement	Urban	URLD	115.1	0.3
Open- woodland	Mixed-forest	FRST	596.3	1.7
Mixed cultivated/wood land	Agricultural Generic	AGRL	6999.4	19.2
Traditionally cultivated land	Agricultural - close grown	AGRC	21098.2	58.1
Grass land	Pasture land	PAST	1506.2	4.2

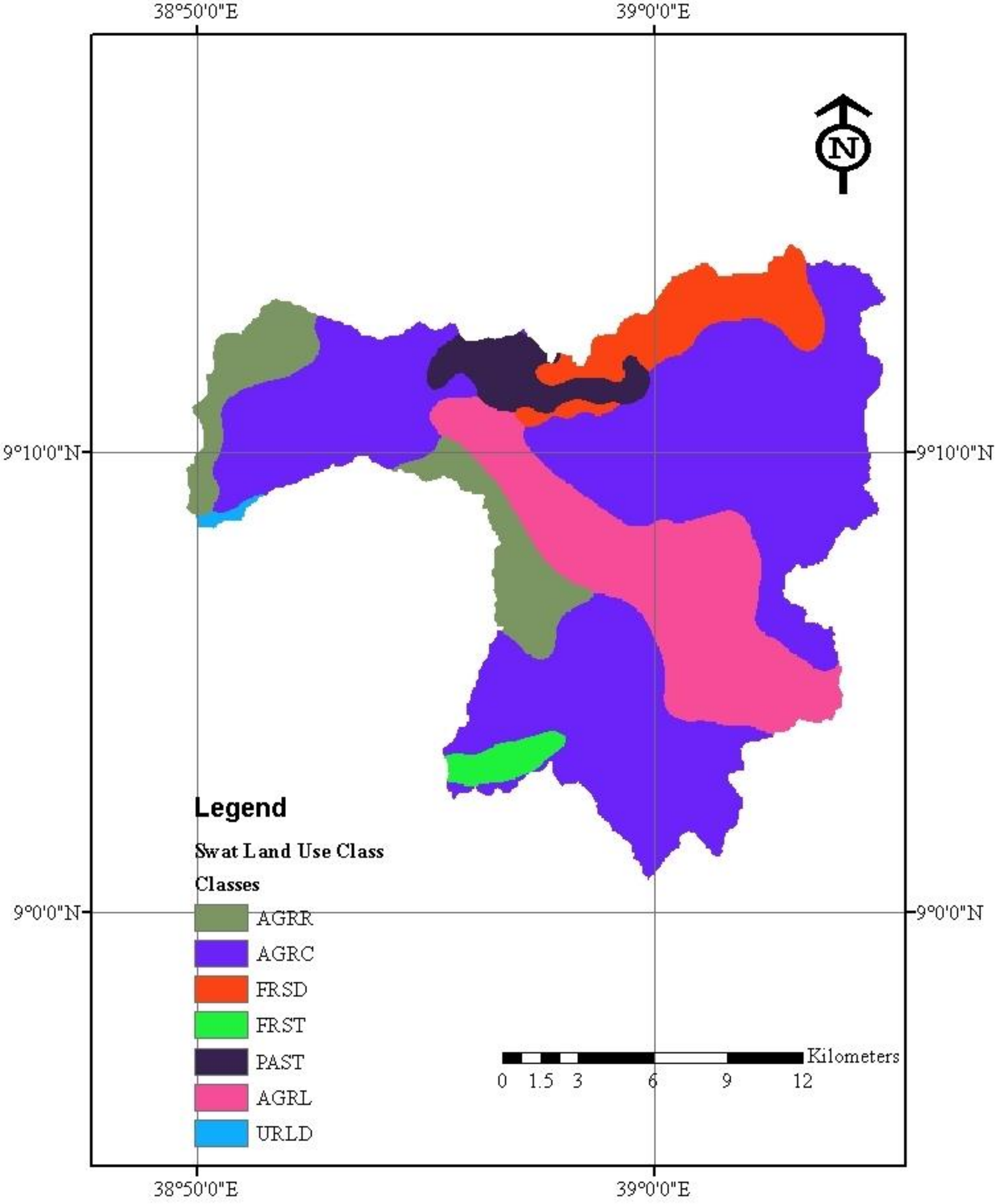

Figure 3.8: SWAT land use classification of the watershed

(b) Soil data

Soil data is also one of the major input data for the SWAT model with inclusive and chemical properties. Soil physical attributes were initially stored to the SWAT's soil database through an edit database interface and relevant information required for hydrological modeling and soil erosion modeling was provided to the model. Like the land use map, the soil map that was collected from MoWIE was not used by the SWAT model. In order to integrate the soil map within the SWAT model, it is necessary to make a user soil database that contains physical and chemical properties of each soil of the study area. To prepare this user database of the soils, the properties of the soils that required in the SWAT model was extracted from FAO-UNESCO Soil data base because the soils of the study area is prepared based on FAO-UNESCO classification . But the database doesn't contain all soil properties which are required by SWAT model. The three most dominant soil types in the area are: Pellic Vertisols , Eutric Nitosols and water (Table 3.3 and Figure 3.9).

Table 3.3: Soil classification of the watershed in SWAT model

Soil Type	Symbol	Area (ha)	% catchment area
Pellic Vertisols	Vp	10098.2	27.8
Eutric Nitosols	N_e	21119.2	58.2
Water	WATER	5079.78	14.0

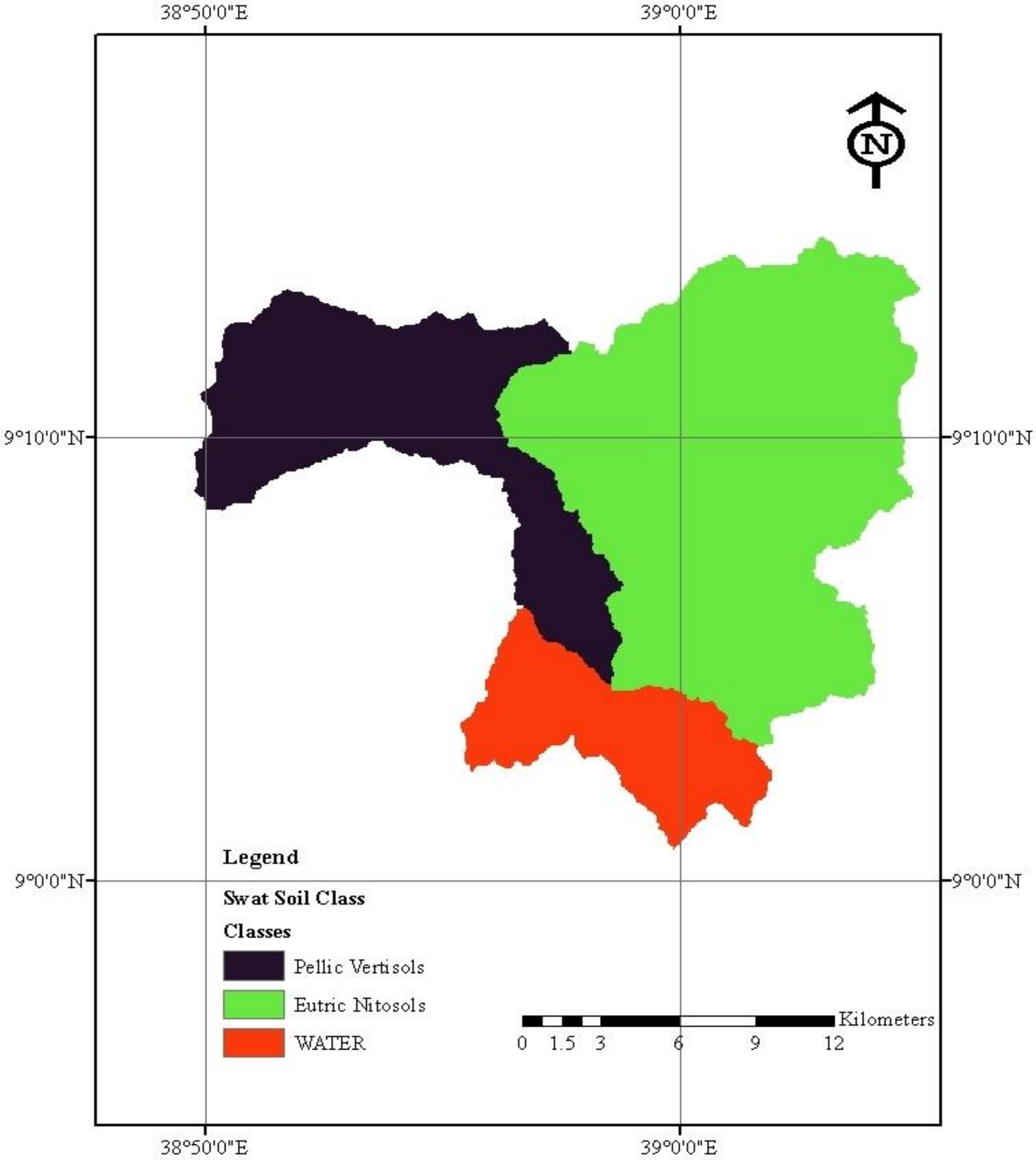

Figure 3.9: Soil classification of the watershed in SWAT model

(c) Slope

The third step in HRU definition is selection of slope classification option (single or multiple) and if multiple slope option is select then defines the range of the slope. For this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified to two and the range was 0-10%, 10-20%.

Lastly, by define the HRUs within a sub-basin complete the HRU setup. For this study the option of multiple HRU was selected and 5%, 20% and 20% were the threshold area of land use, soil and slope in each HRU from the sub-basin values respectively. The reason for taking these threshold values was in order to keep the HRUs to a reasonable and manageable number and also considering computer processing time required. Even though, application of these thresholds eliminates the land uses and soils that covered relatively small areas in the sub-basins it creates a total of 11 HRUs for 3 sub-basins.

3.2.3.3 Weather Generator and writing input tables

Weather generators solve the problem of lack of full and realistic long period climatic data by generating data having same statistical properties as the observed ones. SWAT built in weather generator called WGEN that is used to fill the gaps, for generating missing data. Impacts of land use/ land cover change on sediment yield and stream flow. But, for this study the missing data were filled by linear regression and the data used for weather generator were prepared using different software's. The Write Input tables menu contains items that allow building database files containing the information needed to generate default input for SWAT. Weather data to be used in a watershed simulation was imported once the HRU distribution has been defined. The weather data has been loaded using the weather stations command in the write input tables menu item. Using the file browser the locations of the weather generator stations prepared in the text format was selected. In this study all the weather stations or the weather data definitions (weather generator data, rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data) locations were prepared in text format and loaded.

After the database set up was completed the weather gages selected was added to the monitoring point layer. The Write commands become enabled after weather data were successfully loaded. These commands were enabled in sequence and processed only once for a project. Before the SWAT run, the initial watershed input values were defined. These values were set automatically based on the watershed delineation and land use/soil/slope characterization. There are two ways to build the initial values: activate the Write All command or the individual Write commands on the Write Input Tables menu. The first option has been selected for this study.

3.2.4 SWAT run

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

The SWAT simulation menu allows to finalize the setup of input for the SWAT model, to run the SWAT model and to read the SWAT output by importing files to database and saving to the place of interest or by opening the outut.std. At the last running SWAT check take place for output visualization. After this sensitivity analysis, calibration and validation has been carried out by using SWAT-CUP.

3.2.5 Sensitivity Analysis

According to (Dilnesaw , 2006), sensitivity analysis is a method of identifying the most sensitive parameters that have significant effect on model calibration or on model prediction. Sensitivity analysis describes how model output varies over a range of a given input variable.

