IMPACT OF LAND USE CHANGE ON RESERVOIR SEDIMENTATION
(CASE STUDY OF KARADOBI)


M.Sc THESIS

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTERS OF SCIENCE DEGREE IN CIVIL ENGINEERING MAJOR HYDRAULIC ENGINEERING

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SCHOOL OF GRADUATE STUDIES
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APRIL, 2010

DECLARATION

I hereby declare that I am the sole author of this thesis and have not been presented and will not be presented for any degree in any university.

Dereje Dargie.

Signature--------------------------------

CERTIFICATION

I, the undersigned, certify that I have read and recommend for acceptance by the Addis Ababa University a thesis entitled: "***Impact of Land Use Change on Reservoir Sedimentation (case of Karadobi)"*** for the Partial fulfillment of the requirements of the degree of Masters of Science in Civil Engineering Major Hydraulic Engineering.

Dr. Yilma Sileshi
(Advisor)
Date---

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I. ABSTRACT

The Blue Nile Basin is one of the most affected areas by soil erosion, sediment transport and land degradation. The land and water resources of the basin and the ecosystem are in danger due to the rapid growth of population, deforestation, overgrazing, soil erosion, sediment deposition, storage capacity reduction, drainage and water logging, flooding, pollutant transport, population pressure and over-exploitation of specific fish species.

The lack of decision support tools and limitation of data concerning weather, hydrological, topographic, soil and land use; are factors that significantly hinder research and development in the area. There is a need for hydrological and sediment transport research of the Blue Nile Basin that can improve catchment's management programs. Appropriate decision support tools are needed for better assessment of the hydrology and soil erosion processes for planning and implementations of soil and water conservation measures. The tools concern various hydrological and soil erosion models as well as geographical information system (GIS).

The modelling tools will finally help to save the physical quality of the land. In this paper the influence of land use changes on catchment's hydrology is observed particularly on sediment yield. To carry out this SWAT MODEL was used for simulation. The delineated watershed was divides into 75 sub basins and 293 HRUs by the model. Model calibration and validation was done at Kessie. In addition to this the model efficiency was checked at this station. Based on this values for coefficient of determination (r^2) and Nash–Sutcliffe model efficiency (E_{NS}) were found to be in the acceptable range i.e. (0.80 to 0.95 for r^2 and 0.70 to 0.92 for E_{NS}).The annual sediment load at Karadobi is found to be 855 ton per square kilometre. And in 50 years 7.84% of the active storage will be depleted due to sediment accumulation. Four scenarios are developed to observe the impact of land use changes. Based on this a 10 and 20% of change in agro-pastoral land to agricultural land has resulted in 12% and 61% increase in sediment load. But 60% and 90% change of pasture and forest lands have resulted in a sediment increment by less than 0.5%.

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List of Abbreviations

AAU	Addis Ababa University
ARS	Agricultural Research Service
Bm^3	Billion cubic meters
D	Diameter
DEM	Digital Elevation Model
E	East direction
ET	Evapotranspiration
GIS	Geographic Information System
GW_Q	Ground water flow (mm)
H_2O	water
HRU	Hydrological Response Unit
KINEROS	Kinematics Runoff and Erosion Model,
Km	kilometer
Km^2	Square kilometre
Km^3	cubic kilometer
M	meter unit
M	Million(Mega)
m.a.s.l	mean above see level
Mg/L	milligram per litre
Mkm^2	Million square kilometres
mm	millimetre
MT	million ton
MUSLE	Modified Universal Soil Losses Equation,
N	North direction
NMSA	National Metrological Service Agency
NRCS	Natural Resource Conservation Service
Perc	percolation (mm)
PET	Potential Evapotranspiration
Precip	precipitation (mm)
RUSLE	Revised Universal Soil Loss Equation,
SCS	Soil Conservation Service
SW	shallow water flow (mm)
SWAT	Soil and Water Assessment Tool
SWR_Q	surface runoff (mm)
T/Ha/M	ton per hectare per month
T/ha/yr	tones per hectare per year
USDA	United States of department of Agriculture
USLE	Universal Soil Loss Equation,

1 INTRODUCTION

1.1 Background

Water is the greatest gift to the mankind. Water resources are very crucial renewable resources that are the basis for survival and development of a society. Human health and welfare, food security and industrial developments are dependent on adequate supplies of suitable quality water. Conversely, too much water results in socioeconomic damages and loss of life due to flooding. The liveliness of natural ecological systems is dependent on mankind's stewardship of water resources. Proper utilization of these resources necessitates assessment and management of the quantity and quality of the water resources both spatially and temporally (Dilnesew 2003).

By comparing water demand for food, the environment, industries and domestic use with the water supply available from precipitation, snowmelt and aquifers, International Water Management Institute (IWMI) has predicted that more than twenty developing countries will experience chronic and physical water shortages in 2025 (Seckler et al. 1998). In the meantime, some countries especially in the Middle East and Africa are already confronted with a shortage in water supply (Al-Weshah, 2002). Such studies indicate the need of water resources management in a resourceful manner in order to meet future water demands. In this context, developing management plans would be certainly complimented by quantitative descriptions of spatial and temporal distribution of water resources and the processes influencing them.

Establishing a relationship among various environmental parameters is the central focus of hydrological modelling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. Models are generally used as efficacy in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (intervention of watershed conservation practices).

Sediments are all the basin rock and soil particles which water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. The finer the particles and/ or the stronger the flow turbulence, the greater is the transport in suspension.

The knowledge how land use/cover change influence watershed hydrology will enable local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use/cover change or modifications.

Given that impacts of land use/cover change on water resources are the result of complex interactions between diverse site-specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land –water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002).

Land and water resources degradation are the major problems in the Ethiopian highlands. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. So far limited measures have been taken to combat the problems. In this study a physically based watershed model, SWAT2005 was applied to the Northern Highlands of Ethiopia for modelling of the hydrology and sediment yield. The main objective of this study was to test the performance and feasibility of SWAT2005 model to examine the influence of land use/cover changes on sediment yield.

Ethiopia experiences persistent land, water and environmental degradation due to localized and global climatic anomalies. These leave the country to recurrent crop failures and sever food shortages. Low soil fertility coupled with temporal imbalance in the distribution of rainfall and the substantial non-availability of the required water at the required period are the principal contributing factors to the low and declining agricultural productivity. Hence, proper utilization of the available soil and water resources is essential to Ethiopia's agricultural development and achievement of food security.

Compared to humid climate hydrological studies are often hindered in semi-arid and arid areas by the limited availability of relevant data and information. The main reasons for this are: 1) Quite a lot of river basins are un-gauged, 2) unavailability of high resolution spatial and temporal data like digital elevation model, soil properties, land use, and climate data of the basins.

Moreover in gauged river basins, finding all the information essential for understanding the hydrological process is difficult due to the limited range of measurement techniques in space and time (Beven, 1999). For such conditions, hydrological models provide an alternative solution. There are two basic advantages using hydrological models instead of relying only on collected data. In the first place models can be used to understand the processes that are difficult to measure due to the complexity of temporal and/or spatial scale. Secondly, a model can be used to study the effect of changes in land cover, water management or climate (Kite and Droogers, 2001).

1.2 Statement of the Problem

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. Many farmers in Ethiopian highlands cultivate sloped or hilly land, causing topsoil to be washed away during the torrential rains of the rainy season. The rains also leach the highland soils of much fertility. In most parts of Ethiopia the high intensity rainfall occurs when the cultivated land has low cover, which can reduce the impact of the high intensity raindrop and the high runoff which can be slowed by soil cover.

With the fast growing population and the density of livestock in the basin, 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.

The above things result in sedimentation of reservoirs and short life time. Therefore analysing 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 and this study with little effort and cost, continuously can predict sediment yield in the basin.

1.3 Objective of the Study

The overall goal of this study is to model the hydrological processes that will predict the impact of land use/cover changes on sedimentation in the Blue Nile basin at the Karadobi catchment by integrating spatially estimated hydrological parameters, digital elevation model, and land use, with the Soil and Water Assessment Tool (SWAT).

The specific objectives of the studies are:

1. To predict the amount of sediment with current land use from Abay Master plan and comparing the result with NORPLAN study at Karadobi dam site.
2. To apply SWAT model in predicting sediment yield in the Blue Nile basin, Karadobi catchments.
3. To analyze (simulate) future trend under different land use scenarios.

1.4 Description of the Study Area

1.4.1 Location

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 7^0 45'-12^0 45' N and 34^0 05'-39^0 45' E. It is the largest of the 12 major river basins in Ethiopia with an area of about I76918 km^2 at the border point with Sudan .The headwaters of the river are situated in the mountains surrounding Lake Tana, which has a natural elevation of 1785 m a.s.l. and commands a catchment area of 15320 km^2. The largest tributary to Lake Tana is Gilgel Abay which enters from the south. A large part of the catchments is contained within the highland plateau at elevations generally above 2000 m. Between Lake Tana and the border the basin drains a large portion of the central and south-western highlands of Ethiopia. Over this reach of some 900 km length, the river makes a half-circular course and runs through a deep, incised, valley for much of the time. In some locations the Abay gorge is over 1000 m deep. The entire Abay basin may be partitioned in 14 sub-basins, whose contributing areas are given in Table 1.1. Catchment's area up to Karadobi dam site, located just below the Guder river confluence is 82,300 km^2 and elevation at the site is 910 m.a.s.l.

The study area the Karadobi dam (the target project) is located on the boundary of Amhara and Oromia Regional States in Ethiopia on the Abay River, south of Debre Markos; 65 km downstream of the Kessi bridge and 1.7 km downstream of the confluence of the Abay and Guder rivers. The Blue Nile sub basins which contribute to this point are Tana, Jemma, Beshilo, North Gojjam, South Gojjam, Weleka, Mugger and Guder. Mean streamflow at the border amounts to 1540 m^3/s, which translates to an annual runoff volume of $54.4 * 10^9$ m^3. This represents over 90% of the total Blue Nile flow at Khartoum where the White Nile joins to form the main Nile River. In terms of total Nile river water resource, the average Blue Nile flow leaving Ethiopia contributes to about 65%.

Sr. No	Sub basin Name	Area (Sq KM)	Mean annual rainfall(mm)	Mean annual PET(mm)	Mean annual runoff(mm)	Mean annual flow (m^3/s)
1	Lake Tana	15,320	1313	1136	253	3809
2	N. Gojam	14,389	1336	1242	305	4389
3	Beshilo	13,242	982	1140	296	3920
4	Welaka	6,415	1072	1263	323	2072
5	Jemma	15,782	1105	1059	304	4798
6	S. Gojam	16,762	1633	1183	299	5012
7	Muger	8,188	1347	1210	298	2440
8	Guder	7,011	910	1307	312	2187
9	Fincha	4,089	1766	1290	438	1719
10	Didesa	19,630	1816	1308	289	5673
11	Anger	7,091	1813	1318	298	2355
12	Wenbera	12957	1660	N/A	299	3874
13	Dabus	21032	2276	1112	297	6246
14	Beles	14200	1655	1274	306	4345
15	Dinder	14,891	N/A	N/A	188	2973
16	Rehad	8,269	N/A	N/A	133	1102

N/A not available

Table 1.1 : Major Blue Nile Sub-basins (from IWMI).

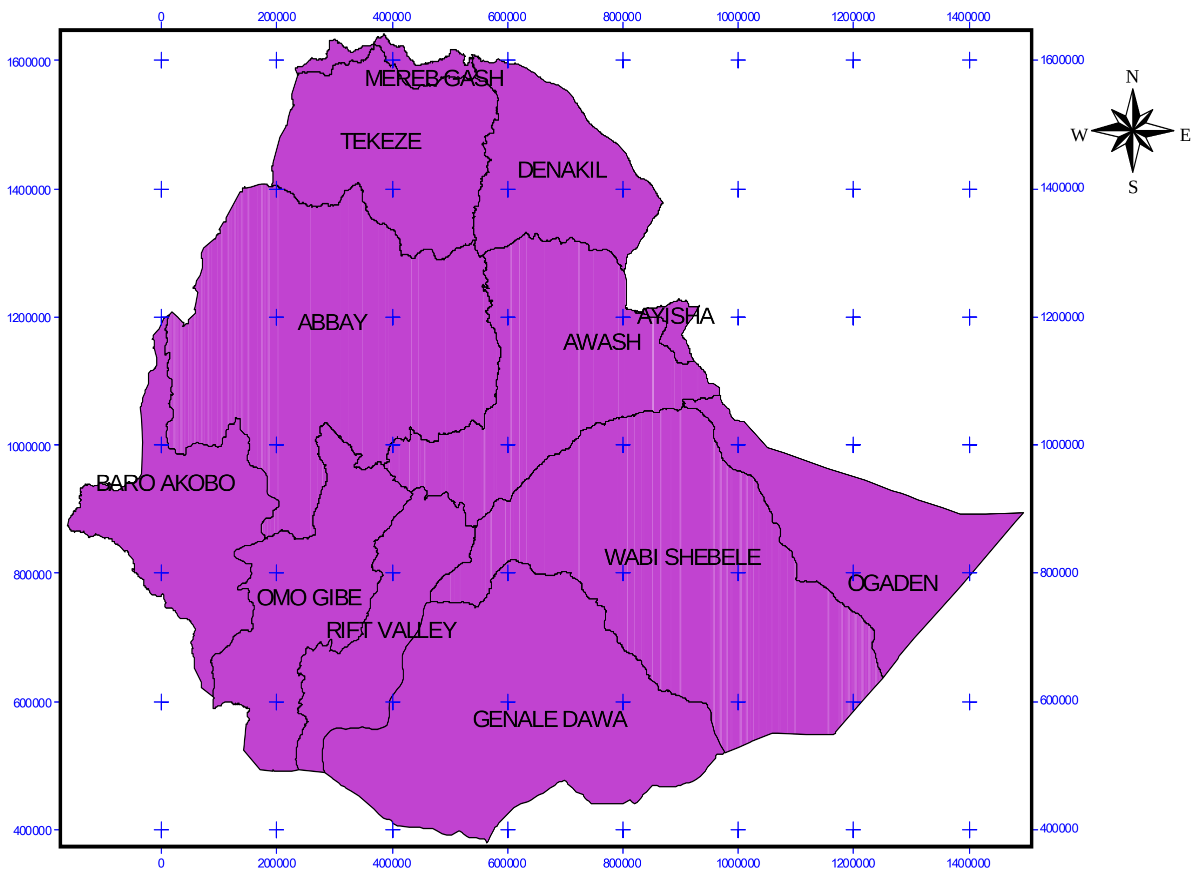

Figure 1.1 Major Ethiopian Basins

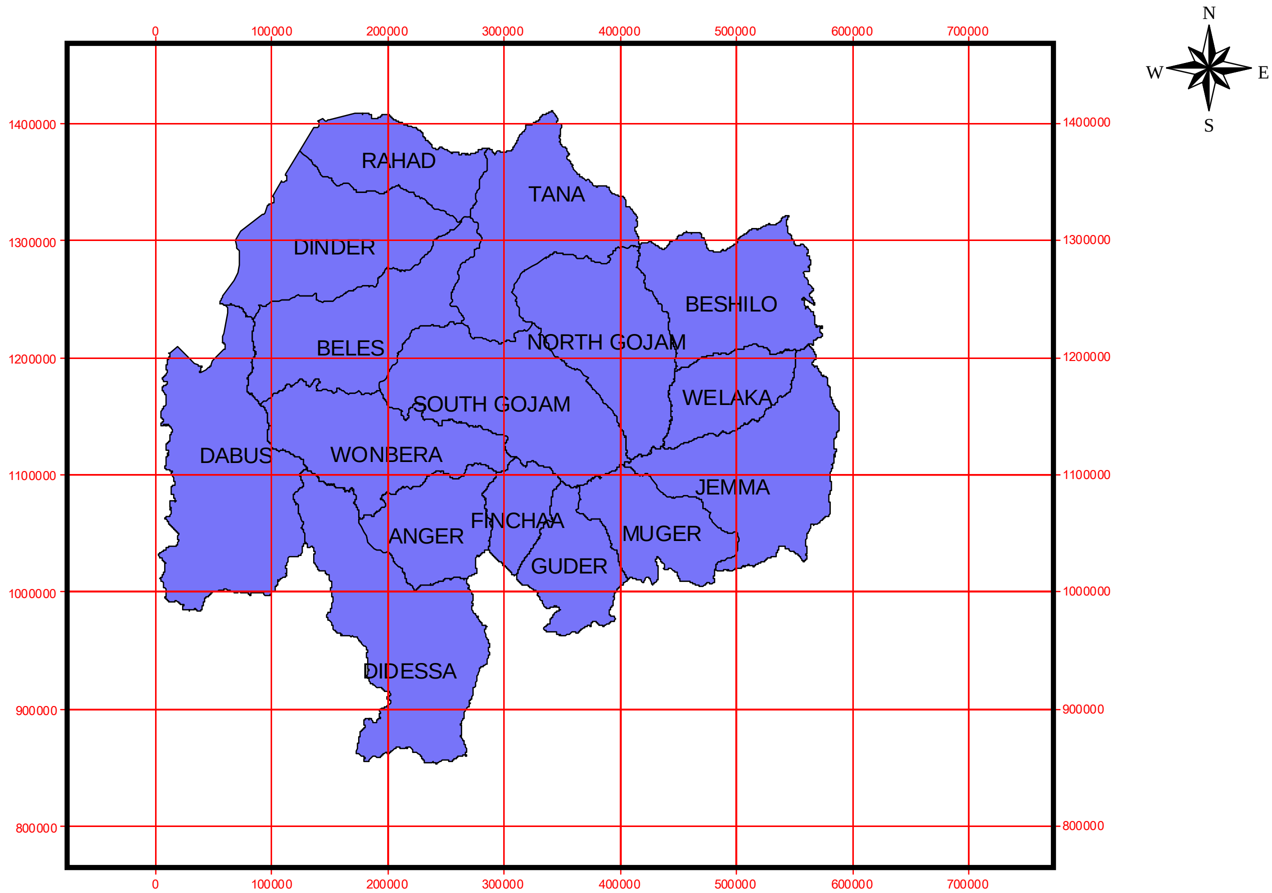

Figure 1.2 The Blue Nile sub basins

Figure 1.3 Abbay River at millennium bridge (Photo in July 2009)

1.4.2 Topography

Blue Nile plateau is marked by extensive and relatively level areas divided by rolling hills, wide valleys and steep escarpments. Highest points in the catchments are defined by isolated mountain peaks of which some are over 4000 m in the north east. At the foot of the plateau elevation drops gradually from around1000 m in the lower reaches of the Main River and tributary valleys up to the border point elevation is 500 m.a.s.l.

1.4.3 Climate and Hydrology

The climate of the Abay basin is humid to sub-humid in the highlands and semi-arid to arid in the Sudan border. The annual rainfall over the basin decreases from the south west (>2000 mm) to the north east (around 1000 mm), with about 70 per cent occurring between June and September (Conway, 2000). The Blue Nile is characterized by severe seasonality with average annual flow of about 50 million m^3 measured at the basin outlet at El Diem station near the Sudan-Ethiopia border (Conway (1997). More than 80% of this flow occurs during the flood season between July and September, while only 4% of that flow occurs during the driest period January-April. In the basin, annual mean PE and rainfall range, with increasing elevation, from 800mm to 2220mm and 924mm to 1845mm, respectively.

Climate in the highlands is strongly influenced by the effects of elevation, which gives rise to distinct zones and characteristics. Traditional classifications based on altitude and temperatures show the presence of five zones, of which the following three are predominant in the Abay river basin.

