THE IMPACT OF LAND USE/LAND COVER CHANGE ON RESERVOIR SEDIMENTATION. (CASE OF TEKEZE HYDRO POWER DAM)

MASTER OF SCIENCE THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

OCTOBER, 2016

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A THESIS SUBMITTED TO THE SCHOOL OF CIVIL ENGINEERING, HAWASSA INISTITUT OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING (SPECIALIZATION: HYDRUALICS ENGINEERING)

OCTOBER, 2016

SCHOOL OF GRADUATE STUDIES

Hawassa University

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(Submission Sheet)

We, the undersigned members of the Board of Examiners of the final open defense by ***Tekleweyni Teklu Bahta*** have read and evaluated his/her thesis entitled **"** ***The Impact of Land Use/Land Cover Change on Reservoir Sedimentation (Case of Tekeze Hydropower Dam*****"**

and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfilment of the reqirement for the Degree of **Master's** of of **Science** in **Civil Engineering** with **Specialization** in **Hydraulic Engineering.**

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DEDICATION

This thesis is dedicated to for all my family especially for my Father "Teklu Bahta" my Mother "Mebrat Gessesew" my Brother's "Mulubrhan, Gebregiyorgis, Gebrehiwet, Grmazgi" and my Sister's "Genet and Kibra"

Acknowledgements

First and foremost, thanks to the Almighty God for granting me His limitless care, love and blessings all along the way. I would like to express my sincere appreciation to my advisors Dr. Mulugeta Dadi and Dr Brook Abate for their advice and valuable suggestions, encouragement and guidance from the commencement of the study to the completion my research work, Furthermore, they have devoted their time and energy to advise me during the whole work and recommended valuable comments to improve the thesis.

My sincere gratitude to Hawassa University for awarding me a scholarship to attend my education and Ethiopian Road Authority (ERA) for awarding me a fund to follow my MSc thesis.

I would like gratefully to acknowledge Ethiopian Ministry of Water, Irrigation and Electric (MoWIE), National Metrological Service Agency (NMSA), Ethiopian Map Agency (EMA) for providing me invaluable input data for my research work.

My special thanks go to my Adore Family for their persistent love, never ending concern, support and encouragement and all my friends. I am highly indebted to them; their blessing, guidance, advice, encouragement, and support are source of my happiness, strength and success.

Last but not least, I would like to thank all my friends for all challenges, knowledge sharing and happy time we spent together at Hawassa University.

List of Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
ARS	Agricultural Research Service
CN	Curve Number
COSAERT	Commission for Sustainable Agriculture and Environmental Rehabilitation in Tigray
DEM	Digital Elevation Model
E	East direction
ENS	Nash-Sutcliffe Efficiency
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographic Information System
HRU	Hydrological Response Unit
LULC	Land Use and Land Cover
m.a.s.l	mean above sea level
MoWIE	Ministry of Water Irrigation and Energy
MUSLE	Modified Universal Soil Loss Equation
NEDECO	Netherlands Engineering Consultants
NMA	National Meteorological Agency
N	North direction
Pcp	Precipitation (mm)
PET	Potential Evapotranspiration

R^2	Coefficient of Determination
RUSLE	Revised Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation,
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
T/ha/y	tons per hectare per year
SWC	Soil and Water Conservation
UNEP	United Nation Environmental Program
USACE	United States Army Corps of Engineers
USDA	United States of department of Agriculture
USLE	Universal Soil Loss Equation
WAPCOS	Water and Power Consultancy Services
WXGEN	Weather Generator

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Abstract

Watershed is considered to be the ideal unit for management of the natural resources. Extraction of watershed parameters using (GIS) and use of mathematical models is the current trend for hydrologic evaluation of watersheds. Soil erosion is a serious threat in the Tekeze watershed. Deforestation, overgrazing, and poor land management accelerated the rate of erosion due to the impact of land use land cover change. To develop effective erosion control plans and to achieve reductions in sedimentation, it is important to quantify the sediment yield and identify areas that are high contributors of sediment at micro-watershed level and over large areas. In this study SWAT (Soil and Water Assessment Tool) having an interface with ArcGIS software was used to estimate sediment yield and identify spatial distribution of sediment yield in the watershed. The model was successfully calibrated and validated for measured stream flow and suspended sediment concentration at Yechila gauging stations. The flow calibration and validation result showed that model performance evaluation statistics coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (ENS)) were in the acceptable range (R^2 in the range 0.89 and0.87, ENS in the range of 0.83 and 0.74). Also the suspended sediment concentration at Yechila gauging stations R^2 0.86 and 0.84, ENS of 0.82 and0.78 for calibration and validation. This indicates that the observed values show good agreement with simulated value for both flow and sediment yield. The model prediction results indicated that about 12.05% of the watershed areas very severely eroded with annual sediment load ranging from 29.54 to 33.36 tones/ha/yr and about 24.67% of the watershed area has severely erosion with annual sediment load ranging 24.97 to 29.53 t/ha/yr. The annual average sediment yield of the watershed was 17.35 t/ha/yr for the land use land cover map of 2010. The result of the study could help different stakeholders to plan and implement appropriate soil and water conservation strategies in the watershed.

Key words: SWAT, land use land cover, sediment yield, Tekeze watershed, erosion, Calibration, Validation, simulation.

CHAPTER ONE

1. NTRODUCTION

1.1 Background

Water is the most essential natural resources for living species. Since the available amount of water is limited, scarce, and not spatially distributed in relation to the population needs, proper management of water resources is essential to satisfy the current demands as well as to maintain sustainability. Land use planning and management are closely related to the sustainability of water resources as changes of land use are linked with amount of water through relevant hydrological processes (Guo et al, 2008). To maintain water sustainability, effective methods and mechanisms should be used. In nowadays, the hydrological models are good to represent the hydrological characteristics (Surur, 2010).

LULC is a term that includes categories of land cover and categories of land use. Land use refers to the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Land covers the physical material at the surface of the earth such as grass, vegetation, bare ground, impervious surfaces and water on which land use occurs (FAO, 2002).

The LULC pattern of a region is a result of natural and socio economic factors and their utilization by man in time and space. From systems theory thinking and the observed interconnectedness within our natural systems, linking LULC and water resources is imperative within the watershed, the hydrological defined boundary, and everything can potentially affect the water (Weiet al., 2007).

LULC has a substantial impact on the hydrological compartment since land use and land cover change has become a central component in current strategies for managing natural resources and monitoring environmental changes. Land use land cover change (LULCC) can be easily observed in forestry on a global scale, the largest change in terms of land area, and possibly also in terms of hydrologic effects, is from deforestation and afforestation. Deforestation, rapid land use change for farming and overgrazing are likely to affect the hydrologic regime of the highlands and rift valley lakes (Ziway,Langano,Abyata and Shala) (Tenalem, 2007).

The other factor that affects hydrologic compartment is agriculture. Agricultural intensification alters transpiration rates and affects runoff and the overall increase in yield on a watershed. However, the timing of storm runoff is greatly impacted through land drainage. The movement of surface runoff also carries pesticides, farm waste and sediment to the receiving stream and dam and other structures (Knisel, 1980).

The dynamics of the hydrological process altered as watershed landscapes are increasingly modified for agricultural and urban uses. As a result of runoff from rainfall, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill, and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in reservoirs and lakes. Besides the above factors, physical changes resulting from urbanization also affect the water flow through reduction of interception of rainfall due to removal of trees, removal of natural vegetation and change in the drainage patterns (Knisel, 1980).

Remote Sensing (RS) and Geographic Information System (GIS) are now providing new tools for advanced ecosystem management (Willkie and Finn, 1996). The collection of remotely sensed data facilitates the synoptic analyses of Earth - system function, patterning and change at local, regional and global scales over time; such data also provide an important link between intensive, localized ecological research and regional, national and international conservation and management of natural resource (Willkie and Finn, 1996). Another major problem caused by erosion is sedimentation of reservoirs and irrigation canals. Reservoirs are the main destination of the sediment eroded from upland area. Since the velocity of water in the reservoir is very low, sediments get deposited in the reservoir unless there exists a facility to avoid the settlement. The sedimentation of reservoirs causes another serious problem by decreasing the capacity of reservoirs. The loss in capacity of reservoirs increases the probability of floods. As more and more sediments get deposited in the reservoirs, its capacity decreases and ultimately will not be able to handle high flood (Willkie and Finn, 1996).

SWAT (Soil and Water Assessment Tool) model integrated with GIS techniques had been used to simulate sediment yield of the study area. SWAT is a physically based and computationally efficient hydrological model, which uses readily available inputs. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch et al, 2002).

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. (Yacob E. 2010)

Soil degradation is wide spread and serious throughout the Ethiopian Highlands, which contain more than 90% of the population including about 93% of the cultivated land, around 75% of the country's livestock and accounts over 90% of the country's economic activity (Solomonet al., 2013). The average soil removal in the country is about 2 billion tyr-1 (FAO, 1986). The highest rate of soil loss occurs from cultivated fields, which is estimated at 42tha-1yr-1 on average and causes an average annual reduction in soil depth of 4 mm (Hurni, 1993).

It is also a major watershed problem in many developing countries causing significant loss of soil fertility, loss of productivity and environmental degradation (Awulachew and Tenaw, 2008). As dams are one of the most important infrastructure investments in a country in which providing essential services such as drinking water, irrigation water, hydroelectric power, fisheries, wildlife, recreation, and other environmental benefits. Acordig Geffersa watershed is one of the catchment that used for water harvesting for the city, Addis Ababa (Hana M. 2014). The Geffersa dam reservoir capacity is reducing through time, at the completion of the second stage construction of Geffersa dam, in 1955 the total capacity of the reservoir (at maximum water level) declined from 7.45 MCM to 6.64 MCM in 1979 and continued to decline to reach a capacity to 6.23 MCM in 1998. In the 24 year period of 1955 to 1998; the total volume of the Geffersa reservoirs declined by 1.23 MCM.When we see the linear yearly siltation rate based on the 1979 and 1998 bathymetric surveys it is 22,252 m^3/yr,but this rate was double on the period of 1955-1966 before the construction of Geffersa III dam, which serve as a silt trap and a reservoir. In between these years (1955-1966) the soil loss rate of the catchment area was 1200 ton/km^2/yr and even if the silt accumulation reduced by24,180 m^3/y on the 1979 and 1998 the soil loss rate of the catchment area is similar to that of 1955-1966 (Hana M., 2014) . Tamene (2005) stated that soil erosion and sedimentation reduces the capacity of reservoirs and drainage ditches and blocks irrigation canals.

Therefore analyzing the impacts of different variables which cause/accelerate the problem is essential. In Tekeze hydro power dam watershed, there are extensive agricultural activities in the hilly areas and the main river and the tributaries which are the main source of sediment. These and other related problems increase the sedimentation of Tekeze Hydro power dam reservoir which is loss capacity. Therefore, understanding the impacts of soil erosion and looking for solutions to minimize is essential.

1.3 Objective

1.3.1 General objective

The general objective of this study is to model the hydrological processes that will predict the impact of land use/cover changes on Reservoir sedimentation in Tekeze hydropower dam

1.3.2 Specific objectives

The specific objectives are :

1. Assess and evaluate the spatial variability of sediment yield in the watershed and identify high erosion yielding areas in the watershed for management intervention.
2. Recommend future soil and water conservation structure or management practice to select best option
3. Evaluation of the yearly sediment transport rate of the Tekeze hydro power dam
4. To evaluate the performance of the hydrological (SWAT) model on the watershed

1.4 Research questions

1. What are the adaptation options to be taken to mitigate the adverse impacts of land use and land cover change on high erosion yield areas on the watershed?
2. How well can SWAT model simulate stream flow in the watershed?
3. What is the spatial distribution of the tolerable soil loss in the study area

1.5 Thesis Layout

The thesis is organized in five chapters:

Chapter 1: Gives a general brief introduction about sediment yield and effect in the water resources utilization, about the problem that initializes this study, the objective of the study, software used and the outline of the thesis.

Chapter 2: describes the reviewed literature related to the study on the concept of sedimentation, models, hydrological models and overview of the SWAT model.

Chapter 3: deals with the methodology and gives detail description of the Tekeze hydropower dam watershed, by beginning the description of the Tekeze Basin as a whole and Tekeze Hydro power dam water shade. In this chapter topography of the basin, the climate, hydrology, soil, slope and land use type of the watershed were well described. Data analysis and model simulations, model calibration and validation

Chapter 4: Results and discussion are presented in this chapter

Chapter 5: presents conclusion and recommendations based on the results of the models and the data used for this study. In addition to this References and Appendixes are attached at the end.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 General Overview

The knowledge and understanding that the scientist has about the world is often represented in the form of models. The goal of the scientific method is to simplify and explain the complexity and confusion of the world. A model is a representation containing the essential structure of some event in the real world. It can be classified as quantitative and qualitative model (Wei et al., 2007). In science and engineering, the most essential attribute of model is that of quantitative which yields numerical value. A quantitative model is essential to determine physical variables that cost much to measure in the field. To understand the hydrological process in the system which is essential in decision making, models has been used long in water resources management model (Wei et al., 2007). A model used in water resources management should be sufficiently accurate to be used for the intended purpose. The existence of observations determines the validity of the model. Model prediction is compared with field measurement to evaluate its performance without any adjustment to the model parameters. This process is termed as model validation or verification (White et al., 2005).

Hydrological, soil and Water assessment models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrological prediction and for understanding hydrological processes. Whenever data is not available, hydrological models are important to establish baseline characteristics and determine long term impacts which are difficult to calculate. A modeler should understand the `hydrological process and then simulate this process at a desired spatial and temporal resolution (White et al., 2005). Two major types of hydrological models can be distinguished:

1) Models based on data: - these models are black box systems, using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output for instance runoff (Lenhart et al., 2002).

2) Models based on process descriptions: - these models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated.

These models are known as deterministic hydrology models. It is essential to determine the amount of water available in the system in order to state the available water potential within the river basin system. Hence, it requires understanding and properly describing water inflow and outflow from the system. In order to describe the movement of water, it would be necessary to have rainfall data and information on runoff, evaporation, infiltration, percolation etc (Lenhart, 2002).

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

Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. However, if transport capacity is less than the amount of eroded soil material available, then the amount of sediment exceeding the transport capacity gets deposited. A basin sediment yield refers to the amount of sediment exported by a basin over a period of time which is also the amount that will enter a reservoir located at the downstream limit of the basin (Morris and Fan, 2009).

The sediment yield from any drainage system is calculated by averaging the data collected over a period of years. It is, therefore, an average of the results of many different hydrologic events.

The sediment yield for each storm or flood will vary, depending on the character of the storm event and the resulting hydrologic character of the floods. High-intensity storms may produce sediment yields above the normal, whereas an equal amount of precipitation occurring over a longer period of time may yield relatively little sediment. During short spans of time (days or years), sediment yields may fluctuate greatly because of natural or man-induced accidents. Collecting sediment flow data over a decade and periodic reservoir survey information are some resources demanding methods for estimating sediment yield rates at a catchment level. Others have also cautioned that long term sediment monitoring of suspended sediment loads does not necessarily give better results. Some workers have suggested that an excellent sediment-rating curve could be constructed from detailed sediment flow data of short period of sampling programs (Summer et al, 1992).

Estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. The sediment transportation monitoring requires good sample techniques which is very lengthy and costly.

Therefore, it is important to develop a model that can estimate accurately the suspended sediment yield from the basin. If the input layer contains variable(s) different from those of the output layer then the term estimation is preferred than the term forecasting. Forecasting is used as in the case of having the same variable in both input and output layers (Cigizoglu, 2006).

2.1.1 Soil erosion process

Soil erosion, soil loss, and sediment yield are terms with distinct meanings in soil erosion processes. Soil erosion is the gross amount of soil moved by drop detachment or runoff. Soil loss is the soil moved off a particular slope or field. Sediment yield is the soil loss delivered to a point under evaluation. Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster, 1988). Spatial and temporal information on runoff, soil erosion, and sediment yield of a catchment can provide a useful perspective on the availability of water, rate of soil erosion, and soil loss in the catchment. The dynamics of the processes of soil erosion and sediment yield are influenced by the spatial and temporal characteristics of the input variables affecting them and controls exerted by the land surface. The controls related to land surface include elevation, soil, vegetation cover, and underlying geology. The major classification of erosion type is by erosive agents, wind or water, which causes erosion. The main types of erosion are rill erosion, sheet erosion and gully erosion. The sheet and rill erosion classification is based on a concept of progressive erosion severity. Sheet erosion, which is a uniform removal of soil from the surface, is assumed to be the first phase of the erosion process, and sheet erosion rates are assumed to be low. As erosion becomes increasingly sever, rill erosion is assumed to begin. Rill erosion progresses to gully erosion, which produces deeply incised channels (Wischmeier and Smith, 1978).

2.1.2 Factors affecting soil erosion

There are several factors influence soil erosion. The main factors are described below:

Rainfall intensity and runoff

The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills for which intensity is generally considered to be the most important rainfall Characteristics. The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity. That is soil movement by rainfall or raindrop splash is usually greatest and most noticeable during short-duration, high-intensity thunderstorms (Foster, 1988).

Topography

Soil erosion by water is a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. Naturally, the steeper the slope of a field, the greater would be the amount of soil loss by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment).

When the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport. Runoff velocity and effective depth of interaction between surface soil and runoff is increased with increase in slope. (Foster, 1988)

Soil erodibility

The erodibility of the soil refers to the resistance of the soil to both detachment and transport by the eroding agent. (Hudson, 1996) defines erodibility as the specific property of soil, which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances. It is the relative ease with which a soil erodes under specific conditions of slope as compared with other soils under the same conditions. The term soil erodibility is limited to inter rill and rill erosion. Generally soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. That is, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. Soil texture (particle size composition i.e. sand, silt, and clay), organic matter, structure, and permeability are major factors that affect soil erodibility (Foster, 1988).

Sealing and crusting

Soil sealing is the formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling, or sedimentation, which is relatively impermeable to air and water. It is due to the effect of raindrop on bare soil, which results in reduction of infiltration; and increase in runoff and the potential for the soil erosion. Sealing soils often generate more surface runoff, and therefore a greater hazard for rill erosion (De Ploey, 1983).

Rainfall with a high cumulative energy causes sealing later, and to a smaller degree than lower cumulative rain energies. Soils breaking into smaller stable micro-structural elements give high splash losses and low rates of surface sealing, while soils that disintegrated into primary particles more readily seal and give rise to lower splash erosion rates. Crusting is a sign of soil degradation caused by deteriorating conditions of plant cover and soil structure which are brought about by over cropping, overgrazing, or over tillage. Crusts are characterized by increased soil surface strength and density that leads to reduced porosity due to change in pore size distribution and infiltration thereby leading to high runoff and erosion rate (De Ploey, 1983).

Vegetation cover and management

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

2.2 Overview of soil erosion and hydrological modeling

Many hydrological and soil erosion models are developed to describe the hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of sediments (Jaroslav, 1996).

2.2.1 Soil erosion model

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster, 1988; Wischmeier and Smith, 1988; Julien, 1998). The major forces originate from raindrop impact and flowing water. Figure 1 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

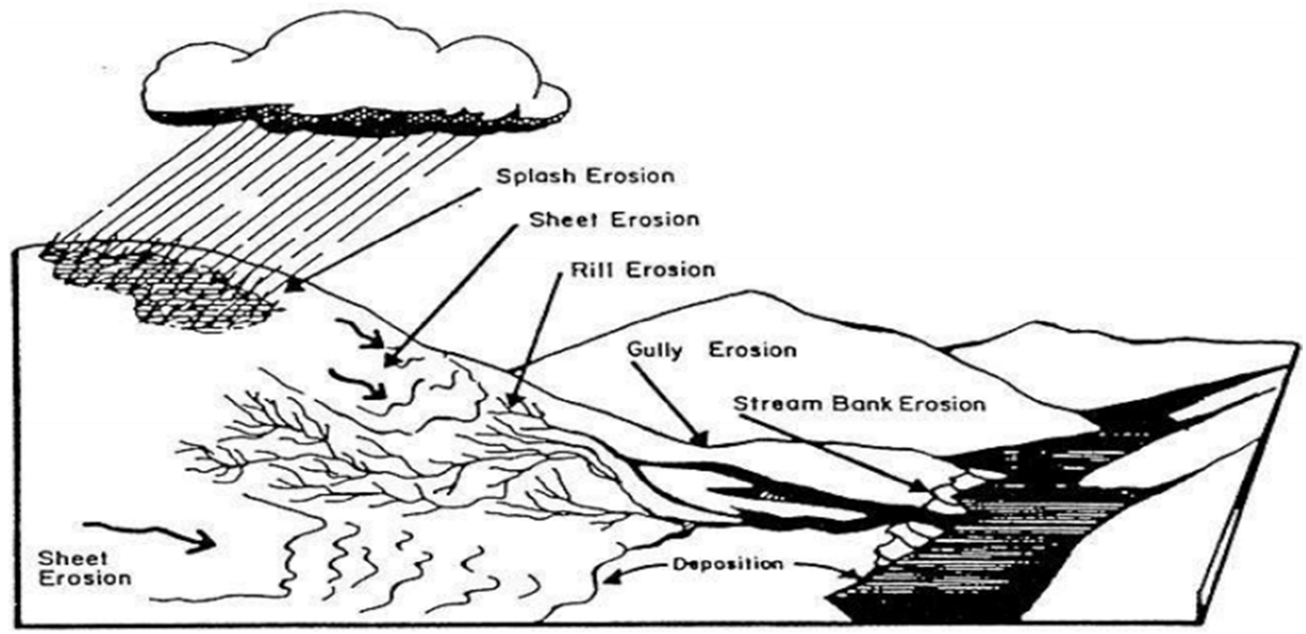

Figure 1: Mechanism of soil erosion (USACE 1985)

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by Wischmeier and Smith in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots. The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley, 1982) and Unit Stream Power- based Erosion Deposition (USPED) (Mitasova et al., 1996) are based on the USLE and represent an improvement of the former. In 1996, when the U.S. Department of Agriculture (USDA) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new calculation procedure to calculate the cover vegetation factor, and the revision of the length and gradient of slope.

2.2.2 Hydrological model

Hydrological models are tools that describe the physical processes controlling the transformation of precipitation to stream flows. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. The focus of these models is to establish a relationship between various hydrological components such as precipitation, evapotranspiration, surface runoff, ground water flow and soil water movement (infiltration). Many of these hydrological models describe the canopy interception, evaporation, transpiration, snowmelt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated subsurface flow. These models range from simple unit hydrograph based models to more complex models that are based on the dynamic flow equations. Simulation programs implementing watershed hydrology and river water quality models are important tools for watershed management for both applied and operational research purposes. There are different categories of hydrological models can be distinguished as physically process based, empirical and statistically based models (Jaroslav et al., 1996).

1. **Physically process based models**:

Physically process based models are described by mathematically formulated fundamental physical laws, where each basin is represented by a concept; a reservoir for instance. They are useful for inferring the distribution, magnitude, and past, present and future behavior of a process with limited observations. These equations can relate the changes of water properties into the reach to those across the surface. These physical processes vary both temporally and spatially, they consider the spatial and temporal changes of different factors. Physically based distributed watershed models play also a major role in analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watershed (Jaroslav et al., 1996).

2. **Empirical models**

Empirical models are a synthesis and a summary of field or experimental observations. Their fundamental parameters are not compulsory physically related. Empirical models are based on defining important factors through field observation, measurement, experiments and statistical methods. They are useful in predicting the hydrology or soil erosion, but are site specific and require long-term data. Empirical models are the result of several years of research data and numerically evaluate the effects of climate, soil properties, topography and crop management (Elirehema, 2001).

3. **Statistically based models:**

Statistically based models use many observations to estimate the behavior of watersheds and their interactions. They can be physically or empirically based. In addition to categorizing both soil erosion and hydrological models with respect to the way they are being synthesized, another distinction is the difference between distributed and global models. In distributed models, the watershed is one single entity and in global models, many units represent the variability of hydrological parameters on the surface. Spatial variability is handled by dividing a drainage basin into smaller geographical units, such as sub basins, land cover classes, elevation zones or a combination of them. The so called hydrological response units (HRUs) represent areas where the modeling has been simplified and where the hydrological response is supposed to be homogeneous (Knisel, 1980).