The theoretical background of the sensitivity analysis method that is implemented in SWAT is called the Latin Hypercube One-factor-At-a-Time (LH-OAT). LH-OAT design is very useful method for SWAT modeling as it is able to analyze the sensitivity of many parameters. The method in the Arc SWAT interface combines the Latin Hypercube (LH) and one –factor-at-a-time (OAT) sampling (Van Griensven, 2005). The LH-OAT merges the one-at- a time (OAT) plan and Latin hypercube sampling by using the Latin Hypercube example as primary points for an OAT design.

This approach combines the advantages of global and local sensitivity analysis method and can efficiently provide a rank ordering of parameter importance.

Two types of sensitivity analysis were generally performed: local, by changing values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. The global sensitivities are determined by calculating the following multiple regression system, which regresses the Latin hypercube generated parameters against the objective function values in file goal.sif2. The sensitivities given above are estimates of the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing.

Sensitivity analyses were therefore carried out for 12 and 20 parameters for flow and sediment yield respectively selected from SWAT documentation and the results of previous studies within the catchment (Taye , 2009) to identify the most sensitive parameters that affect the stream flow. So, on category specified above the parameters changed for calibration were those parameters selected as the most sensitive parameters for this study.

The most sensitive parameters resulted from the sensitivity analysis were adjusted until the output from the model gives an acceptable agreement with the actual measurement. The parameters were adjusted manually and then automatically using sequential uncertainty fitting (SUFI-2) algorithm (Abbaspour *et al.*, 2007). The SUFI-2 algorithm is linked to the SWAT model using SWAT Calibration and Uncertainty Procedures (SWAT-CUP) (Abbaspour *et al.*, 2009).

3.2.6 Model calibration

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neistch *et al.*, 2002) at different spatial and temporal scales.

Model Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Calibration can be accomplished manually or using auto calibration tools in SWAT or SWAT-CUP (Abbaspour *et al.*, 2007). (Rouholahnejad *et al.*, 2012), distinguished three types of calibration methods the manual trial and error method, automatic or numerical parameter optimization method, and a combination of both methods. According to the authors, the manual calibration is the most common and especially recommended in cases where a good graphical representation is strongly demanded for the application of more complicated models. However, it is very cumbersome, time consuming, and requires experience.

Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. The method undertakes a large number of iterations until it find the best parameters. The auto-calibration option in SWAT provides a powerful, labor saving tool that can be used to substantially reduce the frustration and uncertainty that often characterizes manual calibration (Van Griensven, 2005)

The third method makes use of combination of the above two techniques regardless of which comes first. Visual and numerical methods were used to assess the goodness fit between the simulated and observed stream flow and sediment yield. The other calibration tools such as the ‘Sequential Uncertainty Fitting Algorithm’ (SUFI-2) program (Abbaspour *et al.*, 2007) were used. For this study, SWAT-CUP method was considered for calibration because in SUFI-2 both manual and automated calibration incorporates sensitivity and uncertainty analysis.

For each calibration run and parameter change, the corresponding model performance statistics (R^2 and E_{NS}) were calculated. This procedure continued until the acceptable calibration statics recommended by SWAT developer for hydrology was achieved. SWAT developers in (Santhi et al., 2001) assumed an acceptable calibration for hydrology at a $R^2 > 0.6$ and $E_{NS} > 0.5$.

In sediment transporting modeling a two-step calibration procedure has been suggested by (Neistch *et al.,* 2002), first checks water balance contribution, then calibrate stream flow and followed by sediment calibration.

The study was done using historical records of twenty seven years for Dire catchment. However, the calibration was run for 8 years for flow (1990 – 1998) where the first one year (1990) used to “warm up” the model and 4 years for sediment (1997-2001) where year (1997) was used as warm up period. Thus, only results for the period 1991–1998 and 1998-2001 were used for calibration of stream flow and sediment yield respectively.

Warm up is very important part of the simulation process that ensures the establishment of the basic flow conditions for the simulation to follow by bringing the hydrologic processes to an equilibrium condition. The warm-up period allows the model to cycle multiple times in an attempt to minimize the effect of the user’s estimates of initial state variables such as soil water content and surface residue (Srinivasan *et al.*, 2007).

Calibration of stream flow and sediment yield carried out at outlet of sub-catchment 3 near Dire dam). This site was selected due to the availability of measured flow and sediment data. In addition this outlet represents the whole catchment as it is located 5 kms upstream of the dam location. The stream flow and sediment calibration was on annual and monthly average time steps. SWAT developers in (Santhi *et al.*, 2001) assumed an acceptable calibration for hydrology at $R^2 > 0.6$ and $E_{NS} > 0.5$ and these values were also considered in this study as a reference.

3.2.7 Model validation

In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals (Rouholahnejad *et al.*, 2012).

Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios. Flow and sediment validation was carried out at a station similar to the calibration. The statistical criteria ($r^2$and E_{NS}) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits.

To perform validation in SUFI 2, once calibration is finished, the parameter ranges are used without further changes to simulate the validation period by editing the files observed_rch.txt, observed_hru.txt, observed_sub.txt, and observed.txt under objective function as necessary for the validation period also the extraction files and the file.cio to reflect the validation period. The measured data of stream flow of 6 years (1999–2004) and sediment yield of 3 years (2002-2004) were used for the model validation process. In general, graphical and statistical methods with some form of objective statistical criteria are used to determine when the model has been calibrated and validated.

3.2.8 Model efficiency

Two measures for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these numerical model performance measures are coefficient of regression (R^2) and the Nash-Sutcliffe simulation efficiency (E_{NS}).

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

It is calculated by the following equation:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - q_s)(q_{oi} - q_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - q_s)^2 \sum_{i=1}^{n}(q_{oi} - q_o)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: q_{si} is the simulated values of the quantity in each model time step (in this case, monthly and yearly), q_{oi} is the measured values of the quantity in each model time step (in this case, monthly and yearly), q_s is the average simulated value of the quantity in each model time step (in this case, monthly and yearly), q_o is the average measured value of the quantity in each model time step (in this case, monthly and yearly.)

Nash-Sutcliffe simulation efficiency, E_{NS}, indicates the degree of fitness of the observed and simulated plots with the 1:1 line. It is calculated as follows with the same variables defined above.

$$E_{NS=1-} \quad \sum_{i=1}^{n} \frac{(q_{oi} - q_{si})^2}{\sum_{i=1}(q_{oi} - q_o)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where: q_{si} is the simulated values of the quantity in each model time step (in this case, monthly and yearly), q_{oi} is the measured values of the quantity in each model time step (in this case, monthly and yearly).

The statistical index of modeling efficiency (E_{NS}) values range from 1.0 (best) to negative infinity. E_{NS} is a more stringent test of performance than R^2 and is never larger than R^2.E_{NS} measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison.

A value of 0.0 for E_{NS} means that the model predictions are just as accurate as using the measured data average to predict the measured data. E_{NS} values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. This measure is highly affected by a few extreme errors and can be biased if a wide range of events is experienced.

3.2.9 Assessing sediment reduction methods

Watershed managers rely on models to provide an estimate of best management practices impact on improving water quality at the watershed scale. Many watershed management programs have suggested modeling strategies for development and implementation of watershed management plans. In the absence of a standard procedure for representing agricultural conservation practices with watershed models, the results of modeling studies are subject to modelers' potentially inconsistent decisions in evaluating practice performance. Establishing a standard procedure for representation of conservation practices with a selected watershed model would: (i) reduce potential modeler bias; (ii) provide *a roadmap to be followed*; (iii) allow others to repeat the study; and improve acceptance of model results (Hydro Process., 2007).

The Soil and Water Assessment Tool (SWAT) is often used to evaluate sediment management benefits of agricultural conservation practices Kalin and Hantush, (2003) reviewed key features and capabilities of widely cited watershed scale hydrologic and water quality models with emphasis on the ability of the models to represent practices The review indicated that the SWAT model offers the greatest number of management alternatives for modeling agricultural watersheds.

SWAT already has an established method for modeling several agricultural practices and also has the capacity to represent many other commonly used practices in agricultural fields through alteration of its input parameters. A number of previous modeling studies have used SWAT to evaluate conservation practices around the globe. Lack of numerical guidelines for the representation of management practices is not limited to the SWAT model. Most previous work on the evaluation of conservation practices has been done through applying prior empirical load reduction coefficients. Application of this approach is limited because the performances of practices are site-specific, greatly influenced by landscape characteristics and interactions between practices. Process-based approaches should be developed where sediment yield impacts of practices are evaluated based on their physical characteristics and spatial location.

The main concern of this section is to present a step wise procedure for representation and evaluation of hydrologic and sediment yield impacts of several agricultural conservation practices with the SWAT 2012 model and focused on representation of the practices for which SWAT does not offer an established method. These include three practices (contour farming, strip cropping and filter strip). The hydrologic and sediment yield processes affected by each practice are reviewed, and the sensitivity of the SWAT outputs to the proposed representation is evaluated.

Based on the function of a conservation practice, a method was suggested for representing the practice with SWAT. This included a discussion of specific parameters that need to be changed. Definition and purpose of practices were obtained from national conservation practice standards-(USDA-NRCS, 2005).

Contour farming: Implementation of contour farming practices in a field will result in: (1) reduction of surface runoff by impounding water in small depressions; and reduction of sheet and rill erosion by reducing erosive power of surface runoff and preventing or minimizing development of rills. SCS curve number (CN) and support practice factor (USLE_P) was modified to simulate these impacts.

Neitsch, (2005) provides a table with recommendations for curve number in fields with different land use and soil characteristics under various hydrologic conditions. The recommendations also include impacts of contour farming, strip-cropping and filter strip on curve number.

However, curve number is a primary parameter used for calibration of the hydrologic component of the SWAT model and thus the use of these values directly from the table will not represent adequately the effect of the conservation practice. Therefore, the recommendations were used to establish a more general relationship between curve number before and after implementation of contour farming, strip cropping, and filter strip.

For contour farming, curve number was reduced from the default/calibrated value by 3 units. USLE support practice factor (USLE_P) for fields under contouring and strip cropping, conditions, and these values were used to simulate the erosion reduction due to implementation of the corresponding practices. (Appendix 6)

Strip-cropping: Implementation of strip-cropping practices in a field will result in: (1) reduction of surface runoff by impounding water in small depressions, (2) reduction of peak runoff rate by increasing surface roughness and slowing surface runoff; and (3) reduction of sheet and rill erosion by preventing development of rills. SCS curve number (CN), USLE support practice factor (USLEP), USLE cover factor (USLEC) and Manning's roughness coefficient for overland flow (OVN) were modified for representation of strip-cropping practices. Similar to contour farming, in fields where strip cropping is practiced, curve number was reduced from the calibrated value by 3 units. (Appendix 6) provides recommendations for USLE_P value under strip-cropping conditions. USLE_C and OV_N were adjusted based on weighted average values for the strips in the system. The weighted average can be computed based on the area of each strip in the field.

Filter strip: implementation of filter strip along the edge of channel segment were used to reduce sediment, nutrients, pesticides, and bacteria in surface runoff as it passes through the edge-of-the-field vegetative strip. Pollutant loads in surface runoff are trapped in the strip of vegetation. SWAT provides a specific method to incorporate edge of-field filter strips through the FILTERW parameter that reflects the width of the strip. For representation of filter strips, the parameter FILTERW for the fields that constitute the drainage area for the channel segment was adjusted to 5m wide.