1. The Kolla zone below 1800 m.s.l. has mean annual temperatures in the range of 20-28^{o}C.

2. The Woina Dega zone between 1800-2400 m.a.s.l has mean annual temperatures in the range of 16-20^{o}C; and

3. The Dega zone above 2400 m.s.l. has mean annual temperatures in the range of 6-16^{o}C.

According to the amount of rainfall received in the area the upper Blue Nile basin will have different number of seasons.

Two Seasons: The western half of Ethiopia has two distinct seasons (wet from June-September and dry from November-February), with the rainfall peak occurring from July to August.

Three Seasons: The central and most of the eastern part of the country have two rainy periods and one dry period. These season are known locally as the main Kiremt rains (June - September), small Belg rains, (February-May), and dry Bega season (October-January).

1.4.4 Land use/cover

The terms land use and land/cover are often used interchangeably even though the distinction between the two is important. Land use refers to the actual economic activity for which the land is used where as land cover refers to the cover of the earth's surface. Land use can be seen as the ultimate expression of everything else that is going on in the basin. The land use of the study area can be categorized mainly as agricultural, forest, bush, bare-land, savannah, and water bodies. The information contained in the land use map tells how the different uses of the surface are distributed inside the area under study. It can be seen from land use map, that the basin is mainly occupied by Savannah with more than 67% of the basin area. There is also a 20% of the area covered by dry land, cropland and pasture. The rest is mainly woodland and grassland.

Fig 1.4 Typical Land Use in North Gondar (photo taken in July2009)

1.4.5 Soil type

The Upper Blue Nile basin is mainly formed from clay and clay-loam soil type, but the riverbed has a loam and sandy-loam type of soil. The infiltration capacity of the soil depends, among others, on the porosity of the soil, which determines its storage capacity and affects the resistance of the water to flow into deep layers. Since the soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soil. This shows that, surface runoff is higher in heavy clay and loamy which has low infiltration rate. As a result of this fact annual surface runoff from Upper Blue Nile basin in Ethiopia is 54.4 BM^3. Throughout the basin the soils are generally vetisols or latosols. The drainage system is well defined; the gradient of most tributaries is steep. Flood water quickly collect in the drainage channels (Hurst et al., 1959) and the loss to overflowing on flood plains or to evaporation is small over much of the basin. Because of the sparse growth of trees, steep slopes, and the shallow and often denuded soil, runoff is rapid and a relatively small amount of rainfall is retained deep percolation or absorption.

2. LITERATURE REVIEW

2.1 General

Mankind has always been concerned to comprehend and subsequently control the processes of the hydrologic cycle. Many hydrologic phenomena are extremely complex, and thus, they may never be fully understood.

During the past, the processes of the hydrologic cycle were only conceptualized, and causes and effects were just described in relatively simple relations. For example, in ancient Roman times, watercourses were constructed without preceding sound (theoretical) scientific research, yet the construction lasted for ages. Nowadays, however, the state of knowledge and technology makes it possible to even understand rather complex processes of the hydrologic cycle by means of executing a model on the computer. Anderson & Woessner, 1992 attempted to define in such away that model is a simplified representation of a complex system. The purpose of model is to replace reality, enabling measuring and experimenting in a cheap and quick way, when real experiments are impossible, too expensive, or too time-consuming (Eppink, 1993).

A hydrological system is defined as a set of physical, chemical and/or biological processes acting upon input variables to convert them into output variables (Dooge, 1968). In this definition a variable is understood to be a characteristic of the system, which may be measured, assuming different values when measured at different times. A parameter is a quantity characterizing the hydrological system and which is usually assumed to remain constant in time.

Hydrological modelling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modelling, (Lenhart et al. 2002).

There are many classification schemes of hydrologic models, based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle (source: (Cunderlik 2003).

Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow.

Soil erosion models can be separated into models simulating a single hill slope or a single field and models simulating a watershed. Based on their sources of pollutions model can be divided into point sources and non-point sources model. Point sources of pollution are those sources emitted to catchments at a specific point. Common point sources include municipal and industrial pollutants discharged directly to a stream. Non point sources are those sources discharged to a catchment in a way that they depend upon the vagaries of the hydrologic cycle to transport them to the stream system. Nutrients, pesticides, salts, bacteria, heavy loads of organic matter, and sediments are considered as non point source pollutants (DeCoursey, 1985). Non point source pollution is a 'source –transport' problem in which the hydrological cycle provides the transport processes to move the pollutants from the source to groundwater, a stream, or a reservoir. The mode of transport is the flow of water across the soil surface and in stream channels and reservoirs or the flow of water through the soil profile.

Determination of accurate runoff rate or volume from the watershed is a difficult task, because runoff is dependant upon several factors related to watershed and atmosphere, prediction of which is not so easy. However, some common runoff estimation methods are Rainfall-Runoff Correlation, Empirical Methods, Rational Method, Infiltration Indices method, Hydrograph Method and using different models now a days, like HEC-HMS, MOWBAL, SWAT model and others.

Several models are available for predicting erosion too, including the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Losses Equation (MUSLE), Kinematics Runoff and Erosion Model (KINEROS), and Water Erosion Prediction Project (WEPP). .

SWAT is the ellipsis for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA, Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.

To satisfy this objective, the model

i. Is physically based: rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using this input data.

ii. Uses readily available inputs: while SWAT can be used to study more specialized processes such as sediment transport, the minimum data required to make a run are commonly available from government agencies.

iii. is computationally efficient: simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.

iv. Enables users to study long-term impacts: many of the problems currently addressed by users involve the gradual build-up of pollutants and the impact on downstream water bodies. To study these types of problems, results are needed from runs with output spanning several decades.

v. Capability for application to large-scale catchments (>100 km^2).

vi. Capability for interface with a Geographic Information System (GIS).

vii. Input data requirements that allow the model to be applied in a wide variety of Ethiopian situations. (Done by few researchers and applicable and gave good results).

viii. A model that could be made available as part of a freely accessible package.

ix. SWAT is a continuous time model, i.e. a long-term yield model; it is not designed to simulate detailed, single-event flood routing. Generally, physically based models are used to simulate a wide range of complex aspects, (Lenhart et al. 2002).

2.2 Previous Studies on Blue Nile

Various researches were done on the Blue Nile using swat models. The areas of research include land cover changes, sedimentation, and flow and conditions relating these parameters.

A Ph.d thesis was done by Shimelis Gebriye entitled hydrological and sediment yield modeling in Lake Tana. The main objective of this study was to identify the most erosion sensitive areas. Two decision support models, SWAT and MCE, were used. SWAT calculates the soil erosion and sediment yield within each hydrological response units (HRU's) within each sub basin. The GIS tool combines the slope, Land cover, soil and river layers as a major factor which contributes to soil erosion. The output of the SWAT model has shown that 18.4 % of the watershed area has high potential for soil erosion which produces an average annual sediment yield of 30 to 65 tones per hectare.

The other research was done by Fikadu Fetene(M.Sc) with a title of relationship between rainfall, runoff and sedimentation of the Blue Nile. The main objective of this thesis was to determine sediment yield in the different sub basin of Blue Nile in Ethiopia, sediment load and sediment concentration in the main rivers of the tributaries and in the Abbay River. In addition to this, the aim is to look spatial and temporal variation of sediment yield/ concentration in the basin.

In this document the model performance efficiency indicator, regression coefficient (r^2) and the Nash-Sutcliffe (E_{NS}) are in the range of 0.71 to 0.91 in calibration and 0.78 to 0.88 in validation for flow analysis. Similarly, sediment model efficiency by regression coefficient evaluation is in the range of 0.71 to o.89 for calibration and 0.71 to 0.86 in validation. In addition to this the sensitive parameters were identified. Based on this the parameters mostly sensitive to change for calibration of stream flow are the curve number (CN2), soil evaporation compensation factor (ESCO), and soil available water capacity (SOL_AWC). The remaining parameters, SOL_Z, SOL_K, GW_DELAY and ALPHA_BF are the controlling parameters of base flow and adjusted for stream flow calibration.

The result has shown that 34% of soil is eroded from three sub basins, Guder, N.Gojam and Jemma (in between 6-9 t/ha per year) that cover an area of 18.6% of total Blue Nile. In similar manner, more than 50% of soil is eroded from an area of around 16% of the whole basin (ranging from 15-30 t/ha of sediment yield).

According to the finding of the paper the average annual sediment yield of the whole Blue Nile basin is around 4.26 t/ha/yr and 4.58 t/ha/yr including and excluding Rahad and Dinder sub basins respectively. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Millions tones with and without Rahad and Dinder respectively.

Another paper (M.Sc thesis) executed on the Blue Nile is" *Hydrological Responses to Land Cover Change"* by Mustefa Ahmed. The aim of this study was to exploit the capabilities of the simulation hydrological models to identify the past, current and future hydrological responses of Chemoga watershed with area of 382 km^2, to land cover changes. Land sat and Aster images of 1972-2006 were used for the extraction of the land cover changes. The HBV-96 and WEAP21 models were used to simulate the watershed's discharge under different scenarios. The images classification indicates there is a continuous reduction of the forest cover from 26.6% to 1.4% in the courses of the cited period. Results from WEAP21 indicates in the period of the "Current Account" and "Reference" scenario the simulated and the observed values reveal the peak and total wet season discharge increases by 65% and 38% respectively. The "What if" scenario show reforestation in the watershed reduces the peak and the total wet season discharges.

Accordingly 50% reforestation of the deforested area successfully reduces the peak and the total wet season discharges by the order of 23% and 21% respectively. Hundred percent reforestation reduces both the daily peak and the total wet season discharges by 30%.Results from HBV-96 indicates in the calibration period the simulated daily peak and the total monthly/annual discharge deviates from the observed by 8.6 % and 1.5 % respectively. During the validation period the simulated daily peak and total monthly/ annual discharges deviate from the observed by 40% and 3.2% respectively. In both periods the value of the indicators Nash/Sutcliffe coefficient and r^2, Accumulated difference and Relative accumulated difference were found to be in the order of 0.72, 31.9 and 0.09 respectively, confirming the good performance of the model in the area. Thus the techniques applied in this study are quite promising and could be applicable in water resources development and management works of different watersheds in the study area.

In addition to the above many researches and papers are executed by IWMI on sediment and hydrology of the Blue Nile. Among these review of hydrology, sediment and water resource in the Blue Nile basin was carried out by Seleshi Bekele, Mathew $M_c$carthey Tammo S. and Abdella Ahmed. The aim of the project is to provide insight into the likely downstream impacts of upstream development and watershed management options

The other document in the Blue Nile is the Karadobi Multipurpose Project studied by NORPLAN. The Karadobi dam and power plant will be located on Abay River in Ethiopia, approximately 55 km south of Debre Markos, 65 km downstream of the Kessi Bridge and 1.7 km downstream of the confluence of the Abay and Guder rivers. The Abay River will be closed by a Roller Compacted Concrete (RCC) dam of 250 m height; 684 m crest length and a gross volume of 6.5 million m^3. The reservoir thus created will cover a surface area of 445 km^2 and extend 150 km upstream at full supply level at elevation1146 m.a.s.l. The existing Kessi Bridge crossing the Abay 65 km upstream of the dam will be inundated by 70 m.

The total reservoir volume will represent two years average flow (650 m^3/s) of the Abay. The live storage is approx. 17,000 million m^3 between full supply level and minimum level at 1100 m.a.s.l. Gated spillways will be incorporated in the dam, and low level outlets will be provided to facilitate required flow release also when the power plant is not operating. A bridge will be built across the dam, making possible a new north south road connection between Debre Markos and Finchaa. An underground powerhouse will be located in the south bank of the Abay. Four 9 m diameter tunnels of approx. 800 m length will convey the flow from intakes in the reservoir via eight turbines in the powerhouse back into the Abay River some 400 m downstream of the dam. Power plant control room, offices and switchyard will be situated on the plateau at elevation approximately 1320 m.a.s.l near the south river bank.

The overall project description is as follows.

Dam

Dam height=250m

Dam crest elevation=1150m a.s.l

Maximum height above foundation=260m

Dam crest length=684m

Dam volume=6.5 Mm^3

Reservoir

Full supply level (FSL) =1146m.a.s.l

Minimum operation level=1100m.a.s.l

Total volume=40200Mm^3

Active volume=17200Mm^3

Surface area at FSL=445km^2

Extension of reservoir towards upstream=150km

Hydrology

Mean flow=649m^3/s

Annual mean peak flood=4500m^3/s

20 years flood=11900m^3/s

100 years flood=15500m^3/s

1000 years flood=20710m^3/s

PMF=30700m^3/s

Sediment

Maximum accumulated annual sediment=99.1Mm^3

Minimum accumulated annual sediment=60.3 Mm^3/s

Trap efficiency=86.5%

In addition to the above papers Abbay Rive Basin Integrated Development Master Plan Project was done by BCEOM covering major parameters i.e. hydrology, water resources, natural resources, land resources, demography, socio-economy and infrastructure in the basin.

3. DATA COLLECTION

3.1 DEM Data

The Digital Elevation Model of 90m by 90m resolution of different type has been taken from Water Works Design and Supervision Enterprise GIS department. The DEM was in the format of STRM and this was processed on 3 DEM, Global Mapper software's and imported to ArcView GIS environment.

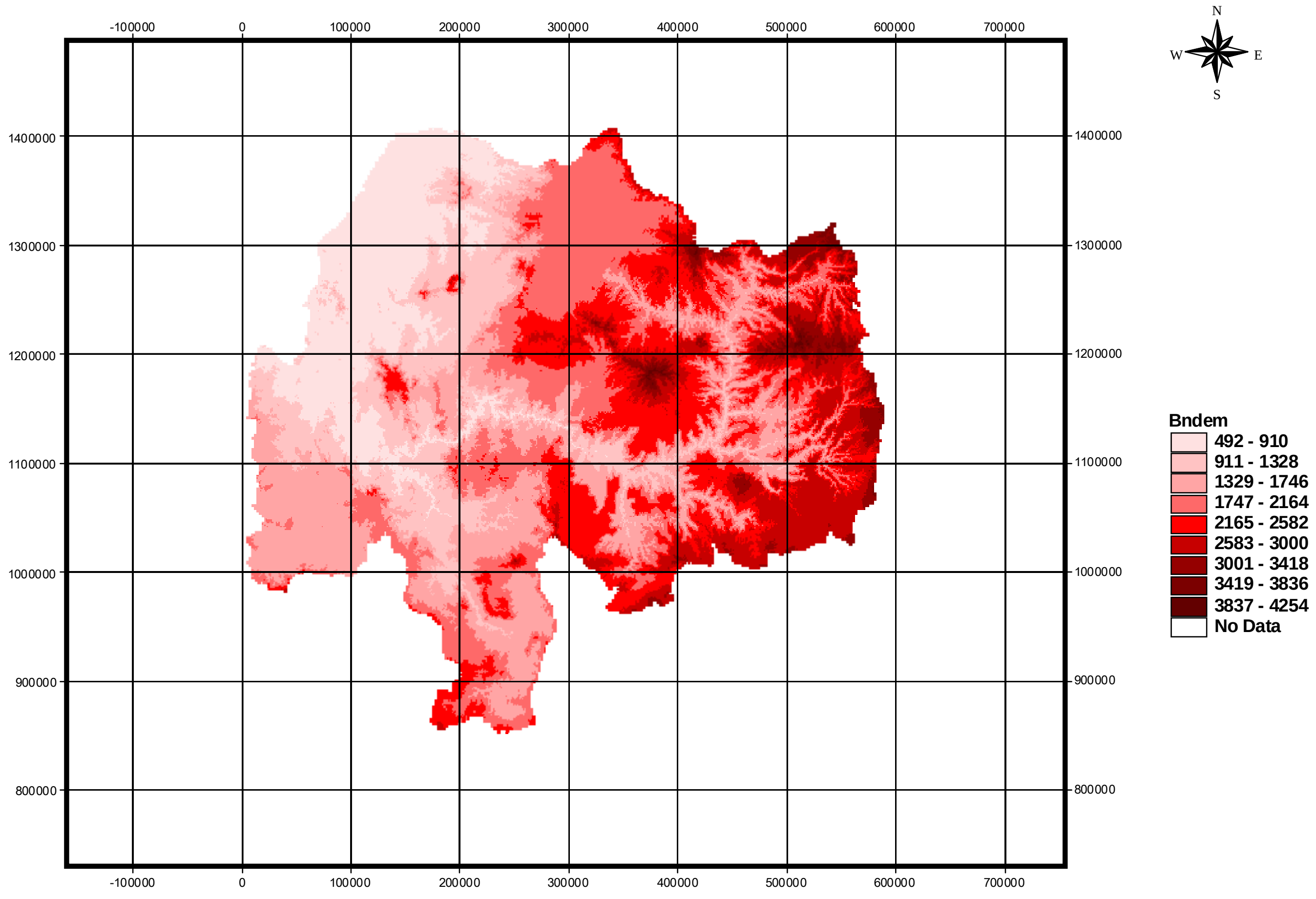

Figure 3.1 DEM of the Blue Nile

3.2 Flow Data

Daily flow data is required for SWAT simulated result calibration and validation. This data was obtained from KARADOBI PREFEASIBILITY study. Depending on the extent of calibration and validation, flow data was collected and arranged as per the requirement of SWAT model. The selected site was Kessie flow station (11.6^0N, 38.18^0E) .This site was selected as it represents the catchments of the whole watershed. In addition this station has long term and reliable data. The mean monthly flow at this site is 632m^3/s.

3.3 Sediment Data

There are few sites which has measured suspended sediment data in Blue Nile with a very short data. However the sediment data was taken from the Abay river basin integrated development master plan at Kessie station (11.6^0N, 38.18^0E. Depending on the observed data the remaining values were generated for calibration and sensitivity analysis.

3.3 Climate Data

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

In Blue Nile basin around 164 metrological stations (D.Tesfahun, 2006). But only some of them have long year data. It is uncommon to see fully recorded stations. Compared to other basin in Ethiopia, it is well equipped and established more than any other basins.

3.3.1 Rainfall Data

The SWAT model requires daily rainfall data arranged vertically parallel to time series. So, among 164 stations, 74 have good daily rainfall data, still a lot of missed data were filled with -99 (data generating code in SWAT). The station distribution is not even, very densely in Tana sub-basin, few in North Gojem, S.Gojam, and scarce in others. Moreover, Rihad and Dinder sub-basins have only one station each. In figure 3.2 rainfall data distribution is located.