2.2.3 Sediment transport in rivers

The sediment which is transported in rivers originates from soil erosion caused by wind and water with heat and frost being significant assisting forces. Sources of Sediment transported in a river are the catchment (sheet, rill, and gully erosion), the tributaries, bed erosion, bank erosion including landslides and falling rocks. Sediment transport can take place in various forms, according to the hydraulic conditions provided by the flow, and according to the properties of the sediment. Bed load and suspended load are only rough and ready, but inaccurate, classifications of the phenomena taking place in the river. The sediment transported by the river flow is usually not uniformly distributed. Transport rate and grain size distributions vary with the flow depth as well as the channel width. The sediment distribution with depth is dependent on flow characteristics and sediment properties: the coarser the sediment and/or lower the flow intensity, the higher the rate of bed load transported and the lower the amount of sediment in suspension (Julien Y. 1998)

2.2.4 The effect of land use change on reservoir sedimentation

Mountain streams are particularly vulnerable to changes in hill slope processes because of close coupling with adjacent hill slopes. Hill slope processes are easily altered by land use changes. An increase of vegetation cover leads in general to a decrease in runoff generation and sediment detachment resulting in the medium term in the stabilization of sedimentary structures at the catchment scale (Beguera et al., 2006). Sometimes a very limited change in land use can have a significant effect on regional soil erosion rates. However, not only the change in the cover of different land uses induces changes on sediment yield, but also the change in landscape structure has important consequences for the sediment yield. For example, changes in temporal patterns of cultivation practices changes in the spatial connectivity between sediment- producing areas and the river network, changes in the combined effects of land use and field sizes and changes in the location of field boundaries have remarkable effects on sediment yield. So although it is well known that changes in land use affect erosion and sediment yield, an integrated evaluation of the effectiveness and impacts of check-dams compared with reforestation and other land use changes is lacking. Recently an evaluation of the effect of land use changes, small farm dams and large reservoirs on sediment yield in an Australian catchment has been carried out (Verstraeten and Prosser, 2008)

2.2.5 Reservoir sedimentation

The reservoir sedimentation involves entrainment, transport and deposition. They originate from the catchments area, river system and settle in reservoirs. As a river enters the reservoir, its cross-section of inflow is enlarged due to the effect of the backwater curve. Thus it causes a decrease in the water flow velocity; subsequently the sediment carrying capacity of water is reduced too. The major part, or all, of the sediment transported will deposit in the u/s part of the reservoir influenced by the back water curve. Reservoir sedimentation undergoes different processes of transportation and settling of sediment. This causes the reservoir to possess different kinds of deposition at different positions. These differences are controlled by the effects of the sediment particle size, hydraulic condition and sediment transportation methods in the reservoir (Julien Y. 1998)

Reservoir sediment deposition is a reflection of watershed erosion and deposition processes which are controlled by terrain form, soil type, surface cover, drainage networks and rainfall-related environmental attributes. In general, countries in Africa are experiencing deforestation, mainly from agricultural expansion and land degradation which are the leading causes of erosion and sedimentation (Julien Y. 1998)

All reservoirs, formed by dams on natural rivers, are subject to some degree of sedimentation, which is continuously supplied by rainfall, runoff, snowmelt and river channel erosion (Randle et al., 2007). The question is: How long will it take before the erosion adversely affects the dam's water control goal? Accumulation of sediment in the reservoir reduces its storage capacity. When this occurs at an accelerated rate, the reservoir's designed life is shortened Combined with this, chemicals and nutrients from cultivated land, industries and other related sources adversely affect water quality in reservoirs. The cost of removing these sediments and treating the pollutants is enormous. Smaller reservoirs (Angereb, Koka, Sennar and Khashm El Girba) are impacted more adversely by reservoir sedimentation than the larger ones (Roseires and Aswan) because the relative loss in capacity is much faster. However, Owen and Bujagali reservoirs receive almost negligible or limited amount of sediment since they are located each after another few kilometers downstream Victoria Lake, where almost all the sediment loads deposits (Abdella, 2008)

2.3 Review of previous studies on Tekeze river basin

Gebreyesus et al., (2012) was developed hydrological model to evaluate the performance of Soil and Water Assessment Tool (SWAT) model for estimating runoff, sediment and nutrient yields in Mai-Negus catchment of Tekeze River, northern Ethiopia and suggest model applicability for management planning. The SWAT model was selected after hydrological models were reviewed using predefined criteria. The extrapolation of response information from similar areas was used to prepare observed data for model calibration and validation for the un-gauged study catchment. Following sensitivity analysis, the SWAT model was calibrated, validated and assessed for evaluation model uncertainty using Nash–Sutcliffe coefficient (NSE) and coefficient of determination (R^2). The model was calibrated from 1992 to 2000 periods and validated from

2001 to 2009 for flow. The annual flow calibration (NSE = 0.67, R^2 = 0.81) and validation (NSE = 0.73, R^2 = 0.84) values were higher than the daily and monthly basis. For sediment yield and nutrient losses, the calibration and validation periods were from 2001 to 2004 and 2005 to 2009, respectively. This study shows model efficiency > 0.50 and 0.60 for NSE and R^2, respectively, which are adequate for SWAT model application for management planning. Such successful evaluation of SWAT model as illustrated in this study can widen model applicability into other ungauged basins.

Gebreyesus B.Kirubel M. (2009) was study in Medego watershed, northern Ethiopia. This study was conducted after massive soil and water conservation practices have been implemented in the past 15-year in the study watershed. Primary data and secondary data were collected related to the factors that influence soil loss estimated by USLE and for area description. The land surfaces in the watershed is mainly a reflection of past erosion processes as indicated by many researchers. In this study, the lowest soil loss is estimated on flat plains (< 2% slope) about 1.59 tons ha^{-1} y^{-1}, which is less than the minimum tolerable soil loss (2 tons ha^{-1} y^{-1}) for the country. However, the highest soil loss is from steep slopes (30-50%) which is 35.43 tons ha^{-1} y^{-1}, about twice the maximum tolerable soil loss (18 tons ha^{-1} y^{-1}). The average soil loss rate at watershed level is 9.63 tons ha^{-1} y^{-1} about half of the maximum tolerable soil loss. The implication is the contribution of the implemented SWC measures in decreasing the rate of soil erosion is encourageable as compared to the results related to high soil loss estimated in the past .However, the present value indicates still a need for wise SWC planning that decreases the amount of soil loss in the watershed at least below the maximum tolerable soil loss rate of the country. Therefore, to maximize the available resources in targeting the effect of water erosion on soil loss, those landforms and land uses having large rate of erosion should be given first priority during the introduction of intensive and well designed soil and water conservation interventions at Medego watershed, northern Ethiopia(Gebreyesus B.Kirubel M.20009).

Even though the adverse influences of soil erosion on soil degradation have long been recognized as a key problem for human sustainability (Tamene, 2005), estimation of soil erosion is often difficult due to the complex interplay of many factors such as climate, land cover, soil, topography, lithology and human activities. In addition to this, social, economic, political, and methodological components influence the rate of estimated soil erosion. In support to the above facts, previous studies showed that average soil loss rates within croplands is estimated at 42 t ha^{-1} y^{-1} but may reach 300 t ha^{-1} y^{-1} in some fields in Ethiopia (Hurni, 1993). Erosion rates are also estimated at 130 t ha^{-1} y^{-1} within croplands and 35 tha^{-1} y^{-1} averaged over all land use types in the Ethiopian highlands (FAO, 1986). Similarly, studies in Tigray region, northern Ethiopia have indicated that the mean rate of soil erosion varies from 7 t ha^{-1} y^{-1} (Nyssen, 2001) to more than 24 t ha^{-1} y^{-1} (Tamene, 2005) and 80 t ha^{-1} y^{-1} (Tekeste and Paul, 1989).

Setegn et al., (2010) used SWAT to simulate the sediment yield simulations for the Anjeni, a small watershed (1.35 km2) in the northern highlands of Ethiopia, using different slope classifications.

Ayana et al., (2012) applied SWAT model to Fincha watershed (3,251 km^2), located in western Oromiya Regional State, Ethiopia. The model was calibrated using a time series dataset of 22 years from 1985 to 2006 estimated monthly sediment yield with R^2 value of 0.82 and ENS value of 0.80 during calibration and R^2 value of 0.80 and ENS value of 0.78 during the validation period.

CHAPTER THREE

3 MATERIALS AND METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

The Tekeze River Basin is located in the northern part of Ethiopia. The basin has an average elevation of 1850 m above sea level and average annual rainfall ranges from 600 mm to 1200 mm and a catchment area of about 63,000 km^2. The Tekezé River rises in the central Ethiopian Highlands near Mountain Qachen within Lasta at a longitude 39°20′E and latitude11°58′N, from where it flows west, north, then west again, forming the westernmost border of Ethiopia and Eritrea from the confluence of the Tomsa with the Tekezé at 14°11′N37°31.7′E between the two countries and Sudan at 14°15′27″N36°33′37″E (NEDECO, 1998).

Tekeze hydropower dam is located at latitude and longitude 13° 21’ North and 38° 45’ East, in the north Ethiopia (Figure 2) approximately 80 km west of the town of Mekele. It originates from the mountainous area of Mountain Qachen within Lasta and from Semien Mountains at an elevation above 4500 m above sea level. The dam is located in a steep, narrow gorge, which the river has carved through the surrounding plateau. Tekeze hydropower dam has drainage area of 30,000 km^2. (NEDECO, 1998).

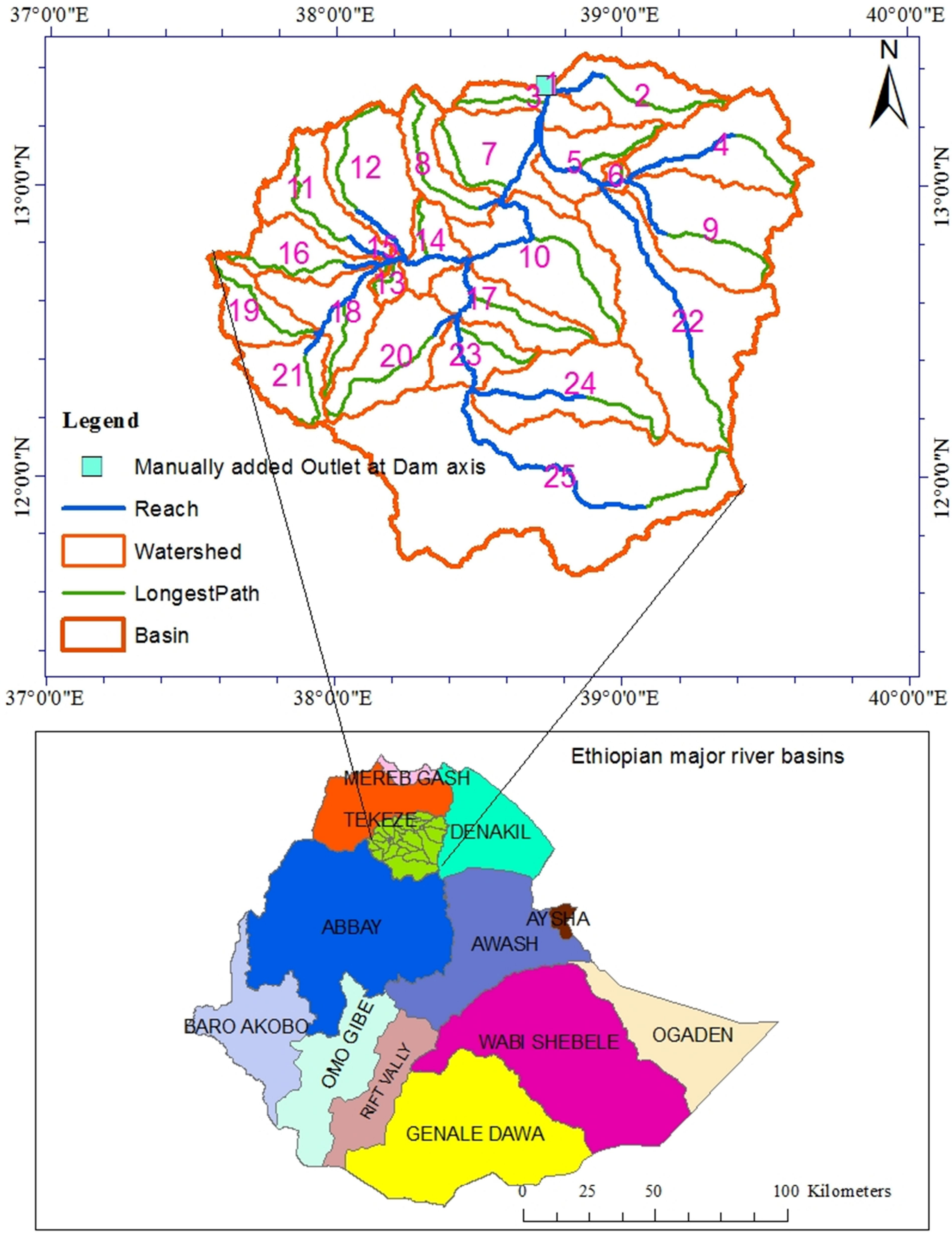

Figure 2: Location of Tekeze hydro power dam watershed

3.1.2 Topography

Tekeze river basin has a catchments area of about 63,000 km^2. Out of this 51% lies in Tigray and 49% in Amhara. About 70% of the basin lies in the high lands at an altitude of over 1500 m a.s.l. The area of land above 2000 m-elevation a.s.l covers about 40% of the total basin. The arable land in the highland part of the basin is found in the plateaus and valleys (COSAERT / WAPCOS, 2001).

3.1.3 Land use and land cover

Land use and land cover is one of the most important factors that affect runoff, evapo-transpiration and surface erosion in a watershed. The land use condition in the upper Tekeze catchment includes mainly of cultivated agricultural land, grassland, forestland, and rural settlements. The cultivated land is subdivided into intensively cultivated, and moderately cultivated. Practically all the land is opened up for cultivation and grazing. Over 70% of the land is under annual crops. Consequently the ground is virtually bare during the dry season. The main land use activities are rain fed cultivation of cereals, oil seeds and pulses and grazing on unimproved pasture and fallow (NEDECO, 1998).

3.1.4 Soil

The soil classification is based on the physical and chemical characteristics which include depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons and others. Soils have many physical and chemical characteristics that are useful in describing and differentiating, among them the most important characters include; effective soil depth, soil color, texture, acidity or alkalinity, electrical conductivity, cat ion exchange capacity and base saturation (Knisel, 1980).
The regional geology of the Tekeze watershed is dominated by the Tertiary volcanic rock and Quaternary Basalts. In this watershed seven main soil types are found which include, Luvisols, Cambisols, Arensols, Nitisols, Vertisols, Lithosols and Regosols. Generally, the soils types of this watershed area are characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay texture types. The erodibility of these soils also varies from medium to very erodible characteristics.

Vertisols are deep to very deep, moderately well to poorly drained, very dark grey to dark yellowish brown in the topsoil, and clay textured throughout. The soils have large surface cracks in the dry season. Run-off formation from Vertisols is high and hence it is susceptible to erosion. shallow and very shallow soils are classified as Lithosols. Lithosols are found in relatively small areas in the watershed area. These are stony and rocky. The texture of Leptosols varies from sandy clay loam to clay and has excessive drainage characteristics. (NEDECO, 1998)

3.2 Data Collection

To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modeling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of Digital Elevation Model (DEM), Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The length of period of weather and climatic data also affect the SWAT model performance. The output from the SWAT model can be affected by the DEM data resolution, mesh size, soil data resolution and soil map scale, watershed subdivision which on the other hand is affected by DEM data resolution etc. (Bosch et al., 2008) found that SWAT stream flow estimates were more accurate when using high-resolution topographic data, land use/land cover data, and soil data. The required DEM data, soil data, land use/land cover data, flow data, climatic and sediment data was collected from different sources. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the upcoming sections (Bosch et al., 2008).

3.2.1 DEM data

Digital Elevation model (DEM) is one of the main inputs of the SWAT (Soil and Water Assessment Tool) model. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRUs). The Digital Elevation Model of 90 by 90 resolution of different type has been taken from Ministry of Water, Irrigation and Electric (MoWIE) GIS department. The DEM was in the format of shape file and this was processed on 90 by 90 DEM, Global Mapper software's and imported to Arc GIS environment.

Table 1: Data source of Tekeze watershed

Data set	Year	Format	Scale	Source	Method of classification
Daily Rainfall	1992-2015	Excel	-	NMSA	
Topographic Map	2005	Digital Raster	1:50,000	MoWIE	GIS 10.1
Soil Map	2005	Digital Raster	1:50,000	MoWIE	GIS10.1
Land Use Map	1986,2000,2005,2013	Digital Raster	1:50,000	MoWIE and EMA	GIS 10.1 and ERDAS Imagine 2013
Daily Flow	1994-2010	Excel	-	MoWIE	
Sediment flow	2005-2015	Excel	-	MoWIE	

3.2.2 Flow data

Daily flow data is required for SWAT for the purpose of calibration and validation. This data was obtained from Ministry of Water, Irrigation and Energy Hydrology Directorate. 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 Yechila, flow station (13°17′ N 39°00′ E). This site was selected as it represents the catchments almost the whole watershed in the upper part of the dam. In addition this station has 1994-2010 flow data.

3.2.3 Sediment data

There are few sites which has measured suspended sediment data in Tekeze with a very short data. However the sediment data was taken for the basin from Ministry of Water, Irrigation and Energy Hydrology Directorate at Yechila, Zamra, Tsirae, Atsela, Areqiwa, Kul Mesk and Tekeze dam site. From these stations dam site station was selected. Depending on the data the remaining values were generated for calibration and sensitivity analysis by SWAT.

3.2.4 Weather data

Weather data are among the main demanding input data for the SWAT simulation. The weather input data required for SWAT simulation includes daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. These are obtained from the Ethiopian National Meteorological Agency. The weather data used for this study are above 30 stations but from those 11 stations was selected such as:Adi Gudom, Amba Giyorgis, Debark, Guhala, Lalibela, Maychew, Nefas Mewcha, Sekota, Tekeze Hydro power dam and Yechila stations as shown in Figure 3 and Appendix 1.

Table 2: Meteorological stations of Tekeze dam watershed

S.No	Station Name	period	Percent of missing (%)
1	Maychew	1992-2015	0.27
2	Tekeze dam	2007-2014	1.67
3	Amde Work	2008-2014	9.85
4	Sekota	1995-2015	11.01
5	Yechila	2001-2014	18.34
6	Amba Giyorgis	2003-2013	12.69
7	Lalibela	1996-2014	9.92
8	Adi Gudom	1990-1015	3.96
9	Debark	1999-2014	5.62
10	Guhala	2003-1013	3.3
11	Nefas Mewcha	1997-2013	2.16

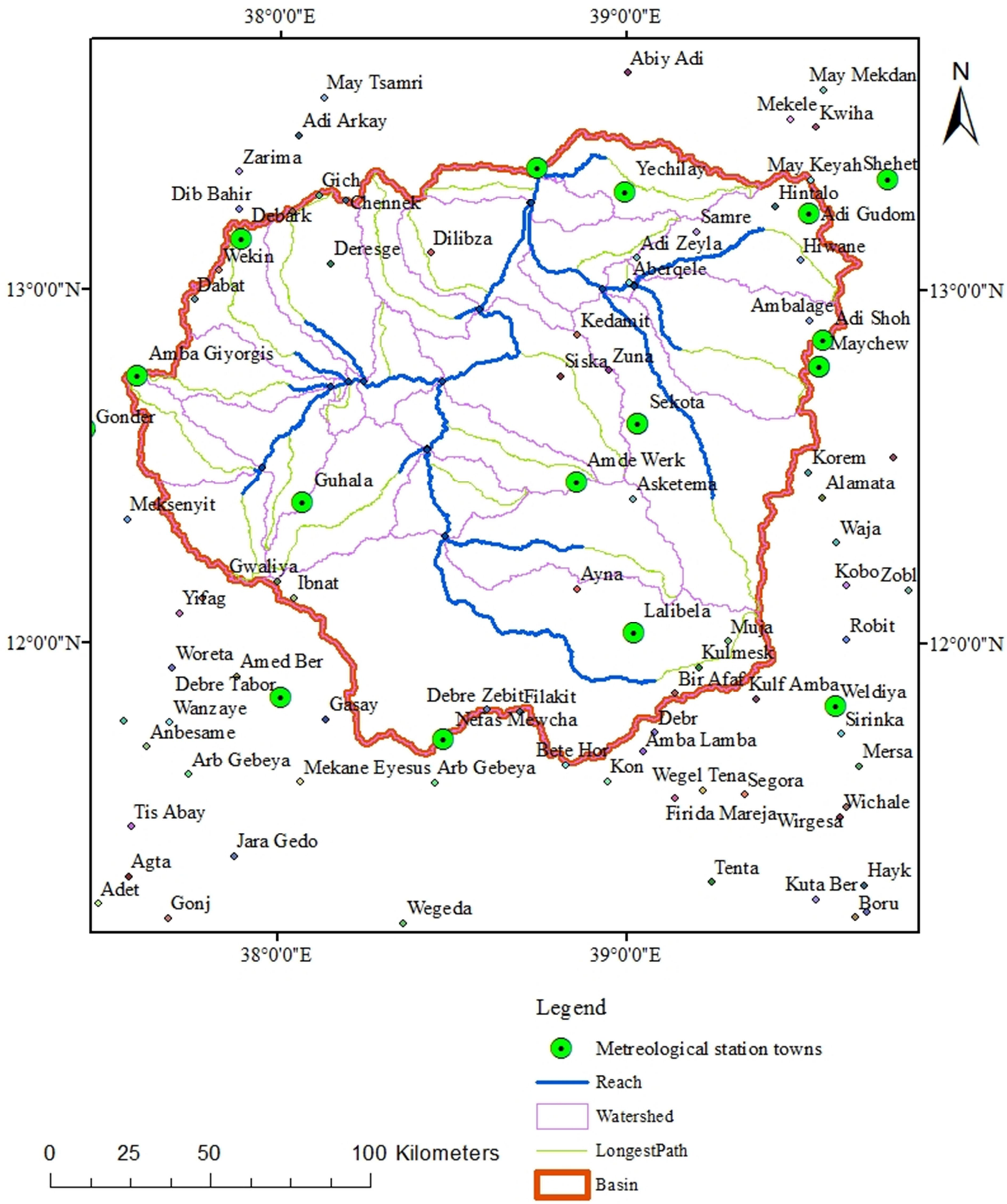

Figure 3: Map of meteorological stations towns for the study area

3.2.5 Software's and materials used

To meet the objectives of the study various software and materials are necessary. Global Mapper, ArcGIS was used to the preliminary data processing, extracting, Erdas Imagine 2013 used for mosaicing satellite images and image classification. For the modeling part, SWAT 2012 model embedded in ArcGIS 10.1 has been used to delineate the DEM, soil, land use and to simulate the meteorological and hydrological sediment and flow data's.

3.3. SWAT Model

Analytical framework: In order to achieve the objectives, ArcSWAT model integrated with remote sensing data and GIS techniques were used for simulating soil loss and runoff

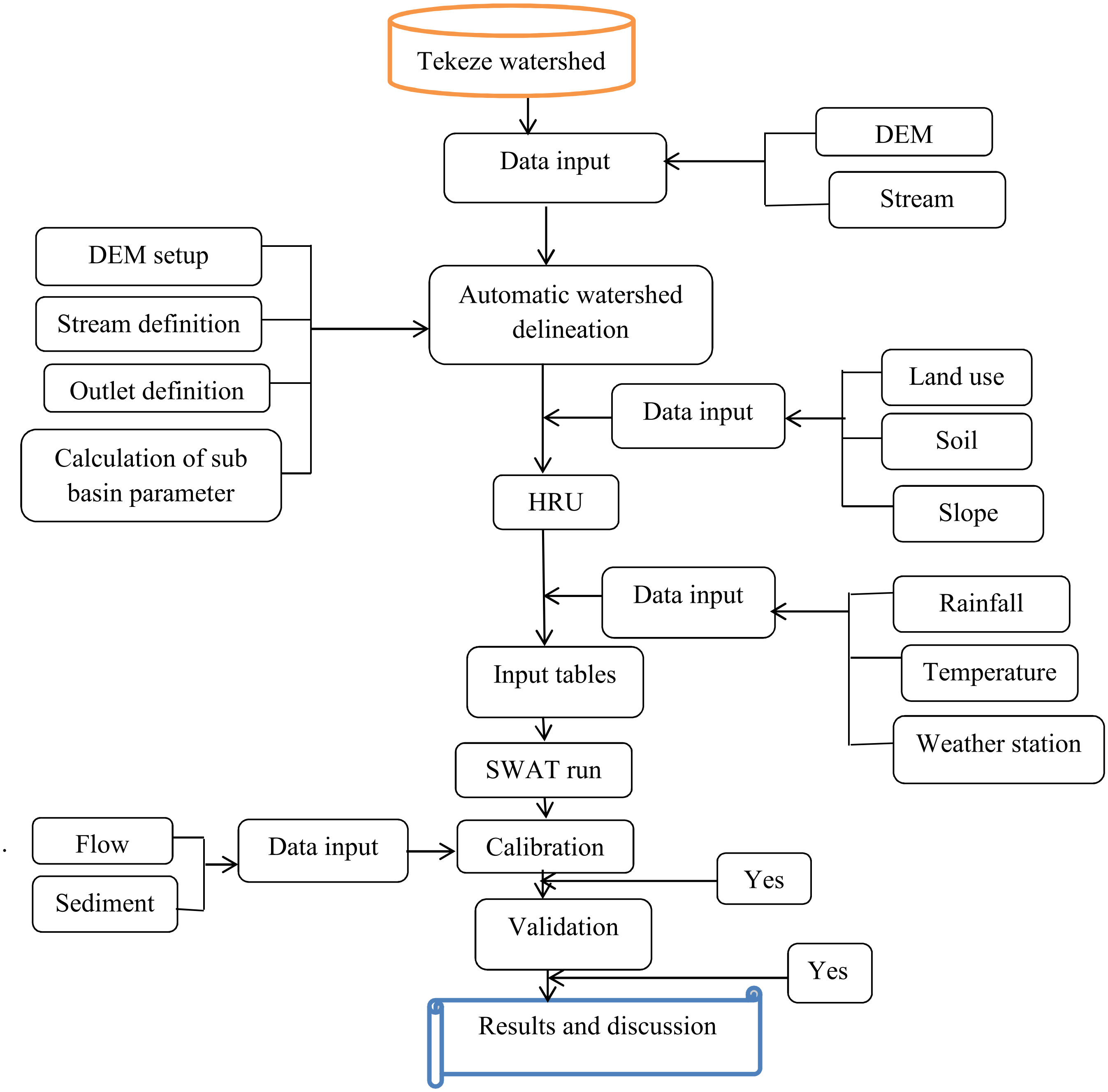

Figure 4: Methodological frame work of SWAT model

3.3.1 SWAT model description

The SWAT (Soil and Water Assessment Tool, Arnold et al., 1998) model is a river basin model developed by US Department of Agriculture - Agricultural Research Service (ARS) in Temple, Texas. The SWAT model is a physically based, continuous time, long term simulation, lumped parameter, deterministic, and originated from agricultural models with spatially distributed parameters operating on a daily time steps (Arnold et al., 1998). 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 that contributed significantly to the development of SWAT were CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) and EPIC (Erosion-Productivity Impact Calculator) (Williams et al., 1985).