4. RESULTS AND DISCUSSION

4.1. Flow sensitivity analysis

Flow sensitivity analysis was carried out for a period of fifteen years, which includes the calibration period (from January 1, 1991 to December 31, 1998) and one year of warm-up period (from January 1, 1990 to December 31, 1990) and validation period (from January1, 1999 to December 31, 2004) by using the SUFI-2 (sequential uncertainty fitting version 2) algorithm, which is a semi-automated inverse modeling procedure for a combined calibration-uncertainty analysis. The objective function selected during the sensitivity analysis was the sum of the squared errors between observed and simulated values. The most sensitive parameters for river flow were further used for calibration of the model via SWAT-CUP. The rank of the most sensitive parameters for river flow from the most sensitive to least sensitive was given in figure 4.1 and table 4.1.

The most sensitive parameters were selected by running the sensitivity analysis. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization (Van Griensven and Meixner, 2006).To find the sensitive parameters Latin hypercube simulation, the one at-a-time (LH-OAT) method was used (Van Griensven and Meixner, 2006). Twelve parameters were considered for the model parameterization or sensitivity analysis. The five most sensitive parameters most responsible for the stream flow assessment for the Dire catchment have been considered for the model parameterization and calibration process. The remaining parameters had no significant effect on stream flow simulations and depicted under appendix 8. The sensitivity analysis has been carried out in all catchment.

CN is the most sensitive parameter in all catchments, which indicating that the importance of this parameter during calibration. The threshold depth of water in the shallow aquifer(GWQMN), which is required for return flow to occur was the second highest sensitive parameter. This is an indication that Dire catchment has shallow depth water which have highest contribution to the flow and the flow was also sensitive to soil properties of the watershed like soil evaporation compensation factor (ESCO).Generally, as we can see from figure 4.1 as p-value increase the sensitivity of parameters become decrease and as p-value decrease the sensitivity of parameters increase.

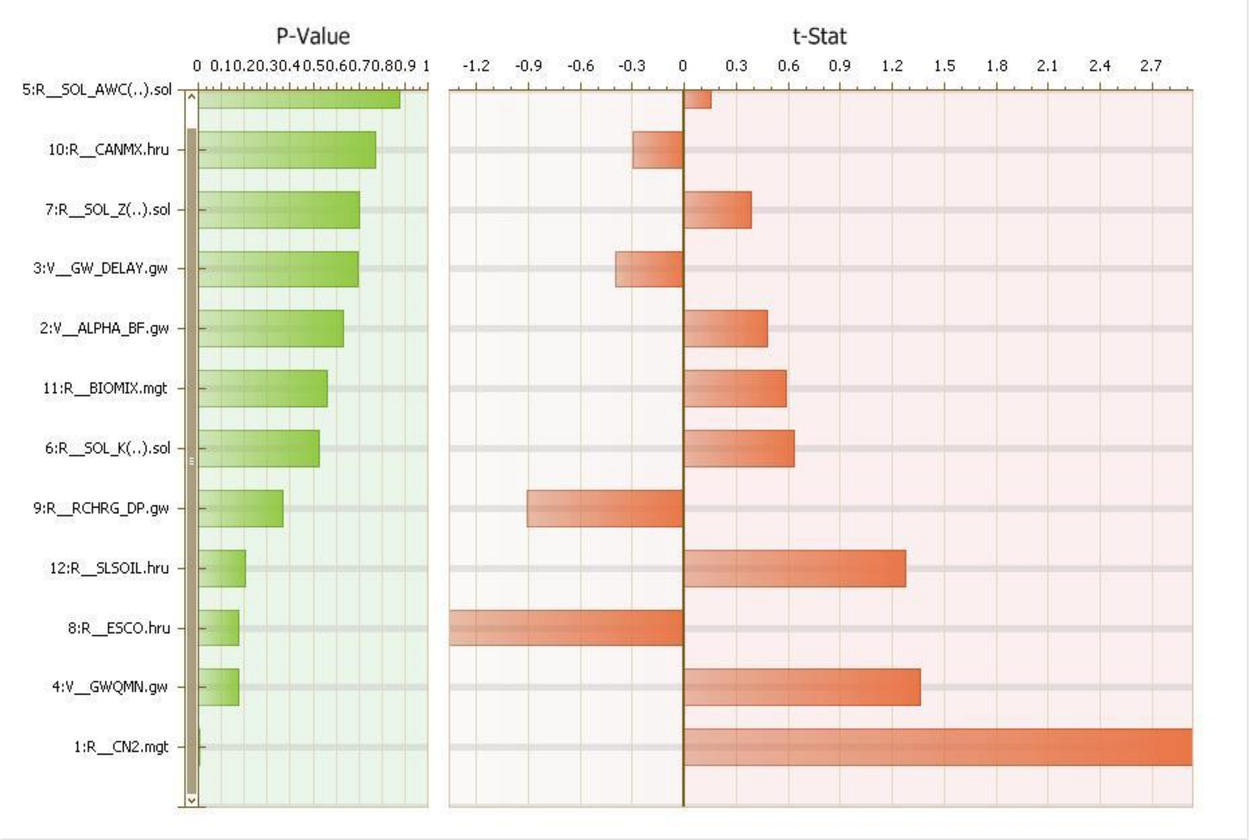

Figure 4.1 Results of flow sensitivity analysis using SWAT-CUP

Table 4.1 Result of sensitivity analysis of flow parameters

Parameters code	Description	Rank
CN_2	Moisture condition II curve number	1
GWQMN	Threshold depth of water in the shallow aquifer for flow	2
ESCO	Soil evaporation compensation factor	3
SLSOIL	Slope length for lateral subsurface flow	4
RCHRG_DP	Deep aquifer percolation fraction	5

4.2. Flow calibration and validation

4.2.1 Flow calibration

Before calibration proceeds, the performance of the model was evaluated from the initial simulation with model default parameter values. The monthly simulations were resulted coefficient of determination (R^2), Nash–Sutcliffe Efficiency (NSE) and percent of bias (PBIAS) of 0.41, 0.30, and 22% respectively. The result shows the performance indicator was below the acceptable limits, i.e. $R^2 > 0.6$, NSE > 0.5 and PBIAS < ±15% (Santhi et al., 2001) .So that, the model flow parameters were required adjustment.

After sensitivity analysis has been carried out, the calibration of SWAT model simulated stream flow at Dire gauging station was done by using SWAT-CUP. The model was calibrated against the historical data collected at Dire in the period 1991-1998.The analysis of simulated result and observed flow data comparison was considered monthly. Until the best fit curve of simulated versus measured flow was obtained, the sensitive parameters were changed again and again in the allowable range recommended by SWAT. In computing the efficiency, the first year of simulated model result was excluded, because it considered as model priming, so that the influence of the initial conditions such as soil water content will be minimized.

The SCS curve number (CN_2) value was adjusted by subtracting 14 % from the default value, Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) was adjusted to 1900 and soil evaporation compensation factor (ESCO) was adding to the default value and adjusted to 0.83.

After each simulation, the model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters shows the R^2, NSE and PBIAS in monthly basis indicates 0.78, 0.72 and 11.2% respectively (table 4.2). The result showed a good agreement between measured and simulated monthly flows. The overall results of flow calibration are given in table 4.2, figure 4.2 and figure 4.3

Table 4.2 Calibration statistics for monthly measured and simulated Stream flow

Time	Mean Annual Stream flow (m^3/sec)		Model Efficiency		
1991-1998	Simulated	Measured	R^2	N_{SH}	PBIAS
	3.86	4.35	0.78	0.72	11.2

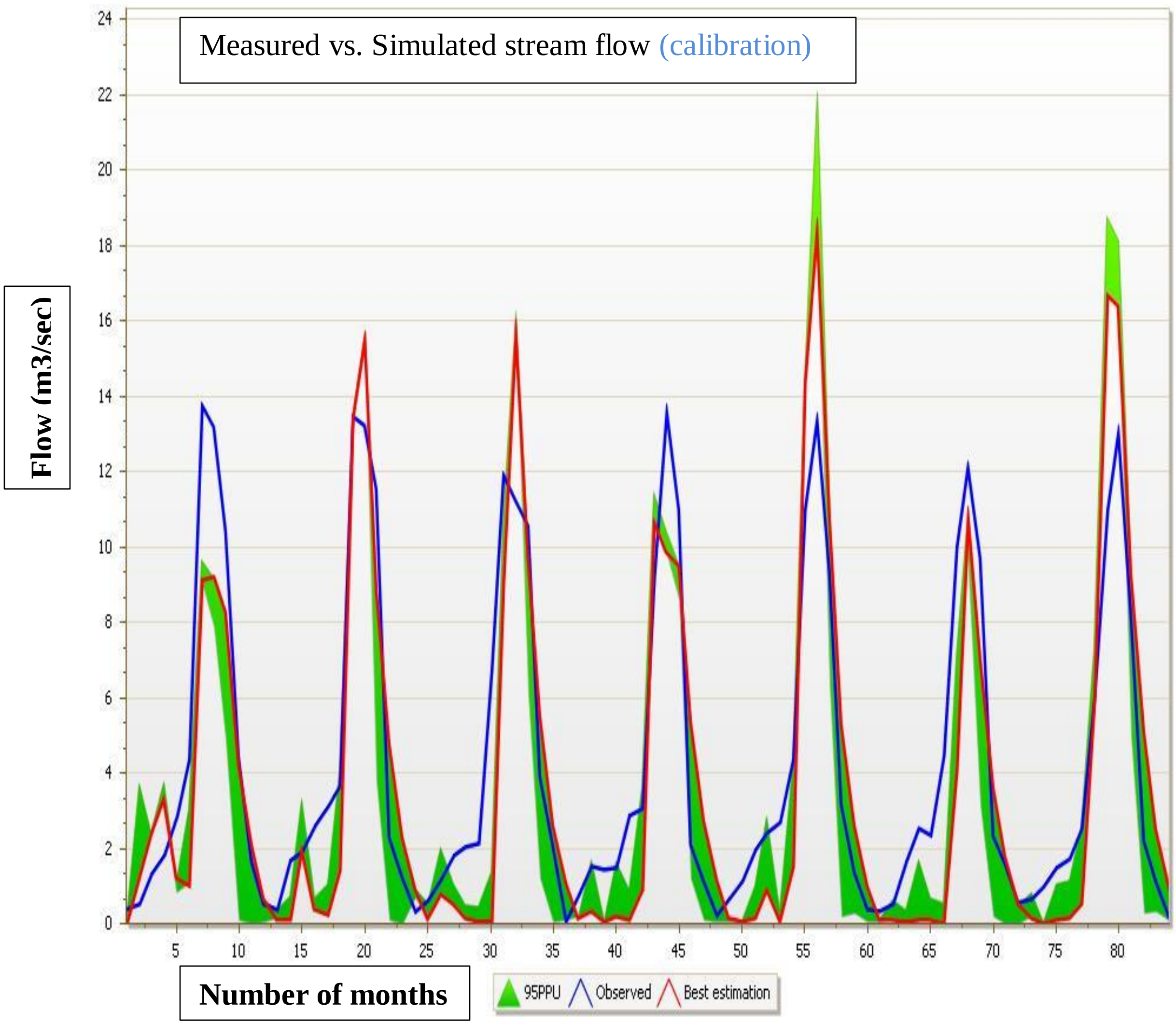

Figure 4.2 Simulated & measured stream flow (calibration)