Sr. No	Station NAME	coordinate		ELEVATION	Mean annual rainfall(mm)
		XPR	YPR		
1	ADISZEMEN	338914	1334729	1850	1019
2	ASGORI	389957	948562	2500	1021
3	ASSOSA	-10500	1108016	1600	752
4	BAHIRDAR	309031	1256360	1770	1382
5	BAKO	285669	1003166	1650	1783
6	BAMBIS	4000	1043807	1460	1418
7	CHAGNI	204520	1169713	1620	1704
8	DANGLA	226949	1233718	2000	1572
9	DEBREBIRHAN	532939	1036878	2750	2580
10	D.MARKOS	324734	1127959	2515	1357
11	DEBRETABOR	393132	1274766	2690	1453
12	DEBREWORK	399307	1154208	2740	1176
13	DEJEN1	400295	1116608	2420	1595
14	DEK ESTIFANOS	299334	1276333	1795	1409
15	DELGI	283411	1338400	1780	816
16	DENEBA	513173	1045711	2900	930
17	DARBA	431901	1023657	2350	1027
18	ENFRANZ	326964	1339221	1950	2016
19	ENJIBARA	230809	1170602	2670	2328
20	FITCHE	436335	1047973	2750	1164
21	FINCHAA	401369	1108864	2280	1770
22	GEBREGURACHA	304509	1032935	2560	1300
23	GEDO	417676	1049115	2500	732
24	GONDER	308737	998625	1967	1344
25	GORGORA	309704	1363666	1830	1116
26	HARO	301956	1343803	2200	1584
27	HAROKELIFA	11000	1148978	900	1572
28	INCHIN	414310	1015951	2690	1290
29	JARSO	80000	1026094	1750	1810
30	JIRU	516438	1107628	2640	874
31	KOMBOLCHA	516438	1107628	2100	972
32	LEMI	313309	1035104	2500	1309
33	MAKESGINT	449509	1049059	1950	1219

Sr. No	Station NAME	coordinate		ELEVATION	Mean annual rainfall(mm)
		XPR	YPR		
34	MENDISCHOOL	70000	1048235	1650	2472
35	MANGE	4275	1129050	1200	1008
36	MERAWI	291486	1244300	2110	2016
37	MOTTA	291486	1244300	2440	1236
38	NEDJO	90390	1029415	1800	1512
39	NEFASMEWUCHA	420379	1268049	3000	1082
40	SHAMBU1	420371	1264732	2430	1512
41	SHEKUTE	286931	1033028	2560	1548
42	WEGELTENA	393456	1023742	3000	948
43	WERETA	514184	1255788	1980	948
44	YETMEN	326612	1277276	2060	1200
45	YIFAG	399230	1127669	1800	983
46	ZEGE	329097	1331465	1800	1485
47	ABAYSHELEKO	302516	1261931	1790	828
48	ADDET	399190	1113293	2080	2016
49	ALEMKETEMA	305622	1234255	2280	1116
50	AMBO	502192	1107624	2130	1093
51	AYKEL	337127	948733	2150	1296
52	BEDELE	285765	1362725	2030	1836
53	DEMBECHA	188223	915255	2100	1584
54	ENEWARI	311668	1143512	2650	1584
55	FERESBET	509877	1054555	2870	1800
56	JELDU	319433	1162275	2880	1944
57	KACHISE	394510	1007153	2520	2016
58	MEKANESELAM	302318	1034052	1720	864
59	PAWEE	439786	1143609	1053	1668
60	YEJUBIE	175509	1227550	2300	1548
61	YETENORE	329612	1226377	2540	1188
62	LAYBIR	400301	1118819	2000	1044
63	SHINDI	233965	1153977	2140	1404
64	LALIBELA	509797	1328767	2500	900
65	UPPERBIR	306223	1149073	2000	1116
66	ADDISALEM	206663	1164160	2010	1476
67	KELALA	610293	1230541	1500	1476

Sr. No	Station NAME	coordinate		ELEVATION	Mean annual rainfall(mm)
		XPR	YPR		
68	KULEMMEDA	533853	1228160	2000	1224
69	WETETABAY	284911	1241025	1900	2052
70	SHASHURA	233240	1329953	2000	1152
71	TIS ABAY	319909	1249659	1620	1260
72	SIRINKA	540375	1252494	2000	1136
73	SULULTA	438466	1007061	2610	1199
74	TILILI	284402	1162477	2570	1908

Table3.1 Rainfall Stations used in SWAT.

3.3.2 Temperature Data

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. Like other climate data even more than precipitation data is difficult to get continuously recorded many years' data in the basin. Nineteen (19) stations data have been collected and analyzed, the missing data again assigned” -99” value to be filled by SWAT.

Sr. No	Station Name	XPR	YPR	ELEVATION	Mean Max. Monthly Temperature	Mean Min Monthly Temperature
1	ABAYSHELKO	302516	1261931	1790	28.9	11.1
2	ADET	399190	1113293	2080	25.8	8.8
3	AMBO	502192	1107624	2130	26.1	11.3
4	AYKEL	337127	948733	2150	23.6	13.5
5	BAHIR DAR	309031	1256360	1770	26.9	13.1
6	CHAGNI	204520	1169713	1620	24.4	8.2
7	DEBRE MARKOS	324734	1127959	2515	22.5	10.4
8	DEBRE TABOR	393132	1274766	2690	21.7	9.6
9	DANGLA	226949	1233718	2000	24.4	8.2
10	DEBRE WORK	399307	1154208	2740	24.5	10
11	DEMBCHA	188223	915255	2100	25.7	11.1

Sr. No	Station Name	XPR	YPR	ELEVATION	Mean Max. Monthly Temperature	Mean Min Monthly Temperature
12	FINCHA	401369	1108864	2280	25.1	10.6
13	GONDER	308737	998625	1967	27	13.7
14	LAYBIR	400301	1118819	2000	28.1	12.6
15	MOTTA	291486	1244300	2440	23.2	-
16	NEDJO	90390	1029415	1800	25.8	12.3
17	NEFASMEWICHA	420379	1268049	3000	17.7	8.1
18	YETMEN	326612	1277276	2060	24	9.6
19	ZEGE	329097	1331465	1800	27	11.2

Table 3.2 Temperature Stations used in SWAT

3.3.3 Wind speed, Relative humidity and sunshine hours

These are also the vital parameters for SWAT model to generate weather. Since, very few stations have daily data of wind speed, relative humidity and solar radiation; it is preferred to generate these data by SWAT model weather generator mechanism.

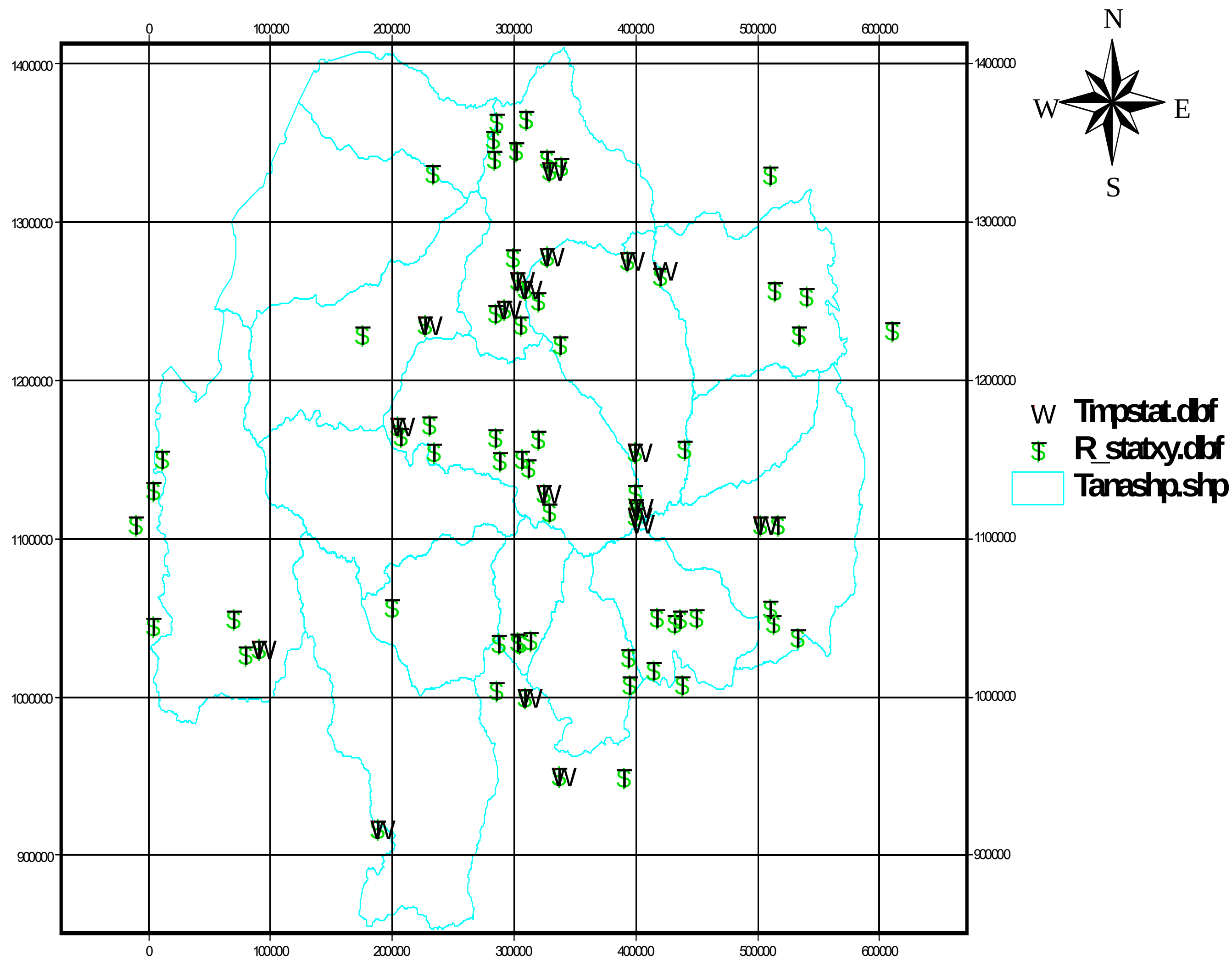

Fig 3.2 Climate Stations of the Blue Nile Basin

4 METHODOLOGY

The methodology of this work has the following components.

1. Data collection
2. Data processing
3. running model
4. calibrating the model
5. Model result interpretation.

The conceptual frame work serves to describe the over all research steps describing the methodology applied to carry out the research .In general the remotely sensed data, Land sat images, ASTER images and SRTM data are collected, processed and verified for accuracy by ground truth to extract useful information like land cover maps, soil type, soil physical and mechanical properties and catchments boundary of the study area. At the same time the necessary hydro-metrological data, daily rainfall, daily maximum and minimum temperatures, daily humidity, sunshine hours, wind speed and observed river discharge and sediment load/concentration at different stations in the basins are collected and processed to make the data ready for use in the models. Once the model is parameterized by converting the results of data analysis into model parameters, then model sensitivity analysis, calibration, validation and simulation for different parameter changing are conducted ending up on some conclusions and recommendations.

4.1 Hydrological Model SWAT

SWAT (Soil and Water Assessment Tool, Arnold et al., 1998) is a time continuous and a river basin, or watershed, scale semi-spatially distributed hydrological model developed by the USDA Agricultural Research Service (ARS). SWAT incorporates features of several ARS models and is a direct outgrowth of the SWRRB model (Simulator for Water Resources in Rural Basins)(Williams et al., 1985). Specific models, which contributed to SWAT model development include: CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems)(Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems)(Leonard et al., 1987), and EPIC (Erosion-Productivity Impact Calculator)(Williams et al., 1985). The purpose of SWAT development is to assess and 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., 2001). The SWAT system, embedded within geographic information system (GIS), can integrate various spatial environmental data, including soil, land cover, climate, and topographic features.

SWAT simulates eight major components (Neitsch et al., 2002):

Hydrology: based on water balance equation, which relates interception, soil water, runoff, evapotranspiration, daily amount of precipitation, percolation and baseflow or return flow,

Weather: weather variables for driving the hydrologic balance are precipitation, air temperature, solar radiation, wind speed and relative humidity, daily inputs can be entered directly or the weather generator can be used to simulate daily values for these variables from aggregated monthly values,

Sedimentation: sediment yield is computed from the MUSLE equation,

Soil temperature: daily average simulated at the centre of each soil layer for use in hydrology and residue decay,

Crop growth: crop growth model is a simplified of EPIC crop model with the concepts of phenological crop development based on daily accumulated energy units, harvest index for partitioning grain yield, Montheith’s approach for potential biomass and water, nutrient and temperature stress adjustments,

Nutrients: amount of NO_3-N contained in runoff, lateral flow and percolation are estimated as the products of the volume of water and the average concentration. Estimating soluble P in surface runoff is based on the concept of partitioning of pesticides into the solution and sediment phase as described by Leonard and Wauchope (Knisel, 1980) as P is mostly associated with the sediment phase,

Pesticides: GLEAMS technology for simulating pesticide transport by runoff, percolate, soil evaporation and sediment is used in the pesticide subcomponent, and

Agricultural managements: provides sub models that simulate tillage systems, application of irrigation water, fertilizer and pesticides and grazing systems.

Major hydrological processes that can be simulated by the model include evapo-transpiration (ET), surface runoff, infiltration, percolation, shallow aquifers and deep aquifers flow, and channel routing (Arnold et al., 1998). The simulation of the processes can be done in four subsystems: surface soil, intermediate zone, shallow and deep aquifers, and open channels. Stream flow in a main channel is determined by three sources: surface runoff, lateral flow and base flow from the shallow aquifers. In SWAT, the impacts of spatial variations in topography, land use, soil and other watershed characteristics on hydrology are considered in subdivisions. There are two-level scales of subdivisions: (1) a basin is divided into a number of sub-basins based upon drainage areas of the tributaries, and (2) each sub-basin is further divided into a number of hydrologic response units (HRUs) based on land cover and soil type. Each HRU is assumed to be spatially uniform in terms of land use, soil, topography and climate.

No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed. To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must match to what happens in the watershed.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin.

The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

The main components of water balance are discussed below but the detail description of the hydrologic cycle could be seen in (Arnold, Srinivasan, Muttiah and Williams et.al, 1998, Neitsch, Arnold, Kiniry and Williams, et.al, 2005).

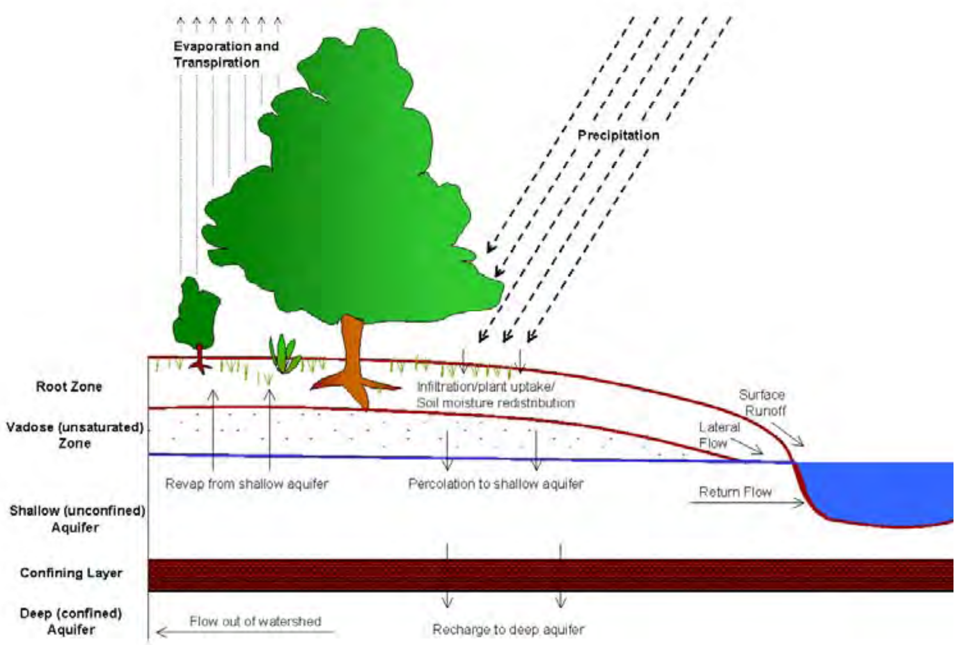

Figure 4.1 Schematic representation of the hydrologic cycle.

4.1.1 Land phase of the hydrologic cycle

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

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (4.1)$$

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 evapotranspiration 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), and

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.

The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. The model allows values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed and relative humidity to be input from records of observed data or generated during the simulation.

4.1.2 Weather Generator

For missing data and shortage of daily data, SWAT generates from average monthly values. The model generates a set of weather data for each sub basin. The values for any sub basin will be generated independently and there will be no spatial correlation of generated values between the different sub basins. These are generation of precipitation, temperature, wind speed, solar radiation and relative humidity of a given station in the basin.

SWAT uses a model developed by Nicks (1974) to generate daily precipitation for simulations which are not available in measured data. This precipitation model is also used to fill in missing data in the measured records. The precipitation generator uses a first-order Markov chain model to define a day as wet or dry by comparing a random number (0.0-1.0) generated by the model to monthly wet dry probabilities input by the user. If the day is classified as wet, the amount of precipitation is generated from a skewed distribution or a modified exponential distribution.

Maximum and minimum air temperatures and solar radiation are generated from a normal distribution. A continuity equation is incorporated into the generator to account for temperature and radiation variations caused by dry and rainy conditions.

4.1.3 Hydrology

As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapo transpired or it may slowly make its way to the surface water system via underground paths.

4.1.3.1 Surface Runoff

Surface runoff, or overland flow, is flow that occurs along a sloping surface. Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU.

SWAT uses two methods for calculating surface runoff namely; the modified SCS curve number method (USDA Soil Conservation Service, 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911). In the curve number method, the curve number varies non-linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation.

The Green & Ampt method requires sub daily precipitation data and calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity. Water that does not infiltrate becomes surface runoff. SWAT includes a provision for estimating runoff from frozen soil where a soil is defined as frozen if the temperature in the first soil layer is less than 0°C.

The SCS curve number equation is (SCS, 1972):

$$\mathbf{Q_{surf} = \frac{(R_{day} - I_a)^2}{(R - I_a + S)}} \qquad (4.2)$$

Where: Qsurf: is the accumulated runoff or rainfall excess (mm H2O),

R_{day} is the rainfall depth for the day (mm H_2O),

I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H_2O), and

S is the retention parameter (mm H_2O).

The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \tag{4.3}$$

Where, CN- is the curve number for the day.

The initial abstractions, Ia, is commonly approximated as 0.2S. Then the above equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \tag{4.4}$$

Runoff will only occur when Rday > Ia. A graphical solution of equation 4.4 for different curve number values is presented in Figure below.

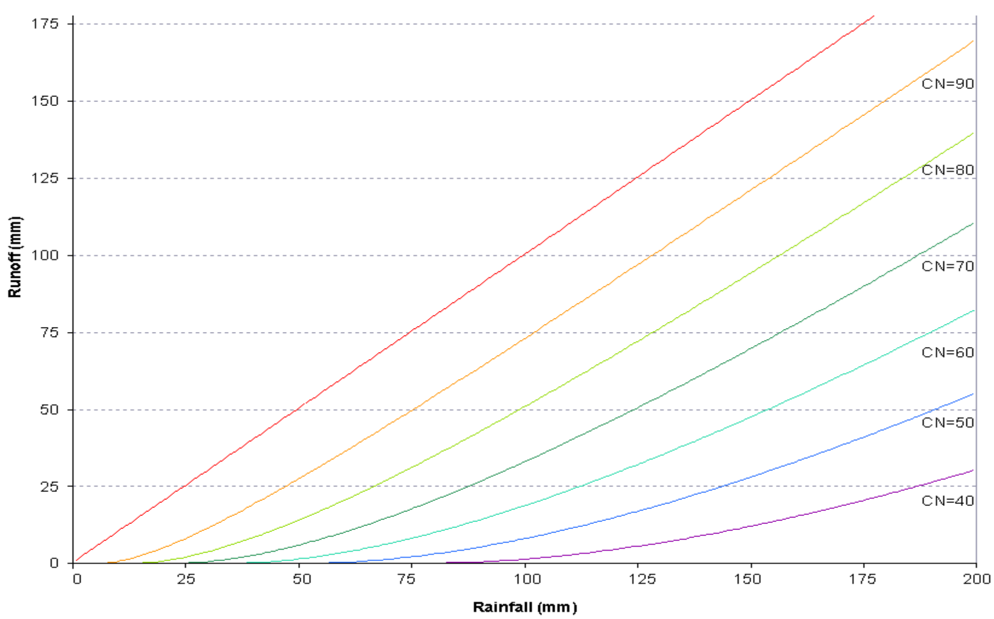

Figure 4.2 Relationship of runoff to rainfall in SCS Curve number method

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method.

