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ESTIMATION OF CATCHMENT SEDIMENT YIELD
(CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)



A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering under Hydraulics Engineering

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

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Requirements of the Degree of Master of Science in Civil and Environmental Engineering (Major in Hydraulic Engineering)

BY

Desta Hagos Redda

APPROVAL BY BOARD OF EXAMINER

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CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa institute of Technology a thesis entitled **Estimation of Catchment Sediment Yield (Case Study: Tekeze Reservoir, Tekeze Basin, Ethiopia)** in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (major Hydraulic Engineering).

Dr. Bayou Chane
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Date

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Finally I gratefully acknowledge to all offices and personalities who has provided me the necessary data for my study: Addis Ababa Institute of Technology School of Civil Engineering Department, Ministry of Agriculture, Ministry of Water Irrigation and Electricity and National Metrological Service Agency.

DEDICATION

I dedicate this thesis to all human being who have pass their life due to corona virus (covid-19). All may God rest your soul always in peace!

Abstract

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river; it is important to predict sediment inflow at Tekeze dam watershed and evaluate its consequences on the reservoir and sustain the reservoir through long term optimum sediment management program. The overall goal of this study focuses on predicting of sediment yield and identification of most appropriate sediment management strategy by using SWAT model with GIS interface in the Tekeze Basin, Tekeze Reservoir watershed. Tekeze Reservoir Dam is located on Tekeze River (Tekeze Basin) approximately at 13° 21' North and 38° 45' east, approximately 80 km west of the town of Mekele.

The model is calibrated and validated for both flow and sediment concentration at Embamedere station and run at Tekeze dam reservoir outlet (28,916.53km²) to estimate the sediment yield. Flow calibration gives coefficient of determination (R²) and Nash-Sutcliffe simulation efficiency (ENS) 0.84 and 0.73 respectively. Flow validation gives 0.74 and 0.71 for R² and ENS values respectively. Sediment calibration gives R² and ENS 0.78 and 0.77 respectively and validation test gives R² and ENS 0.69 and 0.69 respectively. This result indicates that the observed values show good agreement with simulated value for both flow and sediment yield.

In this study the SWAT model yields average annual sediment flow of 2846 ton/km²/yr. or (28.46 ton/ha/yr.) at Tekeze dam outlet site. Identifying erosion prone areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield. Sub basin 19, 10, 24, 25 and 27 ranks first to fifth according to their Sediment yield respectively and are found to be erosion prone areas. For proper management of the watershed, from the scenarios developed, changing 50% of Pasture land to forest mixed reduces 22% of sediment volume and taken as best management method. Moreover, applying **terracing** and **filter strip** in low slope areas reduces 37% and 11% of sediment volume respectively and could give potential effect of best management practice.

Key words Arc SWAT, Spatial and Temporal data, sediment Yield, Tekeze Watershed, simulation, calibration, validation, SWAT CUP, Erosion prone area,

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Acronyms/Abbreviations

DBF	Data base file
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
EMA	Ethiopian Mapping Authority
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GWQ	Ground water flow (mm)
HRU	Hydrologic Response Unit
M.a.s.l	Meter above mean sea Level
Mm	Millimeter
Ha	Hectare
MoWIE	Ministry of water, irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Service Agency
RH	Relative Humidity
SURQ	Surface Runoff
SWAT	Soil and Water Analysis Tool
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UTM	Universal Trans Mercator
USLE	Universal Soil Loss Equation
GIS	Geographical interface system

CHAPTER ONE

INTRODUCTION

1.1 Background

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. This accumulation is a serious problem in many parts of the world and has severe consequences on water management, flood control and production of energy. In the present Situation, the worldwide loss of storage capacity in surface water reservoirs due to Sedimentation is higher than the increase in storage volume achieved through construction of new reservoirs (White, 2010).The worldwide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum (Mahmood, 1987; White, 2010).

Soil erosion is the detachment and transportation of soil particles from their original place to further downstream by erosion agents such as water and wind. It is one of the normal aspects of landscape development. The severity of erosion increases with the decrease in cover material most likely vegetation. The vegetation cover decreases the soil erosion by decreasing the impact of raindrops that cause the detachment of the soil particles. Therefore, bare soil is more likely to be eroded by different soil erosion agents than soil with vegetation cover.

Reservoirs have to be considered as irreplaceable resources and have to be managed in accordance with the objective of sustainable utilization. Sediment production of a watershed is highly influenced by weathering effects caused by climatic factors like temperature variation, action of rain and chemical action from elements contained in the soil and water (ASCE, 1975).

In reservoir, sedimentation is a phenomenon due to which the sediment particles get deposited in the form of bed load and suspended load after separating from their origin. In fluvial hydraulics, sedimentation is an important parameter as it provides a probability of being used as a capacity predicting device in all storage zones due to which life of a reservoir can be predicted; as there is a unique relationship between capacity and life of a reservoir. To be more explicit, for a given reservoir, sedimentation is dependent on sediment yield, which is defined as the sediment discharge through a river outlet per unit catchment area per unit time. Soil erosion in the catchment is also an important parameter as the sediment yield depends on it. In order to reduce the problem corresponding with the amount of sediment particles that ultimately deposit into the reservoir after getting eroded from the catchment, attempts have been made to relate the soil erosion, sediment yield and sedimentation into the reservoir, since these three parameters deal with the life of a reservoir directly or indirectly

The sustainability of water storage reservoirs require a balance to be maintained between the volume of sediment deposited and the volume of sediment removed from the reservoir. In most cases it is difficult to achieve a complete sediment balance as sediment deposit in a reservoir is influenced by several factors (Morris and Fan, 1998). But it is possible to optimize services of the reservoirs through different sediment management strategies (Palmieri, et al., 2003).

The Tekeze reservoir is one of the largest reservoirs planned on the Tekeze River Basin involving large investment cost. Therefore; it is important to predict sediment inflow at Tekeze and evaluate its consequences on the reservoir and sustain the reservoir through long term optimum sediment management program.

Sedimentation and Sustainability of Hydropower Reservoirs: Cases of Tekeze Reservoir Sediments are all the basin rock and soil particles which water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. {Feasibility Study Tekeze Hydropower Project, the Federal Democratic Republic of Ethiopia Ministry of Water Resources}.

1.2 Statement of the Problem

The major problem in Reservoir sedimentation is one of the most important factors in the planning of a storage-dam, because uncontrolled soil erosion, Poor land use practices and improper mitigation management systems, land degradation resulting in heavy sediment transport in streams and rivers causes significant reduction of the capacity of reservoirs.

Soil erosion is a crucial problem in Tekeze River where the land area is mountainous and still tectonically active. Although deforestation, overgrazing and intensive agriculture, due to population pressure, have caused accelerated erosion. Therefore, understanding the impacts of soil erosion and looking for solutions to minimize is essential. It is important to assess the magnitude of the problem so that effective measures can be implemented.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of this study is to estimate sediment yield from Tekeze dam watershed to the reservoir, using SWAT model and to take and recommended appropriate sediment reduction measures.

1.3.2 Specific Objective

- To estimate the amount of sediment yield of Tekeze dam watershed.
- To identify and prioritize critical source areas regarding Soil Erosion
- To determine the temporal and spatial variability of sediment yield in the catchment.
- To determine appropriate mitigation measures to reduce sediment yield of the watershed.