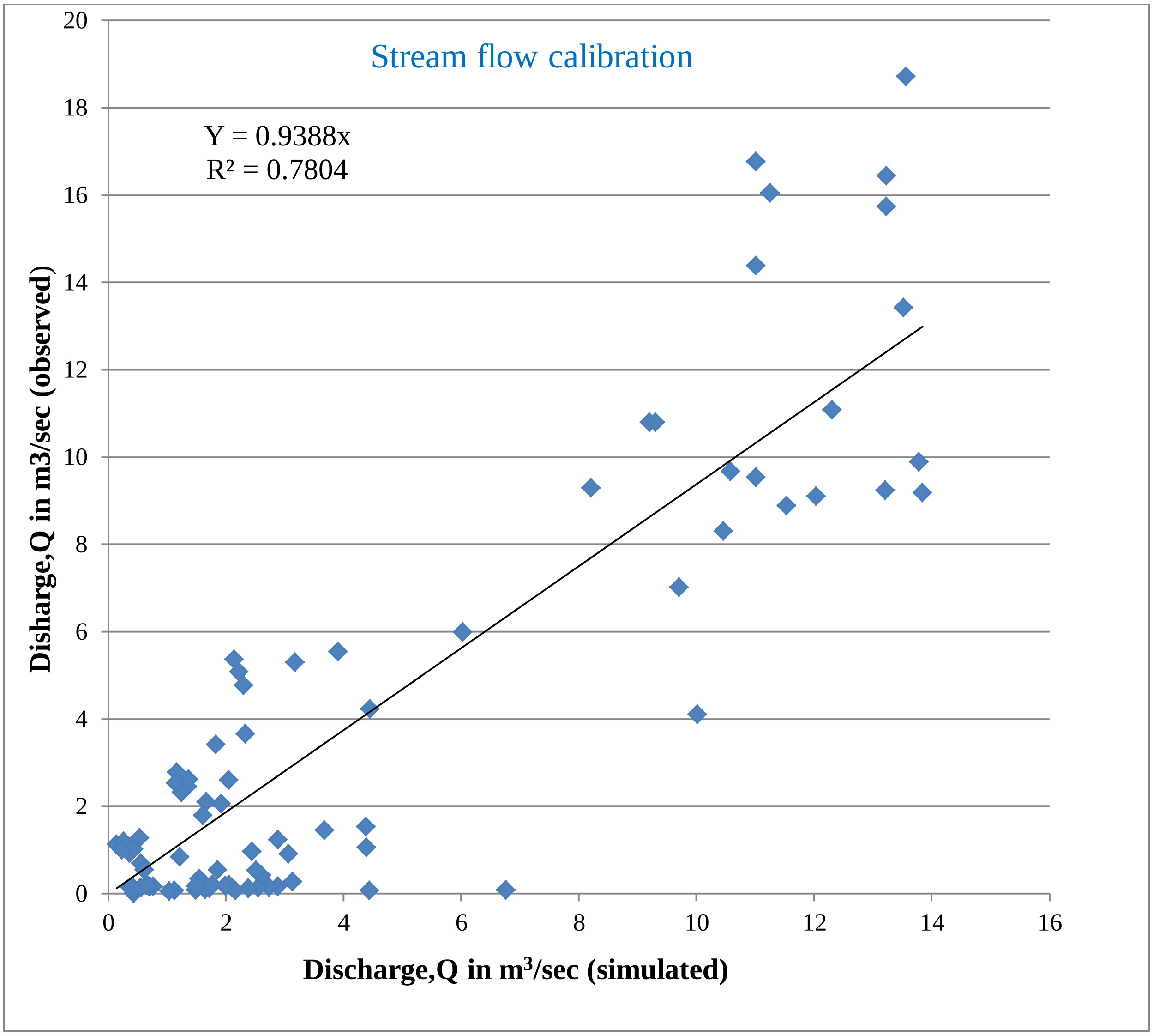

Figure 4.3 1: 1 fit line of measured & simulated flow (calibration)

4.2.2 Flow validation

As it was mentioned earlier, the purpose of model validation is to check whether the model can predict flow for another range of time period or conditions than those for which the model was calibrated for. Model validation involves re-running the model using input data independent of data used in calibration (e.g. differing time period), but keeping the calibrated parameters unchanged. In this study the validation period is from January, 1999 to December, 2004. The site of validation is the same as calibration site.

Like calibration, the two above-mentioned goodness-of-fit measures are calculated and model to-data plots are checked as shown in table 4.3, figure4.4 and figure 4.5 below.

The objective functions that used for evaluation were in the acceptance range for the validation time of the model in monthly time step and the R^2, NSE and PBIAS indicates 0.75, 0.64 and 13.5% respectively (Table 4.3).

Table 4.3 Validation statistics for monthly measured and simulated Stream flow

Time	Mean Annual Stream flow (m^3/sec)		Model Efficiency		
1999 - 2004	Simulated	Measured	R^2	N_{SH}	PBIAS
	3.57	4.63	0.75	0.64	13.5

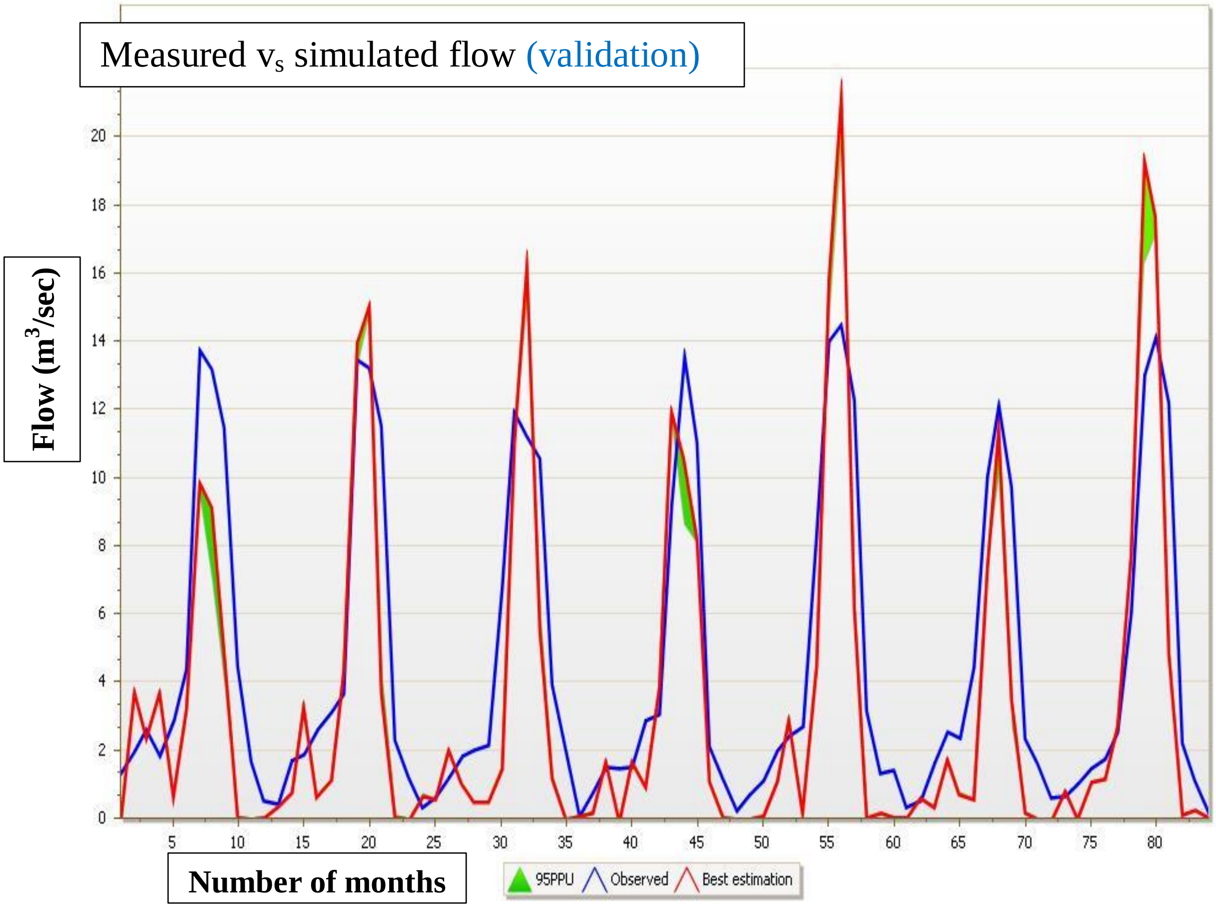

Figure 4.4 measured & simulated flow (validation)

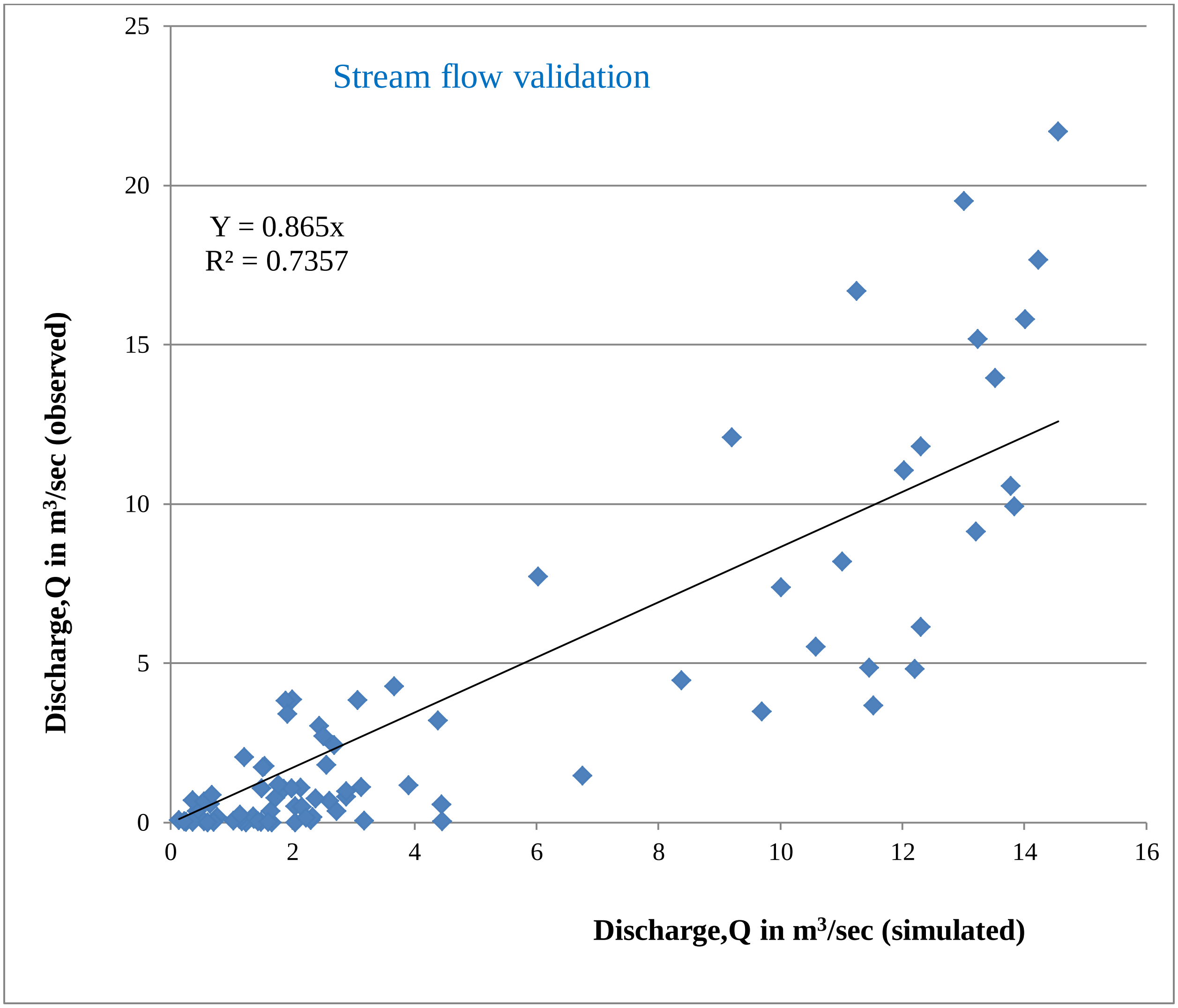

Figure 4.5 1: 1 fit line of measured & simulated flow (Validation)

4.3. Sediment yield simulation

4.3.1 Sediment yield calibration

After calibration and validation of flow, the next was calibrating sediment yield of the catchment. Like flow, sediment calibration for the Dire catchment was conducted for the years 1997 to 2001. One year, 1997, was used for model initialization. So that model was calibrated from 1998 to 2001. The calibration of sediment yield of the catchment was done based on sediment sensitivity analysis that have identified sensitive parameters for sediment yield of the catchment (table 4.4 and figure 4.6) and by varying iteratively within the allowable ranges of the parameters. Six parameters were identified out of 20 parameters analyzed as the most sensitive parameters that significantly affect sediment yield. The result of the rest is depicted on appendix9.