The rational formula is:

$$q_{peak} = \frac{C \cdot i \cdot Area}{3.6} \qquad (4.5)$$

Where: q_{peak}: is the peak runoff rate (m3/s),

C: is the runoff coefficient, i- is the rainfall intensity (mm/hr),

Area- is the sub basin area (km^2) and

3.6 is a unit conversion factor.

4.1.3.2 Routing Phase of the Hydrologic Cycle

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure similar to that of HYMO (Williams and Hann, 1972). In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and streambed.

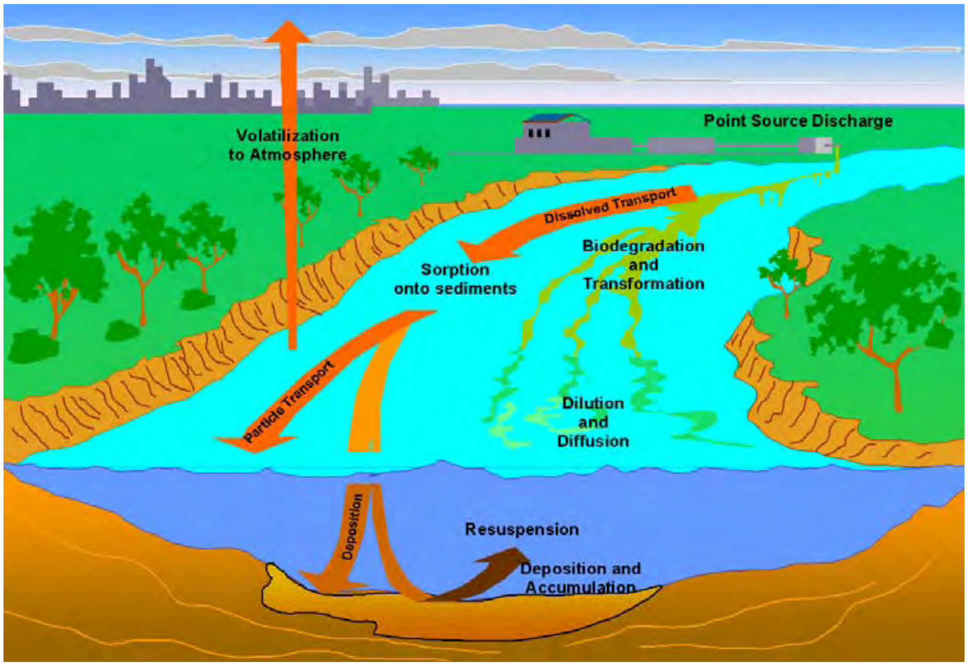

Figure 4.3 in stream processes modelled by SWAT

4.1.4 Soil Hydrologic Groups

The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS Soil Survey Staff (1996) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to seasonally high water table, saturated hydraulic conductivity, and depth to a very slowly permeable layer. Soil may be placed in one of four groups, A, B, C, and D, or three dual classes, A/D, B/D, and C/D.

Definitions of the classes are:

A: (Low runoff potential): The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They mainly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D: (High runoff potential): The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Dual hydrologic groups are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained. Only soils that are rated D in their natural condition are assigned to dual classes.

Mein and Larson (1973) developed a methodology for determining ponding time with infiltration using the Green & Ampt equation. The Green-Ampt Mein-Larson excess rainfall method was incorporated into SWAT to provide an alternative option for determining surface runoff. This method requires sub-daily precipitation data supplied by the user.

Time of Concentration: The time of concentration is the amount of time from the beginning of a rainfall event until the entire sub basin area is contributing to flow at the outlet. In other words, the time of concentration is the time for a drop of water to flow from the remotest point in the sub basin to the sub basin outlet. The time of concentration is calculated by summing the overland flow time (the time it takes for flow from the remotest point in the sub basin to reach the channel) and the channel flow time (the time it takes for flow in the upstream channels to reach the outlet):

$$t_{conc} = t_{ov} + t_{ch} \qquad (4.6)$$

Where: t_{conc} -is the time of concentration for a sub basin (hr),

t_{ov} -is the time of concentration for overland flow (hr), and

t_{ch} -is the time of concentration for channel flow (hr).

The overland flow time of concentration, t_{ov}, can be computed using the equation

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \qquad (4.7)$$

Where: L_{slp} -is the sub basin slope length (m),

v_{ov} -is the overland flow velocity (m/s) and 3600 is a unit conversion factor.

The overland flow velocity can be estimated from Manning's equation as follows:

$$V_{ov} = \frac{{q_{ov}}^{0.4} * Slp^{0.3}}{n^{0.6}} \qquad (4.8)$$

Where: q_{ov} is the average overland flow rate (m^3 /s),

slp is the average slope in the sub basin (m/m), and

n is Manning's roughness coefficient for the sub basin.

Assuming an average flow rate of 6.35mm/hr and converting units

$$V_{ov} = \frac{0.005 * {L_{slp}}^{0.4} * Slp^{0.3}}{n^{0.6}} \qquad (4.9)$$

From the above two equation we will get:

$$t_{ov} = \frac{{L_{slp}}^{0.6} * n^{0.6}}{18 * Slp^{0.3}} \qquad (4.10)$$

The channel flow time of concentration, t_{ch}, can be computed as follows:

$$t_{ch} = \frac{L_c}{3.6 * V_c} \qquad (4.11)$$

Where: L_c- is the average flow channel length for the sub basin (km),

v_c -is the average channel velocity (m/s), and

3.6 is a unit conversion factor.

The average channel flow length can be estimated using the equation

$$L_c = \sqrt{L * L_{cen}} \tag{4.12}$$

where: L- is the channel length from the most distant point to the sub basin outlet (km), and

Lcen -is the distance along the channel to the sub basin centroid (km).

Assuming, Lcen = 0.5*L, the average channel flow length is: L c = 0.71* L

The average velocity can be estimated from Manning's equation assuming a trapezoidal channel with 2:1 side slopes and a 10:1 bottom width-depth ratio.

$$V_c = \frac{0.489 * q_{ch}^{0.25} * slp_{ch}^{0.375}}{n^{0.75}} \tag{4.13}$$

Where: v_c -is the average channel velocity (m/s),

q_{ch} is the average channel flow rate (m3/s),

slp_{ch}- is the channel slope (m/m), and

n is Manning's roughness coefficient for the channel.

To express the average channel flow rate in units of mm/hr, the following expression is used:

$$q_{ch} = \frac{q_{ch}^{*} * Area}{3.6} \tag{4.14}$$

Where: q^*_{ch} -is the average channel flow rate (mm/ hr),

Area is the sub basin area (km^2), and

3.6 is a unit conversion factor.

The average channel flow rate is related to the unit source area flow rate (unit source area =1 ha)

$q_{ch}* = q_o* (100 \ \ Area)- 0.5$ (4.15)

Where: q_0* -is the unit source area flow rate (mm/ hr), and 100 is a unit conversion factor.

Assuming the unit source area flow rate is 6.35 mm/hr:

$$V_c = \frac{0.317 * Area^{0.125} * slp_{ch}^{0.375}}{n^{0.75}} \tag{4.16}$$

Substituting in the above equations we will get

$$t_{ch} = \frac{0.62 * L_c * n^{0.75}}{Area^{0.125} * slp_{ch}^{0.375}} \tag{4.17}$$

Runoff Coefficient: The runoff coefficient is the ratio of the inflow rate, i * Area, to the peak discharge rate, q_{peak}. The coefficient will vary from storm to storm and is calculated with the equation:

$$C = \frac{Q_{surf}}{R_{day}} \qquad (4.18)$$

Where: Q_{surf} is the surface runoff (mm H_2O) and R_{day} is the rainfall for the day (mm H_2O).

Rainfall Intensity: The rainfall intensity is the average rainfall rate during the time of concentration. Based on this definition, it can be calculated with the equation:

$$i = \frac{R_{tc}}{t_{conc}} \qquad (4.19)$$

Where: i is the rainfall intensity (mm/hr),

R_{tc} is the amount of rain falling during the time of concentration (mm H_2O), and

t_{conc} is the time of concentration for the sub basin (hr).

An analysis of rainfall data collected by Hershfield (1961) for different durations and frequencies showed that the amount of rain falling during the time of concentration was proportional to the amount of rain falling during the 24-hr period.

$$R_{tc} = \alpha_{tc} * R_{day} \qquad (4.20)$$

For short duration storms, all or most of the rain will fall during the time of concentration, causing α_{tc} to approach its upper limit of 1.0. The minimum value of α_{tc} would be seen in storms of uniform intensity (i24 = i). This minimum value can be defined by substituting the products of time and rainfall intensity into equation 4.20.

$$\alpha_{tc,\min} = \frac{R_{tc}}{R_{day}} = \frac{i * t_{conc}}{i_{24} * 24} = \frac{t_{conc}}{24} \qquad (4.21)$$

SWAT estimates the fraction of rain falling in the time of concentration as a function of the fraction of daily rain falling in the half-hour of highest intensity rainfall.

$$\alpha_{tc} = 1 - \exp\left[2 * t_{conc} * \ln\left(1 - \alpha_{0.5}\right)\right] \qquad (4.22)$$

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

t_{conc} is the time of concentration for the sub basin (hr).

The modified rational formula used to estimate peak flow rate is obtained as follows

$$q_{peak} = \frac{\alpha_{tc} * Q_{surf} * Area}{3.6 * t_{conc}} \qquad (4.23)$$

Surface Runoff Lag: In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated. SWAT incorporates a surface runoff storage feature to lag a portion of the surface runoff release to the main channel. Once surface runoff is calculated with the curve number or Green & Ampt method, the amount of surface runoff released to the main channel is calculated:

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1}) * \left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \qquad (4.24)$$

Where: Q_{surf} is the amount of surface runoff discharged to the main channel on a given day (mm H_2O),

Q'_{surf} is the amount of surface runoff generated in the sub basin on a given day (mm H_2O),

Q_{stor},i-1 is the surface runoff stored or lagged from the previous day (mm H_2O),

S_{urlag}- is the surface runoff lag coefficient, and

t_{conc} is the time of concentration for the sub basin (hrs).

Note that for a given time of concentration, as surlag decreases in value more water is held in storage. The delay in release of surface runoff will smooth the stream flow hydrograph simulated in the reach.

4.1.5 Potential Evapotranspiration (PET)

The model provides three methods for estimating potential evapotranspiration are also provided: Priestly-Taylor (Priestley and Taylor, 1972), Penman-Monteith (Monteith, 1965), and Hargreaves (Hargreaves and Riley, 1985). The Penman-Monteith method requires solar radiation, air temperature, wind speed and relative humidity. Priestley-Taylor method requires solar radiation, air temperature and relative humidity; where as Hargreves method requires air temperature only.

Priestley and Taylor (1972) used the following equation to estimate PET:

$$\lambda E_o = \alpha_{pet} * \frac{\Delta}{\Delta + \gamma}(H_{net} - G) \tag{4.25}$$

Where: λ is the latent heat of vaporization (MJ/kg),

E_o is the potential evapotranspiration (mm/day),

α_{pet} is a coefficient, ($\alpha pet = 1.28$ when the general surroundings are wet or under humid condition),

Δ is slope of saturation vapour pressure-temperature curve de/dT (kPa/°C),

γ is the psychrometric constant (kPa/°C),

H_{net} is the net radiation (MJ/m^{2}day), and

G is the heat flux density to the ground (MJ/m^{2}day).

The Hargreaves method (Hargreaves et al. 1985) of PET determination is based on the following equation:

$$\lambda E_o = 0.0023 * H_o * (T_{\max} - T_{\min})^{0.5} * (\bar{T}_{av} + 17.8) \tag{4.26}$$

Where: λ is the latent heat of vaporization (MJ/kg),

E_o is the potential evapotranspiration (mm/day),

H_0 is the extraterrestrial radiation (MJ/m2day),

T_{max} is the maximum air temperature for a given day (°C),

T_{min} is the minimum air temperature for a given day (°C), and

T_{av} is the mean air temperature for a given day (°C).

Percolation: Percolation is the downward movement of water in the soil and percolation is calculated for each soil layer. The percolation component uses a storage routing technique combined with crack flow model to predict flow in each soil layer. The volume of water available for percolation in the soil layer is calculated using equations:

$$SW_{ly.excess} = SW_{ly} - FC_{ly} \qquad \text{if} \quad SW_{ly} > FC_{ly}$$

$$SW_{ly,excess} = 0 \qquad \text{If} \quad SW_{ly} \leq FC_{ly} \tag{4.27}$$

Where: SW_{ly},excess is the drainable volume of water in the soil layers in a given day (mm),

SW_{ly} is the water content of the soil layer in a given day (mm), and

FC_{ly} is the water content of the soil layer at field capacity (mm). The amount of water that moves from one layer to the other calculated using the storage routing technique as:

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right) \tag{4.28}$$

Where: w_{percly} is the amount of water percolating to the underlying soil layer on a given day (mm),

SW_{ly},excess is the drainable volume of water in the soil layers in a given day (mm),

Δt is the length of the time step (hrs), and

TT_{per}c is the travel time for percolation (hrs).

The travel time for percolation computed for each soil layer using the linear storage equation:

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}} \tag{4.29}$$

Where: TTperc is the travel time for percolation (hrs),

SAT_{ly} is the amount of water when the soil layer is completely saturated (mm),

FC_{ly} is the water content of the soil layer at field capacity (mm) and

K_{sat} is the saturated hydraulic conductivity of the soil layer (mmh^{-1}).

4.2 Erosion

Erosion is the wearing down of a landscape over time. It includes the detachment, transport, and deposition of soil particles by the erosive forces of raindrops and surface flow of water.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

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

MUSLE: The modified universal soil loss equation (Williams, 1995) is:

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \qquad (4.30)$$

Where: sed- is the sediment yield on a given day (metric tons),

Q_{surf} is the surface runoff volume (mm H_2O/ha),

q_{peak} is the peak runoff rate (m^3/s),

$area_{hru}$ is the area of the HRU (ha),

K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr / (m^3-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

CFRG is the coarse fragment factor.

5. MODEL DATA PREPARATION

5.1 Model Inputs

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

Measured daily rainfall, temperature, solar radiation, wind speed and relative humidity for the study area are used in the model. Missed data for daily rainfall, temperature, solar radiation, wind speed and relative humidity are estimated using the weather generator in SWAT by generating code "-99".

An ArcView GIS interface (AVSWAT) is available to generate model inputs from GIS data (DiLuzio et al. 2001). AVSWAT processes mapped land use and soils data as well as a Digital Elevation Model (DEM) to create a set of default model input files.

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

5.1.1 Digital Elevation Model (DEM)

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A digital elevation model is needed for raster-based hydrological analysis in a GIS. A 90m by 90m resolution of DEM was obtained from Water Works Design and Supervision Enterprise GIS department. The DEM was in the format of STRM and this was processed on Global Mapper software. After the processing is completed it was exported and imported to ArcView GIS environment. Finally this DEM of Karadobi was clipped from the processed Blue Nile and used for SWAT DEM input.

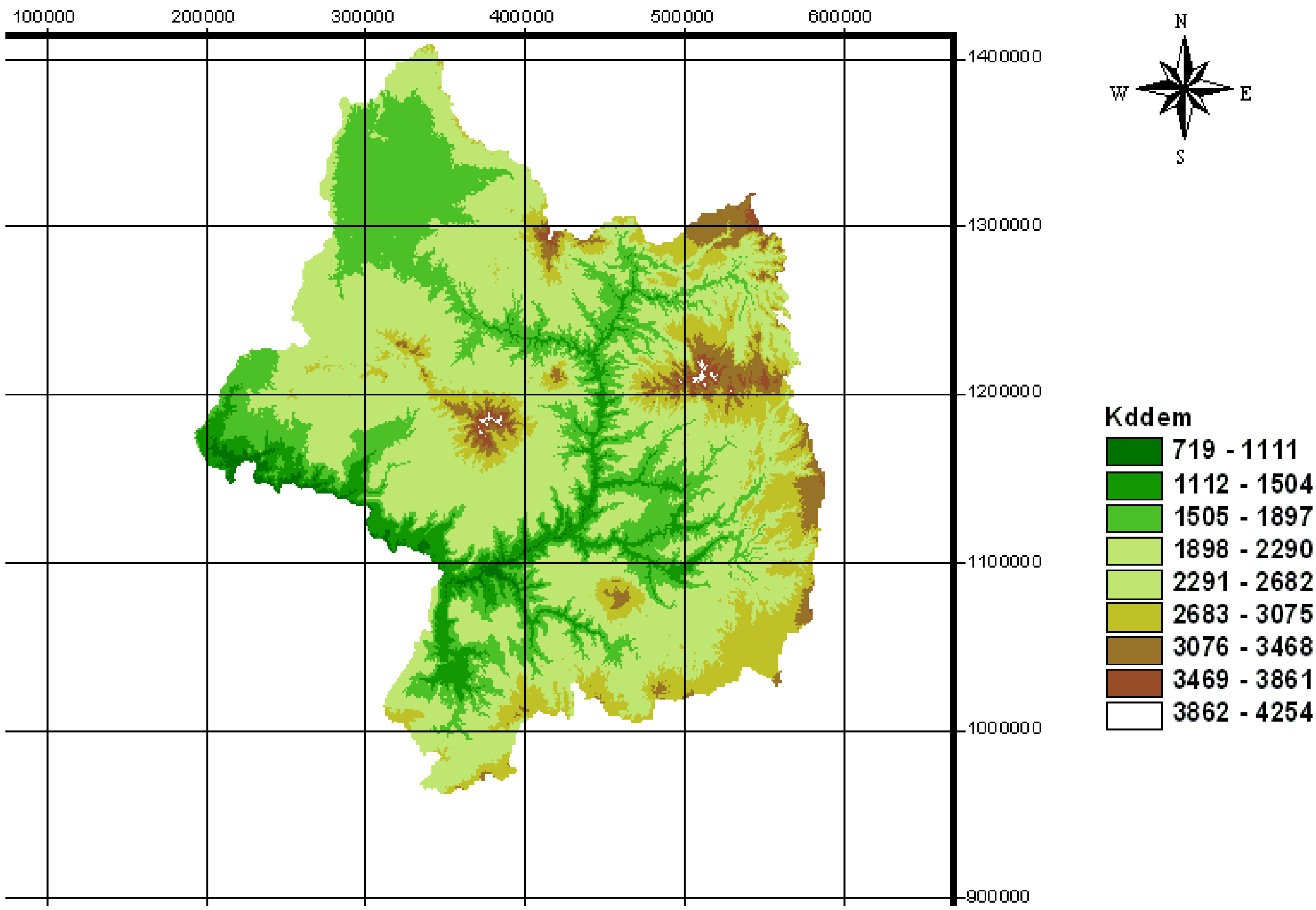

Figure 4 .4 Digital Elevation Model (DEM) of Karadobi

Projection	Custom Transverse Mercator
Spheroid	WGS-84
Datum	GCS
Zone	37
Central Meridian	39
Reference Latitude	0
False Northing	0
False Easting	500000
Scale factor	0.9996

Table 4. 1 Projection of map for Blue Nile Ethiopia,

5.1.2 Land Use/Cover map

Land cover and soil are factors greatly influencing the hydrological properties of a watershed that are required by SWAT to describe a sub-basin or HRU. Once watershed topographic parameters have been computed for each sub basin, the interface uses land cover and soils data to generate multiple hydrologic response units (HRUs) within each sub basin by GIS overlay process to assign soil parameters and SCS curve numbers. HRUs are lumped land areas within the sub watershed that are comprised of distinctive land cover, soil, and management combinations (Neitsch et al., 2002). Such subdivision of sub-basins in to HRUs enables the SWAT model to reflect the spatial variations of the hydrologic conditions for different land cover and soil distributions within the sub-basins.