SWAT is an operational or conceptual model that operates on a daily time step. The main objective of model development was to predict the impact of land management practices on water, sediment and agricultural chemical yields (nutrient loss) in large and complex watersheds with varying soils, land uses and management conditions over a long period of time (Arnold et al., 1998; Santhi et al., 2001; Arnold and Fohrer et al., 2005; Behera and Panda, 2006; Gassman et al., 2007; Neitsch et al., 2011). To satisfy the intended objective, the model is (a) physically based (calibration is not possible on un-gauged catchments); (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous in time and capable of simulating long periods for computing the effects of management changes (Neitsch et al., 2005, 2011). Therefore, the model is a computationally efficient simulator of hydrology and water quality at various scales. The model is semi physically based, and allows simulation of a high level of spatial detail by dividing the watershed into large number of sub-watersheds (Abbaspour et al., 2009). It includes procedures to describe how CO_2 concentration, precipitation, temperature and humidity affect plant growth. It also simulates evapotranspiration, snow and runoff generation, and is used to investigate climate change impacts (Abbaspour et al., 2009). A command structure is used for routing runoff and chemicals through a watershed. Commands are included for routing flows through streams and reservoirs, adding flows, and inputting measured data on point sources.

Using the routing command language, the model can simulate a basin sub-divided into sub-watersheds and further into hydrological Response units. (Arnold et al., 1998)

3.3.2 Model Components

SWAT includes the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, nutrient yielding, groundwater flow, crop growth, pesticide yielding, water routing and the long term effects of varying agricultural management practices (Neitsch et al., 2011).

The sub basin/sub-watershed components of SWAT can be classified into eight major components - hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Each of the components are described below

Hydrology: The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snow melt, transmission losses and ponds. The percolation and return flow or base flow considered in SWAT for hydrological modeling is only the percolation to shallow aquifer from vadose zone and base flow to the channel from the shallow aquifer. The groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream flow somewhere outside the watershed. According to (Arnold et al., 1998), the water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer. The water percolated to the deep aquifer is assumed to be lost from the watershed system and is not included in the water balance (Neitsch et al., 2011).

Weather: The weather variables required to run the SWAT are precipitation, air temperature, relative humidity, wind speed and solar radiation. These variables can be entered directly in to the SWAT model as daily or sub-daily values.

Sediment: SWAT generates the sediment from the watershed using Modified Universal Soil Loss Equation (MUSLE).

Soil Temperature: Soil temperature is important for movement of water through the soil since water cannot flow through the frozen soil.

Therefore, for the water to infiltrate through the soil layers and all the way to saturated zone, the soil temperature must be above the freezing point. Daily average soil temperature is calculated at the soil surface and the centre of each layer (Neitsch et al., 2011).

Crop Growth/Plant Growth/Land Cover: This SWAT component is a simplified version of the EPIC (Erosion-Productivity Impact factor) plant growth model. As in EPIC, the phonological plant development in SWAT, is based on daily accumulated heat units, Monteith's method for potential biomass, a harvest index to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen or phosphorus stress (Neitsch et al., 2011).

Nutrients: SWAT tracks the movement of different forms of Nitrogen and Phosphorus in the watershed. These nutrients are very important for plant growth. Amounts of NO_{3-} N contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. The amount of soluble phosphorous (P) removed in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor (Neitsch et al., 2011).

Pesticides: In SWAT, the movement of pesticides in to the stream network by runoff and percolation (in solution form) is modeled by equations adopted from GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Neitsch et al., 2011).

Agricultural Management: For the computation SWAT uses physically based inputs such as weather variables (precipitation, air temperature, relative humidity, wind speed and solar radiation), soil types and properties, topography, and land use/land cover of the catchment under study and directly models all the processes associated with water flow, sediment transport, crop growth and nutrient cycling, etc. (Arnold and Fohrer, 2005; Arnold et al., 1998)

In this study, the ArcSWAT2012 was used, where the ArcGIS (version 10.1) environment was used for project development. Spatial parameterization of the SWAT model was performed by dividing a watershed into sub basins based on topography, soil, land use, and slope. This subdivision resulted in a smallest spatial unit in a watershed. This units, referred to as hydrologic response units (HRUs), are used as the basis of the sediment calculation. Waterand sediment losses were determined for each HRU, aggregated at the sub basin level, and then routed to the associated reach and catchment outlet through the channel network (Abbaspour et al., 2009).

3.3.3 Empirical description

3.3.3.1 Hydrological processes in SWAT

SWAT allows a number of different physical processes to be simulated in a watershed (Neitsch et al., 2011). SWAT simulates various hydrological processes. The simulated processes include surface runoff, infiltration, evapo-transpiration (ET), lateral flow, percolation to shallow and deep aquifers and channel routing (Arnold et al., 1998). All these hydrological processes are simulated in surface, soil, and intermediate (vadose) zone, shallow and deep aquifers. Among the aforementioned hydrological processes, surface runoff, subsurface or lateral flow and return flow or base flow contributed to stream flow in the main channel. As it was described earlier the water that enters the deep aquifer is assumed to be lost out of the system of the watershed under study. In SWAT, the local water balance is represented through four storage volumes. These storage volumes are: snow, soil profile (0-2 m), shallow aquifer (2-20 m) and deep aquifer storage (>20 m) (Abbaspour et al., 2009). Since there was no significant snow fall in the catchment no process related to snow was considered in this study.

SWAT has a weather simulation model that generates daily data for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables of these data. This provides a useful tool to fill in missing daily data in the observed records.

SWAT first delineates a basin or a watershed and then, a basin is delineated into sub-basins, which are then further subdivided into hydrologic response units (HRUs). In this sub-division SWAT considers spatial variations in topography, land use, soil and other watershed characteristics. Hydrologic Response Units (HRUs) are lumped land areas within the sub basin that are comprised of unique land cover, soil and management combinations and based on two options in SWAT, they may either represent different parts of the sub basin area or sub basin area with a dominant land use or soil type also, management characteristics. (Neitsch et al., 2011)

Therefore, each HRU is assumed to be spatially uniform in terms of slope, land use, soil type and climate. With this semi-distributed (sub basins) set-up, SWAT is attractive for its computational effciency as it offers some compromise between the constraints imposed by the other model types such as lumped, conceptual or fully distributed, physically based models. A full model description and operation is presented in (Neitsch et al., 2011).

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 conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be divided in to two major divisions. (1) The land phase of the hydrologic cycle and (2) the water or routing phase of the hydrologic cycle. The first division controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin. And, the second division is related to the movement of water, sediments, nutrient and pesticide through the channel network of the watershed to the outlet (Neitsch et al., 2011).

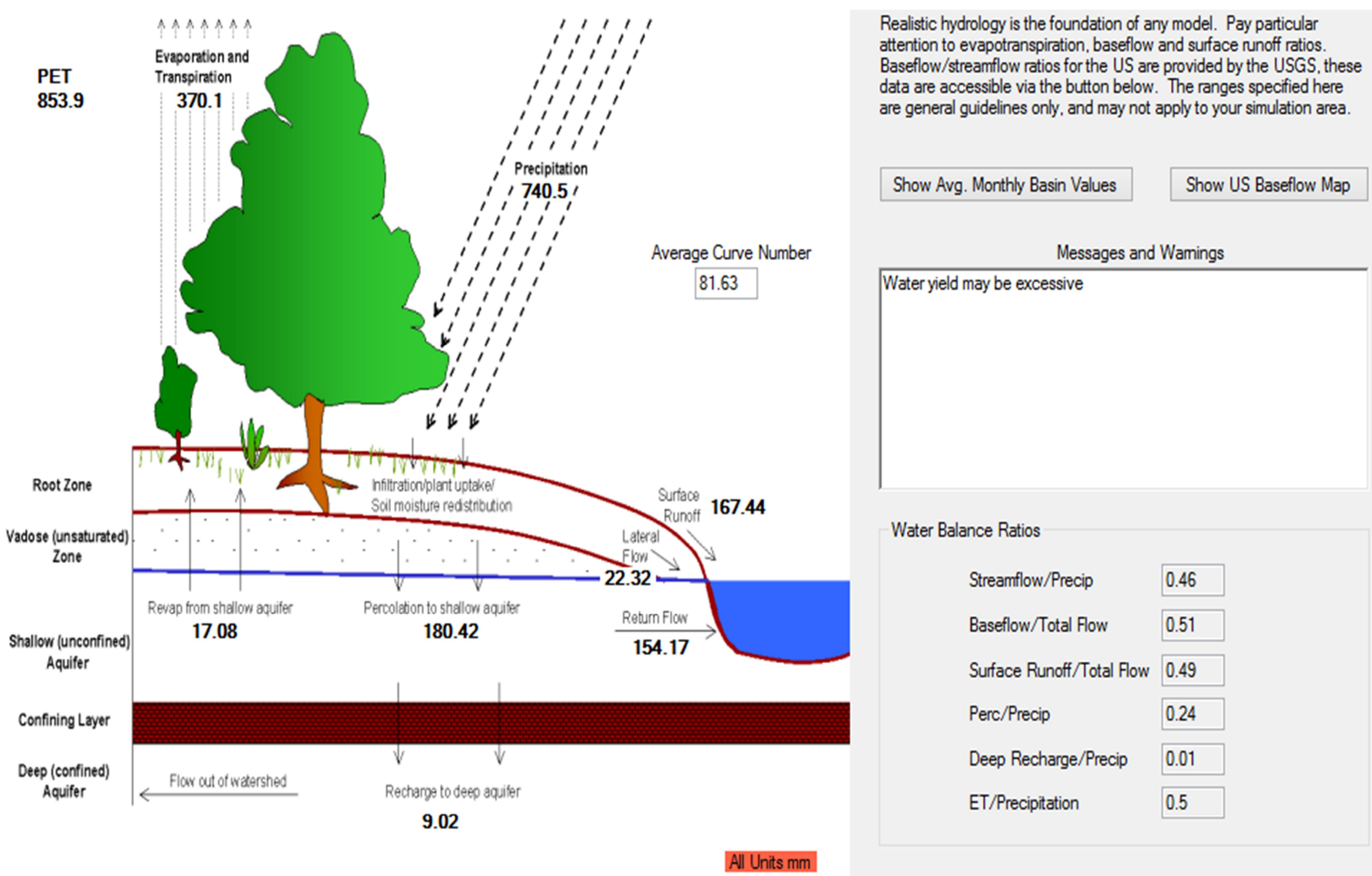

Figure 5: Schematic representation of hydrologic cycle (Neitsch et al., 2011)

Land Phase of the Hydrologic Cycle: that controls the amount of water and sediment loadings to the main channel in each sub watershed. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SW_t = SW_o + \sum_{i+1}^{t}\left(R_{day} - Q_{sur} + E_a - W_{seep} - Q_{gw}\right) \text{..........} 3.1$$

Where SW_t is the final soil water content (mmH_2O), SW_o 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) (Neitsch, Arnold,et.al, 2005).

The subdivision of the watershed into sub-watersheds and further into HRUs enables the model to reflect the differences in evapotranspiration for various crops or land covers and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy and gives much better physical description of the water balance.

Climate: -Climatic variables among the most important variables required by SWAT to model the land phase of the hydrologic cycle. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum daily 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 by the user form records of observed data or generated during simulation.

Weather Generator:-If there is no daily value for weather, 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. Precipitation, temperature, wind speed, solar radiation and relative humidity of a given station in the watershed are generated in this way. For this study the daily measured precipitation and air temperature from 1992 - 2015 was used as input and the other variables were generated by SWAT for different station. SWAT uses a model developed by Nicks (1974) to generate any 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 skewed distribution or a modified exponential distribution (Neitsch et al., 2011). 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 (Neitsch et al., 2011).

Surface Runoff/overland Flow:- Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch et al., 2011). When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the rate of application is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once the all surface depressions have filled, surface runoff will commence (Neitsch et al., 2011). SWAT provides two methods for estimating the surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911). The SCS curve number is a function of the soil's permeability, land use and antecedent moisture conditions (SCS, 1972) whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity (Green and Ampt, 1911). SWAT uses the daily and hourly time steps to calculate surface runoff. For daily time steps, SWAT uses an empirical SCS curve number (CN) method and for daily time steps SWAT uses the Green and Ampt equation.

For this project the SCS curve number was adopted for the simulation of surface runoff in

SWAT since it requires the readily available daily data that can be obtained from easily from government ministries and/or offices.

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

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

Where: Q_{surf}: is the accumulated runoff or rainfall excess (mm H_2O), 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:

$$S = 25.4 \times \left(\frac{1000}{CN} - 10\right) \quad 3.3$$

Where, CN- is the curve number

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

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \quad 3.4$$

Peak runoff rate: -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 for each HRU.

The rational formula is:

$$q_{peak} = \frac{C \times i \times A}{3.6} \quad 3.5$$

Where: q_{peak}: is the peak runoff rate (m^3/s), C is the runoff coefficient, i is the rainfall intensity (mm/hr), A is the sub basin area (km^2) and 3.6 is a unit conversion factor.

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 hydrologic models. In addition to keeping track of mass flow in the channel, SWAT models the transmission of chemicals in the stream and streambed. SWAT routes water, sediment, nutrients and organic chemicals in the main channel. SWAT provides two methods routing (Neitsch et al., 2011):

1. Variable storage method and
2. Muskingum river routing method

Both Variable Storage and Muskingum routing methods are variations of the kinematic wave model. Muskingum River routing method was adopted to model the storage volume in channel length as a combination of wedge and Prism storages (Chow et al., 1988).

SWAT assumes the main channels, or reaches, have a trapezoidal shape. Therefore, Manning's equation for uniform flow in a trapezoidal channel was used to calculate the rate and velocity of flow in a reach segment for a given time step.

$$q_{ch} = \frac{A_{ch} \times R_{ch}^{2/3} \times slp_{ch}^{1/2}}{n} \qquad \text{.......} 3.6$$

$$v_c = \frac{R_{ch}^{2/3} \times slp_{ch}^{1/2}}{} \qquad \text{.......} 3.7$$

Where, q_{ch} is the rate of flow in the channel (m^3/s), A_{ch} is the hydrualic radius for a given depth of flow (m), slp_{ch} is the slopealong the channel length (m/m), n is the manning's coeffcient for the channel and v is the flow velocity (m^3/s)

Soil Hydrologic Group:- 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 (Neitsch et al., 2011). These soil hydrologic groups are defined below

A: Low runoff potential: Soils in this group have 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.

Potential Evapotranspiration (PET):- There are numerous methods that have been developed to calculate potential evapotranspiration (PET). The SWAT model provides three of those methods to estimate the potential evapotranspiration: the Penman-Monteith method (Monteith, 1965), the Priestley-Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves et al., 1985).

Among the aforementioned methods, Hargreaves method was selected for PET calculation in this study. The reason for this is that Hargreaves method requires only daily records of maximum/minimum air temperature to estimate PET. Since there are no measured solar radiation, wind speed and relative humidity for this watershed, Hargreaves method was found appropriate and used in SWAT to estimate PET. The other two methods need measured solar radiation, wind speed and relative humidity data to estimate PET.

The form of Hargreaves equation used in SWAT was published in 1985 (Hargreaves et al., 1985):

$$\lambda E_o = 0.0023 \times H_o(T_{mx} - T_{mn}) \times (\overline{T}av + 17.8 \quad \text{.....3.8}$$

Where: λ is the latent heat of vaporization (MJ/kg), E_o is the potential evapotranspiration (mm/day), H_o is the extraterrestrial radiation (MJ/m^2day), 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).

3.3.4 Sediment Component of SWAT

For a watershed in which erosion and sedimentation process is significant, it is important to identify the source erosion and what causes it. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied. In this study since there was a time limitation to conduct field investigation to the watershed of study, it aimed at applying SWAT (Soil and Water Assessment Tool) model to simulate the sediment yield from Tekeze watershed.

Therefore, a semi-distributed, physical-based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study. SWAT uses a Modified Universal Soil Loss Equation (MUSLE) developed by Williams (1975) to simulate sediment yield from the upland watersheds. MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) (Neitsch et al., 2011)

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times A_{hru})^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \quad \text{.....3.9}$$

Where: Sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume from the watershed (mm /ha), q_{peak} is the peak runoff rate (m^3/s), A_{hru} is the area of the HRU (ha), K_{USLE} is the soil erodibility factor, C_{USLE} is the USLE land cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and CFRG is the coarse fragment factor.

USLE predicts the average annual gross erosion as a function of rainfall energy. Whereas in MUSLE the rainfall energy is replaced with a runoff factor which 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 (Neitsch et al., 2011).

Sediment transport

Sediment transport in the channel network is a function of two processes, deposition and degradation; SWAT compute both of them by using the same channel dimensions for the entire simulation. To do this, SWAT uses the simplified version of Bagnold equation (Bagnold, 1977) and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. (Neitsch et al., 2011)

The amount of sediment degradation in the channel can be calculated by the model by using equation 3.10 and the net amount of sediment deposited in the reach segment is calculated by equation 3.11.

$$Sed_{\deg} = \left(Conc_{sed,ch,mx} - Conc_{sed,ch,i}\right) \times V_{ch} \times K_{ch} \times C_{ch} \quad \text{.......} 3.10$$

$$Sed_{dep} = \left(Conc_{sed,ch,i} - Concmx\right) \times V_{ch} \quad \text{.......} 3.11$$

Where: Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), $Conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m^3), $Conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m^3), K_{ch} is the channel erodibility factor (cm/h/a), C_{ch} is the channel cover factor, V_{ch} is the volume of water in the reach segment (m^3), sed_{dep} is the amount of sediment deposited in the reach (metric tons).

Once the amount of degradation and deposition has been calculated by the above equations, then the final amount of sediment in the reach is determined by equation 3.12 and the amount of sediment transported out of the reach is calculated by equation 3.13

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{\deg} \quad \text{..........} 3.12$$

$$Sed_{out} = Sed_{ch,i} \times \frac{V_{out}}{V} \quad \text{..........} 3.13$$

Where sed_{ch} is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons),Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), Sed_{out} is the amount of sediment transported out of the reach (metric tons), Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $V_{ou}t$ is the volume of outflow during the time step (m^3) and V_{ch} is the volume of water in the reach segment (m^3) (Neitsch et al., 2011) .

Surface Runoff and Sediment lag

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated and also Sediment in the surface runoff is lagged as well. SWAT incorporates a surface runoff storage feature to lag part of the surface runoff release to the main channel (Neitsch et al., 2011). Once surface runoff is calculated, the amount of surface runoff released to the main channel is calculated by equation 3.14 and after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using equation 3.15.

$$Q_{surf} = \left(Q'_{surf} + Q_{stor,i-1}\right)\left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \quad \text{..........} 3.14$$

$$Sed = \left(sed' + sed_{stor,i-1}\right)\left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \quad \text{..........} 3.15$$

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

Sediment in lateral and ground water flow

Even though, it is small in proportion to the surface flow contribution, SWAT allows the lateral and groundwater flow to contribute sediment to the main channel and calculated:

$$Sed_{lat} = \frac{(Q_{lat} + Q_{gw}) \times A_{HRU} \times Conc_{sed}}{1000} \quad \text{..............3.16}$$

Where sed_{lat} is the sediment loading in lateral and ground water flow (metric tons), Q_{lat} is the lateral flow for a given day (mm water), Q_{gw} is the groundwater flow for a given day (mm water), A_{HRU} is the area of the HRU (km^2) and $Conc_{sed}$ is the concentration of sediment in lateral and groundwater flow (mg/l). (Neitsch et al., 2011)

3.3.5 Sedimentation extent and subsequent effect on reservoir

Many reservoirs which have been established for hydroelectric power, urban water supply and irrigation accumulate an alarmingly higher level of sediment than expected. Koka, Angereb, Legedadi, Gilgel Gibe-I and other reservoirs are threatened by this accelerated sedimentation. Consequences of reservoir sedimentation include the loss of storage capacity and its subsequent effects. These effects include water supply shortages for human consumption, irrigation and hydropower; increased hydro-equipment maintenance and repair; a decline in water quality; the cost of removing sediment; blockage of navigational waters and loss of recreation opportunities. Aquatic ecosystems are modified by increased deposition of sediments and adsorbed or dissolved nutrients and chemicals, which commonly causes eutrophication which in turn negatively influences habitats of fish and other organisms. Some of the techniques suggested to reduce reservoir sediment concentration are technically less feasible as it requires design considerations during construction (which is difficult to implement for the existing dams). The deforestation and degradation of the Ethiopian Highlands have a negative impact on the downstream catchments (Awulachewet al., 2008; Hathaway, 2008). More than 95% of Egypt's Aswan High Dam's mean annual suspended sediment load ($120x10^6$ t $year^{-1}$, Teodoruet al., 2006) comes from Ethiopia, in which 72% comes from the Blue Nile and 25% from the Atbara River. Whereas, the White Nile contributes only 3% of the total sediment load (Teodoruet al., 2006).

3.3.6 Scenario development

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. Scenarios are reasonable and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships (Yacob E 2010). Many different activities are carried out in the catchment; mainly urbanization and farming activities. Farming activities are increasing in the area due to the population pressure and depletion of soil fertility to produce the intended demand of food crop for inhabitants. To analyze the effect of these different human activities in the catchment on sediment prediction in relation to demographic changes, development and management practices, we need to develop scenarios. Scenario analysis is a process of evaluating possible future events through the consideration of alternative possible outcomes (scenarios) (Yacob E 2010) . 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, Afforesting hotspot areas of erosion, Parallel terraces targeting hotspot areas, Grassed waterways, Gully/grade stabilization structures and Combined scenarios were developed and the parameters for these scenarios were incorporated in the management input data.

3.4 SWAT Model Data input Preparation

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

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. (Di Luzio et al, 2002)

3.4.1 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 90 by 90 resolution of DEM was obtained from MoWIE GIS department. The DEM was in the format of Tekeze river basin 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 Tekeze dam was clipped from the processed Tekeze River Basin and used for SWAT DEM input.

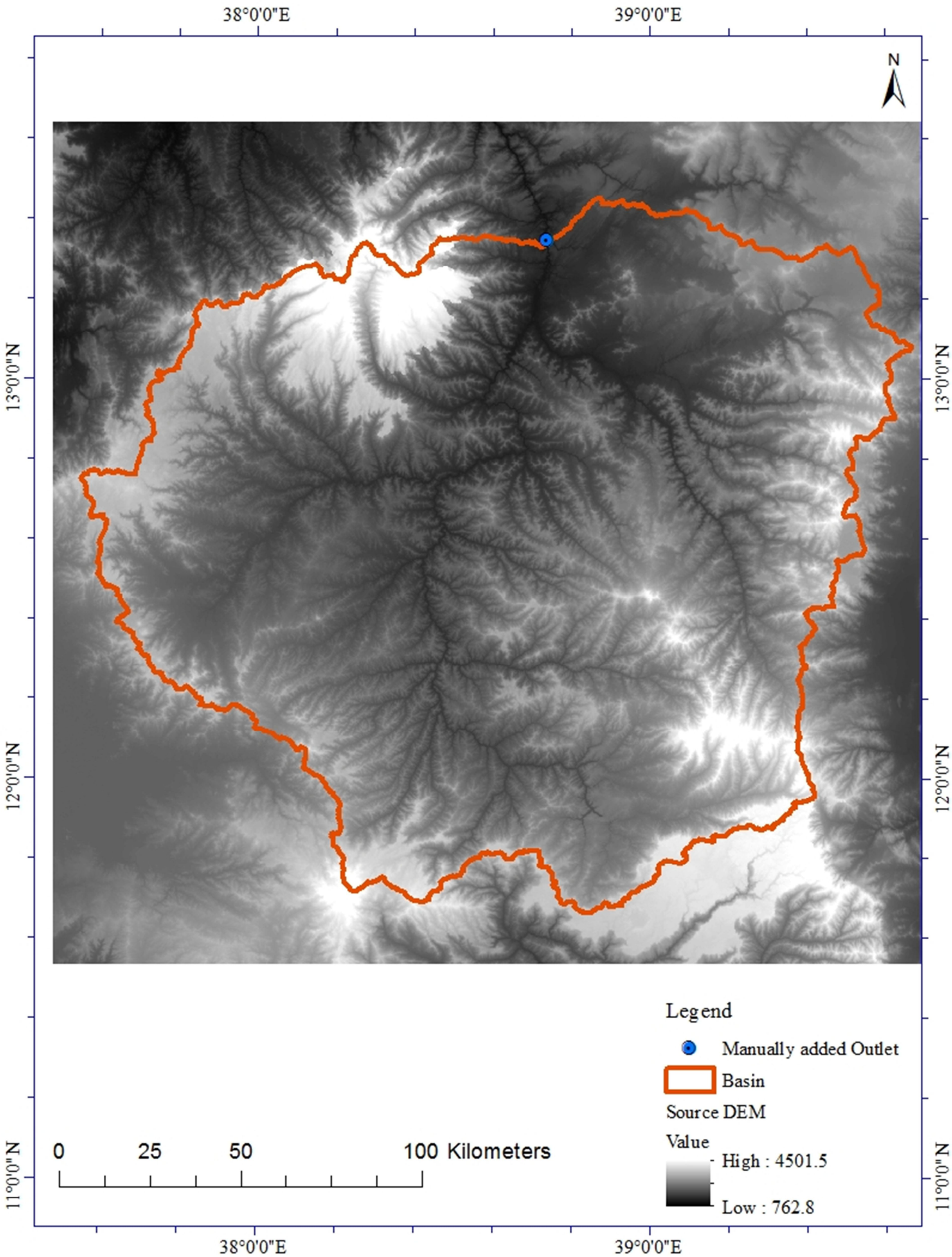

Figure 6: Delineated DEM of Tekeze dam watershed

3.4.2 Land Use/Cover map classification

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 (Neitsch et al., 2011). The land use map was obtained from MoIWE and EMA.