The exponent parameter for calculating sediment re-entrained in channel sediment routing (SPEXP) was adjusted to 1.33, width of edge-of field filter strip(FILTERW) was adjusted to 5 ,the linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) adjusted to 0.008, Sediment concentration in runoff, after urban BMP is applied(SED_CON) was adjusted to 750, land covers status code(IGRO) was also adjusted to 0.63 and moist soil albedo was adjusted to 0.18 finally manning's "n" value for overland flow was adjusted to 1.8.

After adjustment of all the above parameters, the monthly simulations were results Coefficient of determination (R^2), Nash–Sutcliffe Coefficients (NSE) and percent of bias (PBIAS) of 0.66, 0.64 and 0.4% respectively (table 4.5). According to calibration result of SWAT output the at the month of August the catchment produce more sediment than other month, that is because at month of August there is high rain fall and runoff and also the model over estimate at that month.

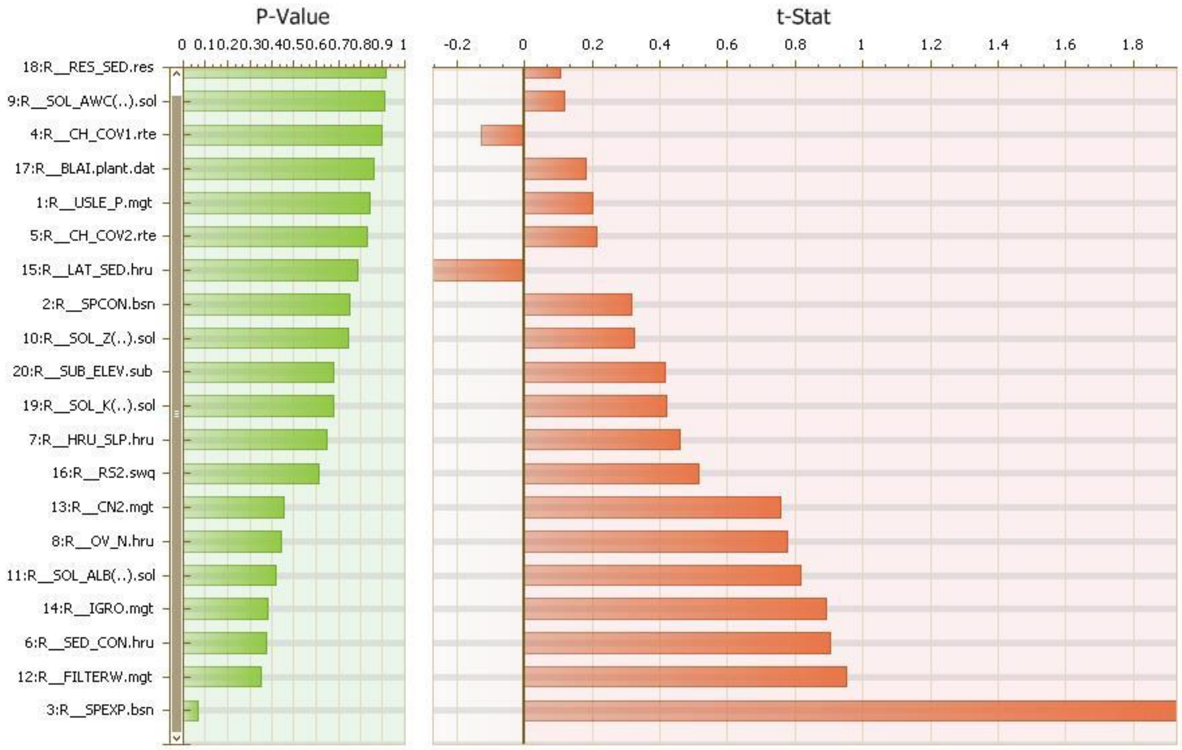

Figure 4.6 Results of sediment sensitivity analysis using SWAT-CUP

Table 4.4: Result of sensitivity analysis of sediment parameters

Parameters Code	Description	Rank
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing.	1
FILTERW	Width of edge-of field filter strip	2
SED_CON	Sediment concentration in runoff, after urban BMP is applied	3
IGRO	Land covers status code.	4
SOL_ALB	Moist soil albedo	5
OV_N	Manning's "n" value for overland flow.	6

Table 4.5 Calibration statistics for monthly measured and simulated sediment yield

Time	Mean Annual sediment yield (ton/ha/$y_{r.}$)		Model Efficiency		
1998-2001	Simulated	Measured	R^2	N_{SH}	PBIAS
	7.09	5.15	0.9	0.82	-13.9

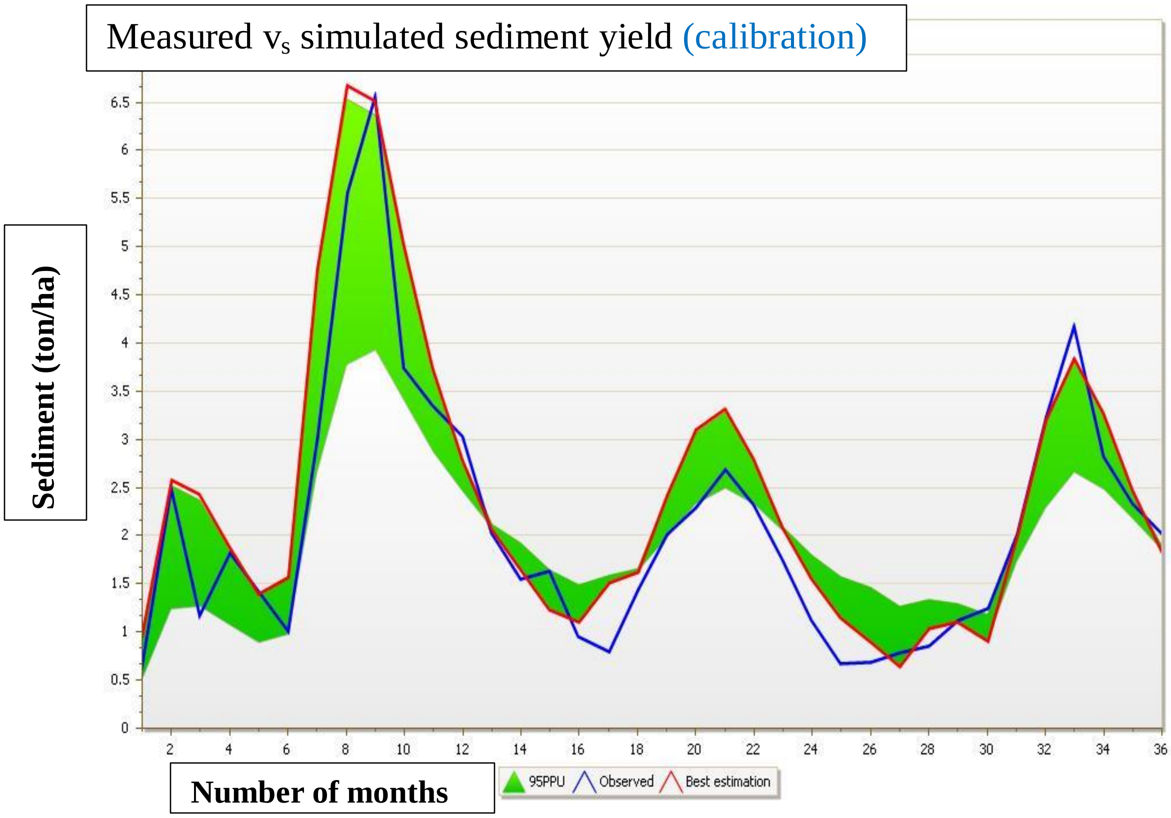

Figure 4.7 measured & simulated sediment (Calibration)

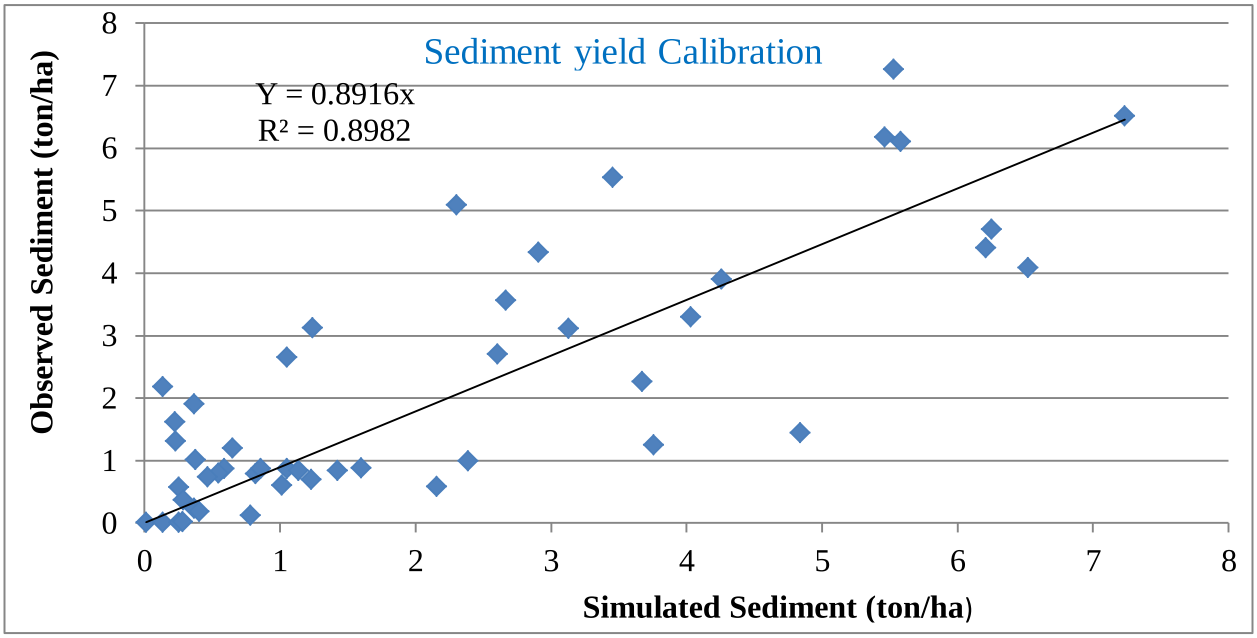

Figure 4.8 1: 1 fit line of measured & simulated sediment (Calibration)

4.3.2 Sediment yield validation

After calibration then SWAT model was validated to sediment yield for the period 2002 to 2004 using the same parameters, which were adjusted during sediment calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically. Coefficient of determination (r^2) value and, Nash-Sutcliffe model efficiency (E_{NS}) computed between the simulated and observed monthly sediment yields for the validation periods are 0.66 and 0.64 respectively.