1.4 Research Question

To structure the study, the problem is divided into two major parts:

First, the sediment yield of the catchment will be determined and needs to define the upstream areas draining into the Tekeze dam reservoir. Moreover, it is necessary to look at the rainfall characteristics, soil properties and land cover of the catchment area. However, criteria like hill slopes and height characteristics will also have an impact on the sediment yield. The research question and sub-questions regarding the sediment yield are the following:

1. What is the sediment yield of the Tekeze dam watershed and what is the impact of different hydrological characteristics on the sediment yield?
2. What are the soil properties, land uses and rain characteristics in the catchment areas?

Second, identifying erosion prone areas and determining of the temporal and spatial changes in land cover as well as determining mitigation methods by making different scenarios is needed. Here also are the sub-questions: -

1. What is spatial distribution of sediment yield in Tekeze dam watershed?
2. What is the temporal variability of sediment yield in the catchment?

3. What are the high erosion prone areas?
4. What are the most sensitive sediment and flow parameters to the catchment?
5. What are best mitigation methods to the erosion exposed areas?

1.5 Scope of the Study

The scope of this study is limited to the estimation of catchment sediment yield using SWAT model. This study did not consider comparison of sediment yield by using another model and also not consider the impact of land use/land cover change on the sediment yield. Generally, the purpose of this study is to estimate catchment sediment yield and how to reduce sediment depositing in the reservoir by using Soil and Water Assessment Tool model and soil conservation measure.

1.6 Thesis Outline

This Thesis contained five chapters.

Chapter one presented the introduction, statement of problem, objective that include general and specific objective and thesis outline. Chapter two describes literature review related to the soil erosion, sediment yield and SWAT model descriptions. Chapter three provides a description of the study area and data availability that include model input data collection and data analysis method presented in the detail. Chapter four deals with presentation of the research findings. The last chapter presented conclusion, recommendation, reference and appendix.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sediment Property

When the sediment particles are non-cohesive, mechanical forces dominate the behavior of the sediment in water. Particle hydrodynamics refers to the propensity of a particle to remain immobile or to become entrained if it is on the bed surface, and to remain in suspension or to cease. Movement if it is in motion. The three most important properties that govern the hydrodynamics of non-cohesive sediments are particle size, shape, and specific gravity. Cohesive sediment behavior is dominated by electrochemical forces. Cohesive sediment behavior is primarily dependent on the particle size, water chemistry, and sediment mineralogy. Sediment properties can be divided into two categories: those related to the particle itself and those related to the sediment mixture or deposit.

2.2 Soil Erosion

Soil erosion is a gradual process of movement and transport of the upper layer of soil (topsoil) by different agents – particularly water, wind, and mass movement – causing its deterioration in the long term. In other words, soil erosion is the removal of the most fertile top layer of soil through water, wind and tillage.

According to a Pereira and Muñoz-Rojas (2017) synthesis, soil erosion is one of the major causes, evidence of, and key variables used to assess and understand land degradation. Soil erosion is a consequence of unsustainable land use and other disturbances, such as fire, mining, or intensive agricultural uses. The loss of soil may have serious impacts on the quantity and quality of soil ecosystem services, with serious economic, social, and political implications.

Soil erosion is a complex process that depends on soil properties, ground slope, vegetation, and rainfall amount and intensity. According to Montgomery, modifications in land use are one of the most impactful ways of accelerating soil erosion. These changes then have a cascade effect as the loss of fertile topsoil cover sends millions of tons of sediments into lakes and reservoirs, changing ecosystems and impacting agricultural production and water quality.

2.2.1 Factors affecting soil erosion

Several factors influence soil erosion which include climate, soil, topography, and vegetation and management practices. The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall. According to (Morgan, 1995) soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity (Foster, 1988).

2.2.2 Rain drop band leaf drip erosion

The rainfall-runoff events and erosion process usually begins with raindrop impact on bare or nearly bare soils with the resulting splash causing the soil particles to become detached and subsequently, overland flow transports these particles towards down slope. Indeed, erosion cannot occur unless first detachment

of soil matrix occurs, and raindrops can provide a temporary disturbance to cause static particles to move. Various factors such as rainfall intensity, infiltration, runoff rates, soil properties and antecedent soil moisture content, roughness, slope length and steepness are important in the process of the soil detachment

2.3 Sediment Transport

The following are the two primary modes of sediment transport:

- Bed load transport is sediment that is moving on or near the bed by rolling, bouncing or sliding. Movement can be either continuous or intermittent but is generally much slower than the mean velocity of the stream. In the upper Puyallup River watershed, bed load consists primarily of coarse sands, gravels and cobbles.
- Suspended sediment is supported by the turbulent motion in the stream flow and is transported at a rate approaching the mean velocity of flow. In the Puyallup River watershed, suspended sediment consists primarily of fine sands, silts and clays.

2.3.1 Sediment transport capacity and sediment load

The sediment transport rate, also called the sediment discharge, the mass of sedimentary material, both particulate and dissolved, that passes across a given flow-transverse cross section of a given flow in unit time. (Sometimes the sediment transport rate is expressed in terms of weight or in terms of volume rather than in terms of mass.) The flow might be a unidirectional flow in a river or a tidal current, but it might also be the net unidirectional component of a combined flow, even one that is oscillation-dominated. Only in a purely oscillatory flow in which the back-and-forth phases of the flow are exactly symmetrical is there no net transport of sediment. Here we focus on the particulate sediment load of the flow, leaving aside the dissolved load, which is important in its own right but outside the scope of these physics-based notes.

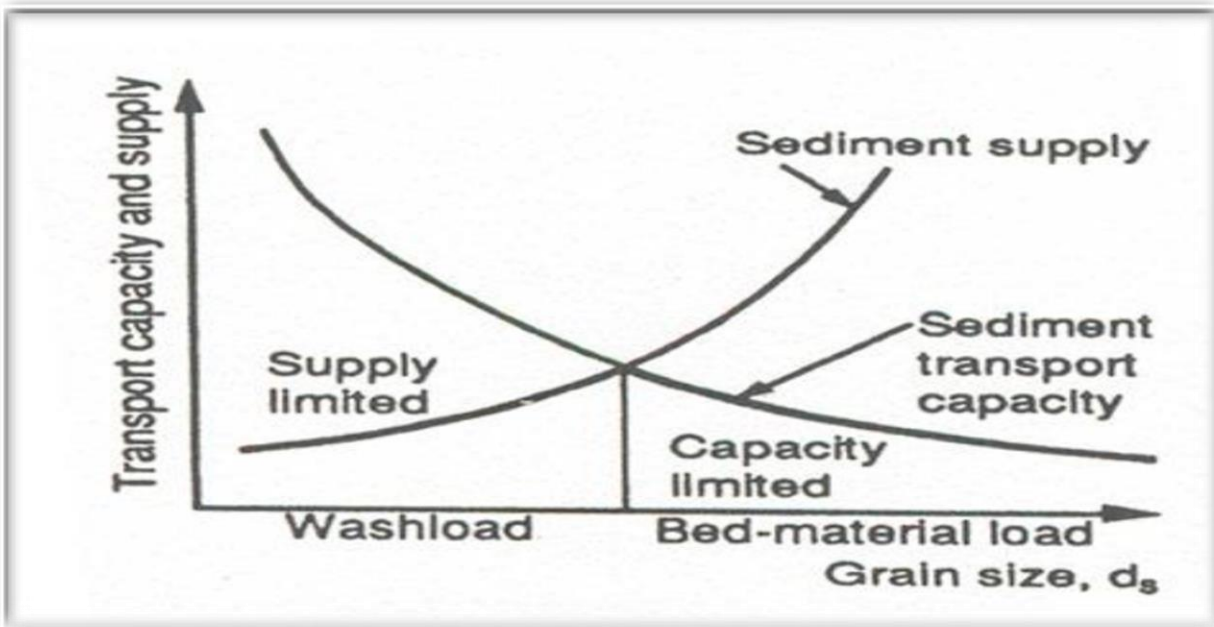


Figure 2. 1 Sediment transport capacity and supply relationship (Julien, 1998)