Image Classification: Image classification is necessary to convert image data to thematic data. According to Lillesand and Kiefer (1994), the overall objective of image classification procedures is to automatically categorize all pixels in an image into land use/land cover classes. Notice that data are transformed into information. Multispectral classification is one of the most often used methods of information extraction. In classifying the images, both unsupervised and supervised image classifications techniques were applied. The unsupervised was done before field work. Supervised classification requires a prior knowledge of the scene area in order to provide the software with unique training classes. It is up to the user to define the original pixels that contain similar spectral classes representing certain land cover classes (Jensen, 1996). Following this, supervised land use and land cover classification has been carried out using ERDAS Imagine software from 1986 and 2010 Land sat Satellite image. The maximum likelihood image classification was utilized for the supervised classification. With the help of visual interpretation elements and the different reflection characteristics of the features in the satellite image of 1986and 2010, the study area has been classified into Seven land use and land cover classes, namely, Forest land, Moderately cultivated, Shrub land , Grass land, Water body, Bush land and Intensively cultivated land as shown in Figure 7. Descriptions of each of the land cover categories of the study watershed are presented in Table 3 and Appendix 5.

Accuracy assessment: Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. To assess the classification accuracy, confusion matrix was employed. The confusion/error matrix consists of rows and columns. The rows represent the classification values and the column represents facts from the field. The diagonal line of the error matrix represents the number of pixels that were correctly classified. The overall accuracy index is produced by dividing all the pixels correctly classified by the total number of pixels in the matrix. The producer accuracy index is produced by dividing the number of correctly classified pixels that belong to a class by the sum of the values of the column of the same class. The user accuracy index is produced by dividing the total number of correctly classified pixels that belong to a class by the sum of the values of the rows of the same class (Jensen, 1996).

Evaluation of the image classification: The overall accuracy is calculated by summing the number of pixels classified correctly and dividing by the total number of pixels. The ground truth image or ground truth Region of interest defines the true class of the pixels. The pixels classified correctly are found along the diagonal of the confusion matrix table, which lists the number of pixels that were classified into the correct ground truth class. The total number of pixels is the sum of all the pixels in the entire ground truth classes. The kappa (K) coefficient measures the agreement between classified and ground truth pixels. A kappa value of 1 represents perfect agreement while a value of 0 represents no agreement. The Kappa coefficient is calculated according to the formula given by Congalton et al. (1999)

$$K = \frac{N\sum_{i}^{n} X_{i,i} - \sum_{i}^{n}(G_i \times C_i)}{N^2 - \sum_{i}^{n}(G_i + C_i)} \quad \text{..........3.17}$$

Where: i is the class number, N is the total number of classified pixels that are being compared to ground truth, $X_{i,i}$ is the number of pixels belonging to the ground truth class i, that have also been classified with a class i (i.e., values found along the diagonal of the confusion matrix), C_i is the total number of classified pixels belonging to class i, G_i is the total number of ground truth pixels belonging to class i,

To assess the accuracy of an image classification, it is common practice to create a confusion matrix. In a confusion matrix, your classification results are compared to additional ground truth information. The strength of a confusion matrix is that it identifies the nature of the classification errors, as well as their quantities (Congalton et al. 1999).

Table 3: Confusion matrix assessment of 2010 land use

Classification	Water body	Grass land	Shrub land	Bush land	Intenssively cultivated	Forest	Moderatly cultivated	Ground truth total	User accuracy (%)
Water body	2	0	0	0	0	0	0	2	100
Grass land	0	10	1	0	1	0	0	12	83.333
Shrub land	0	0	5	1	0	1	0	7	71.429
Bush land	0	0	1	7	0	0	1	9	77.778
Intenssively cultivated	0	0	0	1	9	0	2	12	75
Forest	0	0	1	1	0	6	0	8	75
Moderatly cultivated	0	1	0	0	1	0	8	10	80
Total	2	11	8	10	11	7	11	60	
Producer's accuracy (%)	100	90.91	62.5	70	81.82	85.71	72.7273		

After assessment of uncertainty matrix over all accuracy and Kappa coefficients are 0.783 and 0.742respectively, the value represents perfect agreement between grounds and imagine classification.

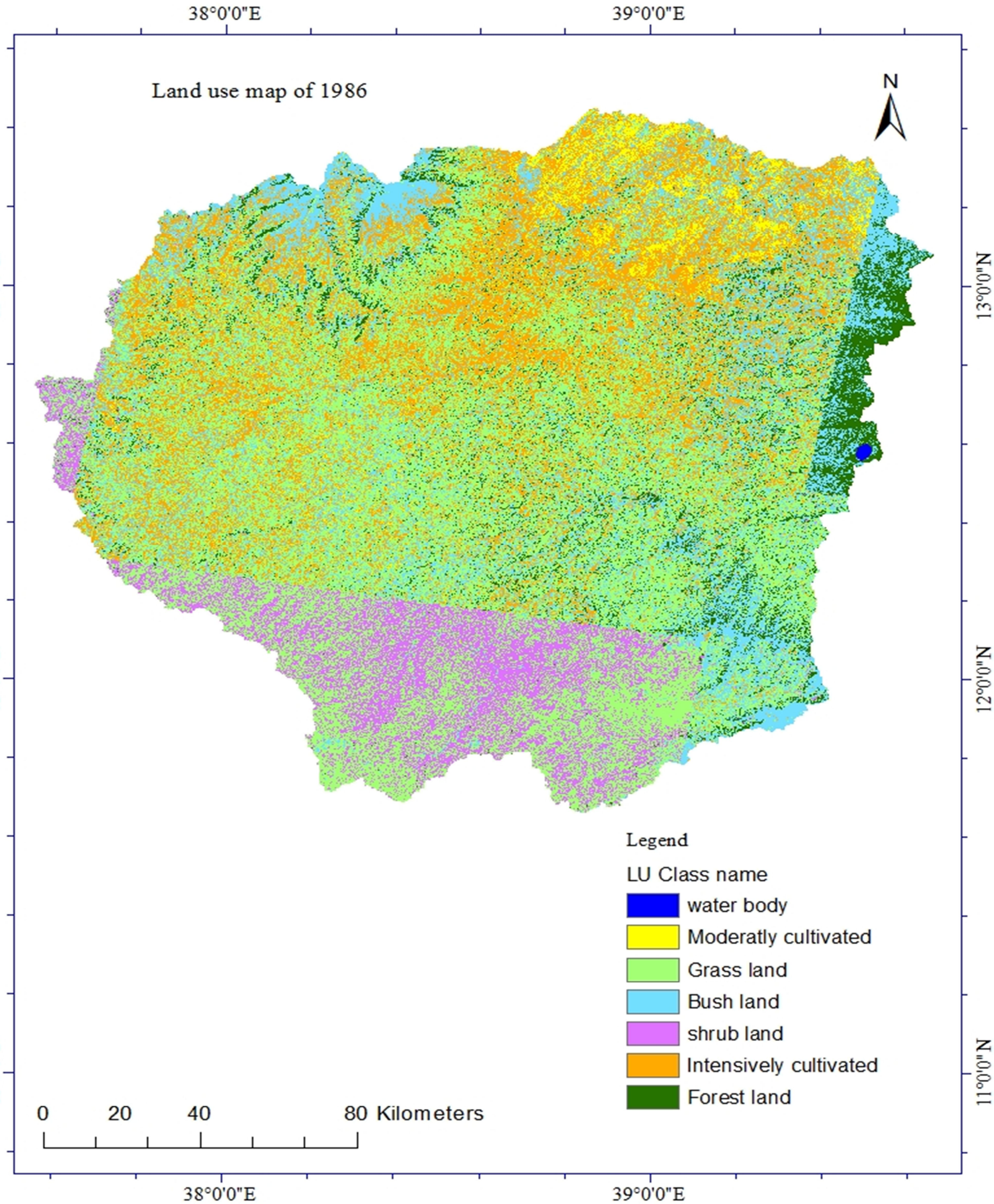

Figure 7: Land use map of Tekeze dam watershed 1986 (EMA)

Table 4: Land use/land cover classification and distribution of Tekeze dam watershed

Land Use /cover Tekeze	SWAT land use	SWAT land use code	Area (Ha)	% of watershed
MODERATELY CULTIVATED	Agricultural Land-Generic	AGRL	705875.4	22.92
OPEN SHRUBLAND	Pasture	PAST	1765613.8	57.32
AFRO-ALPINE HEATH VEGETATION	Evergreen Forest Land	FRSE	69149.47	2.25
INTENSIVELY CULTIVATED	Corn	CORN	535336.49	17.38
WATER BODY	Water	WATR	1689.7427	0.06
OPEN BUSHLAND	Range-Brush	RNGB	1070.712	0.03
OPEN GRASSLAND	Range-Grasses	RNGE	1338.7962	0.04
Total			3080074.41	100

3.4.3 Soil Map

SWAT model requires different soil textural and physio-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic car-bon content or different layers of each soil type. The soil map of Tekze was obtained from MoWIE in the shape file format, Major Soils of the world (FAO, 2002). 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. Major soil types in the watershed are listed in table 5

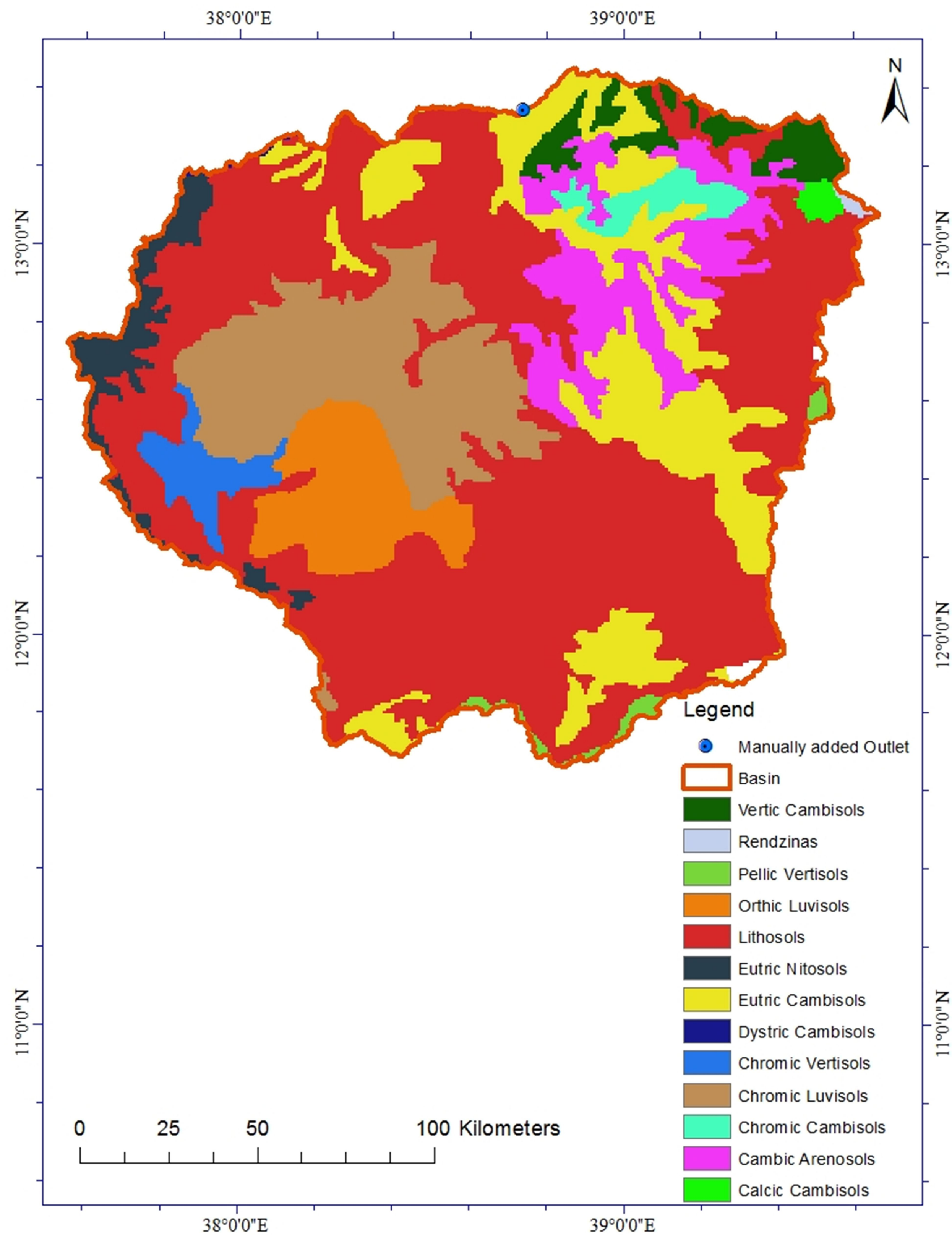

Figure 8: Soil map of Tekeze watershed (MoWIE)

Table 5:Soil type classification of SWAT and area coverage

S.No	Soil Name	Area (Ha)	% of watershed
1	Calcic Cambisols	11854.1951	0.38
2	Cambic Arenosols	228060.8385	7.4
3	Chromic Cambisols	45980.4991	1.49
4	Chromic Luvisols	403019.0747	13.08
5	Chromic Vertisols	61204.4312	1.99
6	Dystric Cambisols	3106.527	0.11
7	Eutric Cambisols	438081.2363	14.22
8	Eutric Nitosols	84411.5852	2.74
9	Eutric Regosols	3878.2845	0.13
10	Lithosols	1514398.609	49.17
11	Orthic Luvisols	179147.6609	5.82
12	Pellic Vertisols	18271.1556	0.59
13	Rendzinas	4026.9494	0.13
14	Vertic Cambisols	83386.3663	2.71
Total		3080074.41	100

Soil loss rate classification: Soil formation rates are vital for evaluation of soil loss rate (the extent to which soil loss can be tolerated) and the potential of soil regeneration once soil erosion can be stopped completely. A study of soil formation rates in different agro ecological zone of Ethiopia indicates that the range of the tolerable average soil loss level for the various agro-ecological zones of Ethiopia were 2 – 18 t/h/y (Hurni H., 1985).

3.4.4 Weather/Climate Data

Climate data is among the most important data required for the SWAT model. Obtaining representative meteorological data for watershed-scale hydrological modeling can be difficult and time consuming. Land-based weather stations do not always adequately represent the weather occurring over a watershed, since they can be far from the watershed of interest and can have a missing data series. It is beneficial to have a meteorological station within the watershed of interest.

Rain gauge data are point measurements which may not represent the whole watershed. This problem can be reduced only when there are multiple rain gauges within the watershed. Otherwise, the problem exists specially for large watersheds which may have large hydro-climatic gradients. The weather data are the main input variables data for SWAT 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 a program dew02.exe (Liersch S., 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.

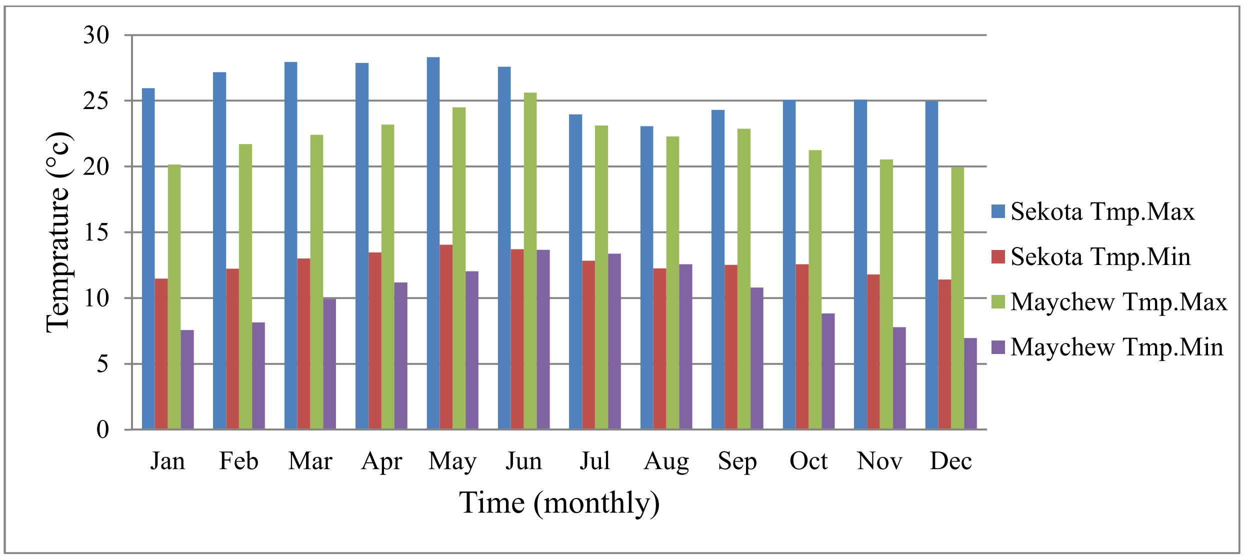

Figure 9: Mean monthly maximum and minimum temperature of Sekota (1995-2014) and Maychew (1992-2015) (NMSA)

The rainfall data was 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 by PCP STAT.

The rainfall in the area has uni-modal characteristics with one rainy and one dry season with annual average rainfall of Maychew 108.12 mm and 115.48 mm for Sekota. The rainy season extends from May to October and dry season from November to April. In period (1992 – 2015) shows that, a high concentration of rainfall occurs in July and August. The mean annual temperature of Maychew ranges between 6.96$°_C$ to 25.62$°_C$ and 11.4 to 28.31 for Sekota (Figure 9 and 10)

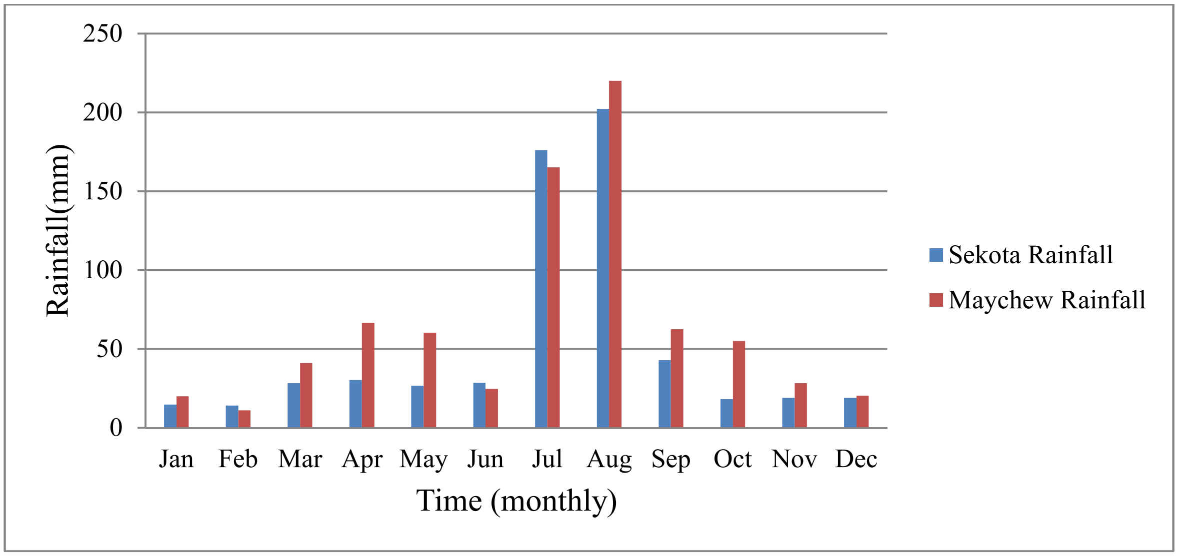

Figure 10: Mean monthly Rainfall Sekota (1995-2015) and Maychew (1992-2015) (NMSA)

3.4.5 Data analysis and filing missing data

Rainfall data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. For the missing data for this study there are methods to estimate these missing values in the given stations. For this study missing values was estimated from other stations around the missed record station by considering the assumptions of at least three as close to and evenly spaced around the station with the missing record station as possible. Simple Arithmetic mean method was used where the mean monthly rainfall of all the index stations is within 10% of the station under consideration (station x) and calculated the missing data by equation 3.18. Also-99 was used during PCP STAT.

$$P_x = \frac{1}{N}(P_A + P_B + P_c \dots \dots \dots .. + P_N) \quad \text{......3.18}$$

Where P_X is the precipitation for the station with missed record, P_A, P_B, P_C….P_N are the corresponding precipitation at the index stations (Garg, 1976).

Checking homogeneity

One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall records and plotted to compare the stations with each other. Non-dimensional values of the monthly precipitation of each station can be computed by:

$$P_i = \frac{P_{i,av}}{Pav} \times 100 \text{ ....} 3.19$$

Where P_i is non-dimensional value of precipitation for the month in station i. Pi,av over years averaged monthly precipitation for the station i and Pav is over year's averaged yearly precipitation of the station i. The stations that used for this study have a rainfall pattern of uni-modal with high rainfall season in July to September and short rainy season march to April (Figure 11)

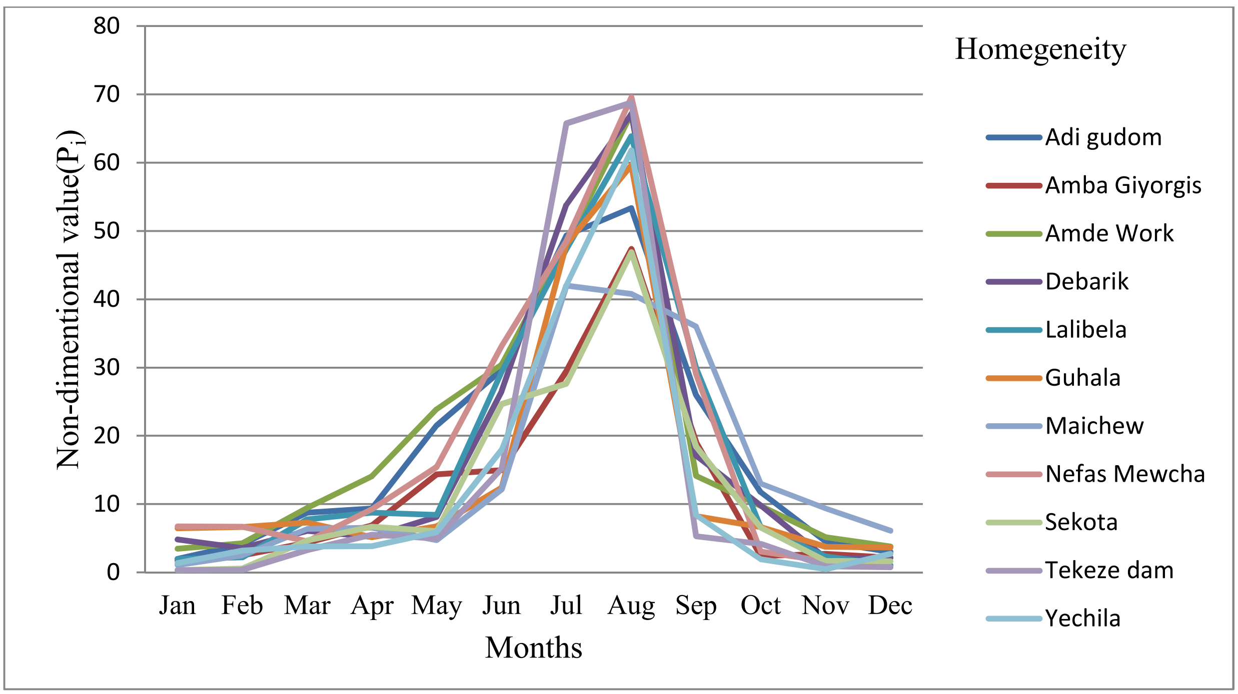

Figure 11: Non-dimensional plots of selected stations in Tekeze watershed

Checking consistency stations: Double mass curve (DMC) was used to check the consistency of rainfall for adjustment of inconsistent. This technique is based on the principle that when each recorded data comes from the same parent sample, they are consistent. A group of 5 base stations was selected due to the long period of record data to cheek these data of the same period starting in common time (1997-2014) and shown in Fig 12. A consistent record is one where the characteristics of the record have not changed with time. A double-mass curve is a graph of the cumulative catch at the rainguage of interest versus the cumulative catch of one or more gauges in the region that has been subjected to similar hydro meteorological occurrences and is known to be consistent. If a rainfall record is a consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope. A change in the slope of the double mass curve would suggest that an external factor has caused changes in the character of the measured values. If a change in slope is evident, then either the record needs to be adjusted with the early or the later period of record adjusted. In order to detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique, called double mass curve method generally adopted (Garg, 1976).

$$P'_x = P_x \times \frac{M_c}{M_o}$$

Where: P'_x is corrected precipitation at station x, P_x is original recorded precipitation at station x, M_o is original slope of the double mass curve and M_c is corrected slope of the double mass curve

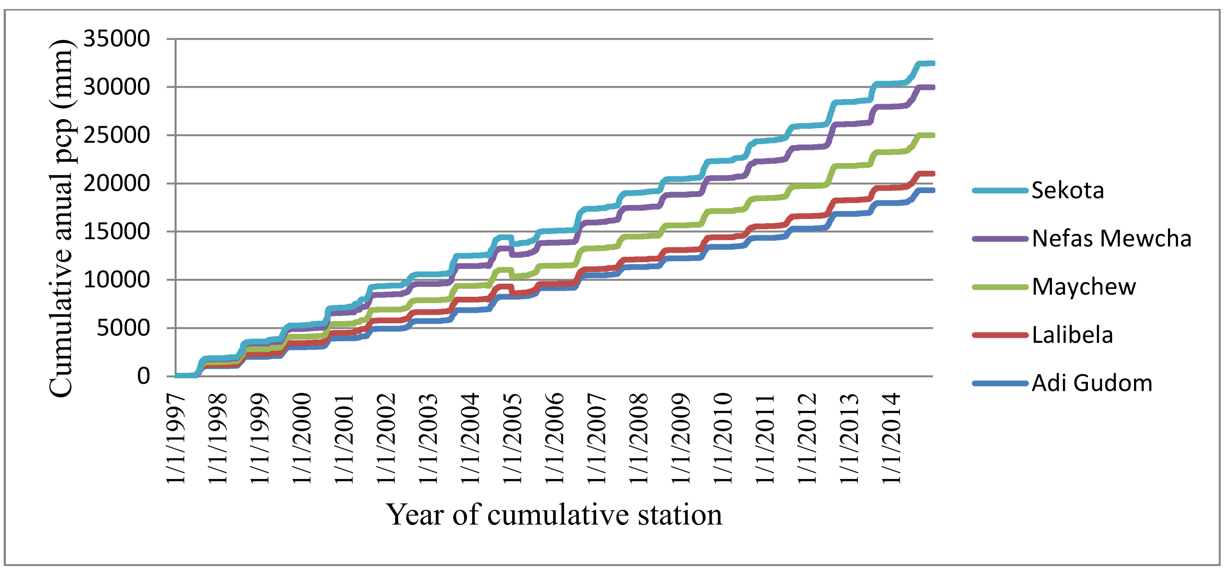

Figure 12: Double mass curve of selected stations1997-2014 (NMSA)

Stream flow

Unlike rainfall, stream flow shows strong serial correlation; the value on one day is closely related to the value on the previous and following days especially during periods of low flow or recession. Flow in the Tekeze River depends on the rainy season which occurs in June to September and also light rains are experienced in other seasons and it have good stream flow records with a small number of missing data in the study and these missing data was fill by Average Station method for Yechila and Tsirare stations for the period (1994 - 2010).