Table 4.6 Validation statistics for monthly measured and simulated sediment yield

Time	Mean Annual sediment yield (ton /ha/$y_{r.}$)		Model Efficiency		
2002-2004	Simulated	Measured	R^2	N_{SH}	PBIAS
	5.16	6.01	0.66	0.64	0.4

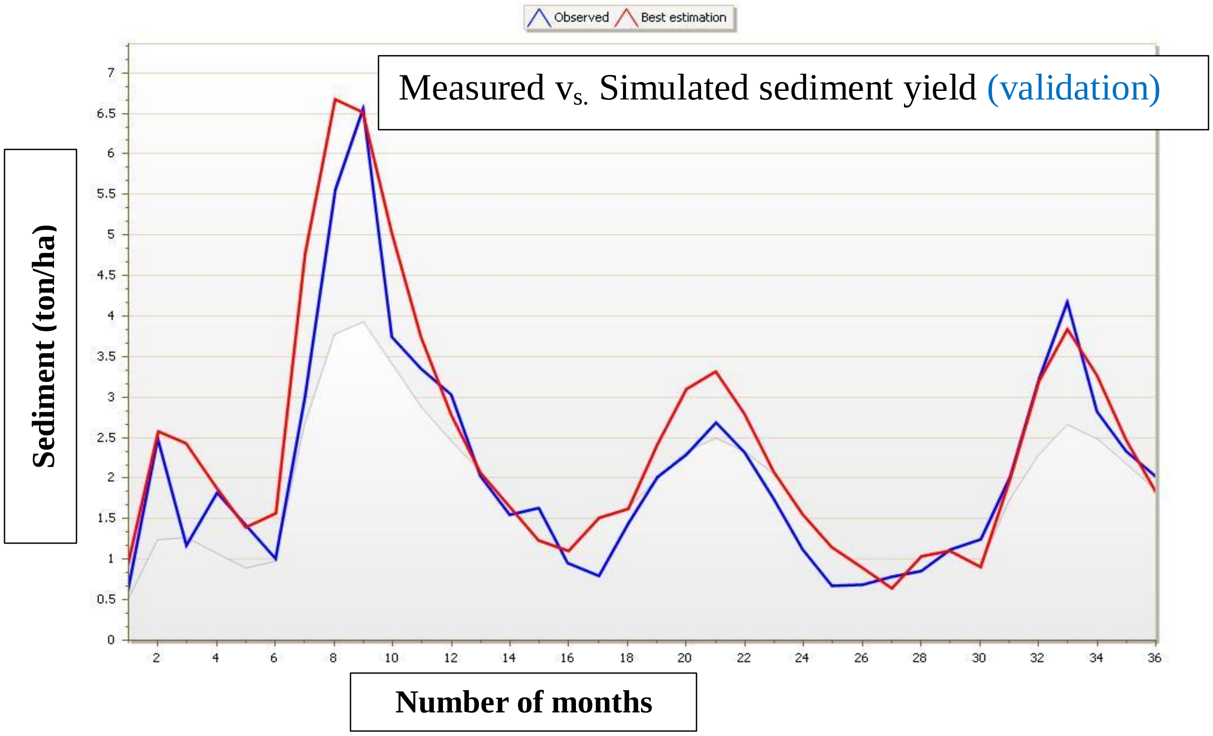

Figure 4.9: measured & simulated sediment (validation)

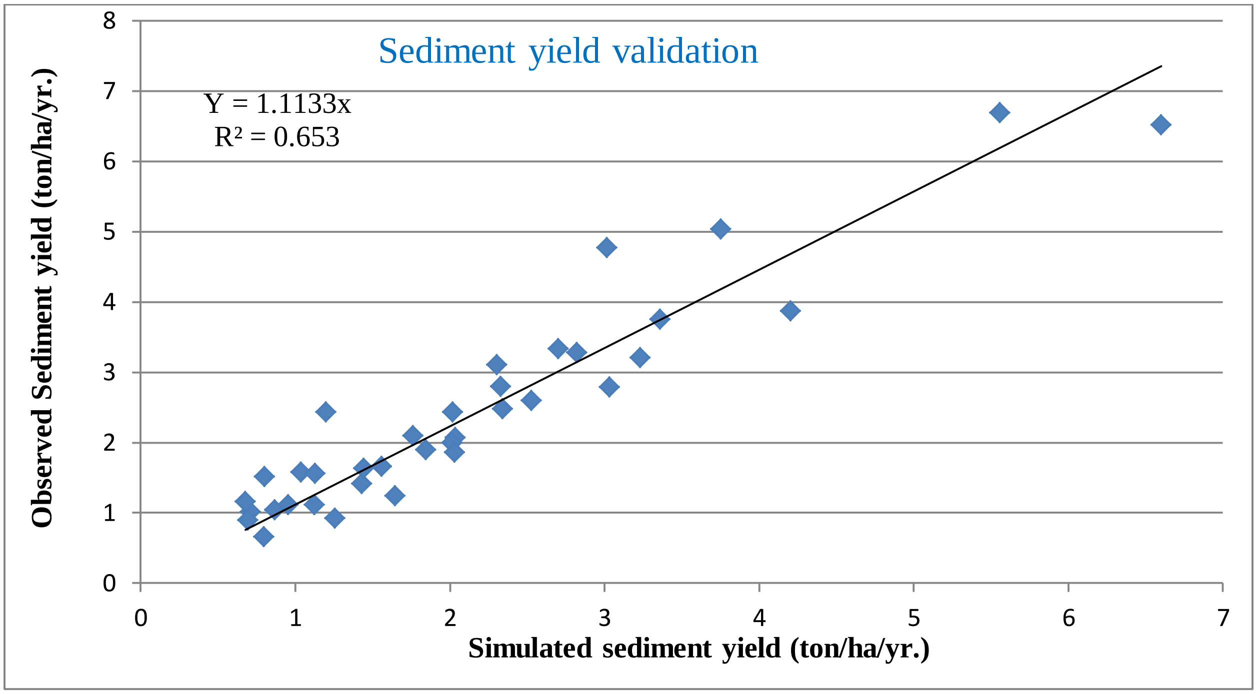

Figure 4.10 1: 1 fit line of measured & simulated sediment (validation)

The model results of sediment yield in each year from Dire catchment are shown in appendix 10.

Spatial pattern of sediment source areas

After calibration and validation, the model was run for a period of 7years .From the model simulation output, sediment source areas were identified in the catchment. 7 years annual average measured suspended sediment generated from the sediment rating curve was 5.15 ton/ha/yr. and the simulated annual average suspended sediment yield by SWAT model was 6.281 t/ha/yr. The spatial distribution of sediment generation for the Dire catchment is presented in Figure 4.9. The spatial distribution of sediment indicated that, out of the total three sub-catchments, sub-catchment 1 produce average annual sediment yields ranging from 0-2.88 ton/ha/yr, sub-catchment 2 produce average annual sediment yields ranging from0-2.4 while sub-catchment 3 produce average annual sediment in the range of 0-1.0005 ton/ha/yr.

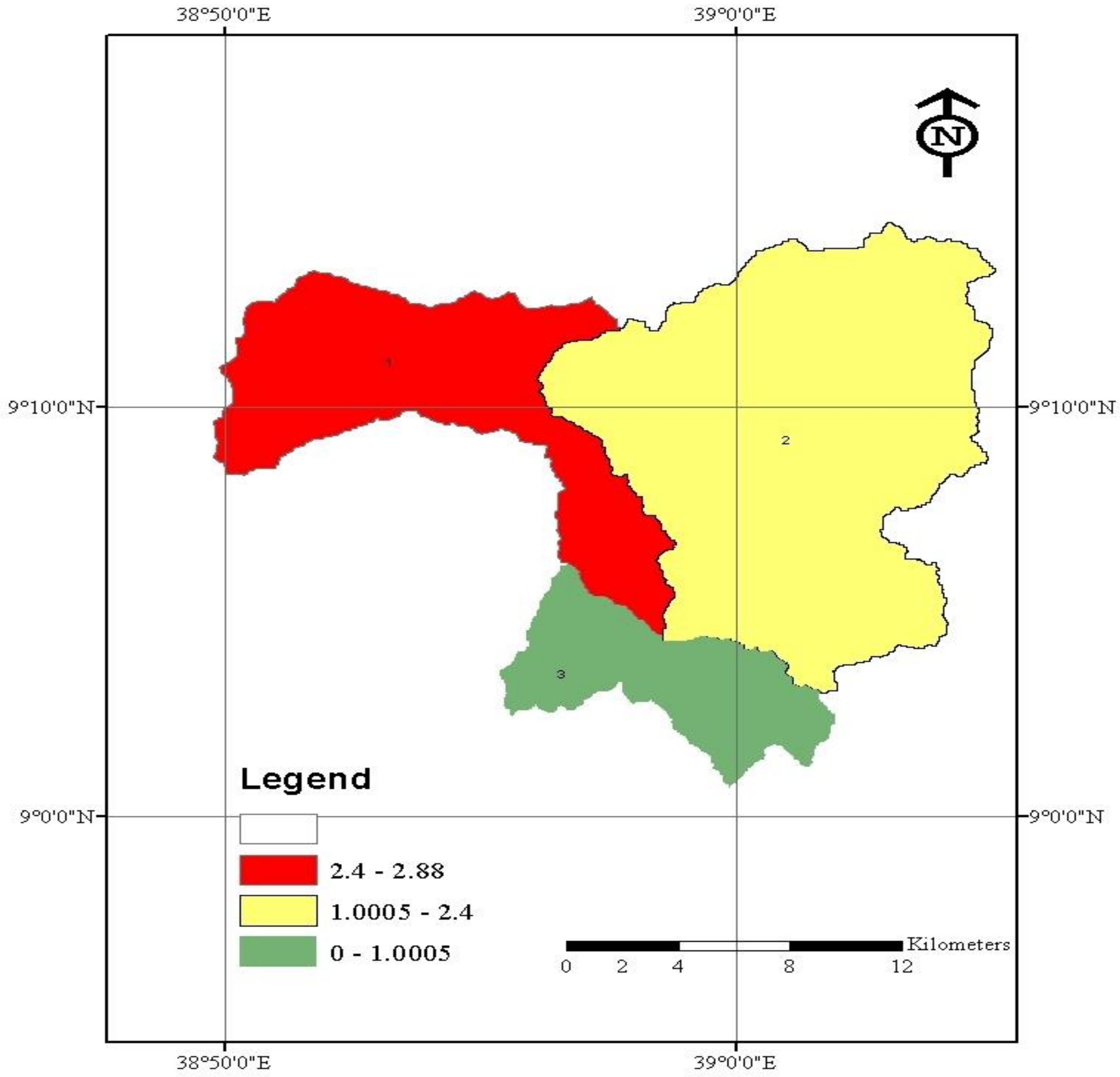

Figure 4.11 Spatial distribution of SWAT simulated annual sediment yield classes by sub-catchment (t/ha/yr.), Number (1-3) are sub-catchment numbers.

4.4. Sediment management scenario analysis

Once the model has been validated and the results are considered acceptable, the model is ready to be parameterized to the conditions of interest (e.g., to evaluate impact of management and conservation practices). After detail analysis of the problems and benefits of the existing physical conservation practices in the catchment, the model has been tested with alternative scenario analysis of base case, filter strip, contour farming and strip cropping on contour to reduce sediment production from sub catchments.