The land use map was obtained from ministry of water resources in the format of shape file. In addition further physical properties of different land cover parameters were collected from Abbay River basin Integrated Development master plan project, 1998. The remaining parameters which are not defined by user would be assigned by the model itself as default value from data base of USA land cover. This land classification is as FAO's classification; hence it is required to convert to format as required by SWAT model. Similarly to the DEM the land use map of Karadobi was clipped from the Blue Nile. While preparing the lookup-table, the land use types were made compatible with the input needs of the model.

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Table 4.2 Land use classification of SWAT

S.No.	SWAT land use	Area (Ha)	% of watershed	SWAT code
1	Agricultural close grown	2903248	36.25	AGRC
2	Agricultural Generic	4011478	50.09	AGRL
3	Forest mixed	98176	1.23	FRST
4	Summer Pasture	3284	0.04	SPAS
5	pastoral	552851	6.9	PAST
6	Forest Deciduous	14625	0.18	FRSD
7	Corn	46230	0.58	CORN
8	wetlands, non forested	69054	0.86	WETN
9	Residential-Med/Low Density	5221	0.07	URML
10	water land	304337	3.80	WATR
	Total	8008504	100	

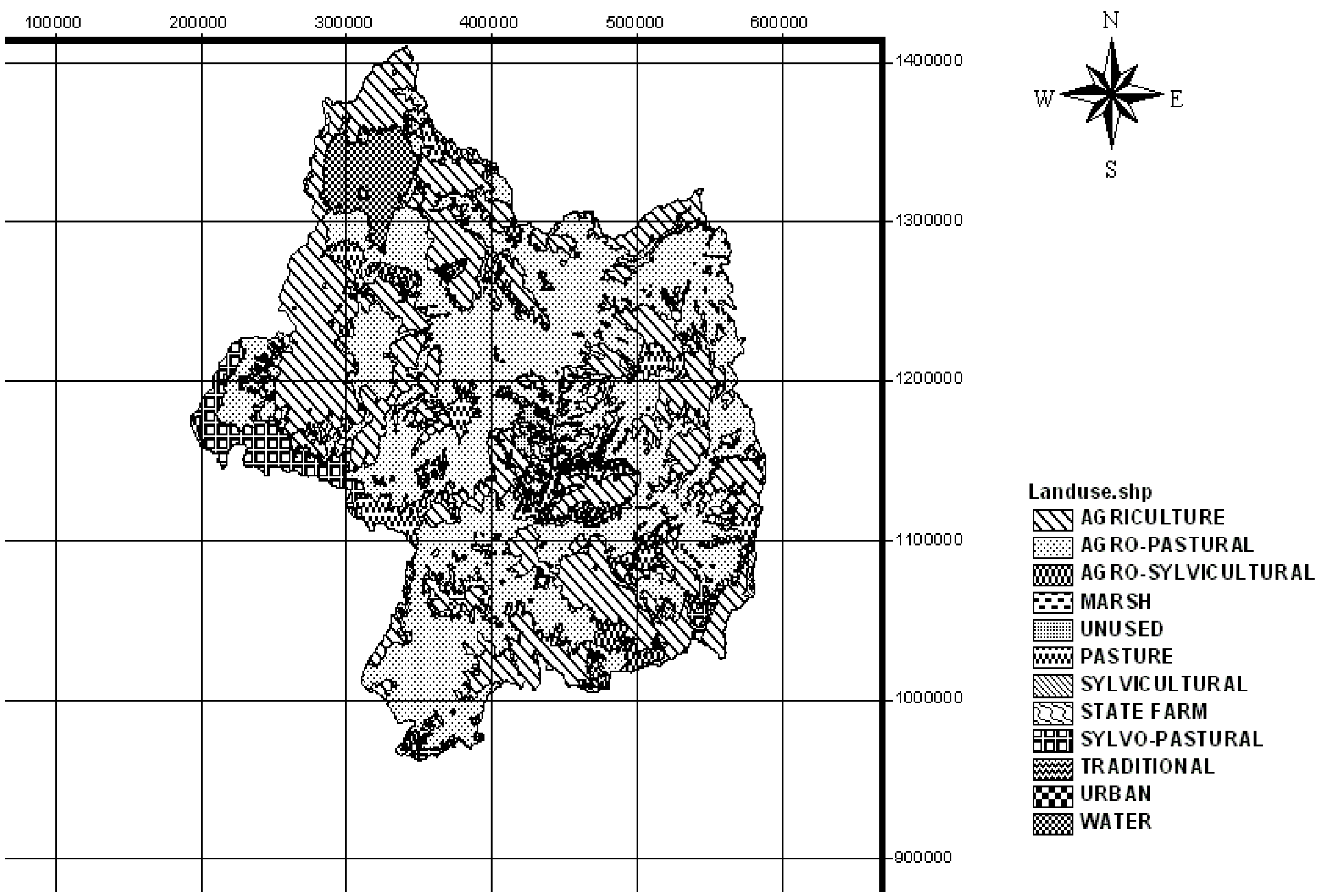

Figure 4. 5 Land use map of Karadobi

5.1.3 Soil Map

The soil map of Blue Nile was obtained from ministry of water resources in the shape format. But the SWAT interface parameters were collected from Abay River basin Integrated development master plan project, 1998.

In order to integrate the soil map within the SWAT model, it is necessary to make a User Soil Database, which contains textural properties and physicochemical properties for each soil layers. Like the DEM and land use the soil map of Karadobi is clipped from the Blue Nile.

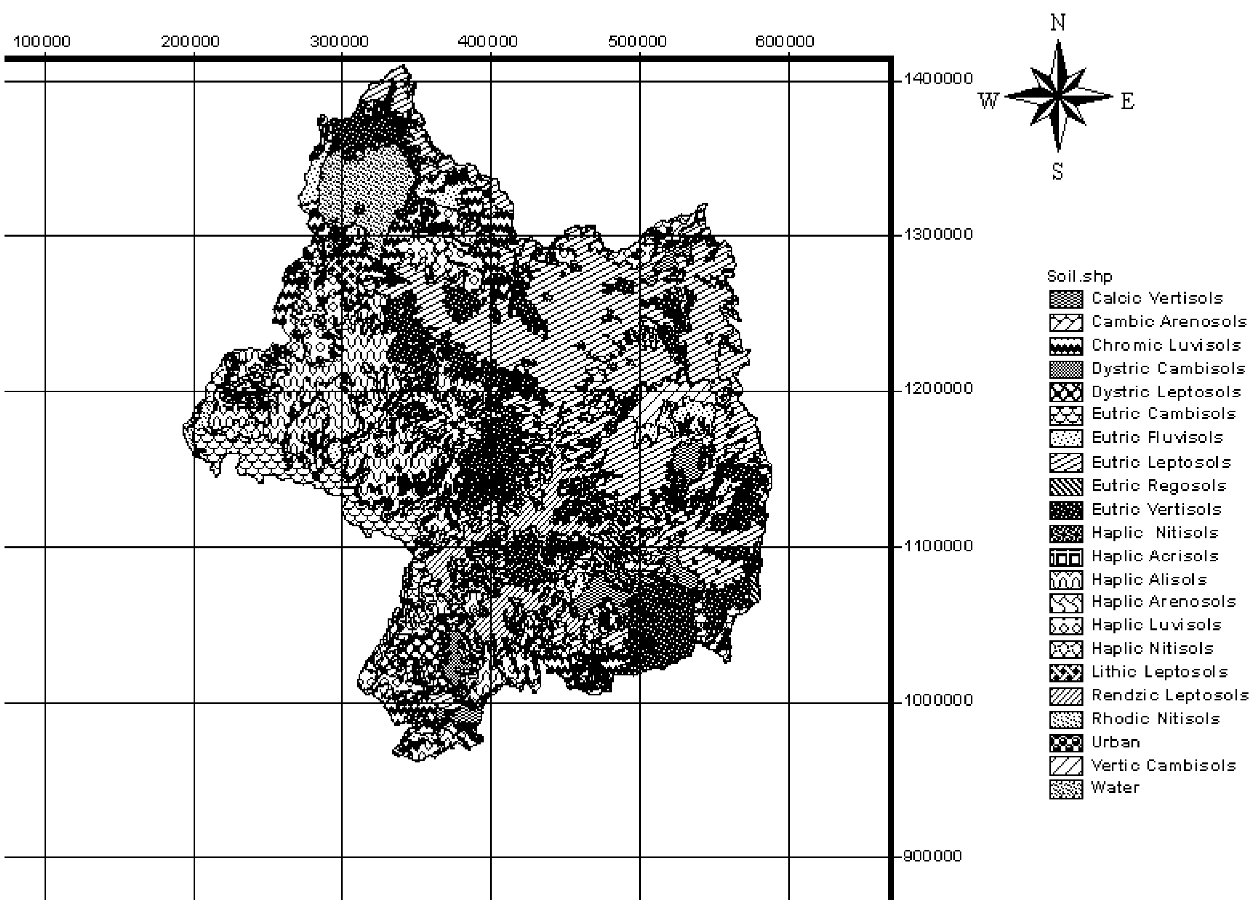

Figure 4. 6 Soil map of Karadobi

Soil type	Area(Ha)	% of Swat
LPk	530288	6.62
LPq	45668	0.57
LVx	417246	5.21
FLe	453318	5.66
ARb	60476	0.76
ARh	22305	0.28
ALh	388014	4.85
NSh	33658	0.42
VRc	225908	2.82
VRe	1131215	14.13
CMd	40872	0.51
CMe	322104	4.02
NTh	83154	1.04
RGe	133610	1.67
NTr	26757	0.33
U	3373	0.04
W	304281	3.80
CMv	105064	1.31
LVh	583750	7.29
LPd	98345.	1.23
LPe	2999097	37.45
Total	8008504	100

Table 4.3 Soil type classification of SWAT and area coverage

5.1.4 Watershed Delineation

The subdivision of a watershed into discrete sub-watershed areas enables the modelling process to characterize the heterogeneity of the watershed. SWAT works on a sub-basin basis and the interface delineates the watershed in to such sub-basins or sub-watersheds based on topographic information. The Blue Nile basin delineation was performed based on topographic information of basins obtained from different sources in the form of digital elevation model (DEM) with X-Y resolution of 90m using a procedure of SWAT 2003. The catchment's water shed was delineated by fixing the outlet point at the centre of the dam axis.

The size of sub-basin in the watershed will affect the assumption of homogeneity. Hence, definition of watershed, sub-basin boundaries and streams is decided by selecting a threshold area or the minimum drainage area to define streams. Configuration of a lot of sub-basin requires a long time simulation period and even difficult to run. On the other hand, too small number of sub-watershed could affect the simulation results by ignoring spatial variability and lumps watershed condition together. Based on this the watershed was divided into 75 sub-basins and 293 HRUs.

5.1.5 Weather Data

The weather data are the main input variables data for SWAT simulation. These data are in daily based long year of many stations as much as possible. They are precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. On top of these data statistical analysis of monthly daily average, standard deviations, and probability of wet and dry days, skewness coefficients and dew temperature were determined by FORTRAN program known as WXGenParm (J.R. Williams, 1991) and program dew02.exe (S. Liersch, 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.

The rainfall data was taken from the National metrology service Agency. The obtained rainfall values are on daily basis. The SWAT model requires daily rainfall data arranged vertically parallel to time series. The missing data are given a value of “-99” so that swat generates and fills from the weather generator.

Similar to the rainfall the temperature data was taken from the National metrology service Agency. The maximum and minimum daily temperature is arranged downward parallel to corresponding date of record. Nineteen (19) stations data have been collected and analyzed, the missing data again assigned” -99” value to be filled by SWAT

SWAT takes data of each climatic variable for every sub basin from the nearest weather station measured from the centroid of the sub basin.

5.1.6 Evaporation Data

Data of evaporation and evapo-transpiration is the main parameter provided for SWAT model simulation. It has two options, either loading measured evaporation data or choosing the methods for SWAT simulation.

There are three methods of Evaporation determination by SWAT model itself: Prestily-Taylor method, Penman-Monteith method and Hargreves methods. Penman-Monteith methods requires all climate data, Prestily method only depends on radiation data and Hargreves method uses maximum and minimum temperature data to determine potential evaporation (PET) and actual evapotranspiration (ET). For this study, since there is humidity, wind speed and solar radiation data limitation for some basins compared to temperature data, Hargreves method was chosen for simulation of evaporation and evapo-transpiration by SWAT model.

5.2 Sensitivity Analysis

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Model sensitivity is defined as the change in model output per change in parameter input. Sensitivity analysis describes how model output varies over a range of a given input variable. Some researchers noted that sensitivity analysis and calibration are difficult with large number of parameters. Hamby (1994) reviewed more than a dozen sensitivity analysis techniques. In general an important aim of the parameter sensitivity analysis is to allow the possible reduction in the number of parameters that must be estimated, thereby reducing the computational time required for model calibration.

The current version of SWAT model provides the algorithmic techniques for sensitivity analysis. Model parameters that have high sensitivity must be chosen with care because small variations in their values can cause large variations in model output, and therefore it is important to ensure that the parameter value is the best possible estimate. Model parameters that have low sensitivity do not require as much examination in their selection because small changes in their values do not cause large changes in model output.

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) design and was proposed by Morris (1991).

5.3 Model Efficiency

Two methods 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 coefficient) and the Nash-Suttcliffe simulation efficiency (E_{NS}) (Nash and Suttcliffe 1970).

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:

$$r^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - \overline{q}_s)(q_{oi} - \overline{q}_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - \overline{q}_s)^2 \sum_{i=1}^{n}(q_{oi} - \overline{q}_o)^2}$$

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)

$\overline{q}_s$ is the average simulated value of the quantity in each model time step (in this case, monthly and yearly)

$\overline{q}_o$ -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 (Santhi et al. 2002). It is calculated as follows with the same variables defined above:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (q_{oi} - q_{si})^2}{\sum_{i=1}^{n} (q_{oi} - \overline{q}_o)^2}$$

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 modelling 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.

5.4 Model Calibration and Validation

5.4.1 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 (Neitsch, 2002) at different spatial and temporal scales.

Parameter estimation for calibration is various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behaviour to that of the watershed. The process of adjustment can be done “manually” or using computer-based “automatic” methods. Refsgaard and Storm (1996) argued that the manual method is the most common, and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite. In sediment transporting modelling a two step calibration procedures has been suggested by Neitsch et al. (2002), first check water balance contribution, then calibrate stream flow and followed by sediment calibration.

Calibration of stream flow and sediment carried out at outlet of sub basin 45 (near Kessie). 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 65 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.

5.4.2 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 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.

6. RESULTS AND DISCUSSION

6.1 Sensitivity Analysis

For the Karadobi catchment sensitivity analysis was carried out at kessie. The simulation of model was from Jan, 1991-Dec to Dec 1996. The simulation result from Jan 1991 to Dec 1991 is used as model warm up period and from 1992-1996 as calibration period. Finally the period from Jan 1997 - Dec 2000 was used as model validation time.

About 280 iteration have been done by SWAT sensitivity analysis at the site of Kessie for flow calibration with the out put of 20 parameters were reported as sensitive in different degree of sensitivity for flow. Among these 20 parameters, only 6 of them have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to medium of sensitivity class as shown in table 6.1.

Similarly About 340 iteration have been done by SWAT sensitivity analysis at the site of Kessie for sediment calibration with the out put of 23 parameters were reported as sensitive in different degree of sensitivity for sediment. Among these 23 parameters, 10 of them have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to medium of sensitivity class as shown in table 6.5.

Parameter	Value	Rank
CN_2	0.160E+01	1
ESCO	0.276E+00	2
sol_k	0.263E+00	3
SOL_AWC	0.251E+00	4
sol_z	0.103E+00	5
GWQMN	0.700E-01	6
BIOMIX	0.367E-01	7
rchrg_dp	0.195E-01	8
epco	0.165E-01	9
canmx	0.117E-01	10
GW_REVAP	0.965E-02	11
surlag	0.872E-02	12
CH_K2	0.431E-02	13
SLOPE	0.269E-02	14
ALPHA_BF	0.183E-02	15
sol_alb	0.180E-02	16
SLSUBBSN	0.176E-02	17
ch_n	0.834E-03	18
GW_DELAY	0.395E-03	19
REVAPMN	0.114E-03	20

Table 6.1 Sensitive Parameters for flow at Kessie

6.2 Flow Calibration and Validation

6.2.1 Flow Calibration

After sensitivity analysis has been carried out, the calibration of SWAT model simulated stream flow at kessie was done manually. 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 (Grizzetti, et al., 2003.)