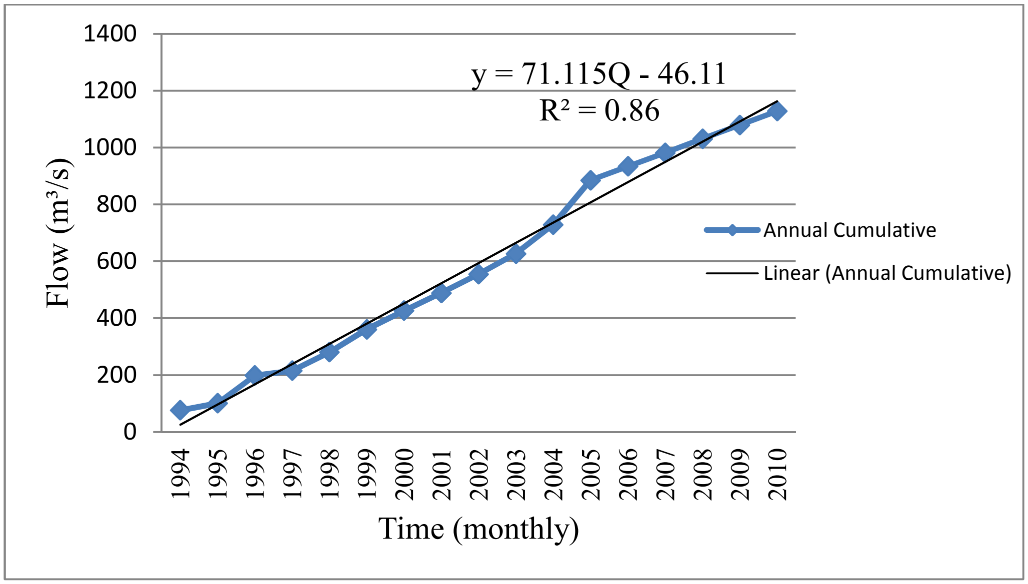

Figure 13: Mass curve of Tekeze river average flow at Yechila station (1994-2010) (MoWIE)

Sediment rating curve preparation

Sediment measurement in Tekeze River was taken by MoWIE at Dam site, Yechila , Zamra, Tsirae, Atsela, Areqiwa and Kul Mesk gauge station was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step, the relationship known as sediment rating curve. The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load and the general relationship can be written as:

$S = aQ^b$ ……………………………………………………………………………………3.21

Where: S is sediment load in ton/day, Q is the discharge in m^3/s and, b and a regression constants.

Hence the measured value that was collected from the MoWIE, hydrology and Water Quality Directorate was sediment concentration; so that the first work was convert this value into sediment load by the following formula:

$$S = 0.0864 \times Q \times C \quad \text{......3.22}$$

Where: S is sediment load in (ton/day),

Q is flow of the stream (m^3/s),

C is sediment concentration (mg/l) and 0.00864 is conversion factor. After calculated the sediment load the next step was making the relation between the continuous (daily time step) measured flow in m^3/s and the measured sediment load (ton/day) in the dam site that measured for 4 months. The relation between the flow and sediment load is presented in (Figure 13)

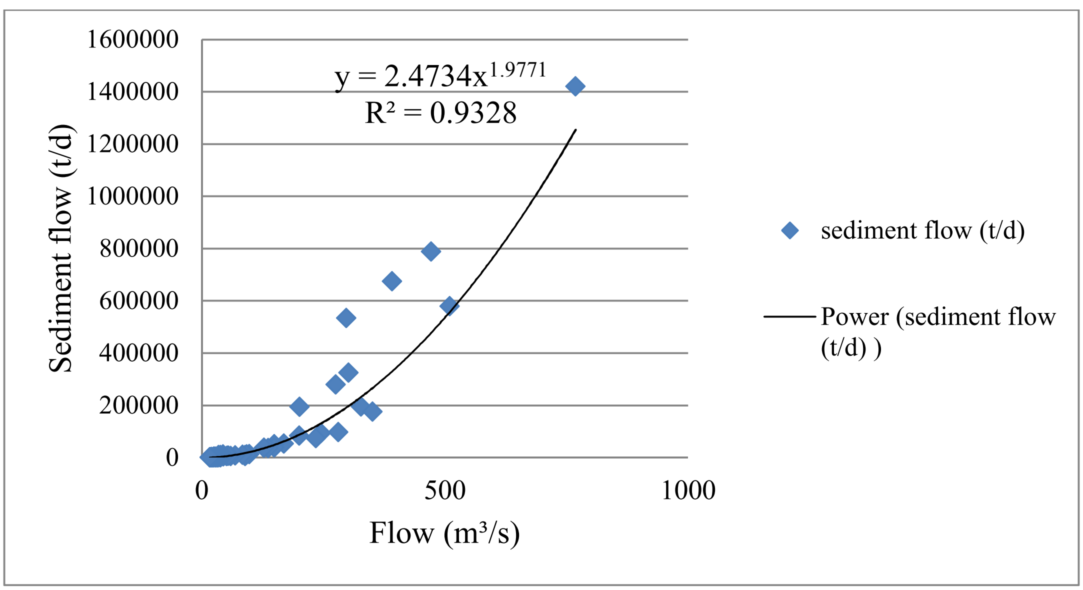

Figure 14: Sediment rating curve of Tekeze River at dam site (MoWIE)

3.5 Model Setup and Parameterization

3.5.1 Watershed delineation

The watershed and sub watershed delineation was performed using 90 by 90 resolution DEM data using Arc SWAT model watershed delineation function. First, the SWAT project set up was created.

The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. Once, the DEM setup was completed and the location of outlet was specified on the dam cross section DEM at13°21'4.34"N and 38°44'27.65"E, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tools.

The stream definition and the size of sub basins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of the streams. Using a threshold value suggested by the Arc SWAT interface Tekeze dam watershed was delineated in to 25 sub watersheds having an estimated total area of 30,800.746 km^2(Figure 14). But the total area of the feasibility study area watershed as obtained from the Minister of Energy and Waters Resources (MoWIE) was estimated to be 30,000 km^2(NEDECO, 1997). There is a slight deviation between the delineated and that obtained from the MoWIE database. The difference in the total area between the delineated and the database may be due to the difference in the DEM resolution or the watershed delineator model used.

The general characteristics of Tekeze dam report (NEDECO1997) is given by :

- Total storage: 9.3 Bm^3
- Maximum retention level: 1145 masl
- Surface area at maximum reservoir level: 147 km^2
- Live Storage: 5.3 Bm^3
- Dead Storage: 4.0 Bm^3
- Catchment area: 30,000 km^2
- Mean Annual rainfall: 850 mm
- Annual inflow: 3.75 Bm^3
- Sedimentation: 30 Mm^3/year

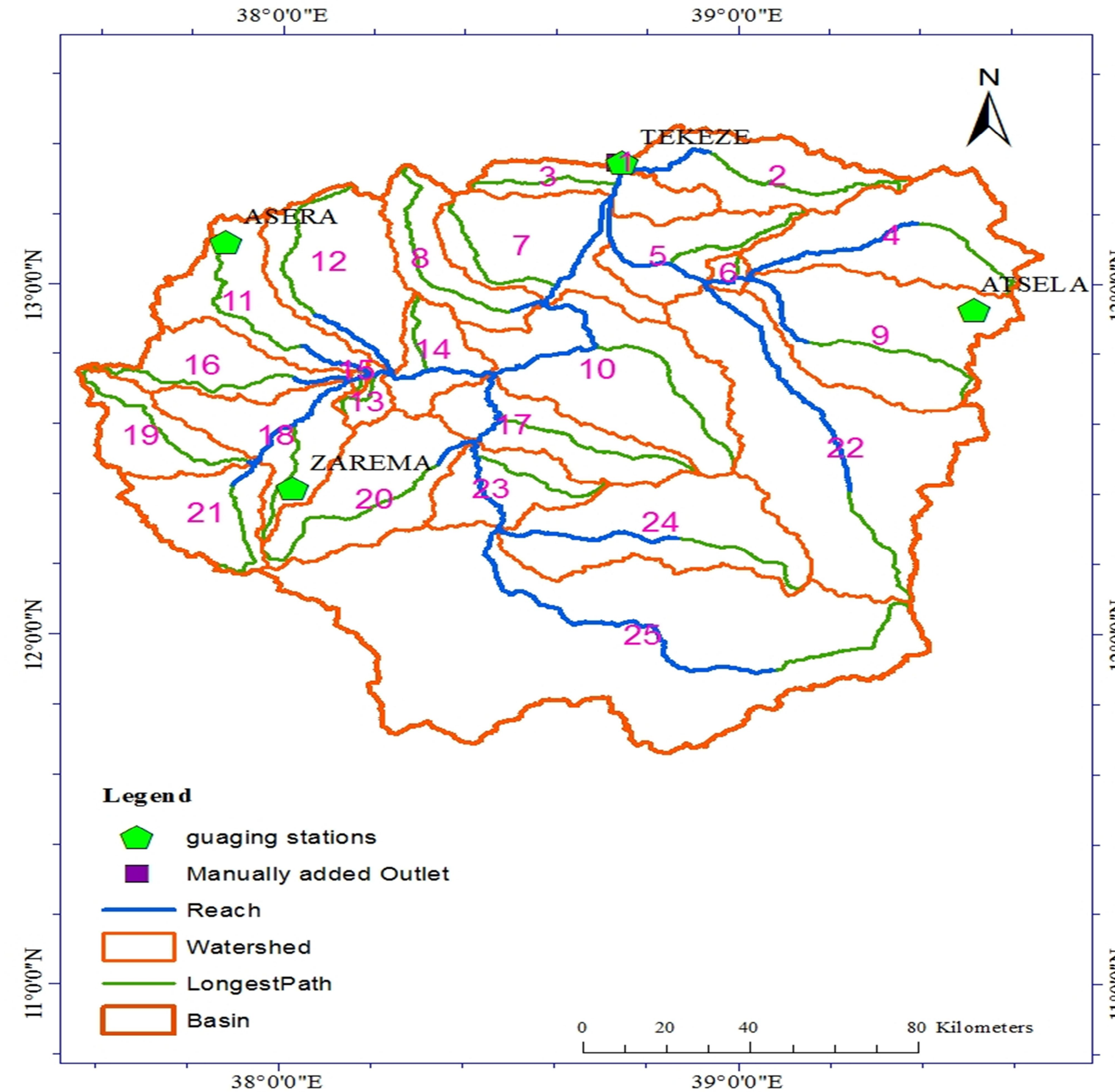

Figure 15: Delineated watershed and sub basins of Tekeze dam

During the watershed delineation process, the topographic parameters (elevation, slope) of the watershed and its sub watershed were also generated from the DEM data. Accordingly the elevation of the watershed ranges from 993 to 4501.5 m above mean sea level, the highest elevation is at the Semen Mountain and the lowest at the watershed outlet, in the dam area. Slope classification was carried out based on the height range of the DEM used during watershed delineation. The slope values of the watershed were reclassified in percent. It reclassified in to five classes (Fig 16, Table 6).

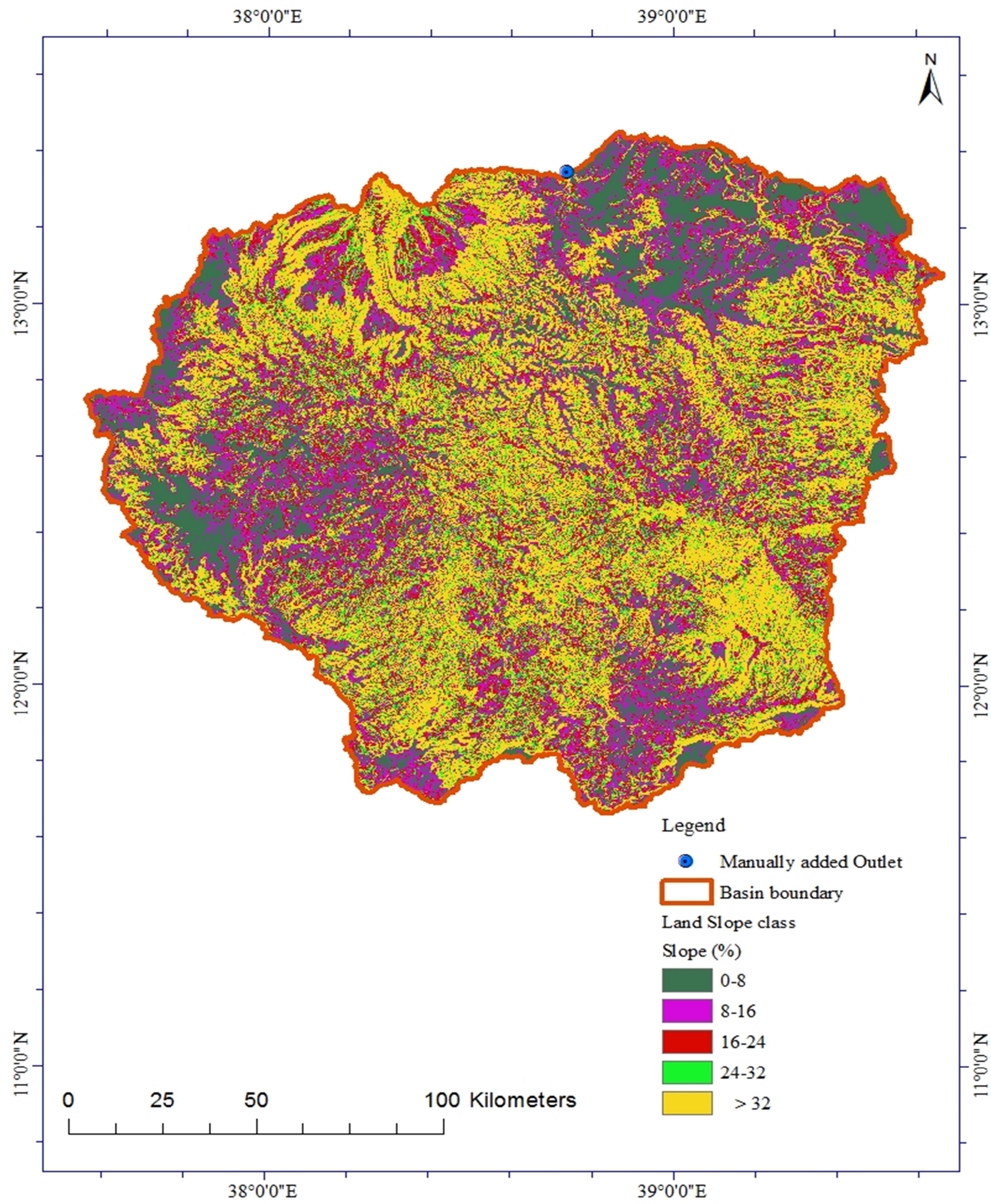

Figure 16: Slope class of Tekezze watershed

Table 6: Slope class of the study watershed

S.No.	Slope range (%)	Description	Area	
			Ha	%
1	0-8	Flat	502360.5	16.31
2	8-16	Sloping	591926.6	19.22
3	16-24	Moderately steep	543414.8	17.64
4	24-32	Steep	459004.8	14.9
5	> 32	Very steep	983367.7	31.93
Total			3080074.4	100

3.5.2 Hydrologic Response Units Analysis

The sub watersheds were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. In general the threshold level used to eliminate minor land use and land covers in sub basin, minor soil with in a land use and land cover area and minor slope classes with in a soil on specific land use and land cover area. Following minor elimination, the area of remaining land use and land covers, soils and slope classes are reapportioned so that 99.71 % of their respective areas are modeled by SWAT. Land use, soil and slope characterization for the Tekeze Hydropower dam watershed was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. These tools allowed loading land use and soil maps which are in raster format in to the current project, evaluates slope characteristics and determining the land use/soil/slope class combinations in the delineated sub watersheds.

In the model, there are two options in defining HRU distribution: assign a single HRU to each sub watershed or assign multiple HRUs to each sub watershed based on a certain threshold values. The SWAT user's manual suggests that a 20 % land use threshold, 10 % soil threshold and 20 % slope threshold are adequate for most modeling application. However, Setegn et al, 2008, suggested that HRU definition with multiple options that account for 10% land use, 20% soil and 10% slope threshold combination gives a better estimation of runoff and sediment components. Therefore, for this study, HRU definition with multiple options that accounts for

18% land use, 12% soil and 18% slope threshold combination was used. The reason for taking these threshold values was in order to keep the HRUs to a reasonable and manageable number and also considering computer processing time required. These threshold values indicate that land uses which form at least 18% of the sub watershed area and soils which form at least 12% of the area within each of the selected land uses will be considered in HRU. These thresholds eliminate the land uses and soils that covered relatively small areas in the sub-basins it creates a total of 185 HRUs for 25 sub-basins.

3.5.3 Weather generator

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed one (Danuso, 2002). The Model requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. This study used measured data for all climatic variables.

However, the weather data obtained for the stations in Tekeze Hydro power dam watershed has missed records in some of the variables. Therefore, these missed values were filled with the weather generator utility in the Arc SWAT Model from the values of weather generator parameters. Weather data of the stations Maychew with continuous records were used as an input to determine the values of the weather generator parameters. Hence, for weather generator data definition, the weather generator data file WGN stations.txt was selected first. Subsequently, rain fall, temperature, relative humidity, solar radiation and wind speed data were selected and added to the model.

The SWAT Model contains weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently.

To generate the data, weather parameters were developed by using the weather parameter calculator WXPARM and dew point temperature calculator Dew02, which were downloaded from the SWAT website. The Pcp STAT program calculates the monthly daily average and standard deviation as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month by reading of the daily values of the variables from Maychew station. Average daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity. Moreover, daily solar radiation was calculated from the daily available sunshine hour's data (Shapley and Williams, 1990). .

3.6 Sensitivity Analysis, Calibration and Validation of SWAT Model

3.6.1 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. (Lenhart et al, 2002), 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.

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results. So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. This appreciably eases the overall calibration and validation process as well as reduces the time required for it. Besides, as (Lenhart et al, 2002) indicated, it increases the accuracy of calibration by reducing uncertainty. The sensitivity analysis method implemented in SWAT is called the Latin Hypercube One-At–a Time (LH-OAT) design as proposed by (Morris, 1991). The four class sensitivity classes are Very high, High, Medium and small.

Once the SWAT model for the Tekeze watershed was compiled using SWAT interface, a stream flow sensitivity analysis was performed on model parameters. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization. The sensitivity analysis was performed using SWAT interface for a period of 1992-2010. It was checked at outlet points of Tekeze hydropower dam then the entire study sub basin the sensitivity showed that parameters were sensitive for flow.

Table 7: Sensitive flow and sediment parameters in Tekeze watershed

S/NO	SWAT Parameter Code	Description of Parameters	Range value
1	ALPHA_BF	Base Flow alpha factor (days)	0 -1
2	CN2	SCS runoff curve number (%)	35 -98
3	ESCO	Soil evaporation compensation factor	0 -1
4	SOL_Z	Soil depth (for each layer)	0 - 3500
5	REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur	0-1000
6	SOL_AWC	Available water capacity of the soil layer (mm/mm)	0-1
7	GW_REVAP	Ground Revap coefficient	0.02- 0.2
8	GW_DELAY	Groundwater delay	0 -500
9	EPCO	Plant uptake compensation factor	0-1
10	SURLAG	Surface runoff lag time	1-24
11	SOL_K	Saturated hydraulic conductivity (mm/hr)	0 -2000
12	CH_N2	Manning's "n" value for the main channel	0-1
13	CANMX	Maximum canopy storage	0 - 100
14	BIOMIX	Biological mixing efficiency	0-1
15	OV_N	Manning's "n" value for overland flow	-0.01-30
16	SOL_BD	Moist bulk density	0.9-2.5
17	RCHRG_DP	Deep aquifer percolation fraction	0-1
18	SLSUBBSN	Average slope length	10-150
19	CH_K2	Effective hydraulic conductivity in the main channel alluvium	-0.01-00

3.6.2 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 at different spatial and temporal scales (Neitsch et al, 2005).

Parameter estimation for calibration is various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. The process of adjustment can be done manually or using computer-based automatic methods. The manual method is the most common, and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite. In sediment transporting modeling two-step calibration procedures has been suggested by (Neitsch et al, 2005), the first is to check water balance contribution, then calibrate stream flow and followed by sediment calibration.

In this study the calibration process was divided into two steps: first stream flow and followed by Sediment calibration. After each calibration, checking the R^2 and NSE values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$ and NSE > 0.5 (Santhi et al, 2001).

Calibration of stream flow and sediment carried out at outlet of sub basin 1 (Dam Axis). This site was selected due to the availability of near the measured flow and sediment data. The stream flow and sediment calibration was on annual and monthly average time steps for flow Calibration period (1994-2002) and Sediment calibration period (1994-2002). The first two year of each period (1992-1994) is used as a model warm up period and is not used for model evaluation

3.6.3 Model Validation

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Flow and sediment validation was carried out at a station similar to the calibration. The statistical criteria (the $R^2$and NSE) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits $R^2 > 0.6$and NSE > 0.5 (Santhi et al, 2001)

After calibration of flow with the given time step the next step was calibration of sediment yield of the watershed. Like flow calibration, it was calibrated based on sensitive parameters that observed at sensitivity analysis of sediment flow. Based on the available model input data parameters the time periods of modeling are flow validation period (2003-2010) and sediment validation period (2003-2010)

3.6.4 SWAT Model efficiency criteria

The systematic and dynamic behavior of the model can be visualized by plotting simulated flow and observed flow on the same coordinate system. By looking at the graph a modeler can understand whether the model over predicted or under predicted and also the timing of the rising and falling limb of the hydrograph and give subjective decision on the performance of the model. But, to quantitatively evaluate the model, we need mathematical measures of model performance (Krause et al., 2005). The reasons to evaluate model performance are:

1) To provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior.

2) To provide a means for evaluating improvements to the modeling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information, and representation of important spatial and temporal characteristics of the watershed;

3) To compare current modeling efforts with previous study results.

To assess the goodness-of-fit of the model, two methods were used during the calibration and validation periods. These are: coefficient of determination (R^2) and the Nash-Sutcliffe efficiency coefficient (NS). These two statistical parameters are used to measure the model performance.

Coefficient of determination (R^2)

The coefficient of determination R^2 measures the fraction of the variation in the measured data that is replicated in the simulated model results. The coefficient of determination $R^2$is defined as (Krause et al., 2005) the squared value of the coefficient of correlation and is given by equation 12

$$R^2 = \left[\frac{\sum_{i=1}^{n} (Q_{ob} - \overline{Q}_{ob}) \times (Q_{si} - \overline{Q}_{si}}{\sum_{i=1}^{n} \left(Q_{ob} - \overline{Q}_{si}\right) \times \sum_{i=1}^{n} \left(Q_{si} - \overline{Q}_{si}\right)} \right]^2 \quad \text{...3.22}$$

Where, Q_{ob} is the observed (measured) stream flow on day i (m^3/s), Q_{si} the simulated stream flow on day i (m^3/s), and bars indicate averages.