Scenarios were set up to examine how best management practices (BMP's) would affect sediment loadings to Dire reservoir. Each scenario was simulated for the 1989 – 2015 period. Effectiveness of conservation practices that are implemented within agricultural fields was evaluated by comparing model simulations with no practice and simulations with the practice implemented in fields. In evaluating impact of those management practices, three management scenarios were considered and simulated:

I. Base Case

II. Filter strip 5 m wide on all HRUs and sub- catchments; and

III. Contour farming on all HRUs and sub catchments

IV. Strip cropping on contour

The results of SWAT simulations for the baseline scenario showed that sediment yield of 6.281 ton/ha yr. has been generated over the 1989–2015 simulation period and with implementation of filter strips, an average annual sediment yields can be reduced by 75 % with 5m width, with implementation of contour farming average annual sediment yields can be reduced by 79 %, with implementation of strip cropping on contour an average annual sediment yields can be reduced by 64 %. Table 4.7, figure 4.10 and 4.11 provides a summary of results on the effect of upland practices on sediment yield of the study area.

Table 4.7: Average annual change in sediment yield due to implementation of different management practices in all Sub-catchments.

Sub-catchment	Average Annual Sediment Yield t/ha/yr.)			
	Base Case	Field Strip (5m wide)	Contour farming	Strip cropping on the contour
1	2.88	0.73	0.61	0.75
2	2.4	0.62	0.50	0.74
3	1.0005	0.24	0.20	0.76
Total sediment yield	6.281	1.59	1.31	2.25
Percent Reduction in Sediment Yield	0	0.75	0.79	0.64

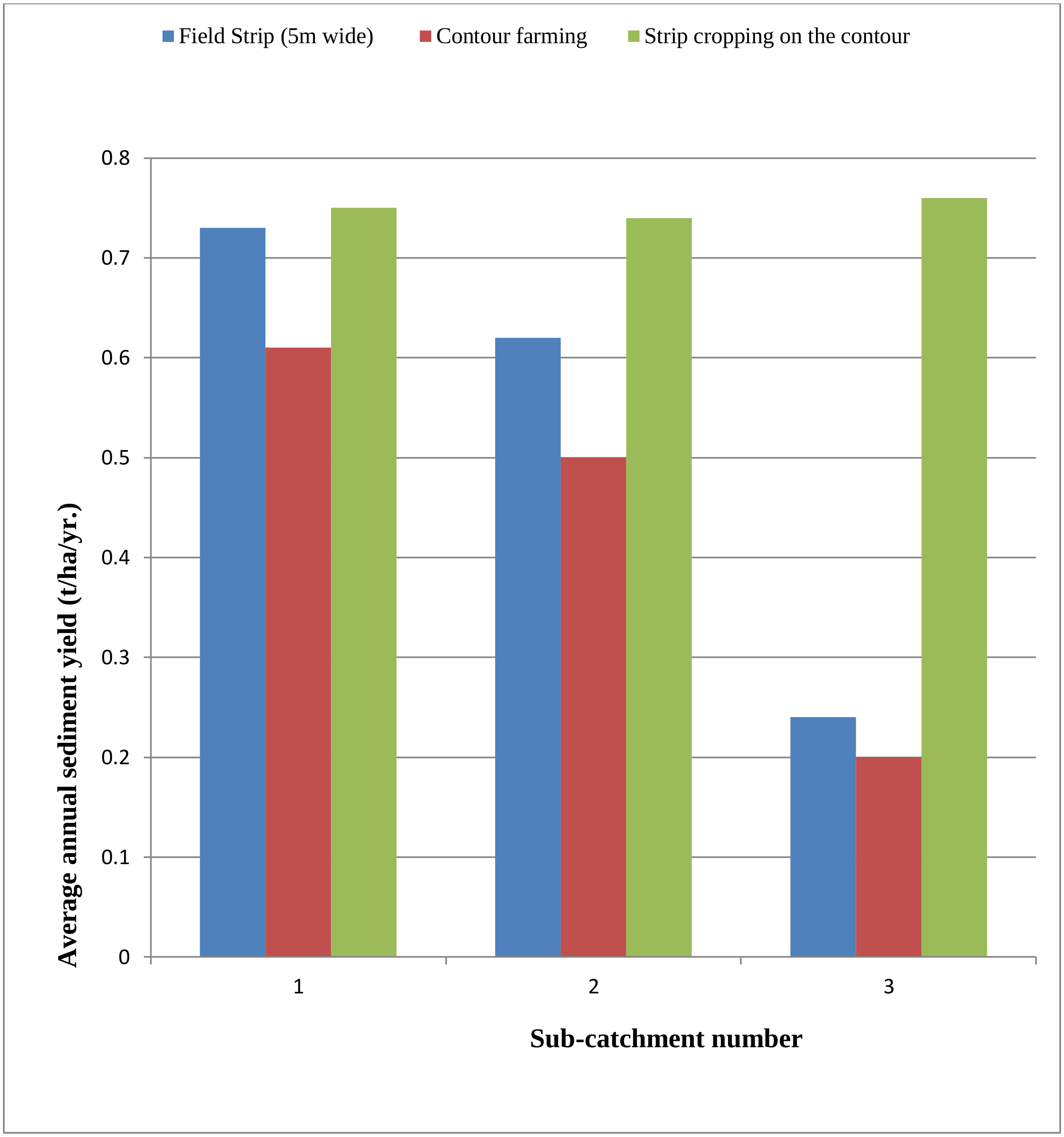

Figure 4.12: Sediment yield (t/ha/yr.) due to implementation of different management practices

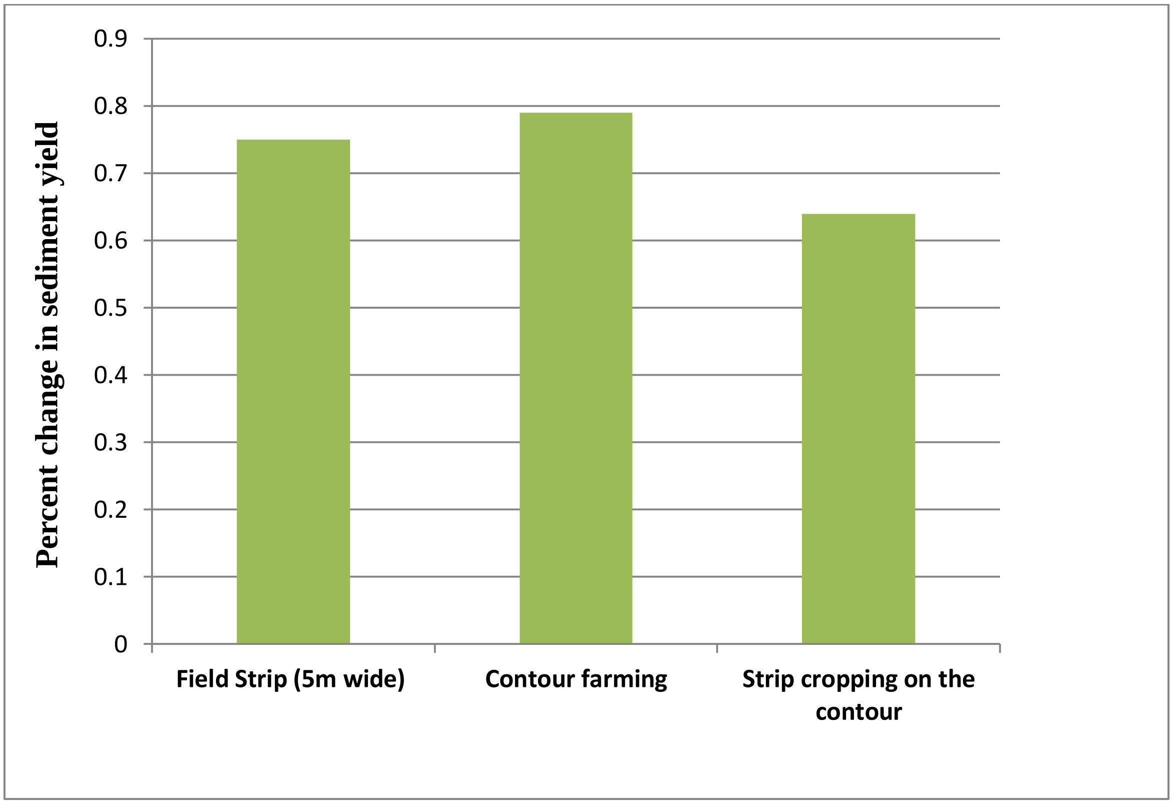

Figure 4.13: Percent Reduction in simulated average annual sediment yield

4.5 Comparison of this thesis result with the previous researches

Many research works have been done in Dire catchment using different approach. However, significant variations of the Dire catchment sediment yield have been obtained.

The AESL report was a reconnaissance study which provided the basis for all future Addis Ababa water supply studies. Due to its preliminary nature, certain assumptions were taken regarding unit runoff rates, flood discharges and sedimentation. A sedimentation rate of (2.4ton/ha/yr.) was assumed based on previous studies. Taye Aduna also conducted a research on dire catchment according to these studies; the annual sediment yield of the catchment was 4.85ton/ha/yr. AAWSA water and sanitation development and rehabilitation project office has estimated the annual sediment inflow to be in range of 4.35ton/ha/yr. – 15.75ton/ha/yr. The result of this thesis was found between the above mentioned previous results. The annual sediment inflow of (6.281 ton/ha/yr.) was obtained in this research nearly approaching to the research made by Taye Aduna, 2007 (4.85ton/ha/yr.). Even though, reasonable results were obtained, still the great variation of results which was done so far requires further research findings in the catchment.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

SWAT model for Dire catchment was compiled and calibrated and then validated for stream flow and sediment yield .Readily available spatial data were collected and combined using GIS. Model parameters were derived, spatial data including elevation (DEM), land use and soil data (shape file) obtained from MoWIE. The watershed parameters were derived from DEM resulting in 3 sub-basins. Sub basins were further broken down in to hydrological response units based on the land use and soil data. This resulted in 11 HRUs.

By using SWAT-CUP sensitivity analysis was performed to select important model parameters, calibration also performed for stream flow using measured data at Dire gauging station for a period of 1991-1998.It is shown that the model could adequately represent stream flow for monthly time steps. It is shown that the model performed well with E_{NS} and R^2 of 0.72 and 0.78 respectively. The model is validated for the stream flow for the period of 1999-2004. The model performed well monthly time steps with E_{NS} and R^2 of 0.64 and 0.75 respectively. The model is then calibrated with sediment flow data that is taken from rating curve equation measured during (1998-2001). Model parameters were selected that control sediment generation processes for calibration and validation. It is shown that sediment yield of Dire catchment could be represented by SWAT model with E_{NS} and R^2 of 0.82 and 0.9 respectively.

The model has been validated for a period of (2002-2004).The model could adequately represent sediment yield from Dire catchment with E_{NS} and R^2 of 0.66 and 0.64 respectively.

The calibrated SWAT parameters value for flow and sediment at Dire catchment then used to re-run the model so that the previous result of simulation and current simulation result were the same. Model calibration reduces the parameter uncertainty, which in turn reduced the uncertainty in the simulated results.

SWAT Model performed well in predicting sediment inflow to Dire reservoir. Apart from intensive effort in preparing the data for the model, the model is very friendly to work with and hence it should be incorporated in the prediction of sediment yield for other cases.

Dire reservoir, which is part of Dire catchment, supplies raw water to Legedadi treatment plant from where treated water was supplied to Addis Ababa city.

The high rate of siltation is a major long-term problem for this reservoir, as it severely affects the capacity of the reservoir and results in a shortage of usable water for Addis Ababa as well as increasing the water treatment costs. A systematic approach to determine the rate of sediment yield from Dire catchment was done using SWAT watershed model.

Following calibration and validation of SWAT model, four sediment management scenario analyses were under taken to reduce sediment yield from catchment. The simulation results of the four scenarios analysis indicated that implementing filter strips can reduce sediment yield by 75%, implementing contour farming can reduce sediment yield by 79%, and implementing strip cropping on contour can reduce sediment yield by 64%. Overall, SWAT performed well in simulating sediment yield on monthly basis at the watershed scale and thus can be used as planning tool for watershed management.