Parameter	Recommended range	Initial value	Calibrated value
CN_2	±50%	Default *	-45%
ESCO	0.0 -1.0	0.95	0.05
sol_k	±50%	**	-48%
SOL_AWC	±50%	**	-20%
sol_z	±50%	**	-20%
GWQMN	0.0-5000	**	4900

Table 6. 2 Calibrated Parameters for flow at Kessie

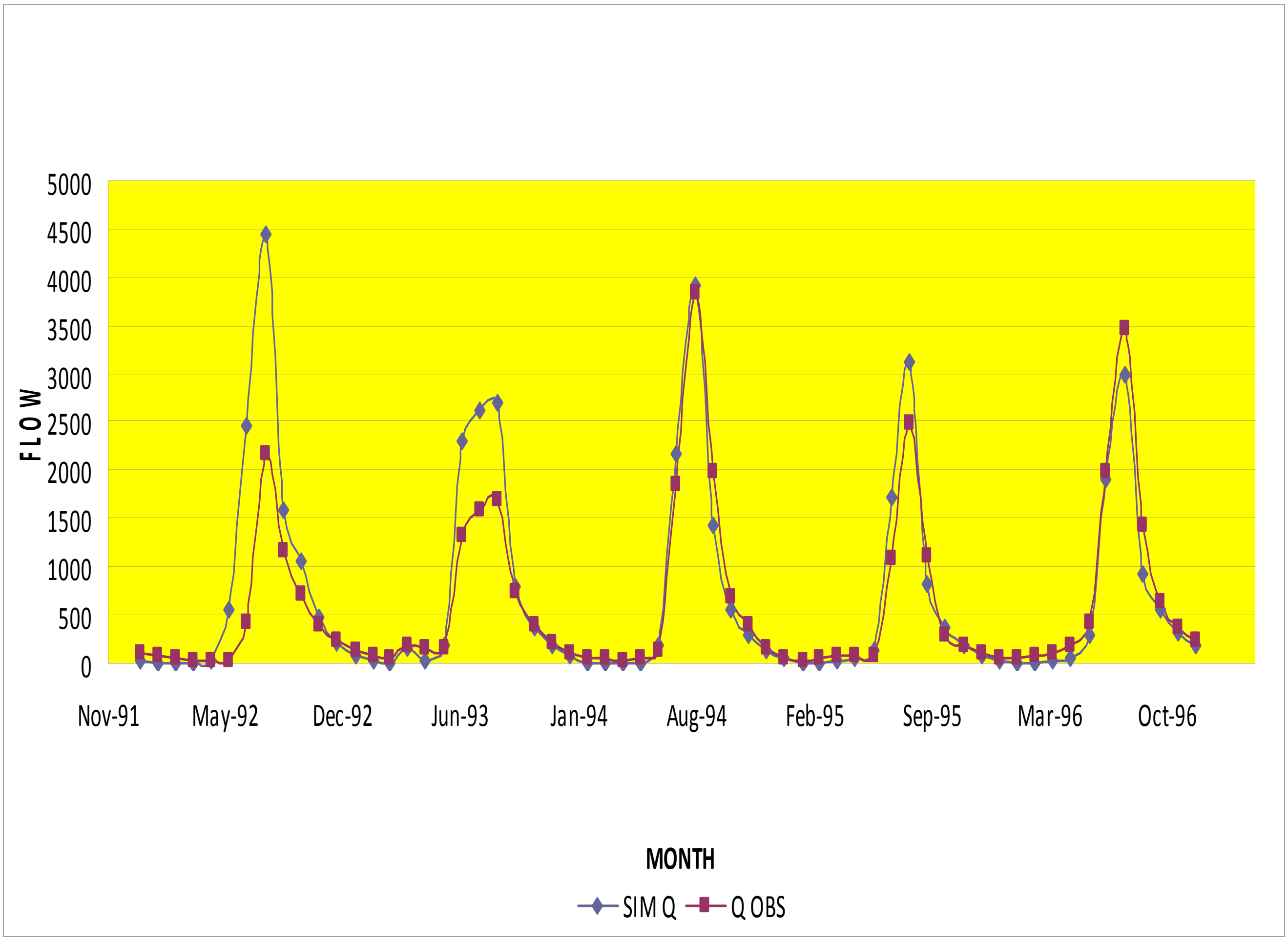

Figure 6.1 Simulated & measured stream flow at Kessie (calibration)

Time	Average Flow(m^3/s)		Model Efficiency (Monthly)	
	Simulated	Measured	r^2	N_{SH}
1992-1996	716.50	602.19	0.81	0.70

Table 6.3 simulated & observed flow at Kessie (Calibration)

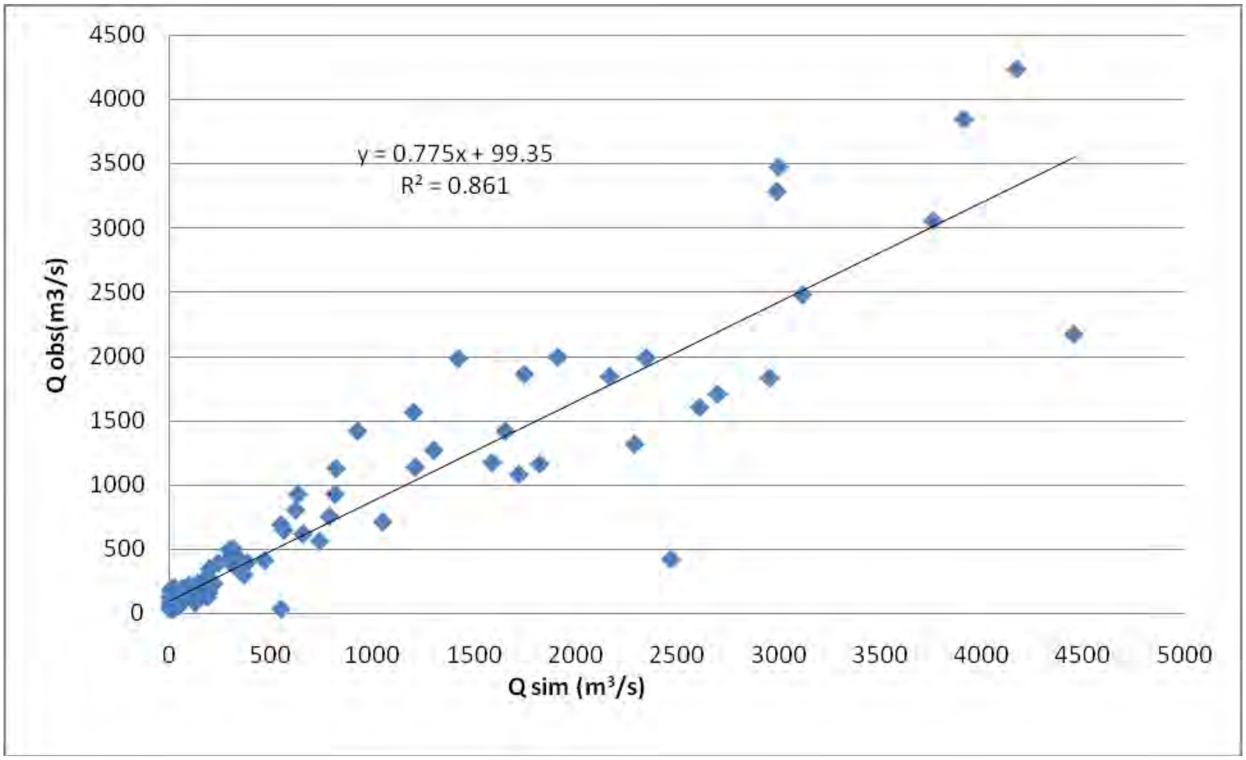

Figure 6. 2 1: 1 fit line of measured & simulated flow at Kessie

6.2.2 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 year Jan, 1997 to Dec, 2000. The site of validation is Kessie.

Like calibration, the two above-mentioned goodness-of-fit measures are calculated and model-to-data plots are checked.

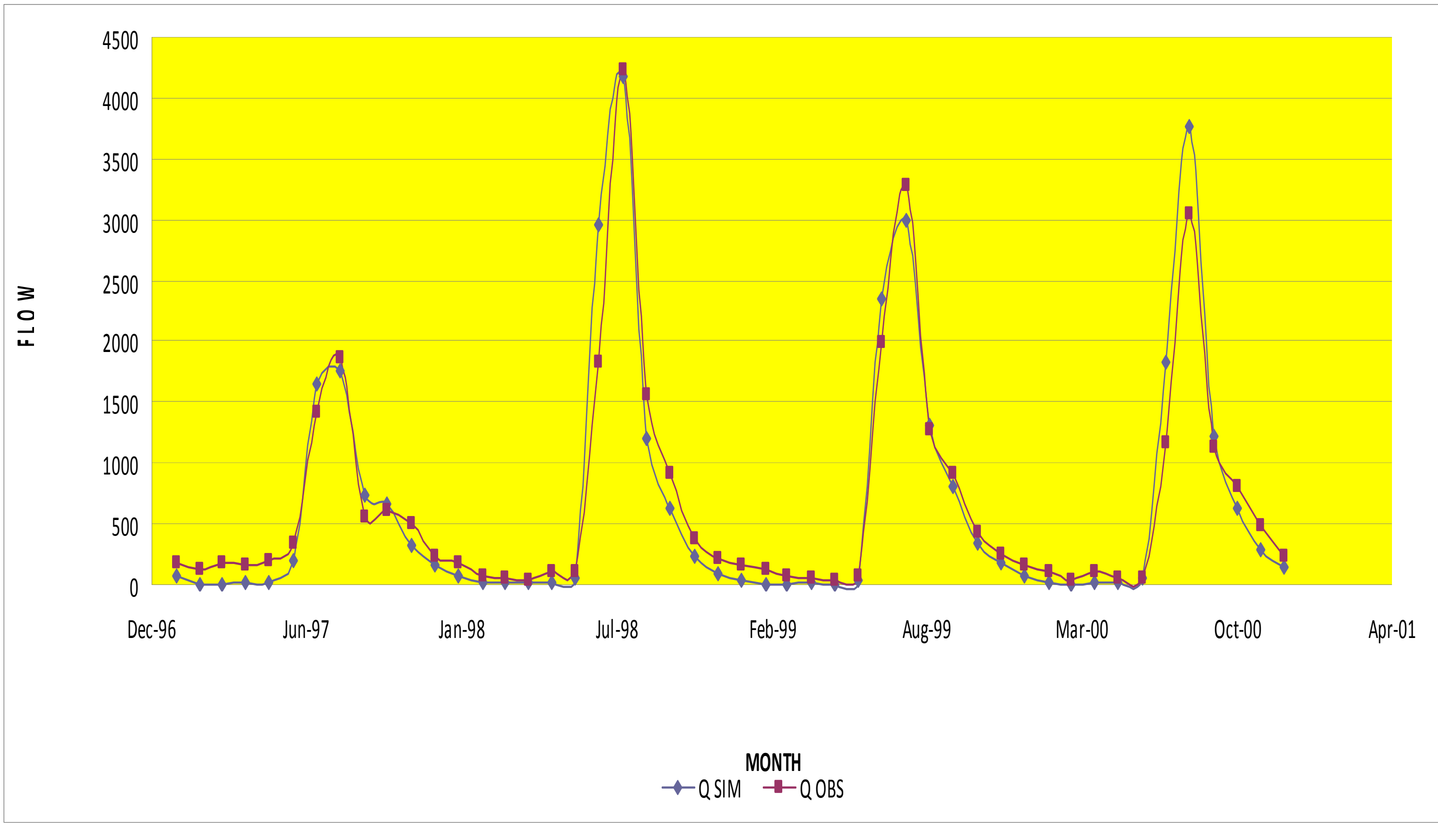

Figure 6. 3 f measured & simulated flow at Kessie(validation)

Time	Average Flow (m³/s)		Model Efficiency (Monthly)	
	Simulated	Measured	r^2	E_{NS}
1992-1996	649.82	668.57	0.95	0.93

Table 6.4 Simulated & Observed flow at Kessie (validation)

6.3 Sediment Calibration and Validation

The SWAT calibration for the sediment load was conducted after the model was calibrated and validated for the streamflow.

SWAT model was first calibrated and validated to flows, then to sediment. The model was calibrated for sediment by comparing monthly model simulated sediment load against monthly measured sediment load from Kessie station for the period 1992 to 1996.

The SWAT model was found to simulate well on monthly basis of sediment load. Coefficient of determination (r^2) value and Nash-Sutcliffe model efficiency (E_{NS}) statistic computed between the simulated and observed monthly sediment loads for the calibration periods are 0.79 and 0.74 respectively. The sediment calibration results displayed a 20 % difference between the simulated and average observed monthly load. Calibration results show that model performance is good with simulation of monthly sediment load.

After calibration then SWAT model was validated to sediment for the period 1997 to 2000 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

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 0.89 and 0.85 respectively.

Paramter	description	Rank	Sensitiveness Value
BIOMIX	Biological mixing efficiency	1	0.205E+01
SLOPE	Average slope steepness [m/m]	2	0.153E+01
ALPHA_BF	Base flow alpha factor [days]	3	0.152E+01
SPCON		4	0.135E+01
surlag	Surface runoff lag time [days]	5	0.134E+01
sol_z	Soil depth [mm]	6	0.123E+01
sol_k	Saturated hydraulic conductivity [mm/hr]	7	0.852E+00
USLE_P	USLE support practice factor	8	0.797E+00
SOL_AWC	Soil available water capacity [mm WATER/mm soil]	9	0.786E+00
SLSUBBSN	Average slope length [m];	10	0.624E+00
ESCO	oil evaporation compensation factor	11	0.416E+00
USLE_C	Minimum USLE cover factor	12	0.349E+00
CN2	Initial SCS CN II value	13	0.286E+00
CH_K2	Channel effective hydraulic conductivity [mm/hr]	14	0.248E+00
canmx	Maximum canopy storage [mm]	15	0.956E-01
ch_n	Manning's n value for main channel	16	0.691E-01
sol_alb	Soil albedo	17	0.640E-01
GWQMN	Threshold water depth in the shallow aquifer for flow [mm]	18	0.565E-01
SPEXP	Exponential factor for channel sediment routing	19	0.504E-01
epco	Plant uptake compensation factor	20	0.474E-01
REVAPMN		21	0.163E-01
rchrg_dp	Deep aquifer percolation fraction	22	0.140E-01
GW_REVAP	Groundwater "revap" coefficient	23	0.736E-02

Table 6. 5 Sensitive Parameters for Sediment at Kessie.

Parameter	Recommended range	Initial value	Calibrated value
BIOMIX	0-1	0.001	0.1
SLOPE	-50 to +50%	**	+15
ALPHA_BF	0-1	0.048	0.1
SPCON	0-0.01	0.001	0.01
surlag	0-10	4	9
sol_z	-50 to +50%	**	+20
sol_k	-50 to +50%	**	-20
USLE_P	-50 to +50%	**	+10
SOL_AWC	-50 to +50%	**	+15
SLSUBBSN	-50 to +50%	**	+20

Table 6. 6 Calibrated Parameters for Sediment at Kessie.

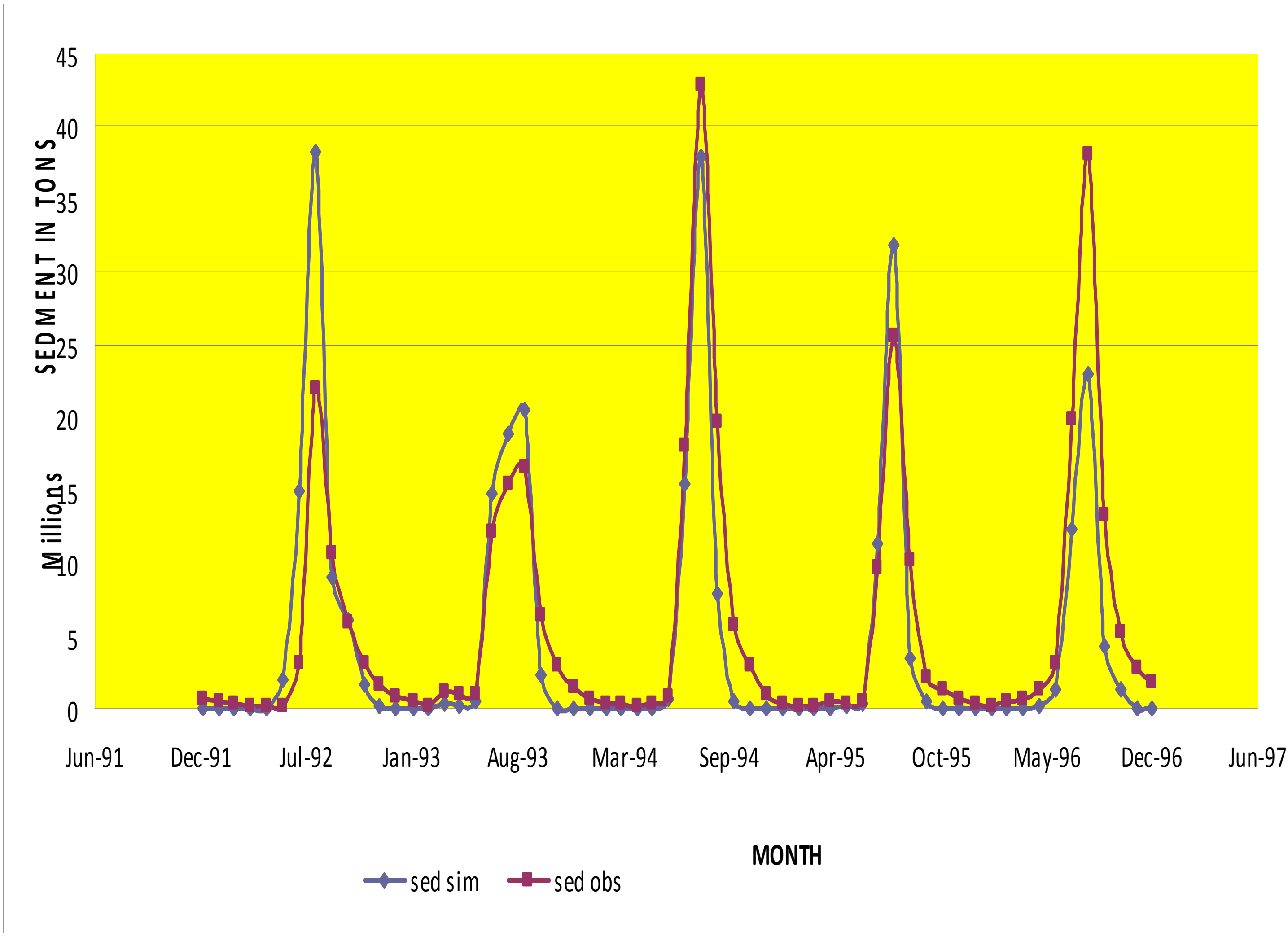

Figure 6.4 Simulated& measured sediment at Kessie (calibration)

Time	**Average sediment load (t/month)**		**Model Efficiency (Monthly)**	
	Simulated	Measured	r^2	N_{SH}
1992-1996	4693718	5657185	0.79	0.74

Table 6.7simulated & observed sediment at Kessie (calibration)

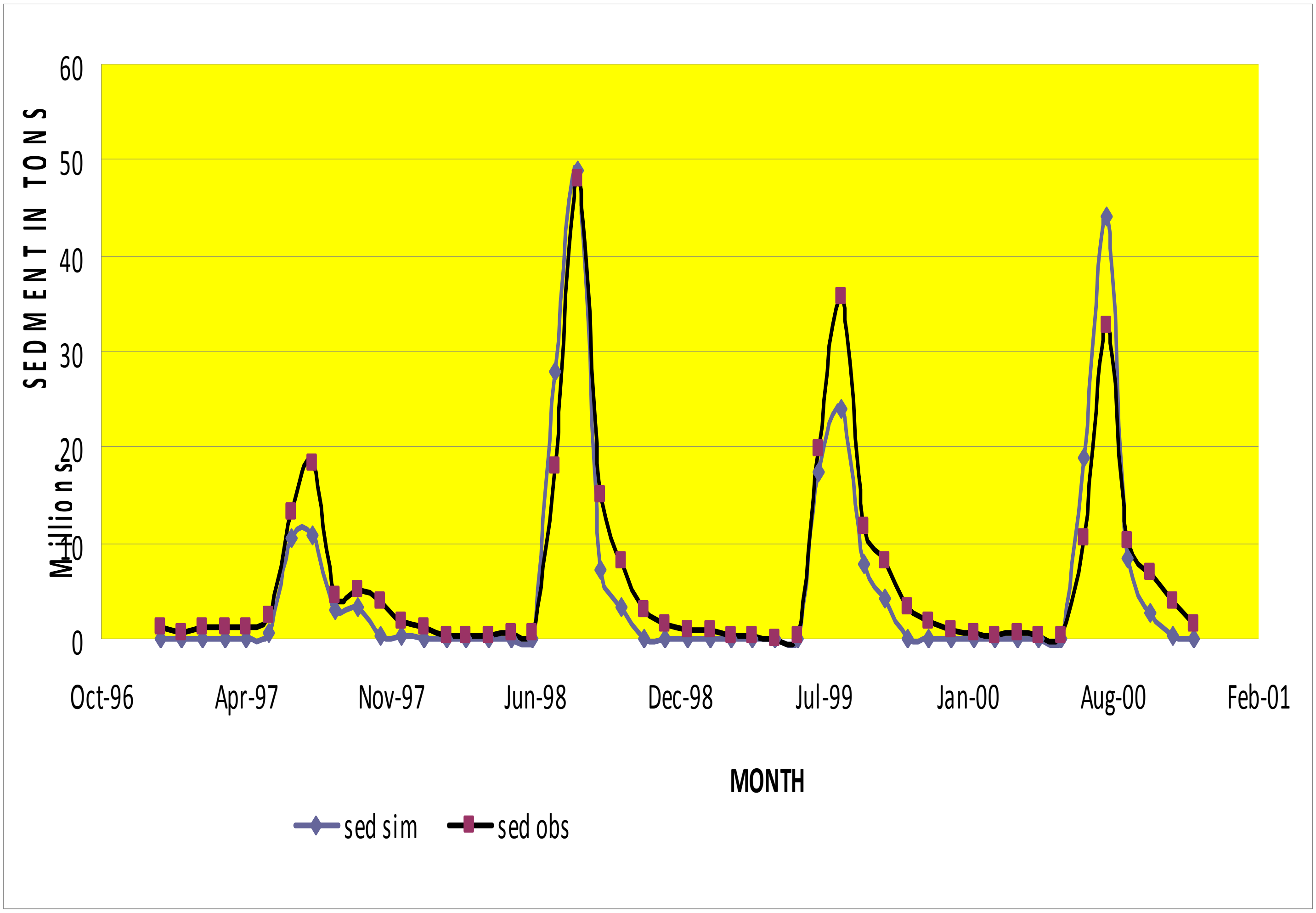

Figure 6. 8 Simulated &. Measured sediment at Kessie

Time	Average sediment load (t/month)		Model Efficiency (Monthly)	
	Simulated	Measured	r^2	N_{SH}
1992-1996	5104772	6437426	0.89	0.85