2.4 Sediment Deposition

Deposition and erosion are the two basic processes inherent to the movement of sedimentary particles in estuaries. As these processes determine the advective sediment load, understanding their mechanics is essential for load prediction. To begin with prevalent classifications related to particle diameter are summarized on a comparative basis. Estuarine sediment usually includes a continuous distribution of diameter from coarse-grained, commonly sand, to fine-grained including silt, clays and colloids. It is therefore useful to review coarse and fine sediment properties and transport behaviors in tandem. The definition of particle size related to settling velocity is introduced in the context of cohesion less particles as well as cohesive particles present as flocs. A separate description is given for the settling velocity of flocs as their diameter and density depend on particle concentration and flow turbulence. The basis of deposition and erosion is described in terms of commonly used mass flux functions. Simple analytical methods for sediment load are referenced, and for cohesive flocs the significance of fluid mud is illustrated in terms of its entrainment potential.

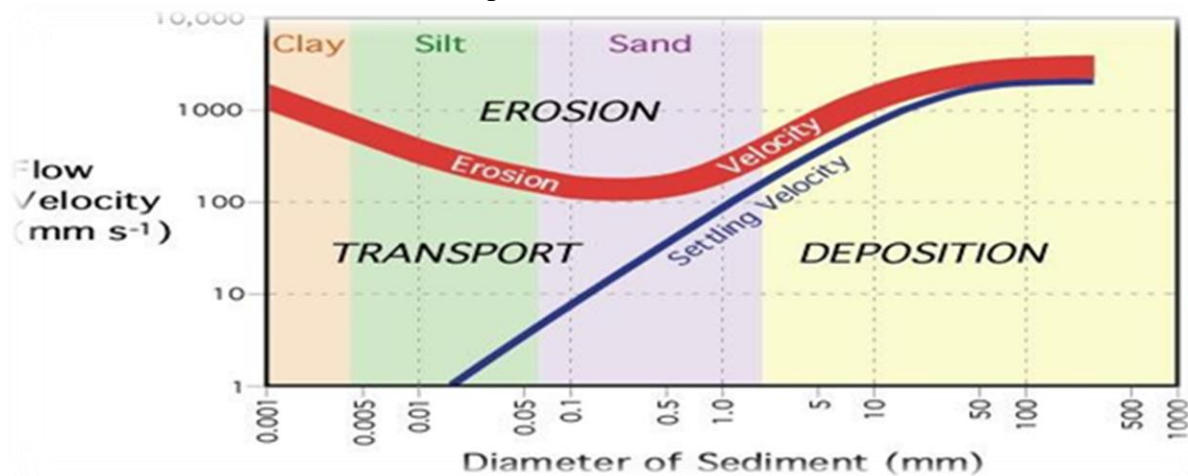


Figure 2. 2 The relationship between flow velocity and particle erosion transport and deposition (Source physical Geography net) (Pedwirny, 2008)

2.5 Erosion and sediment yield relationships

The relationship between the amount of soil eroded at some upstream point and waterborne sediment delivered to a downstream location is important for designing hydrological facilities, planning water resource development, and determining water pollution loadings. The principal sources of the waterborne sediment are sheet (also called 'interrill') and rill erosion on agricultural, forest, and range lands. Other sources are upland gullies, arroyos and valleys, stream channels, roads and highway ditches, various construction sites, and surface mined areas. Erosion takes place in the entire watershed including the channels. During a rainfall event. When rain drops impact on a soil surface. The kinetic energy of the drops breaks the soil aggregates and detaches the particles in the impact area. The detached particles are transported by surface run off.

2.6 Watershed Parameterization

The erosion of soil from upland areas and deposition of sediment in low land and river banks is primarily governed by the hydrology and geomorphology of a watershed. The spatial variability of the topographic and the geomorphologic characteristics of watershed attributes to the variability of soil loss in the upland areas, and of sediment yield at the outlets of watersheds. Understanding the way in which topographic and geomorphologic factors, as well as hydrologic factors influence sediment yield is helpful in arranging the wise handling of sediment models and watershed management activities. Due to the fact that each watershed has its own distinct characteristics, the geomorphology and hydrology of one watershed varies from the other. Watersheds with a large drainage area and steep slopes are more likely to produce high sediment out flow as compared to the large sized watersheds with flat slopes. Additionally, the land cover situation of the watershed is another key factor. Watersheds with dense vegetation cover are more protected against erosion and sediment production. Similarly the hydrology of a watershed mainly rainfall characteristics, runoff and stream discharge is another fundamental factor to govern sediment production. The role of the different watershed factors in sediment production is interrelated with each other. For example, a watershed with a large drainage area, steep slopes and dense vegetation cover may generate less sediment yield as compared to a watershed with the same drainage area, flat slopes but less vegetation cover. In such case, the contribution from the variation of the slope and the vegetation condition determines the amount of the watershed's sediment supply. Because of the interdependency of parameters of a watershed, it is difficult to directly pinpoint a single parameter as the most governing factor for the amount of sediment yield (Habtamu, 2011).

2.7 Hydrological Models

Modeling provides important planning tools that can be used in management of land and water resources which can be used in the understanding of dynamic processes and prediction of the existing processes. which have advance implication in the understanding of physical and biological processes of watershed. The evolution of a wide range of hydrologic catchment models employing the physical based and data driven approach introduces the need for objective test benchmark to assess the merits of different models in reconciling alternative approaches.

Many landscape modelers remain stuck at lower levels, and the catchment scale models required for management and scientific understanding are either not available or are too complex for meaningful use. Emphasis should now be given to either directly modeling the high level, or emergent, properties of catchments, or producing models that can reproduce these high-level properties.

There are different physically based hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. Many of these models share a common base in their attempt to incorporate the heterogeneity of the watershed and spatial distribution of topography, vegetation, land use, soil characteristics, rainfall and evaporation.

2.7.1. Type of Models

Even though, estimates of sediment yield are required in a wide spectrum of practical studies for the planning, design, operation and maintenance of water resources structures, the measurement and sampling of sediment transportation is very lengthy and costly. So that it requires other options to challenge such problems of sediment estimation in water resources development.