The value of R^2 ranges from (0-1) where a value close to 1.0 indicates good performance (good correlation) of the model and the value close to 0.0 indicates poor performance (poor correlation) of the model. The main drawbacks of R^2 are that it only quantifies dispersion. A model which systematically over-or under-predicts all the time will still result in good R^2 values close to 1.0 even if all predictions were wrong to avoid this ambiguity, it is advisable to use additional information which can manage with that problem (Krause et al., 2005).

Nash-Sutcliffe Efficiency coefficient (NSE)

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) is used to assess the predictive power of the hydrological models. NSE is a more stringent test of performance than R^2 and is never larger than R^2. The value of NSE varies from 1.0 (perfect fit) to-∞ .An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al., 2005). The Nash-Sutcliffe efficiency (NSE) is calculated using equation

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(Q_{ob} - Q_{si}\right)^2}{\sum_{i=1}^{n} \left(Q_{ob} - \overline{Q}_{ob}\right)^2} \quad \text{...3.23}$$

Where, Q_{ob} is the observed (measured) stream flow on day i (m^3/s), Q_{si} the simulated stream flow on day i (m^3/s), and bars indicate averages.

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

$$PBIAS = \frac{\sum_{i=0}^{n}(Q_{ob} - Q_{si})}{\sum_{i=0}^{n}(Q_{ob})} \times 100 \quad \text{......} 3.24$$

Root Mean Square Error (RMSE) and Mean Square Error (MSE): The Root Mean Square Error, Mean Square Error, and RMSE-Observations Standard Deviation Ratio are error indices which describe the amount of error associated with the simulated data. (Moriasi, et al. 2007) suggest that the RMSE value be less than half the standard deviation of the measured data in order to be acceptable. Low values of RMSE and MSE are preferred because values of zero suggest that there is no error between the simulated data and the observed (Santhi, et al. 2001).The formulas for RMSE and MSE are shown below:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}(Q_{si} - Q_{ob})\right]^{1/2} \quad \text{......} 3.25$$

$$MSE = \frac{\sum_{i=1}^{n}(Q_{ob} - Q_{si})^2}{n} \quad \text{......} 3.26$$

Where Q_{ob} is the observed (measured) stream flow on day i (m^3/s), Q_{si} the simulated stream flow on day i (m^3/s)

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Flow Calibration

Before calibration proceeds, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this the monthly simulation Coefficient of determination (R^2) of and Nash Sutcliffe model efficiency (NSE) were obtained from the initial model run. The result shows the performance indicator was with the acceptable limits, i.e. $R^2 > 0.6$and NSE> 0.5 (Santhi et al, 2001). But, some the model flow parameters were required adjustment and this adjustment was based on the sensitivity analysis result of flow parameters.

Model parameters were calibrated manually. The calibration processes considered the sensitive parameters are listed below table.

Table 8: Calibrated and simulated parameters

S/NO	SWAT Parameter Code	Initial(Default) value	Calibrated value	Category of Sensitivity
1	ALPHA_BF	0.1480	0.084	High
2	ESCO	0.0847	0.73	High
3	CN_2	38.50	77	High
4	SOL_Z	0.76	300	High
5	REVAPMN	750	450	Medium
6	GW_REVAP	0.080	0.096	Medium
7	GW_DELAY	100	31	Medium
8	EPCO	0.0029	0.0041	Small

Studies that conducted on Gilgel–Abbay Watershed, Lake Tana (Asmamaw A.) take different parameters and give Alpha factor (ALPHA_BF), Curve number (CN2), soil evapotranspiration factor (ESCO), Manning’s roughness coefficient (CH_N2) and Effective hydraulic conductivity of the main channel (CH_K2) are identified to be highly sensitive parameters and retained rank 1 to 5, respectively. The other parameters such as threshold depth of water in the shallow aquifer required for return flow (GWQMN), ground water delay (GW_DELAY), soil available water capacity (SOL_AWC), total soil depth (SOL_Z), and surface lag (SURLAG) are identified as slightly important parameters that were retained rank 6 to 10, respectively.

In addition, (Setegn et al., 2008) through modeling of Gilgel Abbay watershed found ALPHA_BF to retain rank 3. The other most influencing stream flow parameter in this analysis is the curve number (CN2). According to (Setegn et al., 2008) and (Surur, 2010), CN2 retain rank 1. These may be an additional support to the result of the sensitivity analysis.

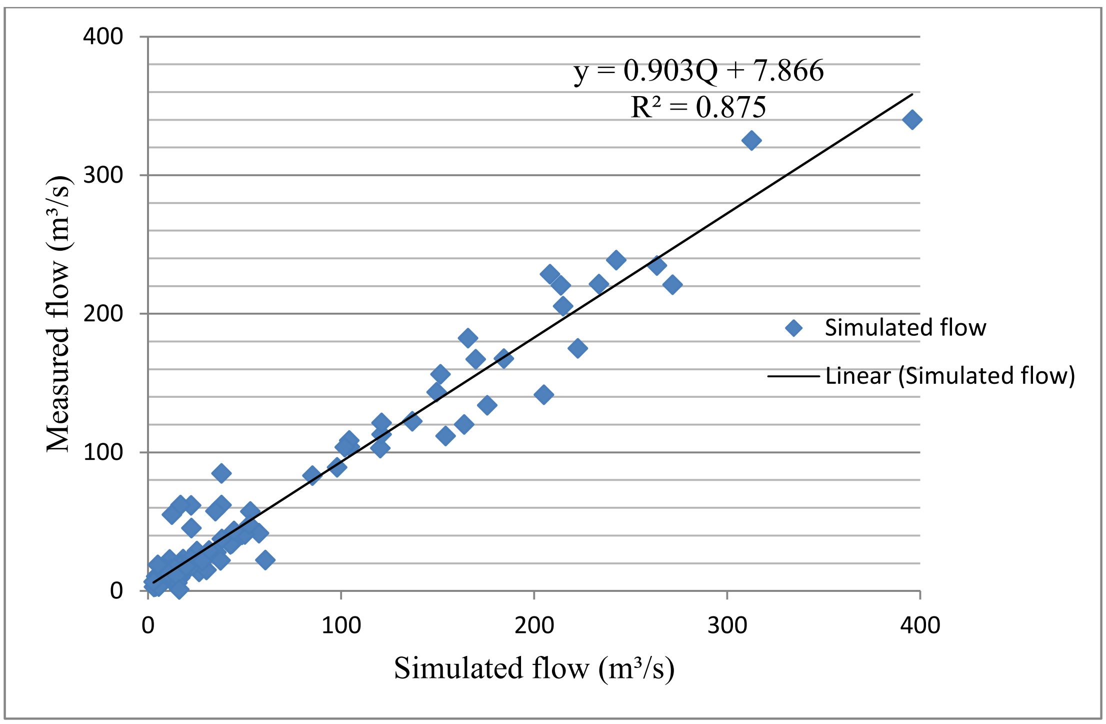

Figure 17: Fit line of measured and simulated flow

The model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters. Calibration resulted after simulation found to be Coefficient of determination (R^2) of 0.875.

The result also indicated that model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates SWAT's ability to predict realistic flow.

Table 9: Calibration result for monthly measured and simulated stream flow

Monthly Time step simulation	Mean annual stream flow (m^3/s)		Model Efficiency	
	measured	Simulated	R^2	NSE
Calibration 1994-2002	85.59	73.16	0.89	0.83

During the calibration period (1994 -2002), the simulated monthly flows matched well with the measured monthly flows (R^2= 0.89 and NSE= 0.83) as shown in Table 9. The trends of seasonal variability and monthly average discharge were generally well captured. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes.

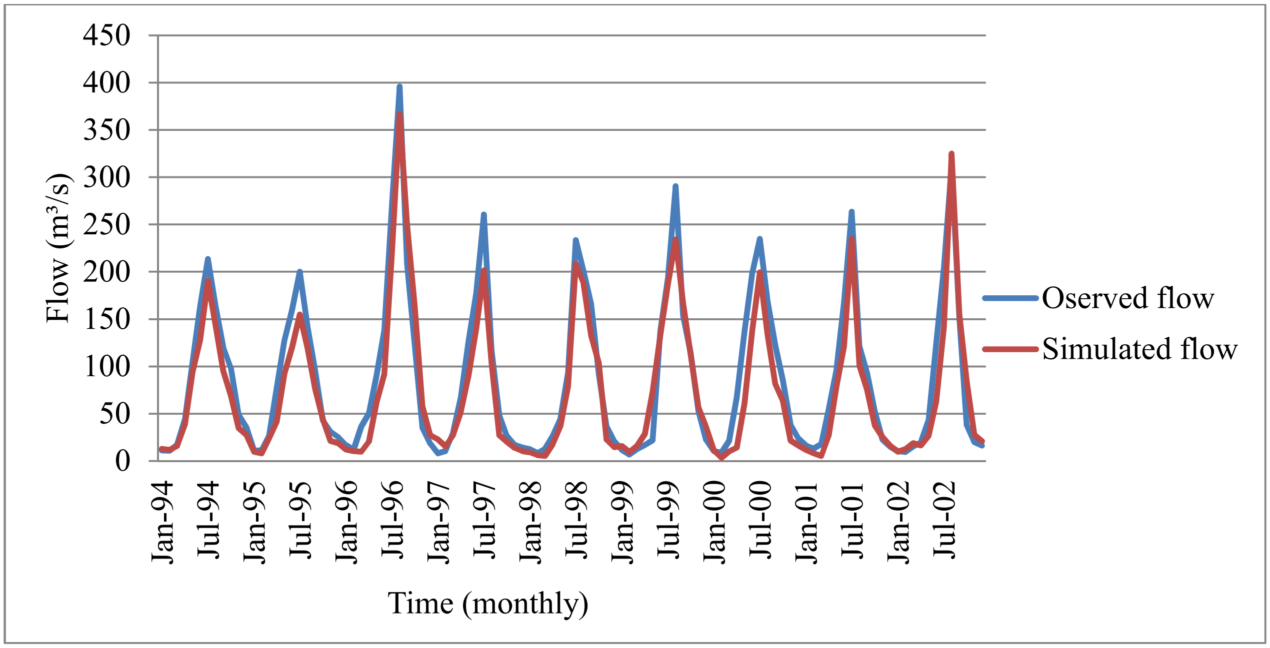

Figure 18: Calibrated results of average monthly measured and simulated flow (1994-2002)

4.2 Flow validation

The model with calibrated parameters was validated by using an independent set of measured flow data.

Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.87 and Nash-Sutcliffe simulation efficiency (NSE) of 0.74 of measured and simulated monthly flow (Table 10).

Table 10: Validation result for monthly measured and simulated stream flow

Monthly Time step simulation	Mean annual stream flow (m^3/s)		Model Efficiency	
	Observed	Simulated	R^2	NSE
Validated 2003-2010	97.97	84.15	0.87	0.74

The hydrograph of the validation period of the observed and simulated flow in monthly estimation, the model slightly over estimates some of the peak flows of the months, like in August 2004 and also July of the year 2008, respectively; and some of the months peak flows were also under estimated by the model in the February 2009 in period of validation period. (Figure 19)

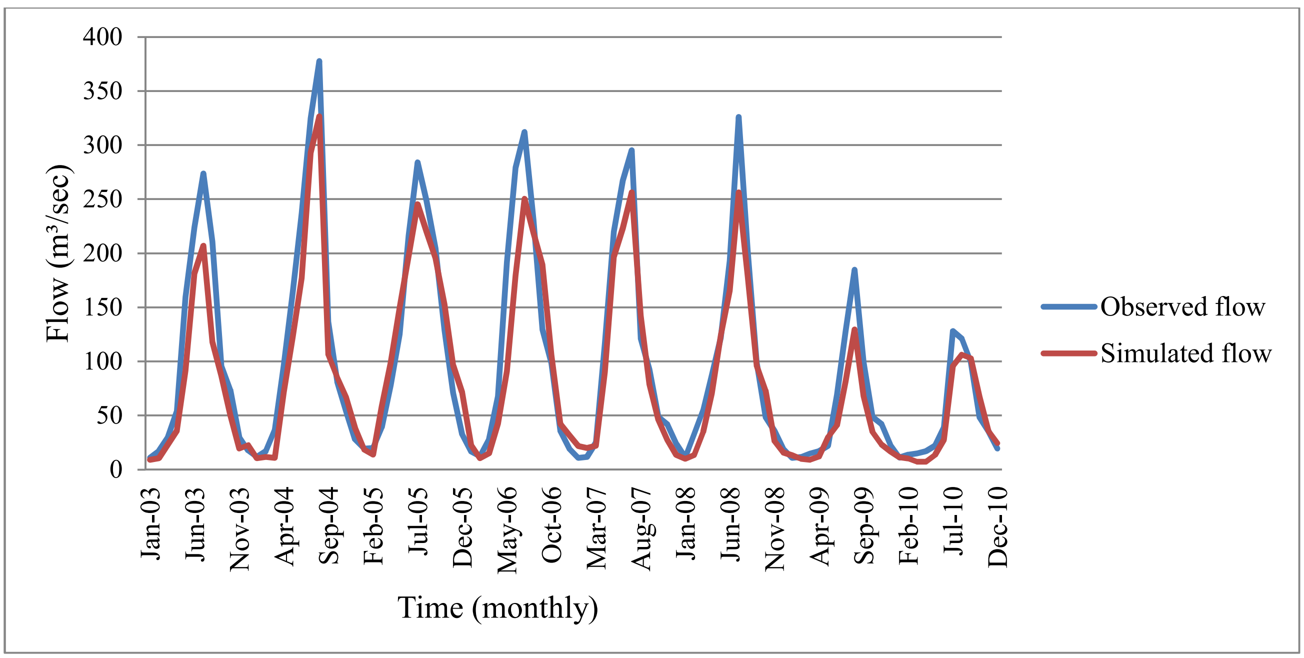

Figure 19: Validation results of average monthly observed and simulated flow (2003-2010)

Studies that conducted in different parts of the country showed that similar results. For example, Asres and Awulachew (2010) reported that the SWAT model showed a good match between measured and simulated flow of Gumera watershed both in calibration and validation periods with (ENS = 0.76 and R^2 = 0.87) and (ENS = 0.68 and R^2 = 0.83), respectively. Through modeling of the Lake Tana basin, Setegn et al, (2008) indicated that the average monthly flow simulated with SWAT model were reasonable accurate with ENS = 0.81 and R^2 = 0.85 for calibration and ENS = 0.79 and R^2 = 0.80 for validation periods.

4.3 Sediment yield calibration

After sensitivity analysis, the next step was calibrating sediment yield of the watershed. For the years (1994 - 2002) Two year, (1992 -1994) was used for model warm up. So that model was calibrated from 1994 to 2002. The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis that has identified sensitive parameters and has effect on the simulated result when changed for sediment yield of the watershed (Table 11), and by varying iteratively within the allowable ranges of the parameter.

Table 11: Final calibrated and validated sediment parameters of the watershed

S/NO	SWAT Parameter Code	Calibrated value	Category of Sensitivity
1	Usle_P	0.9	High
2	Sol_Awc	0.6	High
3	Slope	0.93	High
4	CN2	87	High
5	Biomix	0.1	Medium
6	Spcon	0.09	Medium
7	SPEXP	0.022	Medium
8	GW_DELAY	31	Small
9	ESCO	0.95	Small
10	Sol_Z	2450	Small

After adjustment of all the above parameters, the model is run again with the calibrated parameters. The model was calibrated for sediment by comparing monthly model simulated sediment load against measured sediment load from the dam site station in4 months that measured three times daily for 62 days. The observed and the simulated values of the sediment yield were plotted against each other to determine the Scatter plot of coefficient of determination.

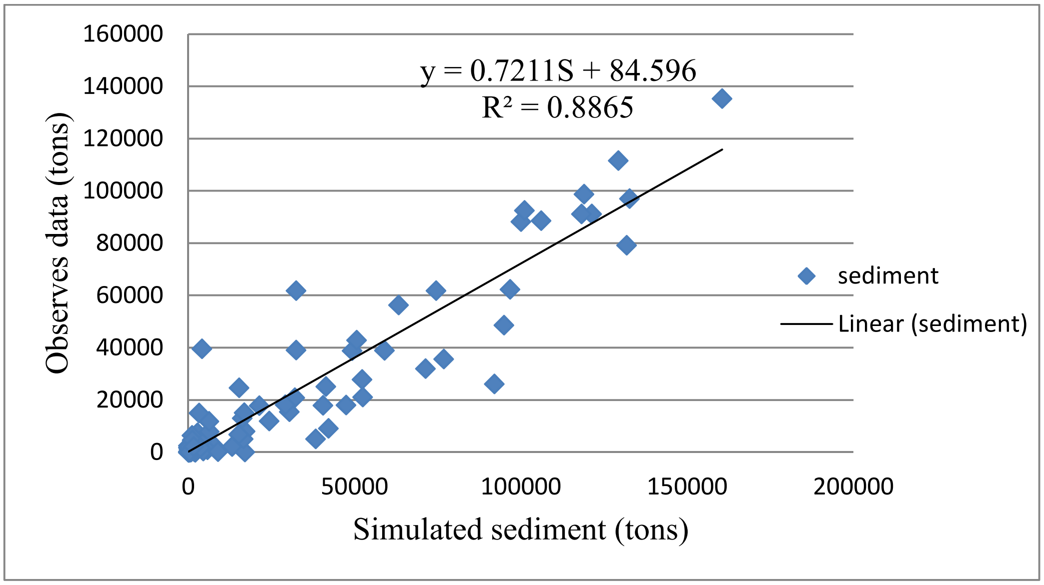

Figure 20: Fit line of measured and simulated sediment flow at Tekeze dam site

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 (NSE) statistic computed between the simulated and observed monthly sediment loads for the calibration periods are 0.86 and 0.82 respectively (Table 12). Calibration results show that model performance is good with simulation of monthly sediment load.

Table 12: Calibrated of observed and simulated sediment load

Monthly Time step simulation	Average calibration sediment(tons/year) monthly		Model Efficiency	
	Observed	Simulated	R^2	NSE
Calibration (1994-2002)	974,869.957	934,023.38	0.86	0.82

The hydrograph of the calibration period of the observed and simulated sediment load in monthly basis shows the model slightly overestimated some of monthly sediment yields of the watershed and slightly under estimate the sediment yield. (Fig 21).

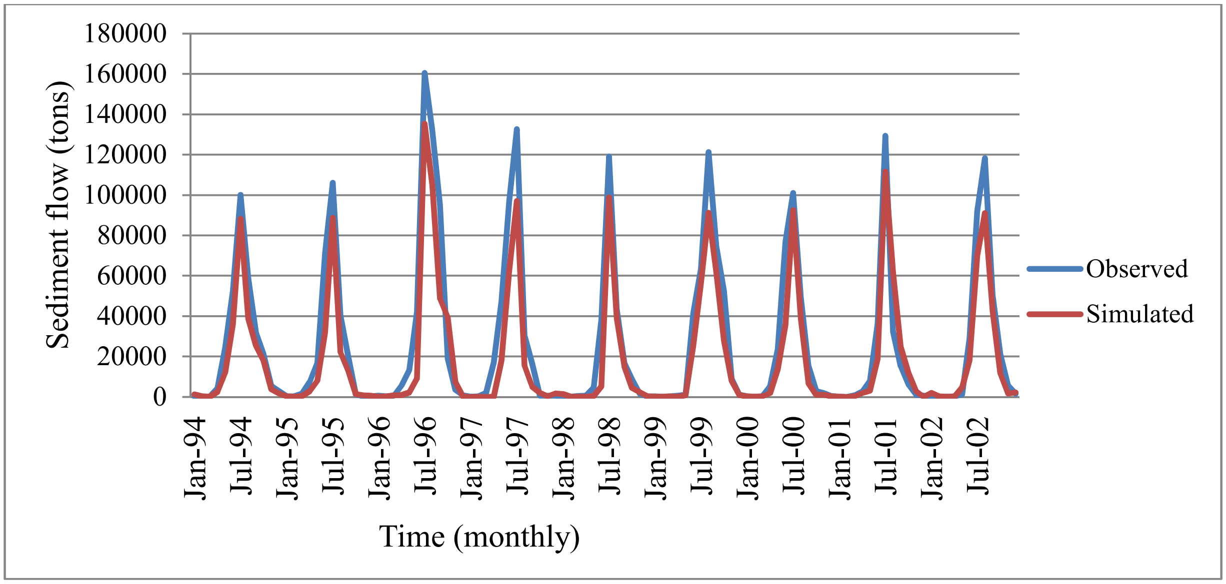

Figure 21: Observed and Simulated sediment flow for calibration (1994-2002)

4.4 Sediment yield validation

After calibration then SWAT model was validated to sediment for the period 2003 to 2010 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

The statistical values in the monthly basis of sediment yield estimation in the validation period results the R^2 and NSE of 0.84 and 0.78

Table 13: Validation value for monthly observed and simulated

Monthly Time step simulation	Average validated sediment (t/y)monthly		Model Efficiency	
	Observed	Simulated	R^2	NSE
Validation (2003-2010)	939,906.267	806,365.44	0.84	0.78

The observed and simulated sediment yield in monthly time step of the validation period shows that model slightly over estimate the sediment yields of highly flow time periods, and in low and medium flow periods the model simulation and the observed sediment yield were good fit but there was also in some months under estimation.

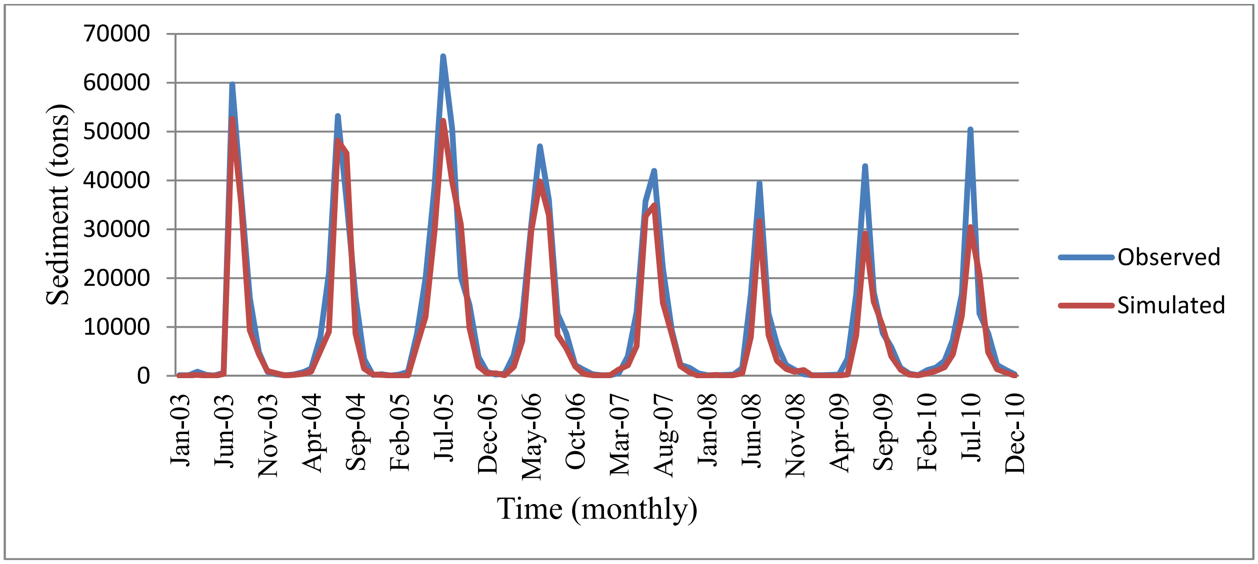

Figure 22: Validation results of average monthly observed and simulated sediment (2003-2010)

Engidayehu C. (1992 -1999) used SWAT model was found to simulate well on monthly basis of sediment load. Coefficient of determination (R^2) value and Nash-Sutcliffe model efficiency (ENS) statistic computed between the simulated and observed monthly sediment loads for the calibration periods are 0.87 and 0.74 respectively. Also the validation period results the R^2 and ENS of 0.89 and 0.79 respectively.

According to AAWSA,2011study report the effects of soil erosion in Legedadi watershed have significant impact on the reservoir. The sediment volume of the Legedadi reservoir increased by 2.1 MCM (million cubic meters) in the 19 years passed since the previous bathymetric study of 1979. The live storage capacity was reduced from 45.9 MCM in 1979 to 43.8 MCM in 1998. The average annual siltation rate Legedadi Reservoir is 120,000 m^3/yr within 1979-2010 and 135,000 m^3/yr within 1998-2010. These translate to an average annual Dam volume reduction rate of 0.26%/yr for the period 1979-2010 and 0.31%/yr for the period 1998-2010 (AAWSA, 2011). In Legedadi reservoir catchment have been facing serious soil erosion problem as based on the siltation amount reached in to the reservoir. In this regard the master plan review of Addis Ababa dams (Geffersa, Legedadi and Dire) indicated that an average annual siltation rate of 120,000 m^3/yr in 1979-2010 and 135,000 m^3/yr in 1998-2010 (AAWSA, 2011).