Table 6.8 Simulated & observed sediment at Kessie (validation)

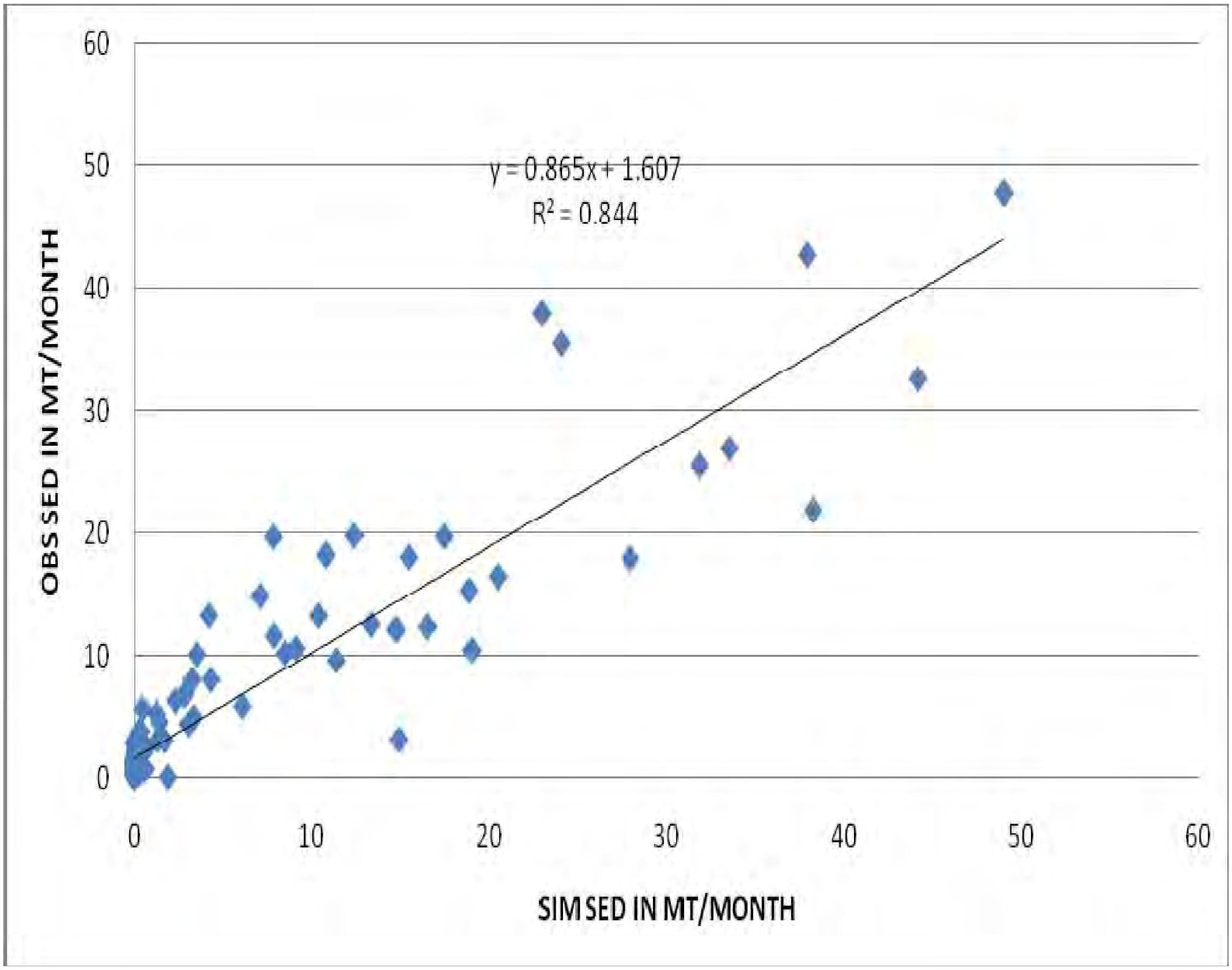

Figure 6. 5 1:1 fit line of measured Vs simulated sediment load at Kessie

With the existing land use pattern the sediment yield from the catchment in the years 1992 to 2000 was found to be **0.75** ton/ha/month which is equal to **8.98** ton/ha/year and **0.71** ton/ha/month and **8.55** ton/ha/year at Kessie and Karadobi respectvely.Norplan has studied on Karadobi multi project pre-feasibility the annual sediment concentration to be in the range of **7.2** t/ha and **11.5** t/ha. BCEOM has estimated the annual sediment concentration to be **7.51** t/ha on the Abbay Rive Basin Integrated Development Master Plan Project Phase II. When we compare these values with the model output it is possible to conclude that SWAT has well estimated the sediment load in the reach and sediment yield of the sub-basins.

Karadobi Reservoir Sedimentation			
Parameter	Karadobi Study(Norplan) Result		Simulated with SWAT
	Low	High	
Specific Sediment Yield(T/Km^2-a)	720	1150	855
Total Sediment(MT/a)	59.21	94.56	70.31
Sediment Deposition			
After 25 Years(Mm^3)	1322	2111	1575
After 50 Years(Mm^3)	2643	4222	3150
After 100 Years(Mm^3)	5286	8443	6300
Depletion of Active Storage in 50 Years (%)	6.57	10.50	7.84

Table 6.9 comparison of simulated & Norplan values of Karadobi Reservoir sedimentation.

6.4 Developing Scenarios

In order to analyze the effect of different land use activities in the upper catchments of the basin, which are increasing in the area due to the population pressure, on water quantity and sedimentation in relation to land use changes and management practices, it is necessary to develop scenarios.

Scenario analysis is a process of evaluating possible future events through the consideration of alternative possible outcomes (scenarios). The analysis is designed to enable improved decision-making and assessment through a more complete consideration of possible outcomes and their implications. The development of strategies for water resources planning and management and the assessment of impacts of potential environmental change are often guided by analyzing various future scenarios. The scenarios are developed based on the possible future activities considered in the master plan.

Therefore, in order to use model as a tool for analyzing the effects of different land use changes on sediment yield in the study area, the following scenarios were developed and the parameters for these scenarios were incorporated in the management input data.

1. 60 % of pasture land is changed to agricultural land.
2. 90 % of forest is changed to agricultural land.
3. 10 % of agro pastoral land is changed to agricultural land.
4. 20 % of agro pastoral land is changed to agricultural land.

Depending on the above land use scenarios the amount and variation from the original sediment yield is analysed.

Month	Original	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Monthly Average(t)	5707555	5715341	5715341	6448073	9224225
Annual(t)	68490662	68584091	68584091	77376881	110690695
Yield(T/Ha-a)	8.55	8.56	8.56	9.66	13.82
% Change of Sediment	0	0.14	0.13	12.97	61.61

Table 6.10 Amount of sediment change due to land use changes.

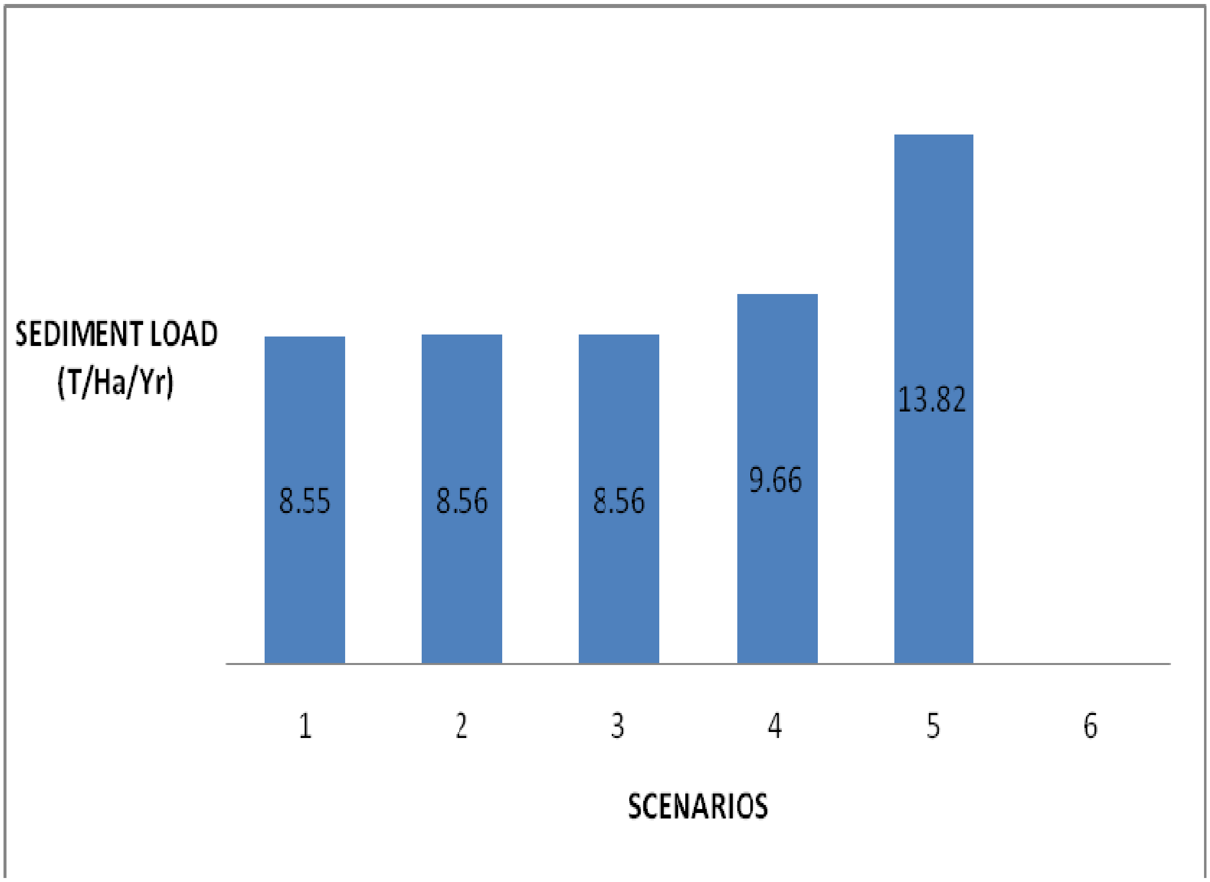

Fig 6.7 graphical comparison for sediment of the four scenarios

1=original

2= scenario 1

3=scenario 2

4=scenario 3

5=scenario 4

7. CONCLUSIONS AND RECOMMENDATION

7.1 Conclusion

The main objective of this thesis is to analyze the impact of land use changes on Karadobi reservoir sedimentation. In addition to this, the aim is to come across the amount of sediment load under different land use scenarios and these are attained in the paper.

As it is looked from the model performance efficiency indicators, regression coefficient (r^2) and the Nash-Sutcliffe (E_{NS}) are found to be 0.81 and 0.70 in calibration and 0.95 and 0.93 in validation for flow analysis. Similarly, sediment model efficiency indicators r^2 and E_{NS} 0.79 and 0.74 for calibration and 0.89 and 0.85 in validation respectively. This shows that, the SWAT model simulates well both for stream flow and sediment yield/load in the Karadobi catchment and particularly for Karadobi multipurpose project reservoir.

The SWAT model is a good approach to deal with sediment load and sediment concentration as the model considers the factors affecting soil erosion and sediment transport and this was observed in this thesis work. At initial stage before calibration, the model efficiency is poor and finally by fine adjustment of parameters affecting stream flow and sediment yield respectively, a good result was achieved. The calibration of these parameters was done manually as automatic calibration requests extraordinary computers which I could not get. Once the model is calibrated different scenarios are developed and corresponding results are analyzed.

The parameters mostly sensitive to change for calibration of stream flow are the curve number (CN_2), soil evaporation compensation factor (ESCO), and soil available water capacity (SOL_AWC). Similarly, in the sediment yield calibration, biological mixing efficiency (Biomix), HRU slope and base flow alpha factor (ALPHA_BF) are found to be the most sensitive parameters and are adjusted manually till the simulation is good fit to the measured sediment yield/load.

It is observed from the simulation of SWAT that the annual sediment load at Kessie and Karadobi are 8.98t/ha and 8.55t/ha respectively. Norplan has indicated on Karadobi multi project pre-feasibility study the annual sediment load in the range of 7.2t/ha and 11.5 t/ha. BCEOM has estimated the annual sediment concentration 7.51t/ha on the Abay Rive Basin Integrated Development Master Plan Project Phase II. When we compare these values with the model simulation outputs we can say that SWAT has well estimated the sediment concentration in the catchments and reservoir sedimentation of Karadobi multi purpose project.

To analyze the impact of land use change on reservoir sedimentation four scenarios are developed. The scenarios are developed simply to show the potential change of sediment from the corresponding land use change and should not be considered as the real land use change condition of the area. Based on this the change of agro-pastoral land to agricultural land has great alteration on sediment yield. Change of 10% and 20% agro-pastoral to agriculture land has increased sediment by 12% and 60% respectively. But change of 60% of pasture and 90% of forest land to agriculture has increased sediment by an amount less than 0.5%. This is because of small proportion of the two land use uses compared to agriculture and agro-pastoral lands. The other reason for small change of sediment due to change of pasture land is that most of the pasture land is located in sub-basins generating small sediment yield i.e. sub-basins 31, 34,37,38,39, 45 and 72. If we consider sub-basins 40 and 44 the percentage of pasture land is 22% and 21% but the monthly sediment per hectare yield from the two sub-basins are 4.54 and 0.61 respectively (shown in the appendix). This indicates that land use is not the only factor for sedimentation. Similar to pasture land the area coverage of forest land is very small compared to agricultural and agro-pastoral land i.e. sub-basins 64, 70 and 72 which have small potential of sediment yield. Generally the scenarios have shown the possible future sedimentation risks in the catchments and reservoir. In addition to this the annual and 50 years reservoir sediment accumulation and percentage depletion of reservoir storage capacity is determined (7.84%) and compared with the finding of NORPLAN (6.57-10.50%) which indicates good performance of the model for reservoir sediment prediction.

7.2 Recommendation

Sedimentation of reservoirs of various purposes, erosion of agricultural soil, degradation of cultivable and potential areas, etc is a big challenge in Ethiopia for many years and will continue in the future except appropriate mitigation measures are taken. To manage this problem impact of land use changes on reservoir sedimentation was considered in this thesis so as to contribute something in problem solving in this area.

Observing the consequences of land-use change for hydrologic processes, and integrating this considerate into the rising center of attention on land-change skill are major needs for the future works in the basins. Using the SWAT model I have tried my best to estimate the amount of sediment at Karadobi reservoir with current land use condition and under different land use scenarios. As the study area is very large I have faced a problem of high processor speed computers for watershed delineation and sensitivity analysis. In addition to this the thesis was done in a few months' time and short time of site visit and the result of this work has to be considered as a start of the work (Impact of Land Use Changes on Karadobi Reservoir Sedimentation). However I think the results of this study give an indication and increase attentiveness on the possible future risks of land use change and its impact on reservoir sedimentation and will contribute to some extent to the researchers, planners and policy makers of water resource projects and the capacity of SWAT model in sediment load and yield estimation.

Lots of researchers in the world suggest that SWAT is efficient in predicting suspended sediment yield from a watershed and sediment concentration in streams. Therefore Ethiopians researchers are beneficial if they use the model for prediction of sediment before planning and design of reservoirs for several of projects.

I have attempted to deal with the impact of land use changes on Karadobi multi purpose project reservoir sedimentation by developing scenarios. The scenarios are developed depending on possible changes from master plan study and short time field visit and are some how rough. Therefore extra research has to be carried out on the exact trend of the land use changes so that prediction of better accuracy can be made. In addition to this I suggest other researchers to see the impact of other parameters such as slope and climate on reservoir sedimentation so that appropriate alleviation measures can be made. Because sub-basins with similar land use may have very different potential of sediment yield; if we consider sub-basins 40 and 44 the percentage of pasture land is 22% and 21% but the monthly sediment per hectare of sediment yield from the two sub-basins are 4.54 and 0.61 respectively which indicates that land use is not the only factor in sediment yield and there are other main factors which have major influence on basin sediment yield. Therefore researches have to investigate other factors which have series impact on reservoir sedimentation so that reservoirs with good efficiency can be planned, deigned and constructed.