Many soil erosion models have been developed and tested at worldwide scale. Some of these are Chemical Runoff_ and Erosion from Agricultural Management Systems (CREAMS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), Agricultural Nonpoint Source Pollution Model (AGNPS), Water Erosion Prediction Project (WEPP), USLE, Modified Universal Soil Loss Equation, and RUSLE. Similarly, Sediment Delivery Ratio (SDR), Transport Limiting Sediment Delivery (TLSD), Unit Stream Power Erosion and Deposition model (USPED), and Sediment Distributed Delivery (SEDD), EROSION 3-D, SWAT (Soil and Water Assessment Tool) have been used to model the sediment removal, transportation, and outflow. Employing soil erosion models to estimate the soil erosion severity at a place is gaining popularity nowadays as field-based erosion studies are tedious, costly, and take a considerable amount of time. Instead, soil erosion models can assess the soil loss within a short time, provided data are available handy. I calculated the soil loss of the study area using the SWAT model, and then compared those with real soil loss observations. Some of the models are experienced below.

❖ WEPP Model

One of the most promising models currently used for erosion modelling is the Water Erosion Prediction Project (WEPP) model. WEPP is a process-based continuous simulation erosion model (Flanagan and Nearing, 1995) developed by the USDA-ARS that is applicable to both hill slopes and watersheds. An advantage of WEPP over other existing models such as the popular Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is that soil loss is estimated spatially at a minimum of 100 points along a profile and deposition of sediment also can be predicted. In other words, soil loss and deposition on a complete continuous hill slope profile can be calculated, which is important in watershed modelling because it enables enhanced predictions of sediment yields to channels and to the watershed outlet. Additionally, runoff and soil loss are predicted for every rainfall event, allowing detailed temporal analyses and development of probability distributions.

In 1985, the USDA initiated the Water Erosion Prediction Project (WEPP) model for soil erosion prediction. This model is used in soil and water conservation planning and assessment (Foster and Lane 1987). The WEPP model is a process-based, distributed parameters, capable of doing both single-event and continuous simulation erosion prediction. This model relies on the fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics and erosion mechanics (Flanagan et al. 1995). Although this model does not implement the USLE for parameter estimation, it can predict soil erosion, sediment transport, and deposition across the landscape by using a steady-state sediment continuity equation for predicting rill and interrill erosion processes. WEPP model can be used for small watersheds or hill slopes.

In the last decades, several studies have been carried out to build models suitable for quantifying sedimentation. Among these models, the Water Erosion Prediction Project (WEPP), is a physically based, distributed-parameter model that has been developed and mainly validated in America. Only few studies have investigated its applicability to environmental conditions that differs from those where the model was developed. The aim of this work is to test the efficiency of WEPP model to predict runoff and sediment yield at catchment scale in a semi-arid area. The watershed version that is an extension of WEPP hill slope model can be used to assess soil loss on the small watershed.

❖ EROSION 3-D Model

EROSION 3-D is a physically-based model developed in Germany for estimating catchment rain induced soil erosion and deposition as well as runoff for single storm events (Novakova et al, 2005). It is one of several physically-based models but it was chosen as a tool for this project mainly because of its small number of input parameters in simulating soil loss and sediment yield on an event basis. The model is compatible with Geographic Information Systems (Schmidt et al, 1999). The model had previously only been used in European agricultural watersheds so this study provided an opportunity to assess its capability for tropical catchments.

❖ HEC HMS

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a computer program designed to model watershed hydrology. Historically, HEC-HMS has focused on modeling rainfall-runoff processes; however, a significant effort is underway to add sediment and water quality modeling capabilities. The sub basin element is one of seven hydrologic elements that compose a basin model network in an HEC-HMS model. The sub basin element is used to represent a drainage basin where precipitation falls, infiltration occurs, and surface runoff may result. Outflow from the sub basin element is calculated by subtracting precipitation losses due to interception by the canopy, storage on the land surface and infiltration into the soil from the total precipitation. Once losses have been computed, the excess precipitation is treated as surface runoff and transformed to stream flow at the sub basin outlet, and base flow is added.

The reach element is one of seven hydrologic elements that compose a basin model network in an HEC-HMS model. The reach element is used to convey stream flow downstream in the basin model. Inflow into the reach element can come from one or many upstream hydrologic elements. Outflow from the reach is calculated by accounting for translation and attenuation of the inflow hydrograph. Multiple methods for modeling sediment transport and erosion/deposition within the channel will be added to the reach element. Several sediment transport equations can be used to route sediment through the stream network in HEC-HMS. The sediment continuity equation was used in conjunction with a sorting algorithm to solve for the actual volume of deposition or erosion. Additionally, temporal entrainment and deposition functions similar to those employed in HEC-RAS have been adapted for use in HEC-HMS.

❖ SWAT Model

SWAT (Soil and Water Assessment Tool) (Arnold et al. 1998) is a semi-distributed, time continuous watershed simulator operating on a daily time step. It is developed for assessing the impact of management and climate on water supply, sediment yield and agricultural chemical yields in watersheds and larger river basins. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds.

2.7.2 Selection of model

SWAT model is selected to be used in this study because it is physically based, spatially distributed, and suitable to identify vulnerable (erosion prone areas) and to adopt best management practice for the watershed, it belongs to the public domain, and it is free model and the model has been tested in different tropical watersheds (Tadele and Forch 2007).

Hydrologic parameters are the main driving force behind the production and transportation of sediment load. Rainfall depth, intensity, surface runoff and stream flow are the major hydrologic factors that play a

fundamental role in erosion generation and sediment transport. Rainfall initiates soil detachment and transportation, while surface runoff and peak flow transport the eroded soil as sediment load. Surface runoff and peak flow are estimated from available empirical formulae, while the stream flow component is measured physically. Nevertheless, for large basins with many river networks there is a limited amount of measured stream flow data available for each tributary and main river section. Therefore, physically based models like SWAT and other hydrologic models can help to simulate the surface runoff, peak flow and stream discharges, which can then be used as primary input for sediment modeling.

2.7.3 Features of Soil and Water Assessment Tools (SWAT)

2.7.3.1 Development and Interface

2.7.3.2 Theoretical Description of SWAT

The Soil & Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer.

SWAT is a continuous time model that operates on a daily time step at basin scale. Its objective is to predict the long-term impacts of management and of the timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies.

SWAT uses a two-level disaggregation scheme; a preliminary subbasin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same topographic characteristics, soil type, land use and management form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

SWAT predicts surface runoff using the Soil Conservation Service (SCS) curve number (CN) method and it used daily rainfall data as an input. The modified universal soil-loss equation is used to predict the sediment loss.

The Arc SWAT, ArcGIS extension evolved from AVSWAT2000 an ArcView extension developed for an earlier version of SWAT. The interface requires the designation of land use, soil, weather, groundwater, water use, management, soil chemistry, pond, and stream water quality data, as well as the simulation period, in order to ensure a successful simulation.

2.7.3.3 Hydrological component of SWAT

The primary elements of hydrologic processes of the SWAT model are evapotranspiration, infiltration, surface runoff, return flow, lateral flow, tile drainage, water stored in the soil profile, and transmission losses.