5.2. Recommendation

In order to achieve the design life of the Dire reservoir and to fulfill the objective of the construction of the Dam, the Dire catchment shall be prevented from erosion or sediment. To reduce sediment inflow into the reservoir in sustainable manner, appropriate sediment management practices such as contour farming, which is mentioned in the study should be applied.

If the sediment yield of the Dire catchment will continue in this manner, it will dangerous to the Dire dam life with respect to its storage capacity and stability of the structure, so the responsible bodies must take action in the catchment; like recommended management intervention or any other sediment minimization technique even though it requires further study.

Model prediction output depends on the quality of input data .One of the constraint in conducting this study was lack of continuous measured sediment data. The sediment data used for this study were generated from sediment rating curves developed from limited sediment measurement data. There is therefore, possible difference between actual sediment and sediment data derived based on rating curves. Therefore, responsible bodies should give due attention to the time and frequency of sampling, method of sampling and recording of reliable sediment data together with flow measurement. The study can be further extended to similar catchment or watershed in Awash River basin, other similar areas and can bridge the gap of adequate information between processes at the micro watershed and large watershed level.

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APPENDICES

Appendix1.Definition of Weather Generator statistic and probability value

TMPMX	Average or mean daily maximum air temperature for month (0^C)
TMPMN	Average or mean daily minimum air temperature for month (0^C)
TMPSTDMX	Standard deviation for daily maximum air temperature in month (0^C)
TMPSTDMN	Standard deviation for daily minimum air temperature in month (0^C)
PCPMM	Average or mean total monthly precipitation (mm H_2O)
PCPSTD	Standard deviation for daily precipitation in month (mm H_2O/day)
PCPSKW	Skew coefficient for daily precipitation in month
PR_W1	Probability of a wet day following a dry day in month
PR_W2	Probability of a wet day following a wet day in month
SOLARAV	Average daily solar radiation for month(MJ/m^2/day)
DEWPT	Average daily dew point temperature in month(0^C)
WNDAV	Average daily wind speed in month(m/s)

Appendix.2. Weather Generator statics and Probability value (1989-2015)
(Using dew02.exe)

Month	tmp_max	tmp_min	hmd	dew pt
Jan	25.5	9.33	0.46	-46.06
Feb	27.03	10.39	0.41	-45.95
Mar	27.58	11.79	0.45	-45.08
Apr	27.38	12.37	0.43	-44.96
May	27.14	12.05	0.4	-45.69
Jun	25.71	11.77	0.6	-42.93
Jul	22.34	11.61	0.78	-41.29
Aug	22.02	11.11	0.86	-41.03
Sep	23.64	10.4	0.66	-42.64
Oct	24.52	8.98	0.54	-44.99
Nov	24.81	8.05	0.43	-46.42
Dec	24.82	8.12	0.43	-46.67

Appendix.3. Weather Generator Statics and Probability value (1989 -2015) Using pcpSTAT

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	11.59	2.6263	13.6131	0.0558	0.3944	2.73
Feb.	10.52	2.3739	9.018	0.0606	0.4459	2.85
Mar.	44.98	4.6465	5.083	0.1429	0.5735	8.12
Apr.	50.09	5.3842	4.9875	0.1713	0.5738	9.12
May	39.7	3.852	4.2022	0.1481	0.551	8.15
Jun.	84.82	4.9708	2.4088	0.4	0.775	20
Jul.	164.44	7.0126	2.0409	0.806	0.8945	28.42
Aug.	163.66	7.9326	3.0396	0.7568	0.8893	28.15
Sep.	64.84	4.5819	3.4439	0.26	0.73	16.5
Oct.	12.71	2.3462	8.8694	0.0644	0.5234	4.12
Nov.	2.71	0.841	12.3165	0.024	10.375	1.23
Dec.	6.43	2.4378	16.2683	0.0179	0.3478	0.88

Appendix4. Measured Vs. Simulated sediment data (calibration & validation)

YEAR	MEASURED (ton/ha/yr.)	SIMULATED (ton/ha/yr.)	Calibration
2000	1.173438959	1.191166667	
2001	0.205336164	1.843583333	
2002	0.120538767	0.492000003	
2003	0.653937753	0.591583333	
2004	1.003715288	0.88525	Validation
2005	0.76867674	0.139	
2006	1.228900986	1.138416667	
TOTAL	5.15454466	6.28103333	

Appendix5.

SWAT model simulation Date: 8/31/2017 12:00:00 AM Time: 00:00:00

MULTIPLE HRUs Land Use/Soil/Slope OPTION THRESHOLDS: 5 / 20 / 20 [%]

Number of HRUs: 11

Number of Sub-basins: 3

	Area [ha]	Area[acres]	
Watershed	36297.1800	89692.1466	
	Area [ha]	Area[acres]	%Wat Area
LANDUSE:			
Agricultural Land-Row Crops	3405.7636	8415.8120	9.38
Agricultural Land-Close-grown	21590.9442	53352.3027	59.48
Pasture	769.3929	1901.2084	2.12
Agricultural Land-Generic	7235.5584	17879.4267	19.93
Forest-Deciduous	2698.3716	6667.8111	7.43
Forest-Mixed	597.1493	1475.5858	1.65
SOILS:			
Vp14-3a-286	10098.1800	24953.1077	27.82
Ne10-3b-154	21119.2200	52186.6486	58.18
WATER	5079.7800	12552.3904	13.99
SLOPE:			
10-20	32394.9918	80049.6445	89.25
0-10	3902.1882	9642.5022	10.75

	Area [ha]	Area[acres]	%bWat .Area	% Sub.Area
SUBBASIN # 1	10098.1800	24953.1077	27.82	
LANDUSE:				
Agricultural Land-Row Crops	3405.7636	8415.8120	9.38	33.73
Agricultural Land-Close-grow	5067.3937	12521.7832	13.96	50.18
Pasture	769.3929	1901.2084	2.12	7.62
Agricultural Land-Generic	855.6298	2114.3040	2.36	8.47
SOILS:				
Vp14-3a-286	10098.1800	24953.1077	27.82	100.00
SLOPE:				
10-20	10098.1800	24953.1077	27.82	100.00
HRUs				
1 Agricultural-Row Crops --> AGRR/10-20	3405.7636	8415.8120	9.38	33.73
2 Agricultural Land-Close-grown --> AGRC/10-20	5067.3937	2521.7832	13.96	50.18
3 Pasture --> PAST/10-20	769.3929	1901.2084	2.12	7.62
4 Agricultural -Generic --> AGRL/10-20	855.6298	2114.3040	2.36	8.47

	Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN # 2	21119.2200	52186.6486	58.18	
LANDUSE:				
Agricultural-Close-grown --> AGRC	12040.9198	29753.7149	33.17	57.01
Forest-Deciduous --> FRSD	2698.3716	6667.8111	7.43	12.78
Agricultural-Generic --> AGRL	6379.9286	15765.1227	17.58	30.21
SOILS:				
Ne10-3b-154	21119.2200	52186.6486	58.18	100.00
SLOPE:				
10-20	18156.7870	44866.3286	50.02	85.97
0-10	2962.4330	7320.3200	8.16	14.03
HRUs				
5 Agricultural-Close-grown --> AGRC/Ne/10-20	12040.9198	29753.7149	33.17	57.01
6 Forest-Deciduous --> FRSD/Ne/10-20	2698.3716	6667.8111	7.43	12.78
7 Agricultural-Generic--> AGRL/Ne/10-20	3417.4957	8444.8027	9.42	16.18
8 Agricultural-Generic--> AGRL/Ne/0-10	2962.4330	7320.3200	8.16	14.03

	Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN # 3	5079.7800	12552.3904	13.99	
LANDUSE:				
Agricultural Land-Close-grown --> AGRC	4482.6307	11076.8046	12.35	88.24
Forest-Mixed --> FRST	597.1493	1475.5858	1.65	11.76
SOILS:				
WATER	5079.7800	12552.3904	13.99	100.00
SLOPE:				
0-10	939.7552	2322.1822	2.59	18.50
10-20	4140.0248	10230.2082	11.41	81.50
HRUs				
9 Agricultural-Close-grown--> AGRC/WATER/0-10	939.7552	2322.1822	2.59	18.50
10 Agricultural-Close-grown--> AGRC/WATER/10-20	3542.8755	8754.6224	9.76	69.74
11 Forest-Mixed --> FRST/WATER/10-20	597.1493	1475.5858	1.65	11.76

Appendix 6 USLE_P factor values for contouring, strip-cropping
(Source: Wischmeier and Smith, 1978)

Land slope (%)	contour farming	strip cropping
1 to 2	0.6	0.3
3 to 5	0.5	0.25
6 to 8	0.5	0.25
9 to12	0.6	0.3
13 to 16	0.7	0.35
17 to 20	0.8	0.4
21 to 25	0.9	0.45

Appendix 7 Values of Manning's roughness coefficient for overland flow (source: Neitschet al., 2005)

Characteristics of land surface	OV_N
No till, no residue	0.14
No till, 0.5–1 t ha^{-1}residue	0.20
No till, 2–9 t ha^{-1}residue	0.30

Appendix 8 Result of sensitivity analysis of flow parameters

Parameters code	Description	Rank
CN_2	Moisture condition II curve number	1
GWQMN	Threshold depth of water in the shallow aquifer for flow	2
ESCO	Soil evaporation compensation factor	3
SLSOIL	Slope length for lateral subsurface flow	4
RCHRG_DP	Deep aquifer percolation fraction	5
SOL_K	Saturated hydraulic conductivity	6
BIOMIX	Biological mixing efficiency	7
ALPHA_BF	Base flow alpha factor (days)	8
GW_DELAY	Ground water delay (day)	9
SOL_Z	Soil depth	10
CANMX	Maximum canopy storage	11
SOL_AWC	Available water capacity	12

Appendix 9: Result of sensitivity analysis of sediment parameters

Parameters code	Description	Rank
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing.	1
FILTERW	Width of edge-of field filter strip	2
SED_CON	Sediment concentration in runoff, after urban BMP is applied	3
IGRO	Land cover status code.	4
SOL_ALB	Moist soil albedo	5
OV_N	Manning's "n" value for overland flow.	6
CN_2	Initial SCS CN II value	7
RS2	Benthic (sediment) source rate for dissolved phosphorus in the reach	8
HRU_SLP	Average slope steepness	9
SOL_K	Saturated hydraulic conductivity.	10
SUB_ELEV	Elevation of sub-basin	11
SOL_Z	Depth from soil surface to bottom of layer	12
SPCON	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing	13
LAT_SED	Sediment concentration in lateral flow and groundwater flow	14
CH_COV2	Channel cover factor	15
USLE_P	USLE equation support practice	16
BLAI	Max leaf area index	17
CH_COV1	Channel erodibility factor	18
SOL_AWC	Available water capacity of the soil layer	19

Appendix 10 Yearly sediment yield result of SWAT simulation

Year	Sediment yield	2002	0.243805556
1989	0.288513889	2003	0.265263889
1990	0.263430556	2004	0.214208333
1991	0.202986111	2005	0.221527778
1992	0.272222222	2006	0.202666667
1993	0.293819444	2007	0.281583333
1994	0.299527778	2008	0.219944444
1995	0.158055556	2009	0.219680556
1996	0.356402778	2010	0.138583333
1997	0.232305556	2011	0.180097222
1998	0.205208333	2012	0.136097222
1999	0.189833333	2013	0.199930556
2000	0.365194444	2014	0.126097222
2001	0.373930556	2015	0.130083333
2002	0.243805556	Total	6.281