4.5 Land Use/Land cover change analysis

The analysis of land LULC shows that there was significant change in the period between 1986 to 2010. It is easily shown that the increase of cultivation land, water and marshy body andgrass land, decrease of forest, shrub land and bush land over the last 24 years. The land use and land cover map of 1986 in the Figure 23 shows that the total cultivated land coverage class was about 30.61% of the total area of the watershed. It increased rapidly and became 38.69 % of the watershed in 2010 land use and land cover map (Figure 24). This is mainly because of the population growth that caused the increase in demand for new cultivation land and settlement which in turn resulted shrinking on other types of land use and land cover of the area. On the land use and land cover map of the year 1986 the total forest coverage was about 9 % of the total area of the watershed. On the land use and land cover map of the year 2010 it reduced to 5.79% of the total area. This is because of the deforestation activities that have taken place for the purpose of agriculture. The individual class areas and change statistics for the two periods are summarized in Table 14.

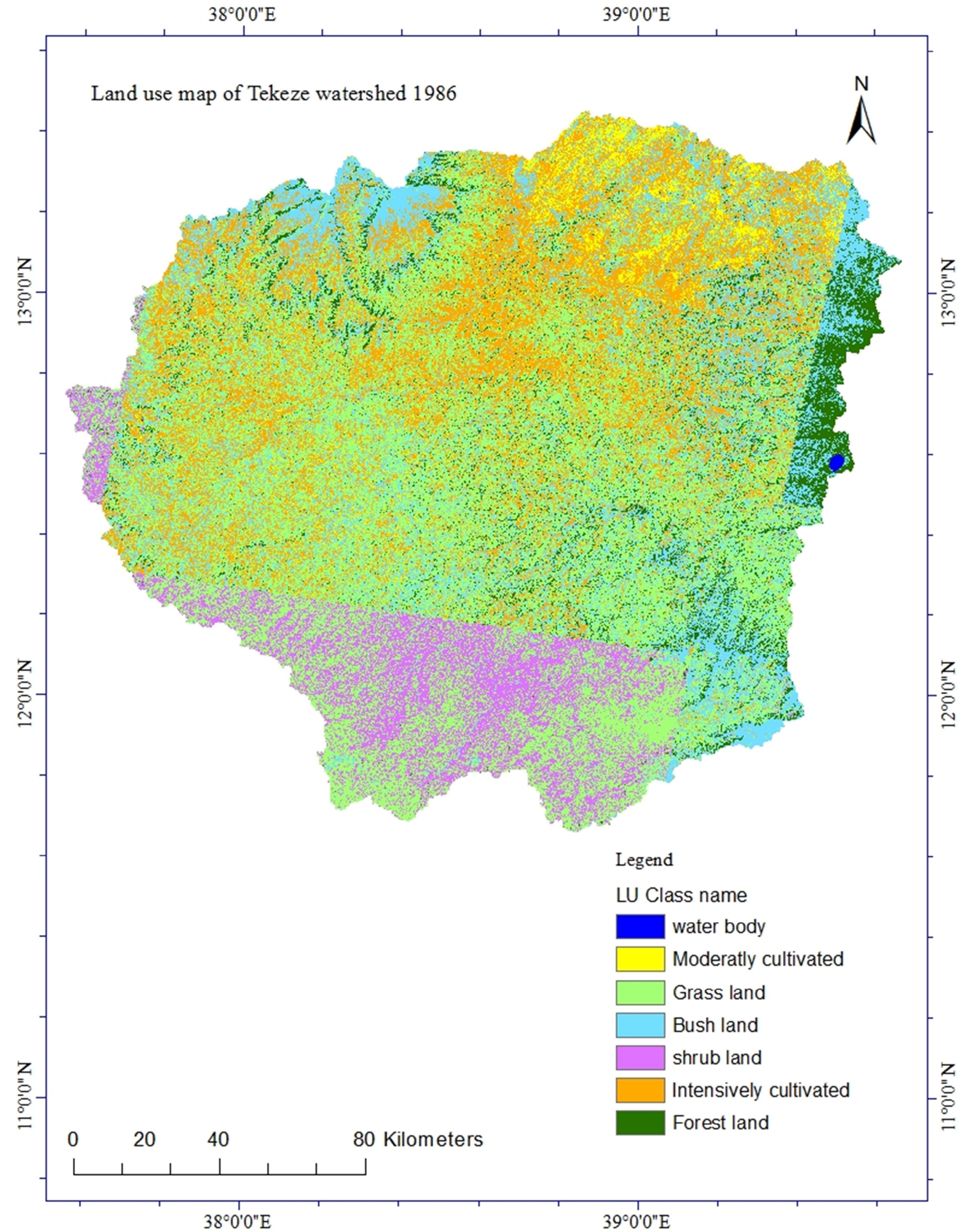

Figure 23: Land use 1986 of Tekeze watershed (EMA)

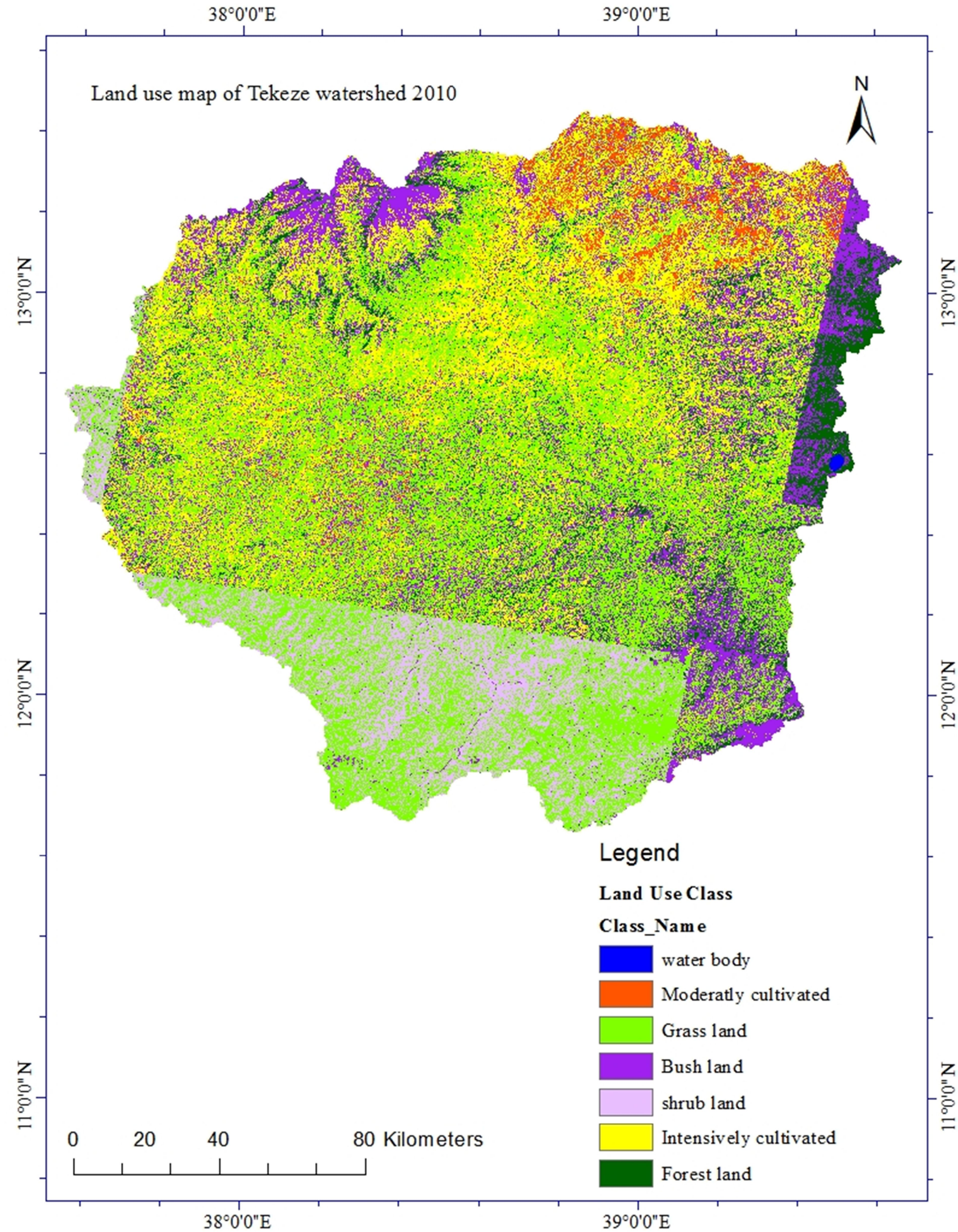

Figure 24: Land use map of 2010 Tekeze watershed (EMA)

Table 14: Area of land cover change statistics of Tekeze watershed between1986 and 2010

Land cover types	1986		2010		2010 – 1986
	Ha	%	Ha	%	Change by %
Water body	1750.045	0.06	1848.04465	0.06	0
Grass land	1097430.512	34.52	1114062.91	36.17	1.65
Shrub land	436754.5513	14.18	328951.947	10.68	-3.5
Bush land	357596.639	11.61	265194.407	8.61	-3
Intensively cultivated	382545.2417	12.42	537472.985	17.45	5.03
Forest land	277822.7118	9.02	178336.308	5.79	-3.23
Moderately cultivated	560265.5352	18.19	654207.805	21.24	3.05

4.6 Estimated soil loss from the watershed

After Calibration and validation, the model was run for a period 19 years from 1992 to 2010. From the model simulation output, sediment source areas were identified in the Tekeze Watershed. The result showed that the potential annual soil loss of 1986 the watershed ranges from 1.63 to 29.08 t/h/y. The average annual soil loss rate is 13.05 t/h/y, which is in the tolerable level 2-18 t/h/y (Hurni, 1985). According to an estimate by FAO (1986), 50% of the highlands of Ethiopia were already significantly eroded and erosion was causing a decline in land productivity at the rate of 2.2% per year. The average rate of soil erosion from croplands in the highlands is estimated at 42 t/ h/y (Hurni 1986). The result of study falls within the ranges of the findings by Hurni for the Ethiopian highlands.

The ranges of sediment yield (soil loss) rates and their severity categories suggested by Tamene (2005) were also used for identification of critical hotspot soil degradation sub-catchments based on the simulation result of the baseline scenario. According to this author, soil losses 0-5, 5-15, 15-30, 30-50 and > 50 t/ha-1 y-1 are rated as very low, low, medium, high and very high erosion categories, respectively.

In order to obtain a better view and understanding and at the same time be able to compare areas, the quantitative output of potential soil erosion rate for the watershed resulted from the land use/land cover were computed and grouped into six ordinal classes (Table 15). The soil loss map also further classified into six soil losses severity classes in ArcGIS environment (Figure 25).

Table 15: Sub basin sediment distribution

Class	Range of soil loss potential (t/h/y) 1986	Range of soil loss potential (t/h/y) 2010	Soil erosion risk class
1	1.63-2.33	3.62-7.61	Very slight
2	2.34-5.14	7.62-13.71	Slight
3	5.15-9.08	13..72-19.07	Moderate
4	9.09-12.67	19.08-24.97	High
5	12.68-22.27	24.97-29.53	Severe
6	22.28-29.08	29.54-33.36	Very Severe

The spatial distribution of sediment generation for Tekeze River watershed as simulated by the model are presented in Figure 25 and 26. The figures allow as identifying sub catchments which are producing high sediment yield. The spatial distribution of sediment indicated that, out of the total 25 SWAT sub basins. Based on the model's prediction, sediment yield in the watershed varies from HRU to HRU depending on the type of soil, slope and land use in each HRU. In this study Sub-watersheds 3, 9, 14, 19, for 1986 LU are produced the highest sediment yield and more exposed for erosion.

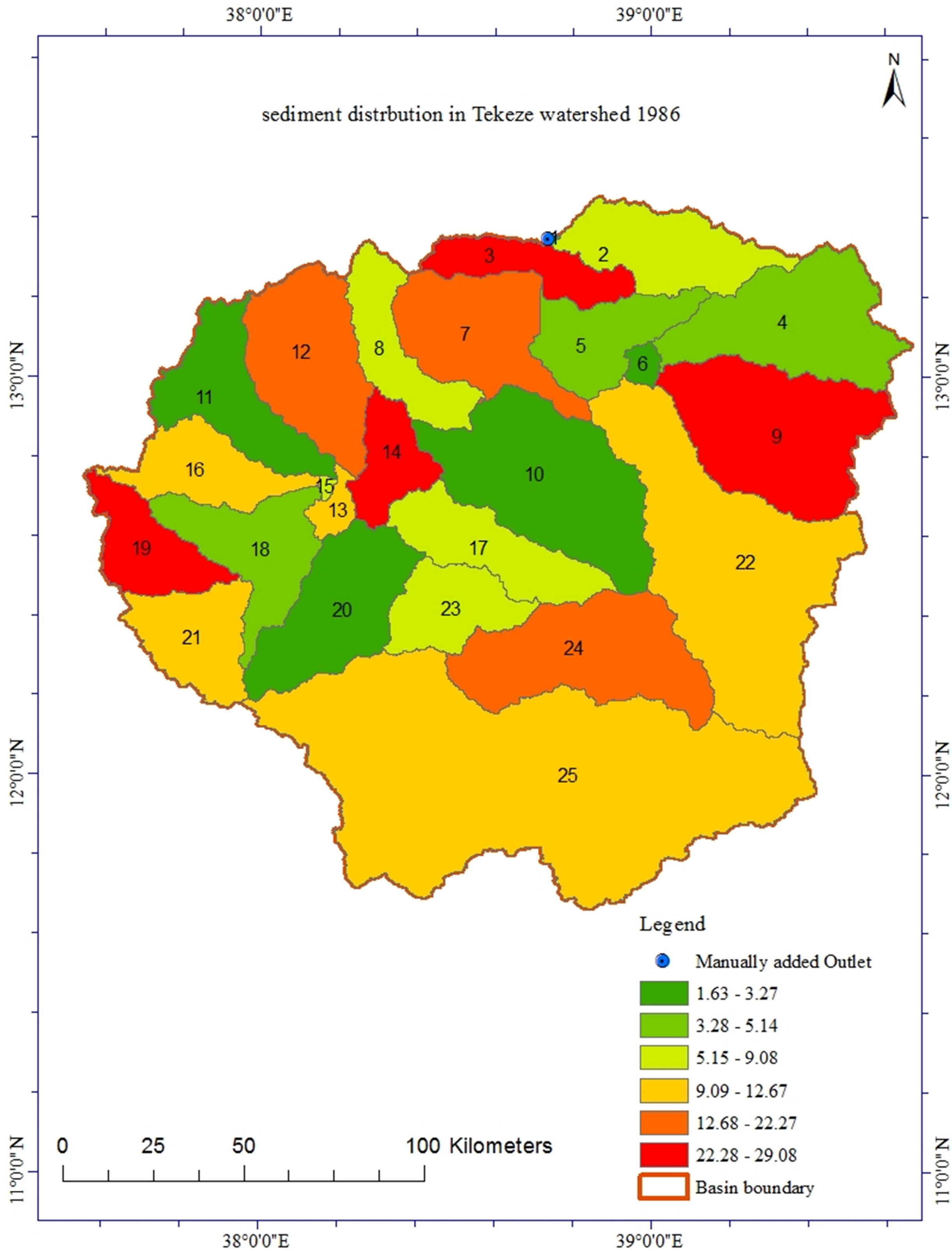

Figure 25: Average annual soil loss rate of sub watersheds 1986

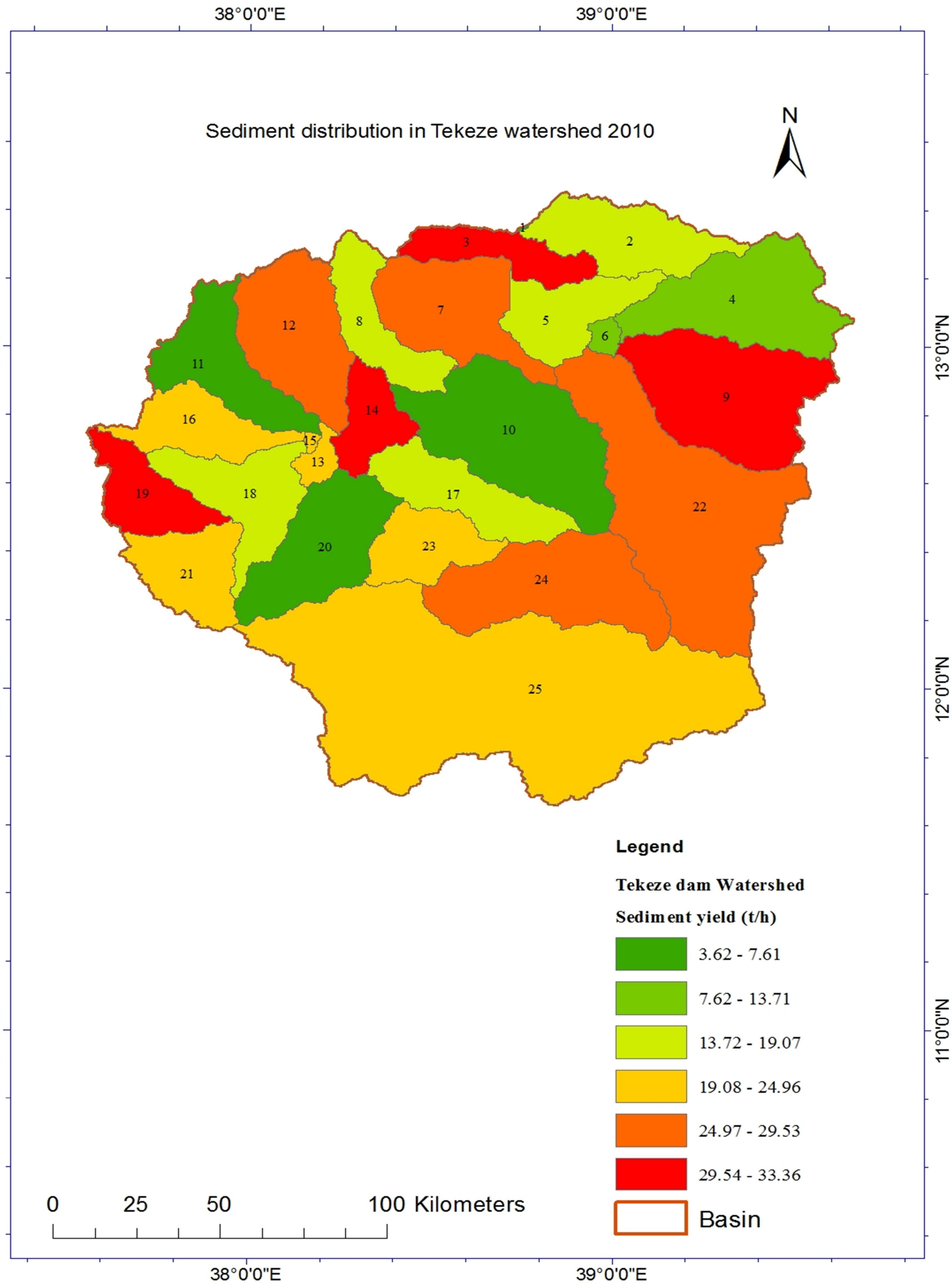

Figure 26: Average annual soil loss rate of sub watershedsin 2010

4.7 The impact of land use land cover change on sedimentation

Soil erosion by water is a serious problem, in the Ethiopian highlands, with estimated soil loss rate of 1.5 billion tons per year (Hurni 1986). According to an estimate by FAO (1986), 50% of the highlands of Ethiopia were already significantly eroded in the mid-1980s and erosion was causing a decline in land productivity at the rate of 2.2% per year. The average rate of soil erosion from croplands in the highlands is estimated at 42 t ha−1 per year (Hurni 1986)

In most cases, since Tekeze watershed the slope gradient is higher (> 32%) it created opportunity for the runoff to get high velocity. Besides to this the cultivated and open shrub land use system facilitated the runoff to wear out the top soil in a higher rate. Generally sub-watersheds which were characterized by high soil loss rate are found on slopes their gradient greater than 30 % with intensively and Moderately cultivated land use system but this situation may not always be true. Because sub watersheds which were characterized by low soil loss rate are found on slopes gradient. The reason to this situation was due to the Land use system of those sub watersheds were dominated by open shrub land and cultivated land.

The major causes of higher sedimentation in the study area are largely attributed to the bio-physical characteristics of the watersheds and anthropogenic reasons. Significant proportions of the watershed (31.93%) is under very steep slope ranges (slope>32%) and as a result it contribution to high sediment yield.

The actual erosion result for the watershed shows that the value ranges from1.63t/ha/year to 29.08 t/ha/year for 1986 land use and 3.62 t/ha/year to 33.36 t/ha/year for 2010 land use type. The mean erosion rate is 13.08 and 17.35 t/ha/year for 1986 and 2010 respectively. The yearly increase of sediment rate on these years is 0.18 t/h/yr. Besides to this the bare and open shrub land use system facilitated the runoff to wear out the top soil in a higher rate. Generally sub-watersheds which were characterized by high soil loss rate are found on slopes.

Another major reason, for a higher sediment yield, could be land use in which large parts of both watersheds are under cultivation and pasture or bare land and being often disturbed and can be easily detached by runoff. The other possible factor that positively contributes for the sediment load was the shape of the watersheds. Since both schemes have smaller watershed size where as greater elevation difference, the suspended sediment being carried by the flood. Lack of proper implementation of watershed development plans to treat major sediment sources by soil and water conservation mechanisms had also accelerate erosion and consequently increased the sediment yield of sub basin 3,9 and 14 which have high soil erosion. For sub basin 3 the land use is 39.01 pasture and 31.33% is >32% slope range and for sub basin 9 the dominant land use 40% Agricultural land and 42.02% is >32% slope range, for the sub basin 14 the land use 21.32% Agricultural land and 78.98% Grass land with the slope range >32% of 32.06% for the sub watershed.

4.8 Scenario Development and Analysis

4.8.1 Scenario development

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. Scenarios are reasonable and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships (Niehoff et al., 2002). Many different activities are carried out in the catchment; mainly urbanization and farming activities. Farming activities are increasing in the area due to the population pressure and depletion of soil fertility to produce the intended demand of food crop for inhabitants. To analyze the effect of these different human activities in the catchment on sediment prediction in relation to demographic changes, development and management practices, we need to develop scenarios. Scenario analysis is a process of evaluating possible future events through the consideration of alternative possible outcomes (scenarios) (Niehoff et al., 2002).

Given the spatial variability of the extent and intensity of erosion and delivery processes, land-use redesign, conservation or management measures, in general, should be applied at appropriate sites of the catchment so as to use resources efficiently. The modeled mean annual soil erosion estimated for each sub-catchment was considered in developing the management strategies (scenarios), as well as for the mean losses at the outlet of the entire catchment sources of erosion. In order to compare the effectiveness of alternative management strategies that may reduce soil degradation due to soil erosion, it is necessary to develop and describe the relevance of the scenarios. When developing the scenarios, the severity of the erosion rate/sediment yield soil losses (hotspot areas), and the most strongly influencing (sensitive) factors and their relevance were considered. Scenario simulated and analysis can be used to select the most effective strategies for reducing soil degradation. The details scenarios (management strategies) are described below.

Scenario 1: Baseline scenario: The baseline scenario corresponds to the 2010 catchment land-use and land-cover, terrain, management and other factors. This includes cultivated land dominated by the teff crop cover-factor (C = 0.25) a conventional tillage system of contoured plowing (P factor = 0.9) and degraded grazed lands (C-factor = 0.05) Appendix 6-8. In such poor hydrologic conditions, the curve-number (CN) values are high and ranging from 79-88; values depend on the hydrologic soil groups. This indicates that the runoff flow that derives the loss of sediment yield and soil nutrients is high in this scenario. Runoff, sediment yield, and soil nutrient losses were determined using existing catchment factors. The baseline scenario was used as a benchmark against which the results of the other scenarios were rated.

Scenario 2: Afforesting hotspot areas of erosion: Afforesting all cultivated fields in the study catchment is impractical for many reasons. Instead, afforesting hotspot areas of degradation due to erosion is feasible (Figure 26). Such areas in the catchment were identified by the local farmers´ defined indicators of degradation and model-estimated erosion rates. Dialogue with local stakeholders about the physical conditions and management practices in the catchment was used for obtaining reliable information for the location of degraded land by erosion to be afforested. Besides, on the basis of the results of the baseline scenario, sub catchments with erosion rates > 18 t/h/y were taken into account for the simulation of the afforestation scenario. This threshold was set based on the maximum tolerable soil loss of 18 t/h/y for Ethiopia soils reported by Hurni (1985). This scenario afforested only the prioritized sub-catchments that comprised of cultivated land (38.69%) and grazing land (36.17%). This area covers about 74.86% of the catchment. The scenario 2 changes the C-factor to 0.05 (degraded grass) in the long-term and to 0.01 (dense grass) when simulated as pasture area in the short-term. The curve-number (CN) values for this scenario ranging from 40-60 on the basis of the hydrological soil groups, and were lower than in scenario 1. The CN determines the separation of precipitation between surface runoff and infiltration as a function of soil hydrologic group, land-use, and antecedent moisture condition (Mishra and Singh 2003). These areas were simulated with dense grass covers that reduce CN and the USLE's C-factor values but increase the Manning's n-value as given in Table 16.