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \dots \dots \dots 2.2$$

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Where: S_{wt} is the final soil water content (mm), S_{wo} is the initial soil water content for day is (mm), t is the time (days), R_{day} is the day precipitation (mm), Q_{SURF} is the surface runoff (mm), E_a is the evapotranspiration (mm), W_{SEEP} is the seepage from the bottom soil layer (mm) and Q_{qw} is the groundwater flow on day (mm).

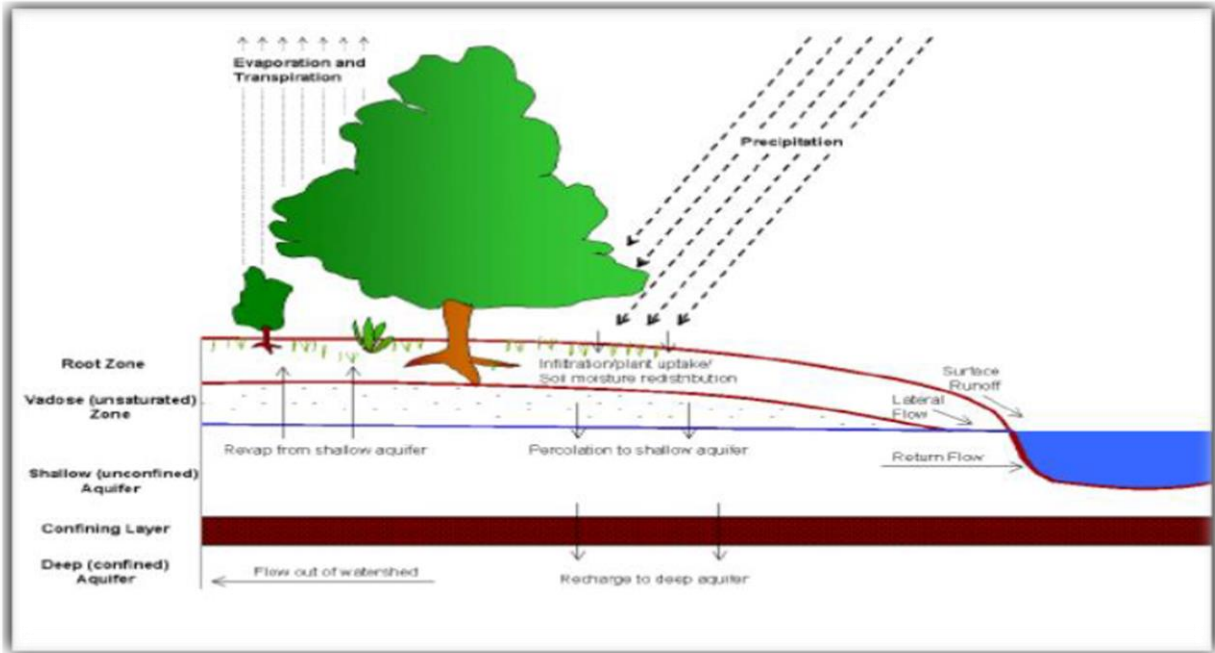


Figure 2. 3 Hydrological cycle component consider by SWAT (Neitsch et al., 2005).

2.7.3.3.1. Surface runoff

Therefore, the SCS curve number method was adopted. The general equation for the SCS curve number method is expressed by equation 2.3.

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \dots\dots\dots 2.3$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm water), I_a is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water), and S is retention parameter (mm water). The retention parameter S can be calculated by using equation 2.4.

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \dots\dots\dots 2.4$$

Where, CN is the curve number for the day and its value is the function of land use practice, soil permeability and soil hydrologic group. The initial abstraction, I_a , is commonly approximated as $0.2S$ and equation 2.5 becomes: -

$$Q_{surf} = \frac{(R_{day} - 0.2s)^2}{(R_{day} + 0.8s)} \dots\dots\dots 2.5$$

2.7.3.3.2. Peak discharge

The peak discharge or the peak surface runoff rate is the maximum volume flow rate passing a particular location during a storm event. The peak run off 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 see equation 2.6 (Neitsch et al. 2011).

$$Q_{peak} = \frac{C * i * Area}{3.6} \dots\dots\dots 2.6$$

Where: Qpeak is peak runoff rate (m3/s), C is the runoff coefficient, i is the rainfall intensity (mm/hr.), sub-basin area (km2) and 3.6 is conversion factor.

2.7.3.3.3. Estimation Erosion and Sediment yield using SWAT model

Erosion and sediment yield in SWAT are estimated of each HRU with the Modified Universal Soil Loss Equation (MUSLE) developed by Wischmeier and Smith (1965; 1978). While the Universal Soil Loss Equation (USLE) uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. The hydrology mode supplies estimates of runoff volume and peak runoff rate, which, with the subbasin area, are used to calculate the runoff erosive energy. The crop management factor is recalculated every day that runoff occurs. It is a function of aboveground biomass, residue on the soil surface, and the minimum C factor for the plant.

2.7.3.3.4. Sediment Routing using SWAT model

The studies by (Setegn et.al, 2008) show that sediment transport in the channel network consists of two components operating simultaneously, which are deposition and degradation. To determine the deposition and degradation process the maximum concentration of sediment is calculated using Equation 2.7 below.

$$conc_{sed,h,mx} = C_{sp} * V_{ch,pk}^{spexp} \dots\dots\dots 2.7$$

Where $conc_{sed,h,mx}$ is the maximum concentration of sediment that can be transported by the water (ton/m3 or kg/L), C_{sp} is the coefficient defined by the user, $V_{ch,pk}$ is the peak channel velocity (m/s), and $spexp$ is an exponent parameter for calculating sediment re-entrained in channel sediment routing that is defined by the user and set at 1.5 for this particular study. It normally varies between 1 and 2. The peak channel velocity, V_{ch} , is calculated by using equation 2.8.

$$V_{ch} = \frac{prf * qch}{Ach} \dots\dots\dots 2.8$$

Where prf , is the peak rate adjustment factor (a user specified parameter), qch is the average rate of flow (m3/ s), and Ach , is the cross-sectional area of flow (m2).

The maximum concentration of sediment ($Conc_{sed, ch, mx}$) that is calculated from the previous equation is compared to the concentration of sediment in the reach at the beginning of the time step $Conc_{sed, ch, i}$. If $Conc_{sed, ch, i} > Conc_{sed, ch, mx}$, deposition is the dominant process in the reach segment, Equation 2.9 below is used to calculate the net amount of sediment deposited in the reach.

$$Sed_{dep} = (Conc_{sed,h,i} - Conc_{sed,ch,mx}) * V_{ch} \dots\dots\dots 2.9$$

Where Sed_{dep} is the amount of sediment deposited in the reach segment (metric tons) and V_{ch} is the volume of water in the reach segment (m3). If $Conc_{sed, ch, i} < Conc_{sed, ch, mx}$ degradation is the

dominant process in the reach segment and the net amount of sediment re-entrained is calculated by Equation 2.10 below.

$$Sed_{deg} = (Conc_{sed,h, mx} - Conc_{sed,ch,i}) * Vch * Kch * Cch \dots\dots\dots 2.10$$

In which, *Seddeg* is the amount of sediment re-entrained in the reach segment (metric tons), *Kch* is the channel erodibility factor (cm/hr/pa), and *Cch* is the channel cover factor.