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APPENDIX

SUB BASIN	PRECIP (mm)	PET (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)	SYLD (t/ha/yr)
1	1441	1583	770	39	339	327	316	643	15.44
2	1631	1378	758	71	445	417	416	835	17.81
3	1697	2037	1101	77	391	463	362	825	12.80
4	1309	1697	809	14	291	191	271	465	18.25
5	1219	2181	1398	112	284	198	266	463	2.11
6	1219	1966	1100	62	263	202	241	443	8.19
7	947	1155	549	16	245	144	0	150	7.71
8	1234	1148	671	24	146	201	0	416	14.21
9	1234	1149	694	33	244	282	0	288	15.84
10	965	1159	547	5	87	104	0	331	6.85
11	1243	1162	683	8	269	281	0	287	16.52
12	1243	1330	800	13	173	266	0	266	17.11
13	1234	1149	746	24	203	277	0	277	18.61
14	965	1159	657	0	140	169	0	169	10.73
15	965	1158	657	0	140	166	0	166	10.18
16	965	1159	561	24	214	181	0	187	11.25
17	1376	1658	765	49	275	326	0	329	24.35
18	1631	1380	760	34	393	463	0	472	21.21
19	1234	1150	746	24	203	280	0	280	17.91
20	965	1160	657	0	140	166	0	166	10.71
21	1631	1380	784	46	313	516	0	523	22.88
22	1252	1682	802	63	277	161	0	169	11.06
23	1631	1381	792	42	333	491	0	496	32.56
24	1246	1538	805	57	255	173	0	179	17.80
25	1234	1150	746	24	203	276	0	276	17.76
26	965	1160	657	0	140	166	0	166	10.58
27	1234	1150	694	33	246	279	0	284	16.06
28	1234	1151	746	23	203	281	0	281	17.95
29	933	1539	698	52	125	103	0	106	12.24
30	1060	1155	636	2	109	107	0	314	7.29
31	1060	1540	431	20	3	0	0	628	0.00
32	1060	1540	750	32	173	128	0	133	7.93
33	1060	1541	624	60	265	159	0	166	7.85
34	1060	1540	439	5	4	0	0	620	0.00
35	1060	1304	723	33	190	139	0	143	19.78
36	1040	1330	653	24	230	150	0	152	7.50
37	1060	1541	717	16	221	100	0	121	5.81
38	1060	1541	640	10	309	65	0	112	1.43
39	1220	1695	830	21	256	100	0	133	5.56
40	1570	1561	751	38	421	372	0	394	33.24

SUB BASIN	PRECIP (mm)	PET (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)	SYLD (t/ha/yr)
41	1040	1331	649	40	219	163	0	166	7.46
42	1040	1330	638	25	120	124	0	276	6.88
43	935	1577	705	63	142	81	0	84	7.11
44	935	1577	672	72	166	86	0	90	5.19
45	1570	1707	543	0	8	31	0	1022	0.09
46	1570	1561	694	18	518	297	0	358	27.15
47	1118	1530	621	13	338	151	0	159	6.23
48	1118	1531	634	18	295	182	0	188	13.06
49	2500	1509	868	60	634	963	0	974	63.80
50	1040	1333	706	21	154	180	0	181	7.44
51	1040	1333	706	21	154	180	0	181	7.71
52	1040	1332	634	39	220	174	0	180	8.69
53	1040	1334	665	36	183	182	0	187	13.20
54	1040	1333	642	33	213	173	0	180	9.91
55	1040	1333	627	29	256	149	0	154	10.37
56	1413	1491	817	65	386	195	0	198	4.18
57	1300	1710	844	28	273	176	0	179	18.25
58	1300	1711	836	15	293	158	0	168	19.16
59	1094	1704	779	13	209	87	0	107	11.44
60	1355	1564	812	30	322	203	0	218	20.83
61	1094	1568	747	12	237	91	0	109	13.86
62	1344	1541	818	56	377	121	0	146	9.89
63	1413	1491	858	54	316	230	0	230	5.22
64	1233	1510	754	70	284	176	0	176	2.40
65	1276	1572	750	41	342	171	0	181	13.68
66	1355	1566	805	30	356	178	0	193	14.99
67	1344	1583	838	67	373	115	0	131	7.33
68	1344	1583	837	80	369	127	0	135	13.03
69	1521	1536	856	65	456	189	0	202	22.59
70	1233	1510	770	37	343	116	0	118	1.95
71	1521	1587	828	32	478	203	0	208	38.88
72	1276	1535	687	65	406	177	0	178	5.91
73	1344	1584	856	41	333	150	0	151	13.58
74	1768	1582	959	48	461	337	0	340	32.20
75	1467	1431	600	26	2	4	0	868	0.03

Table A - 1 Output of the sub-basins after SWAT

Month	***Original***	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Jan	366	367	367	25	30727
Feb	14	14	14	115	20313
Mar	9064	9064	9064	24260	184241
Apr	115177	115517	115517	170126	651162
May	67380	68184	68184	154504	1077401
Jun	720805	724265	724265	1130260	2886300
Jul	19397000	19416000	19416000	23121000	36192000
Aug	34572000	34602000	34602000	37720000	48781000
Sep	10390400	10411900	10411900	11437700	15093900
Oct	2906690	2922090	2922090	3299050	4863500
Nov	259097	261597	261597	260266	675750
Dec	52670	53094	53094	59575	234400
Average(T)	5707555	5715341	5715341	6448073	9224224
Annual(T)	68490662	68584091	68584091	77376881	110690695
Yield	8.55	8.56	8.56	9.66	13.82
% Change of Sediment	**0**	**0.14**	**0.13**	**12.97**	**61.61**

Table A - 2 **Sediment amount change in different scenarios**

SUB BASIN	SED YIELD (T/Ha/Mon)	AREA(Ha)	SED YEELD X AREA
1	0.96	277144	267109
2	1.77	148096	261541
3	0.42	714992	302963
4	1.64	66472	108935
5	0.16	108748	17585
6	0.61	172068	105234
7	0.48	166584	79148
8	0.95	52760	49891
9	1.08	55380	60057
10	0.51	54456	27765
11	1.57	113676	179014
12	1.60	86196	137765
13	1.22	92956	113852
14	0.79	12676	10068
15	0.78	213636	166213
16	0.92	90756	83257
17	2.25	235788	531319
18	2.10	65816	138380
19	1.19	18228	21698
20	0.80	64392	51795
21	2.28	15100	34441
22	0.95	181411	171675
23	3.22	186136	600130
24	1.61	67672	109013
25	1.17	69696	81437
26	0.80	82264	65592
27	1.10	202499	222525
28	1.20	14928	17852
29	1.41	128132	180573
30	0.57	191796	109196
31	0.00	4104	0

SUB BASIN	SED YIELD (T/Ha/Mon)	AREA(Ha)	SED YEELD X AREA
32	0.75	82840	62280
33	0.72	80052	57407
34	0.00	696	0
35	1.66	123048	204542
36	0.65	286828	186157
37	0.56	53940	30106
38	0.12	35964	4399
39	0.44	90124	39356
40	4.54	114612	520415
41	0.66	74328	49301
42	0.64	287188	183711
43	0.83	80292	66753
44	0.61	70692	42997
45	0.02	276	5
46	4.06	14160	57439
47	0.60	54348	32557
48	1.27	59940	76332
49	3.49	111216	388183
50	0.67	204	137
51	0.70	276	192
52	0.76	87216	66277
53	1.19	125276	149381
54	0.88	103784	91442
55	0.92	184768	169929
56	0.38	132108	49816
57	1.80	68976	123981
58	1.88	104132	196161
59	0.72	8496	6098
60	1.88	125280	235281
61	0.79	106176	84076
62	0.73	88768	64876

SUB BASIN	SED YIELD (T/Ha/Mon)	AREA(Ha)	SED YEELD X AREA
63	0.48	100604	48049
64	0.15	77584	11255
65	0.81	328700	265186
66	1.40	142300	198657
67	0.57	19356	11025
68	1.02	5036	5148
69	1.48	77996	115749
70	0.13	60028	7677
71	2.80	104584	292748
72	0.38	62852	23640
73	1.03	102516	105779
74	0.89	216115	193409
75	0.00	268	0
		8008501	**8823932**
AVERAGE(T/HA/MON)			**1.16**

Table A - 3 Monthly sediment yields from the sub-basins

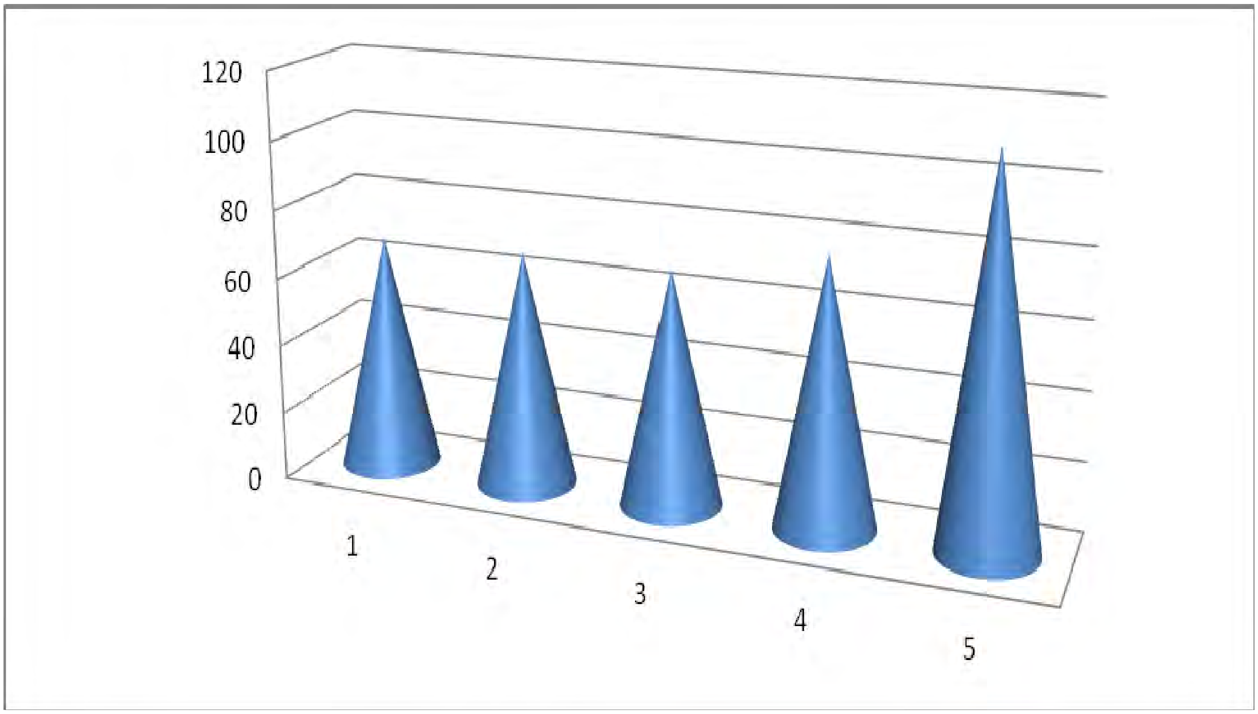

Figure A - 1 Comparison of annual sediment of the scenarios.

1=original

2= scenario 1

3=scenario 2

4=scenario 3

5=scenario 4

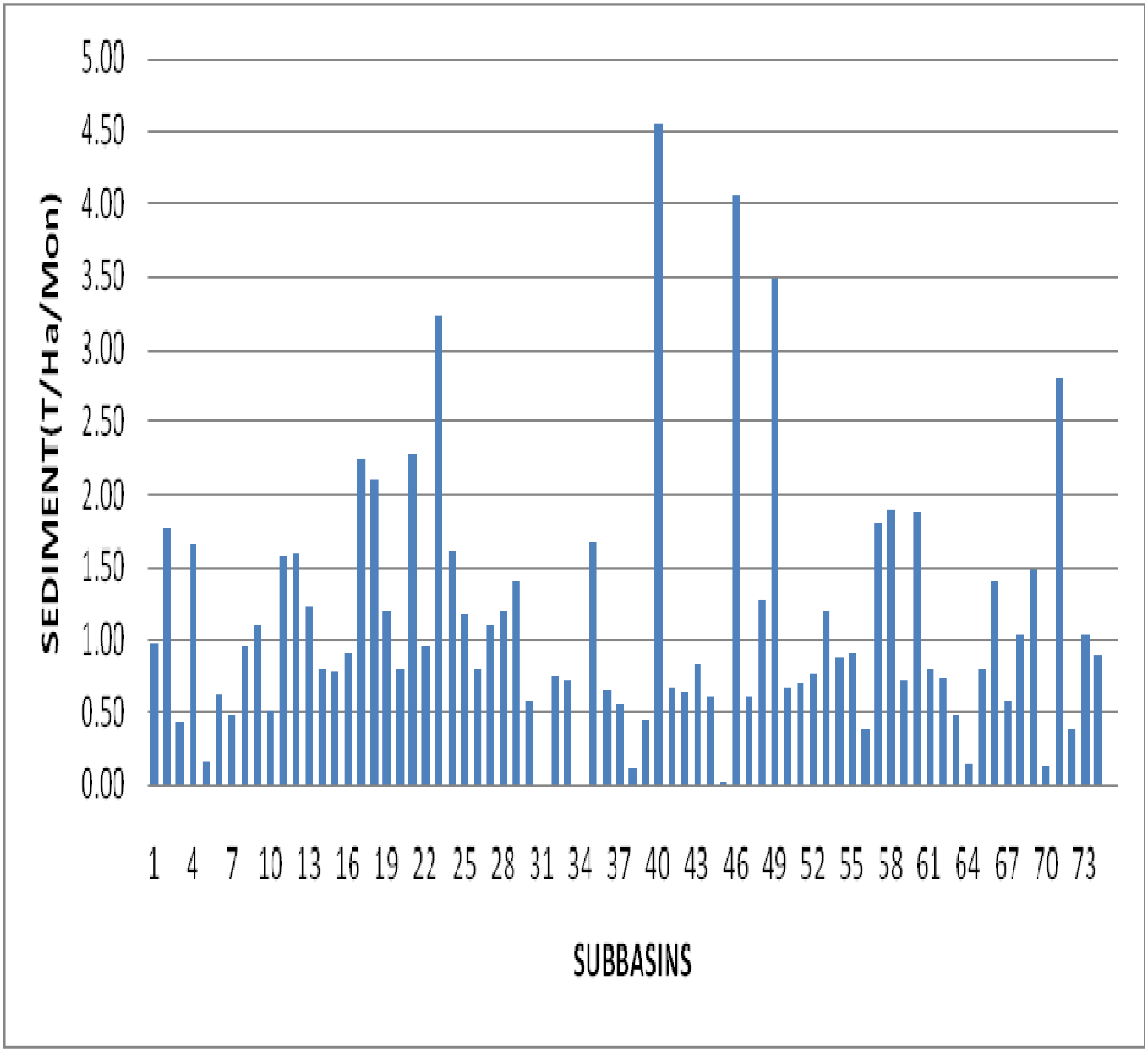

Figure A - 2 Graphical representation of monthly sediment yield.

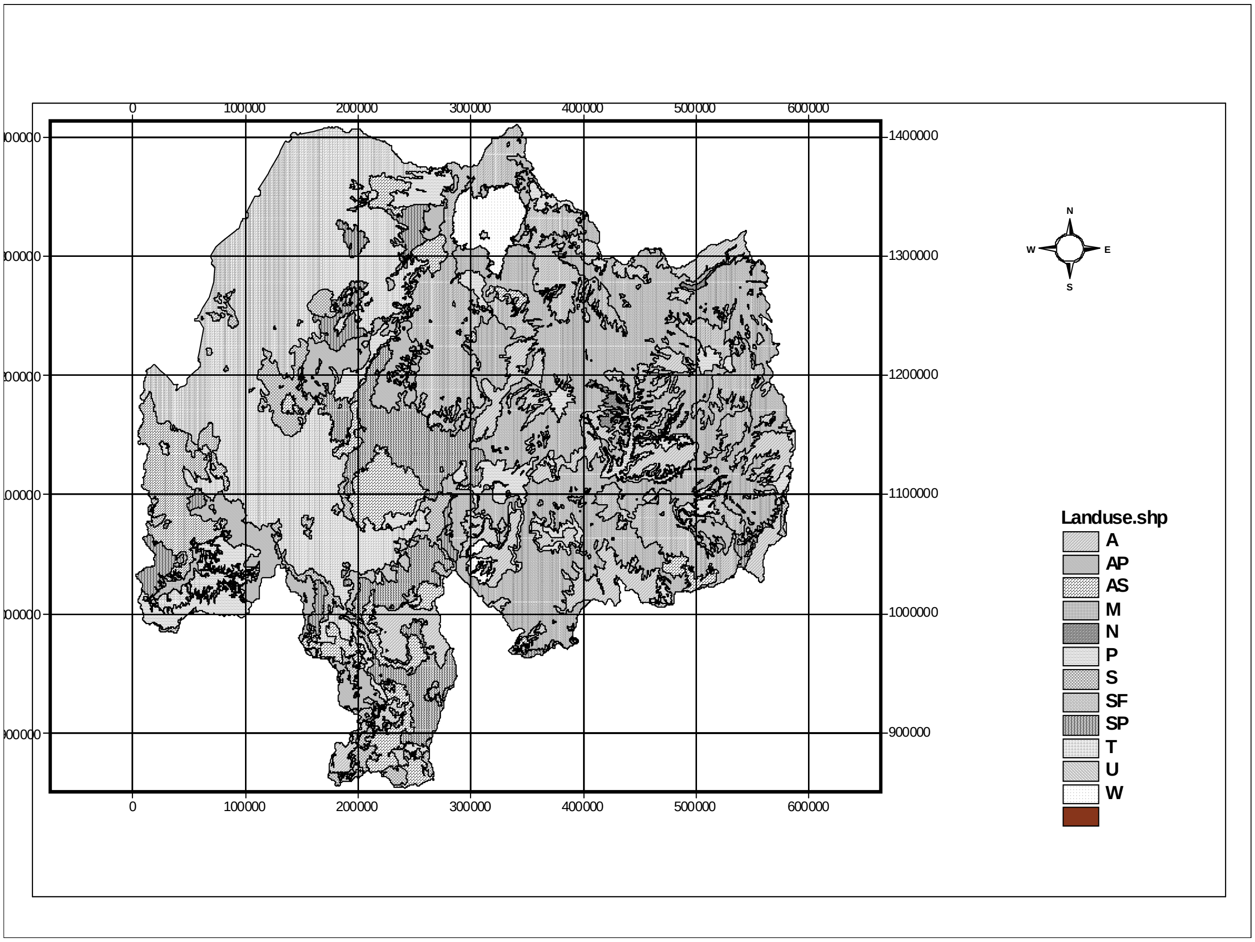

Figure A - 3 Land Use Map of Blue Nile

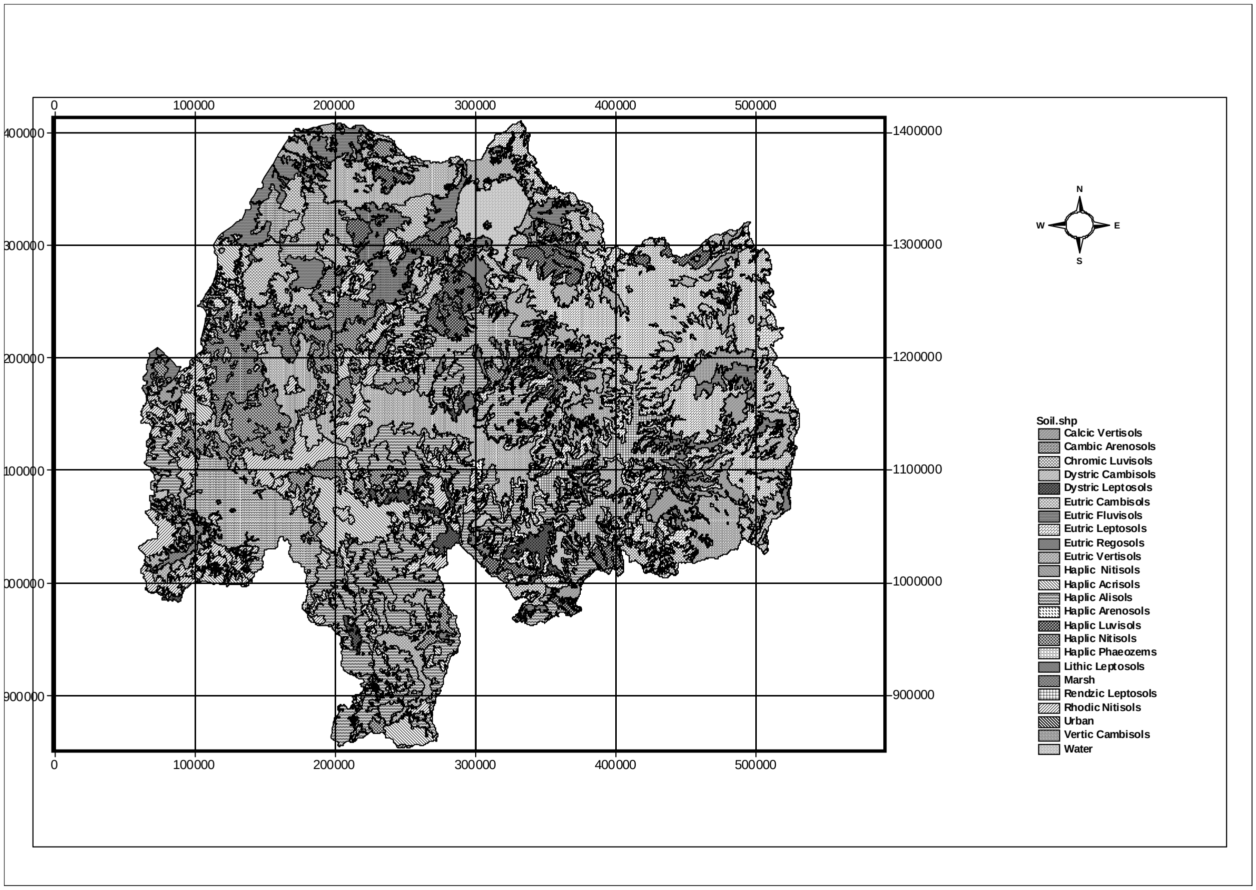

Figure A - 4 Soil map of Blue Nile