Scenario3: Parallelterraces/conservation measures: In a catchment vulnerable to erosion, there is a need for conservation measures such as terraces that reduce further soil degradation. Wherever soil loss rates exceed 16-18 t/h/y in Ethiopia, soil conservation measures are recommended (Hurni, 1985). This is therefore the reason for scenario 3 targeting vulnerable sub-catchments that are shown in Fig 26. Terraces act as a barrier to runoff, increasing infiltration and decreasing flow volumes and speed, and ultimately reduce the transport capacity and encouraging sediment deposition (Tamene et al., 2007). Erosion computation of the SWAT model is most sensitive to the curve-number (CN) and slope, as this influence the rate of runoff and sediment losses. The CN and the consequent simulated surface runoff amount can be expected to decrease significantly under terraced scenario. The sensitivity analysis indicated that simulation of the SWAT model is very sensitive to USLE_P. The expected slope length and steepness reduction due to scenario 3 was 50% and 25%, respectively, as compared to in the baseline scenario. During the calibration for the baseline scenario the USEL_P was 0.9. This value was changed to 0.6 for the targeted sub-catchment in scenario 3 (Table 16)

Scenario 4: Grassed waterways: Grassed waterways are used to cover a stream or gully channels, and act as a barrier for sediment and also filter some of the nutrient loadings carried in the surface runoff (Borin et al. 2005). Grassed waterways reduce runoff and soil loss using the grasses in the channels. In the SWAT model, three parameters that represent grassed waterways were modified. These were the channel cover-factor (Ch_Cov), the channel erodibility factor (Ch_Erod), and the channel Manning's ''n'' value (Ch_N2) (Table 16). The SWAT model uses Manning's equation to compute the velocity of flow in the channel segments (EPA 2004). Runoff (flow) velocity decreases with an increase in Ch_N2. The SWAT model default value for Ch_N2 is 0.014 whereas during calibration it was 0.030. These values were modified to 0.24 for the channel segment with grassed waterways (EPA 2004). Such channel segments were considered fully protected by the vegetation cover (Ch_Cov = 0) and thus to be non-erosive (Ch_Erod = 0). The simulation was targeted to the rehabilitation of the waterways in the study catchment by covering these areas with grass.

Scenario 5: Gully/grade stabilization structure: The grade stabilization structure scenario was developed on the basis that it can stabilize the channel grade so as to control erosion and prevent the formation or advance of gullies. Such structures can be vertical drop structures, check dam, concrete, earth or riprap chutes, gabions, or pipe drop structures which are physical conservation measures. Permanent ponds or detention basins can also be part of a grade stabilization structures. Check dams built across an existing gully reduce water flow and the associated sediment yield and soil nutrient losses through gully erosion (Borin et al., 2005). Before implementation of scenario 5, these areas with steep-slopes in the natural water course caused bank collapse and gully erosion advancement. Hence, in the baseline scenario, areas along the streams/gullies with degraded grass, steep-slope land and high C-factor in the MUSLE in the SWAT model accounted for bank sloughing and gully erosion. In scenario 5, the assumption is that building small earthen structures such as check dams can stabilize channel grade that reduce gully erosion. As a result, USLE_P = 0.9 was used for this scenario along the streams/gullies in the catchment. In addition, the slope and channel erodibility factors were modified in the SWAT model to values presented in Table 16.

Scenario 6: Combined scenarios: Catchment management should not focus on single soil conservation or sediment control measures or land-use redesign strategies. Therefore, integrated land-use redesign and conservation measures were evaluate through scenario 6a-6c. Scenario 6a was the combination of scenarios 2 and 3, 6b the combination of scenarios 2, 4 and 5 and scenario 6c combined scenarios 2, 3, 4, and 5. Such scenarios assume that it is possible for more parameters in the SWAT model to be modified at the same time (Table16)

Table 16: Scenario and representation as the SWAT model parameters

Scenario		Representing SWAT parameter			
No	Description	Function	Variable	Range	Value when scenario simulated
1.	Baseline	Used as bench mark -	-		-
2.	Afforesting hotspot areas of erosion	Reduce rill-sheet erosion Reduce overland flow Increase surface roughness-value	USLE_C CN2	0-0.5 0-100 0.17-0.3	0.01 40-60 0.2
3.	Parallel	Reduce overland flow	CN2	0-100	70-80

terraces	Reduce rill-sheet erosion	USLE_P	0-1	0.6
	Reduce slope length	SLSUBBSN	10-150	maximum 75 m
	Reduce slope gradient	Slope (S)	0.0-475	Reduced by 25% for S >25%
4. Grassed waterways	Increase channel cover	Ch_Cov	0-1	0.0 (completely protected
	Reduce channel erodibility	Ch_Erod	0-1	0.0 (non-erosive channel)
	Increase channel roughness	Ch_N2	0-0.3	0.24
5. Gully/grade stabilization structures	Reduce gully erosion	Ch_Erod	0-1	0.0 (non-erosive channel)
	Reduce slope steepness	Ch_S2	0.006	0.0015
	Reduce rill-sheet erosion	USLE_P	0-1	0.6
6a. 2 and 3	Combination of the above	-	-	-
6b 2, 4 and 5	Combination of the above	-	-	-
6c 2, 3, 4 and 5	Combination of the above	-	-	-

4.8.2 Scenario simulation

After the types of scenarios were defined and described, the parameters were modified in the appropriate SWAT input files such as management file, crop database file, channel input data and other HRU related files. First, the runoff and sediment yield soil losses were simulated based on the baseline scenario to determine the reference conditions. The model was run using 18-year daily weather data (1992-2014) from a single gauge nearest to the catchment. The same simulation was performed using each of the alternative scenarios after modifying the parameter inputs. Average annual values of the alternative scenarios were compared with the baseline to compute percent change in average values for the simulation period. A comparison of model simulations of different scenarios enables the determination of the long-term impacts of the alternative management strategies on runoff, sediment yield losses at the outlet of the catchment and the prioritized sub-catchments.

4.8.3 Scenario Results

Reductions by individual scenarios at catchment level

Results of the simulations at watershed level are presented in Table 17 and Figure 27. The figure shows the relative reduction of sediment yield (soil loss) in the alternative scenarios simulated as compared to the baseline. The percentage reduction in these losses due to the interventions in the simulated scenarios as compared to the baseline scenario:

Scenario 1: Baseline scenario: Mean sediment yield in the baseline scenario was nearly 419000 t/y at catchment level. In general, Evaluation of catchment management strategies through SWAT modeling in a GIS most of the sediment source areas are located on steep-slopes, cultivated and open grazed fields, whereas lower slope positions show low soil loss despite the poor surface cover and inappropriate management practices that increase the hydrological losses due to gully expansion and initiation.

Table 17: Results of scenario for sediment yield in Tekeze watershed

Scenario	Sediment yield(t/y)	Sediment reduction (%)
1	419,000	-
2	205,000	51
3	281,000	34
4	369,000	12
5	356,000	26
6a	147,000	65
6b	176,000	58
6c	92,000	78

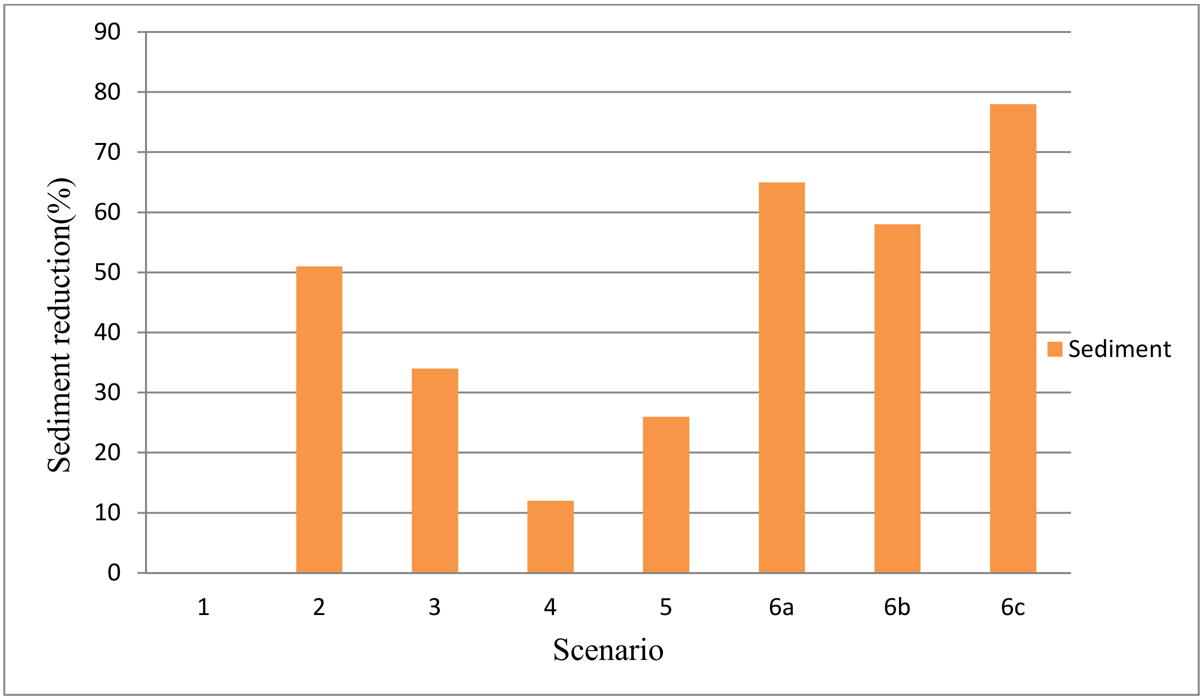

Figure 27: Percentage reduction in sediment yield losses compared to the baseline scenario at catchment level in Tekeze watershede.

Scenario 2: Afforesting hotspot areas of erosion: When parts of the catchment considered as degraded by the local farmers and confirmed with the SWAT model to have soil erosion rates of > 18 t/h/y were afforested, runoff and sediment yield could be reduced by about 51%.

Scenario 3: Parallel terraces targeting hotspot areas: The use of parallel terraces on the prioritized areas can reduce the potential sediment yield 34% losses at catchment level.

Scenario 4: Grassed waterways: This scenario of biological conservation measures targeted to waterways and gullies in the catchment. Reductions in 12% were achieved as compared to the baseline scenario. The lowest sediment yield reduction was simulated in this scenario (Fig 27)

Scenario 5: Gully/grade stabilization structures: This scenario involved stabilization of gullies in the catchment which reduced sediment yield by 26%. This indicates that when gullies are stabilized through appropriate structures, losses can be reduced to a certain extent. Further reductions could be achieved through introducing additional support structures in the upstream parts of a catchment. Thus, adequate soil conservation practices are needed in the upstream of the catchment for gully stabilization structures to effectively reduce excess runoff and sediment that come from gully initiation and expansion.

Scenario 6: Combined scenarios: Combination of measures yielded the lowest hydrological losses. Combining scenarios 2 and 3 (scenario 6a) reduced the sediment yield by 65%. The combination of scenarios 2, 4 and 5 (scenario 6b) resulted in the reduction sediment yield by 58%. A reduction of sediment by 78% was achieved by integrating scenarios 2, 3, 4, and 5 (scenario6c) (Fig 27), leading to higher reductions than the other scenarios. The rate of reduction in sediment yield losses is lower in scenario 4 and 5 than in scenarios 2, 3 and 6 (Figure 26). This is due to the fact that additional conservation and management measures are needed in the upper hotspot areas for scenario 4 and 5 to be effective across the catchment. Thus, the integration of conservation measures with land-use redesign such as afforestation can conserve soil quality, which inturn decreases the runoff that drives sediment yield and soil losses.

In this study, scenarios of land-use redesign, conservation measures and their integration were simulated for targeted erosion-hotspot areas. The scenarios assessed increasing soil cover, infiltration, and surface roughness, and decreasing raindrop and runoff detachment impact, channel erodibility, slope length and steepness through afforestation, grassed waterways, and conservation measures. The study indicates that afforestation (scenario 2) of erosion-hotspot areas (degraded lands) alone would be less effective in reducing soil erosion rate at catchment and sub-catchment level if other catchment management measures are not applied.

Similarly, the application of soil conservation measures individually such as terracing (scenario 3), grassed waterways (scenario 4) or gully stabilization structures (scenario 5) in such erosion-hotspot lands can reduce soil loss, but this is not as effective as the combination of these scenarios with each and other measures (e.g., scenarios 6a-6c). Of the tested scenarios, scenario 6c followed by scenario 6a reduced sediment yield at the catchment level by about 78% and 65%, respectively. In the erosion-hotspot sub-catchments, the reduction of sediment loadings by scenario 6c was more than 90%. Thus, scenario 6c provides the most effective potential management option for reducing soil degradation by erosion at both catchment and sub catchment level (Figure 27).

Based on the SWAT model scenario simulations, grassed waterways (scenario 4) and gully/grade stabilization structures (scenario 5) reduced soil losses at the outlet of the catchment and at the sub-catchments level more effectively than it reduced sediment yield. However, the construction of terraces (scenario 3) showed higher reductions in sediment yield than grassed waterways or grade stabilization structures. This indicates that application of management strategies such as parallel terraces would be more successful for catchments such as in the case of the study catchment where upland areas are the dominant sources of sediments and nutrient losses as stated by EPA (2004). On the other hand, if scenario 4 and 5 are to effectively reduce both sediment yield and nutrient losses, the erosion source areas should be targeted by different management measures that reduce the velocity and volume of runoff at its origin and prevent undercutting, piping or scouring of erosion channels. This is because without decreasing the runoff speed and volume in the source area, the erosion route may be diverted in a new direction in scenario 4 and 5, which could be more destructive than the current condition (Chow 1964; Goldman et al. 1986).

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The main objective of this thesis is to analyze the impact of land use changes on Tekeze Hydro Power dam reservoir sedimentation. In addition to this, the aim is to come across the amount of sediment load under different land use, to assess and evaluate the spatial variability of sediment yield and identify vulnerable sub- watersheds for erosion and sediment yield in the watershed.

The SWAT model was calibrated from 1994 to 2003 and validated from 2004 to 2010 on a monthly basis to examine its applicability for simulating flows and sediment yields from the Tekeze hydro power dam watershed. As it is looked from the model performance efficiency indicators, regression coefficient (R^2) and the Nash-Sutcliffe (ENS) are found to be 0.89 and 0.83 in calibration and 0.87 and 0.74 in validation for flow analysis. Similarly, sediment model efficiency indicators R^2 and ENS of 0.86 and 0.84 for calibration and 0.82 and 0.78 in validation respectively. This shows that, the SWAT model simulates well both for stream flow and sediment load in Tekeze River basin and particularly for Tekeze hydro power dam project reservoir.

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

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

From the land use and land cover change analysis, it can be concluded that the land use and land cover of the Tekeze watershed for the period of 1986 to 2010 showed significantly changed. Tht Intensively and moderately cultivated land was drastically changed from 30.61% in 1986 to 38.69 % in 2010 in the expenses of the other classes. The expansion of agricultural land and rural settlement has an impact on the decrement of forest land. Thus, the forest land which constituted 9 % in 1986 diminished to 5.79 % in 2010. Thus, by the expense of forest land and other land cover types, the cultivated land includes areas for crop cultivation and the scatter rural settlement that are closely associated with the cultivated fields dynamically increased in the period of the last 24 years (1986-2010). This might be due to the population pressure has caused a high demand for additional land as a result shortage of cultivated land is the major problem for farmers in the study area.

The sediment yield simulation result indicates that the simulated annual average sediment yield by SWAT which is 17.35 ton/ha/. The result shows annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 33.36 t/ha/y at some sub basins. But the average annual sediment yield of the whole Tekeze watershed is 17.35 t/ha/yr in 2010.

The model prediction verified that about 36.75% of the watershed is erosion potential area contributing high and very high sediment yield exceeding the tolerance limit (soil formation rate) in the watershed area has high potential for soil erosion which produces above an average annual sediment yield of the watershed and need soil conservation management.

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

5.2 Recommendations

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 some techniques for management practice to reduce erosion problem in this watershed area to increase the life span of the hydropower dam. As a result, the following recommendations were forwarded depending on the findings of the study

☞ Based on the result of the study, the areas which have fallen under high, sevre, and very severe classes need immediate attention in their order of soil erosion potential.

- ☞ Responsible bodies including MoWIE,NGOs and local mangers in the sub basin should incorporate during land use planning and soil and water resource conservation and management practices.
- ☞ Weather stations should be improved both in quality and quantity in order to improve the performance of the model.
- ☞ A special investigation of theoretical and practical aspects of sediment measurements should be established.
- ☞ Creating awareness among the society concerning sustainable use of natural resources and conservation methods.
- ☞ The participation of the local population in water resource management is an important requirement to establish equilibrium between the upstream and downstream areas of the reservoir. It is important that the land users be made aware of the negative consequences of some land use practices on erosion and its attendant impact on the water resource through siltation.
- ☞ Indiscriminate slashing, cutting and burning of natural vegetation should be stopped.

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Appendixes

Appendex 1: Tekeze hydro power dam watershed meteorological station used for SWAT

S.No	Station Name	coordinate		Elevation(m)	Daily metrological data			
		Longi(°)	Lati(°)		Pcp	Temp	RH	WI&SU
1	Maichew	39.55	12.79	2479	✓	✓	✓	✓
2	Tekeze Hydropower	38.25	11.54	1145	✓	✓	✓	
3	Amde Work	38.75	12.35	2885	✓	✓	✓	
4	Sekota	39.03	12.63	2266	✓	✓		
5	Yichila	38.99	13.28	1585	✓	✓		
6	Amba Giyorgis	37.62	12.77	2653	✓	✓		
7	Lalibela	39.04	12.03	2240	✓	✓		
8	Adi Gudom	39.51	13.25	2100	✓	✓		
9	Debark	37.89	13.15	2850	✓	✓		
10	Guhala	38.05	12.24	1960	✓	✓		
11	Nefas Mewcha	38.47	11.73	3160	✓	✓		

Appendix 2: Weather generator statistic and probability value of Michew Station

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	TMP_MAX	TMP_MIN	HMD	DEWPT
Jan.	20.03	2.5921	6.5454	0.0702	0.5983	4.88	20.15	7.58	54.37	5.05
Feb.	10.97	2.2477	8.3875	0.0417	0.4815	2.25	21.71	8.15	55.21	6.92
Mar.	40.95	4.3325	5.7419	0.1168	0.5679	6.75	22.41	9.93	55.66	8.08
Apr.	66.52	5.9371	4.3293	0.1891	0.5605	9.29	23.2	11.19	55.1	8.78
May.	60.19	6.0237	6.436	0.1633	0.4819	8.04	24.5	12.05	54.54	9.73
Jun.	24.52	2.6473	4.6838	0.1604	0.4088	6.63	25.62	13.66	49.85	9.62
Jul.	165.05	8.3851	2.1851	0.4364	0.7164	19.54	23.11	13.37	52.67	8.19
Aug.	219.99	10.8346	2.5367	0.4923	0.7025	20.17	22.28	12.57	55.33	8.78
Sep.	62.48	5.7029	4.6949	0.225	0.5167	10	22.88	10.79	54.33	8.36
Oct.	54.88	6.382	6.0481	0.1163	0.5833	7	21.25	8.84	54.81	6.93
Nov.	28.2	4.2179	6.6742	0.0523	0.6067	3.71	20.53	7.78	56.1	6.38
Dec.	20.35	3.3163	6.8925	0.046	0.5286	2.92	19.95	6.96	54.17	5.13

PCP_MM = average monthly precipitation (mm)

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

TMPMX -Average or mean daily maximum air temperature for month (^{o}c).

TMPMN -Average or mean daily minimum air temperature for month (^{o}c).

DEWPT - Average daily dew point temperature in month (^{o}c).

HUM- average daily humidity in month (%)

Appendix 3: Annual Sediment Yield of Sub Basins

sub basins	Area (ha)	sediment yield (tone/yr/ha) 1986	sediment yield (tone/yr/ha) 2010
1	238.14	3.276552632	3.765526316
2	103780.4	9.079407895	19.07940789
3	60212.97	25.08106579	30.08106579
4	158755.95	3.715991228	7.715991228
5	81499.77	4.824991228	14.82499123
6	9369.27	1.816653509	7.816653509
7	127461.6	22.27829825	25.27829825
8	76664.07	6.971846491	13.97184649
9	188299.89	28.36137719	33.36137719
10	204094.89	2.332675439	4.332675439
11	102710.43	27.69113158	3.962113158
12	136824.39	19.43244737	25.43244737
13	15398.1	11.07700439	20.07700439
14	53519.13	23.92360088	30.92360088
15	2380.59	7.117739605	19.77538759
16	75806.28	11.45461404	24.45461404
17	93400.29	8.274078947	17.27407895
18	99936.18	5.148118421	15.14811842
19	69354.63	29.08050877	30.08050877
20	126300.06	1.630723684	3.630723684
21	81451.17	12.67354386	17.35438596
22	326522.34	24.70755263	25.07552632
23	71319.69	7.964394737	24.96439474
24	169993.08	17.53167544	29.53167544
25	644781.06	10.89792105	21.89792105
Total	3079936.23	Ave =13.05375702	Ave = 17.35286

Appendix 4: Mean monthly stream flow of Tekeze River at Yechila gauge

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Mean**
1994	11.15	10.63	7.31	0.30	104.48	104.23	213.82	163.73	120.19	97.92	48.63	35.40	**76.48**
1995	10.87	11.58	26.46	57.44	37.54	30.15	22.31	25.34	25.12	22.90	2.04	25.18	**24.74**
1996	16.73	11.65	16.46	50.19	60.76	38.04	271.64	395.86	208.22	42.66	34.94	18.48	**97.14**
1997	8.15	10.51	30.28	16.68	17.00	17.42	17.65	16.67	16.94	16.44	17.05	17.35	**16.85**
1998	12.37	8.46	12.92	16.20	44.54	31.61	233.47	120.91	165.76	101.82	26.60	11.00	**65.47**
1999	11.81	3.80	12.29	16.84	22.05	136.87	169.61	175.71	184.29	154.02	52.94	22.20	**80.20**
2000	10.27	4.82	2.22	7.60	6.85	8.10	214.94	149.50	242.46	85.12	38.21	13.83	**65.33**
2001	6.36	3.08	7.80	4.20	5.60	28.07	263.49	120.91	222.55	52.37	22.44	15.08	**62.66**
2002	10.28	5.53	5.00	10.42	2.83	14.57	204.99	312.71	151.51	37.94	19.81	16.21	**65.98**
2003	11.12	12.45	29.70	15.57	9.35	24.25	270.75	130.79	236.11	73.76	30.16	17.72	**71.81**
2004	11.67	7.16	6.76	9.51	3.88	37.10	255.00	377.75	137.03	151.45	123.89	107.59	**102.40**
2005	91.44	96.88	129.01	118.17	125.34	116.52	284.10	248.39	254.23	129.09	190.78	84.61	**155.71**
2006	16.60	12.22	27.95	17.54	22.04	39.04	128.04	120.91	99.50	48.55	35.73	19.29	**48.95**
2007	10.87	11.58	15.05	16.84	22.05	37.18	125.33	121.44	102.76	48.51	41.81	23.86	**48.11**
2008	11.13	32.99	15.00	17.01	22.04	39.04	128.04	120.91	99.50	48.55	35.73	19.29	**49.10**
2009	10.87	11.58	15.00	17.01	22.04	39.04	128.04	120.91	99.50	48.55	42.06	22.57	**48.10**
2010	10.96	33.87	15.00	17.01	22.04	39.04	128.04	120.91	99.50	48.55	35.73	19.29	**49.16**
Montly Mean	**16.04**	**16.99**	**22.01**	**24.03**	**32.38**	**45.90**	**179.96**	**167.26**	**145.01**	**71.07**	**46.97**	**28.76**	**66.36**

Appendix 5: Description of the land use/cover classes SWAT identified in Tekeze Watershed

Land cover types	Description
Forest land	Areas covered with dense growth of trees that formed nearly closed canopies (70-100%). This category included plantation forests, mainly eucalyptus and junipers, mixed with regenerating “indigenous” species of trees and bushes.
Shrub land	Areas with shrubs, and small trees, with little wood, mixed with some grasses.
Grass land	Areas covered with grass used for grazing, as well as bare lands that have little grass or no grass cover. It also includes other small seized plant species.
Moderately cultivated land	It is estimated that of this mapping unit 40 – 70% of the land is under annual and perennial crop while the remaining area can be covered by covered by trees, shrubs or herbs
IntensivelyCultivated land	It is estimated that of this mapping unit over 70% of the land is under annual and perennial crops while the remaining area can be covered by trees, shrubs or herbs
Bush land	Areas with sparse trees mixed with short bushes, grasses and open areas; less dense than the forest.
Water body	Areas which are water logged and swampy throughout the year,lakes, the rivers and its main tributaries.

Appendix 6: P factor values and slope-length limits for contouring (Wishmeier & smith,1978)

Land slope (%)	P_{USLE}	Maximum length (m)
1-2	0.6	122
3-5	0.5	91
6-8	0.5	61
9-12	0.6	37
13-16	0.7	24
17-20	0.8	18
21-25	0.9	15

Appendix 7: Support practice factor (P-values) defined for Ethiopia (Hurni, 1985)

Parameter description	P-value
Contour ploughing	0.9
Ploughing up and down slope	1
Appling mulch	0.6
Strip cropping	0.8
Terraces	0.6
Prtected area	0.5

Appendix 8: Cover and management factor (C-values) defined for Ethiopia (Hurni,1985)

Parameter Descripition	C-value
Cover or managment factor (USLE_C) (Teff)	0.25
Cover or management factor (USLE_C) (Barely and Wheat)	0.15
Cover or management factor (USLE_C) (Maize and Sorghum)	0.1
Cover or management factor (USLE_C) (Bush or Shrub)	0.02
Cover or management factor (USLE_C) (Forest)	0.003
Cover or management factor (USLE_C) (Dense Grass)	0.01
Cover or management factor (USLE_C) (Degraded Grass)	0.05