The channel erodibility factor (*Kch*) is conceptually similar to the soil erodibility factor in the Universal Soil Loss Equation. Channel erodibility is a function of properties of the bed or bank materials. In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility. The channel cover can be defined as a ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface.

After the amount of deposition and degradation is calculated, equation 2.11 is used to determine the final amount of sediment in a reach.

$$Sedch = Sedch,i - Seddep + Seddeg \dots\dots\dots 2.11$$

where, *Sedch* is the amount of suspended sediment in the reach (metric tons), *Sedch,i* is the amount of suspended sediment in the reach at the beginning of the time period (metric tons), *Seddep* is the amount of sediment deposited in the reach segment (metric tons), and *Seddeg* is the amount of Sediment re-entrained in the reach segment (metric tons).

Finally, Equation 2.12. Below is used to calculate the amount of sediment transported out of the reach.

$$Sedout = Sedch * \frac{Vout}{Vch} \dots\dots\dots 2.12$$

where, *Sed out* is the amount of sediment transported out of the reach (t), *Sedch* is the amount of suspended sediment in the reach (t), *Vout* is the volume of out flow during the time step (m3), and *Vch* is the volume of water in the reach segment (m3).

2.7.3.4 SWAT- CUP (SWAT Calibration Uncertainty Procedures)

SWAT-CUP is a program for calibration of SWAT models. The program could be used to perform calibration, validation, sensitivity analysis (one-at-a-time, and global) and uncertainty analysis. The program links SUFI2, GLUE, ParaSol, MCMC, and PSO to SWAT. Any of the procedures could be used to perform calibration and uncertainty analysis of a SWAT model. SWAT-CUP also has graphical modules to observe simulation results, uncertainty range, sensitivity graphs, watershed visualization using Bing map, and statistical reports.

CHAPTER THREE

MATERIAL AND METHOD

3.1. Location and description of the study area

3.1.1 Location of Study Area

Tekeze Basin

Tekeze river basin has an area of 82,350 Km², covering parts of the Amhara and Tigray regional states. There are two main tributaries (Angereb and Goang) that contribute to Tekeze River which rises in the central highlands of Ethiopia, and joins the Atbarah River, the lower course of which is a tributary of the Nile. The river basin has a lowest elevation of 557 (536) m and a highest elevation of 4420 (4517) m. The total mean annual flow from the river basins is estimated to be 8.2 BMC. The amount of rainfall varies considerably ranging from 1300 mm in the Seimen Mountain to 600 mm in the lowland areas. Tekeze basin has a potential for three large-scale irrigation sites with an estimated potential irrigable area of 83,368 hectares.

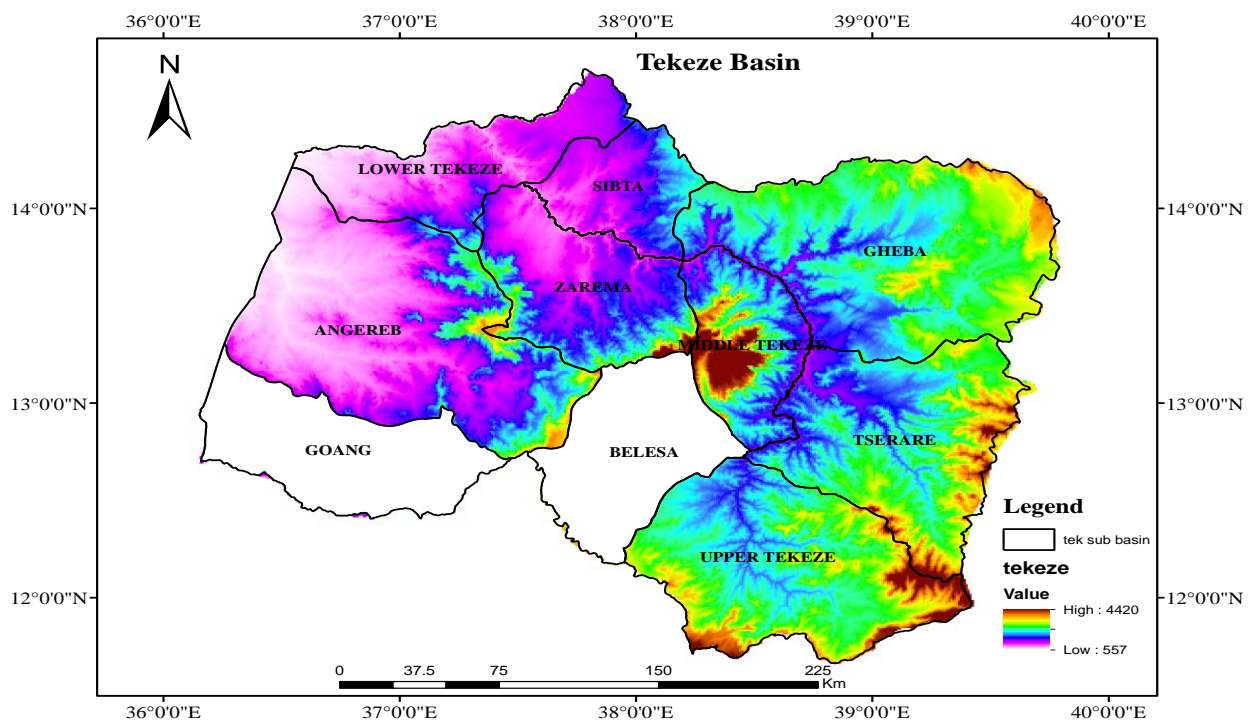


FIGURE 3.1 Tekeze river basin

Tekeze Hydropower Reservoir

Tekeze hydroelectric power reservoir is located in Tigray Region on Tekeze River, a tributary of Nile. The Tekeze project includes the tallest arch dam in Africa with 188 meters height. The Ethiopian Electric power corporation constructed the Tekeze hydroelectric power plant as part of the Country's general development plan with the aim of expanding the electric power generation capacity to bringing the total capacity to 4 x 75 MW. With anticipated annual firm energy production of 981GWhr, the plant will play

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an important role in the development of the Ethiopian economy. A feasibility study carried out in 1997, investigated 6 potential dam sites and the one, designated Tk5, was selected, at coordinates 13° 21' North and 38° 45' East, approximately 80 km west of the town of Mekele.

The dam is located in a steep, narrow gorge, which the river has carved through the surrounding plateau during the course of many millions of years. The powerhouse is located in an underground cavern, excavated in the rock on the downstream side of the dam, adjacent to the right bank of the river at an altitude of 970m above mean sea level, whereas the crest of the dam is 1145m above sea level and the substation on the right bank plateau is at approximately 1300msl.



FIGURE 3. 2 Tekeze Dam

TABLE-3.1: Tekeze Hydroelectric Reservoir

DAM	
LOCATION	
SITE LOCATION	935KM NORTH EASTERN OF ADDIS ABABA
LOCALITY	TEMBIEN, TANQUA ABERGELE
CONSTRUCTION COMMENCEMENT	1998
COMMISSIONED	2002
Type	Double curvature concrete arch
Height	188 meters
Crest length	420 meters
Reservoir	
Maximum storage capacity	9.3 billion cubic meters (1140 masl)
Live storage capacity	5.3 billion cubic meters (1096 masl)
Dead storage	4 billion cubic meters
Catchment/ drainage/ area	33000 square kilometers
Total length	70 kilometers
Nominal Head	162.8 meter
Power House	
No. of turbine & type	4 Francis turbines

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generating capacity of each units	75 Mega Watt
Power Plant maximum generating capacity	300 Mega Watt
Firm energy	981 Giga Watt Hour
Discharge or water consumption of each units to generate their maximum generating capacity	55 cubic meters per second
Discharge or water consumption of plant to generate plant maximum generating capacity	220 cubic meters per second

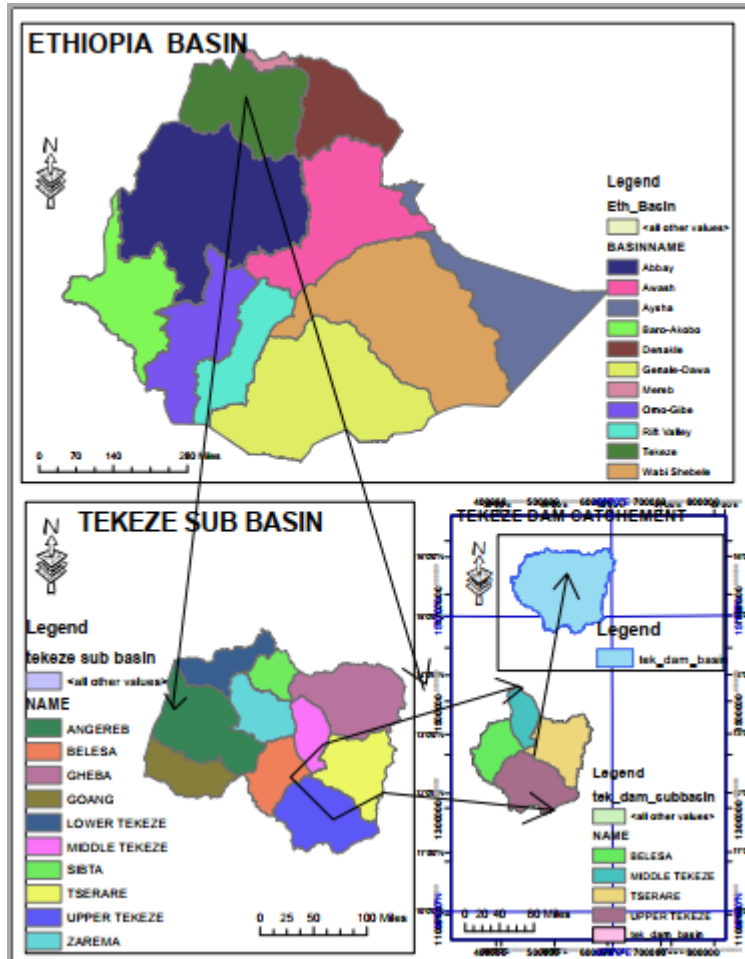


FIGURE 3.3 Location of Tekeze dam watershed

3.1.2. Description of the study area

3.1.2.1. Topography

The Tekeze Dam watershed, part of the Tekeze river basin covers an area of about 29404 km² and is situated between 11° 39' 32.17" and 13° 27' 15.96" North latitude, and 37° 33' 27.63" and 39° 40' 7.24" East longitude in the north-western part of Ethiopia. Administratively, the major part of Tekeze dam watershed is in Amhara regional state and small part in Tigray regional state. It is much diversified watershed in terms of topography, climate land use and socio-economics. The average altitude is 2064 m with a mean slope of 12.5 %.

3.1.2.2. Climate of the Study Area

The Tekeze dam watershed has an annual rainfall ranging between 775 mm to 1220 mm. The majority of the area characterized by a semiarid climate with moderate rainfall and most of the total annual rainfall is received during one rainy season (June to September). There is high temporal variation rather than spatial variation of rainfall in the study area. It has high diurnal change in temperature i.e. there is high variation between the daily maximum and minimum temperature with an average temperature of 18 ° C. According to the Ethiopian Ministry of water resources (MoWR), (2008), the local climate of the Tekeze dam watershed can be divided into three agro-ecological zones (Dega (high altitude), Woina Dega (mid altitude) and Kolla (low altitude). Tekeze River basin have high seasonal variability and about 70 percent of the total runoff occurs during the main rainy season in the period June to October. The Tekeze River alone contributes 13% and 22% of the total annual flow of the Nile water during the dry and flood season respectively (Degefu, 2003).

3.1.2.3. Geology

The geology of tekeze catchment consists of a basement complex plateau (metamorphic rocks) having an upper sedimentary rock layer (sandstone, shale, limestone, and limestone-marl) with some doleritic intrusion, which is capped by basalt trap series (HTS, 1976). Alluvium occurs along narrow incised river valleys. The dominant geology of the tekeze River basin are Basalt, Dolerite, Granite, Limestone, Metamorphic rock, Sandstone and Shale.

3.1.2.4 Soil

The MoWR (2008b) characterized the soils and land use as follows. The soils on the basin are Vertic Cambisols, Rendzic Leptosols, Eutric Cambisols, Humic Nitisols, Lithic Leptosols, Eutric Leptosols, Eutric Vertisols, Chromic Luvisols, Dystric Leptosols, Haplic Luvisols, Chromic Cambisols and Petric Calcisols. The dominate soils are Lithic Leptosols, Haplic Luvisols and Eutric Cambisols respectively.

3.1.2.5 Land Use and Land Cover

The major land use and land cover classes of the basin includes intensively cultivated land (7%), sparsely cultivated (58%), open woodland (12%), open grass land (5%), sparsely vegetated (0.2%), complex land (15%), and others (2.8%) (NEDECO 1997b; Belete, 2007). Most of the climax vegetation of the basin has disappeared and the Afro-alpine and sub-afro-alpine heath vegetation lies between 3700 and 3900 m.a.s.l around Simien Mountains (MoWR, 2008b).

3.2. Data collection and analysis

3.2.1. Spatial data

3.2.1.1. Digital elevation model (DEM) data

The DEM (Digital Elevation Model) data with (30x30) resolution was collected from ministry of water irrigation and electricity (MoWIE), GIS Department. 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 resolution of the digital elevation model (DEM) is the most critical input parameter when developing a SWAT model (Gassman et al., 2007). DEM resolution affects the watershed delineation, stream network and sub basin classification in the SWAT model. It affects the number of sub-basins and HRUs. The number of sub-watersheds in the sub basin affects the predicted sediment yield for a watershed (Bingner et al., 1997). (Jha et al., 2004) found that SWAT sediment predictions were sensitive to HRUs and sub-watershed configurations. According to

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(Chaubey et al., 2005) a decrease in DEM resolution resulted in decreased stream flow and watershed area. Since the runoff volume and total sediment load depends on the watershed area, the decrease in the DEM resolution results in large Error in the predicted output. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and sub basin classification (Chaubey et al., 2005). In this research paper digital elevation model (DEM), 30mX30m resolution was used to delineate the watershed.

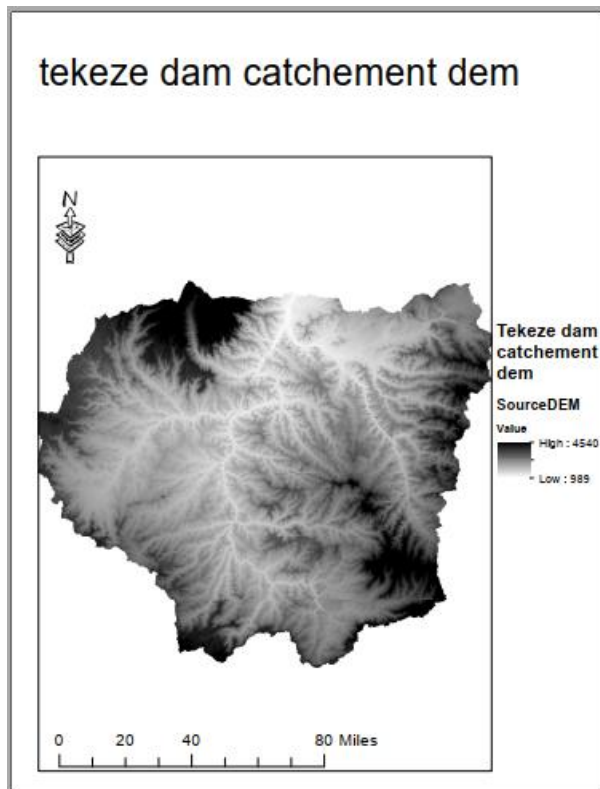


FIGURE 3.4 DEM 30mX30m of Tekeze dam watershed

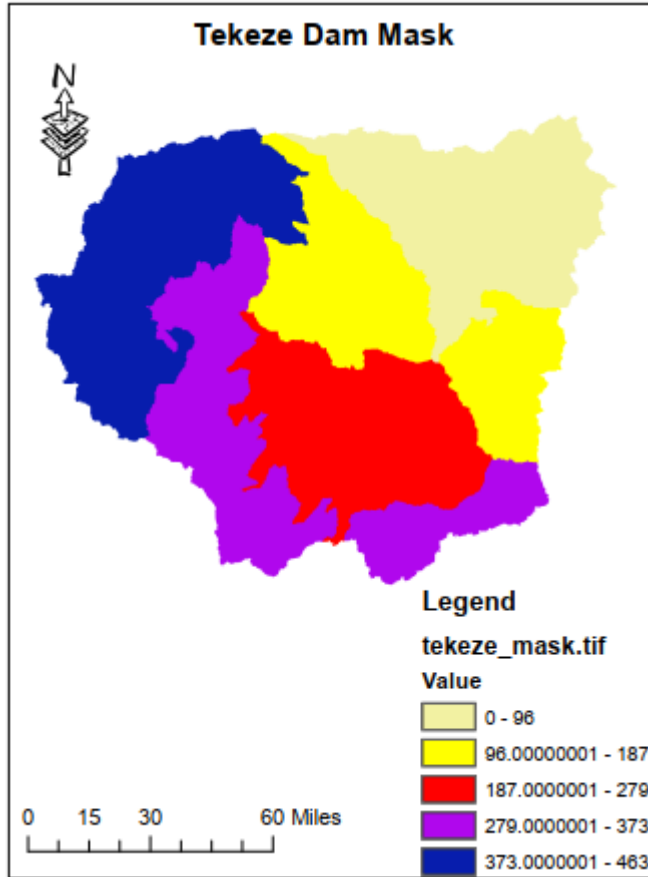


FIGURE 3.5 Mask of Tekeze dam watershed

3.2.1.2. Soil data

The major aim of soil classification is to convert user's soils into SWAT database (or grid properties). Since swat soil data base is developed in U.S database SWAT does not recognize the soils of the catchment. To reclassify the soils, new FAO soils and their properties were added to the soil database with the soil Database Editor. The soil characteristics were entered manually and to facilitate their manipulation, they were rearranged in an excel table.

I used map window swat model and map window GIS model software to change the SWAT model database to FAO database.

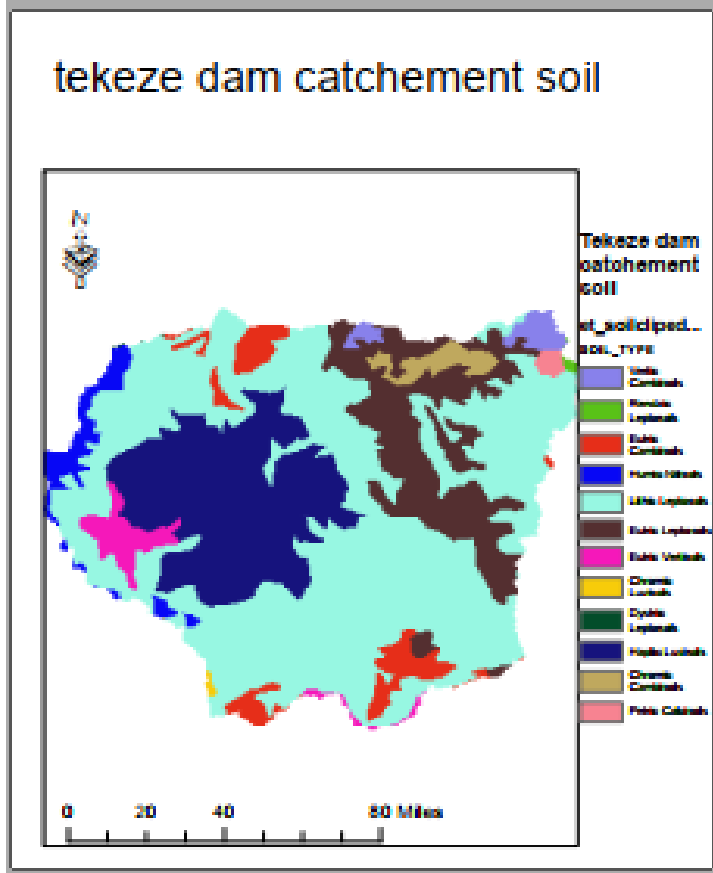


FIGURE 3.6 Ethio Soil of Tekeze Dam Watershed

No	Soil type(FAO)	Description	Area (km2)	% of total area
1	Cmv	Vertic Cambisols	3925592.447	1.36
2	Lpk	Rendzic Leptosols	346677.3865	0.12
3	Cme	Eutric Cambisols	11998913.83	4.15
4	Ntu	Humic Nitisols	7359806.588	2.55
5	Lpq	Lithic Leptosols	156451439.2	54.10
6	Lpe	Eutric Leptosols	39296695.91	13.59
7	Vre	Eutric Vertisols	6901045.261	2.39
8	Lvx	Chromic Luvisols	271428.4788	0.09
9	LPd	Dystric Leptosols	36374.39225	0.01
10	Lvh	Haplic Luvisols	56928552.39	19.69
11	Cmx	Chromic Cambisols	4538825.298	1.57
Total			2891653.00	100.00

TABLE 3.2 Ethio Soil of Tekeze Dam Catchment

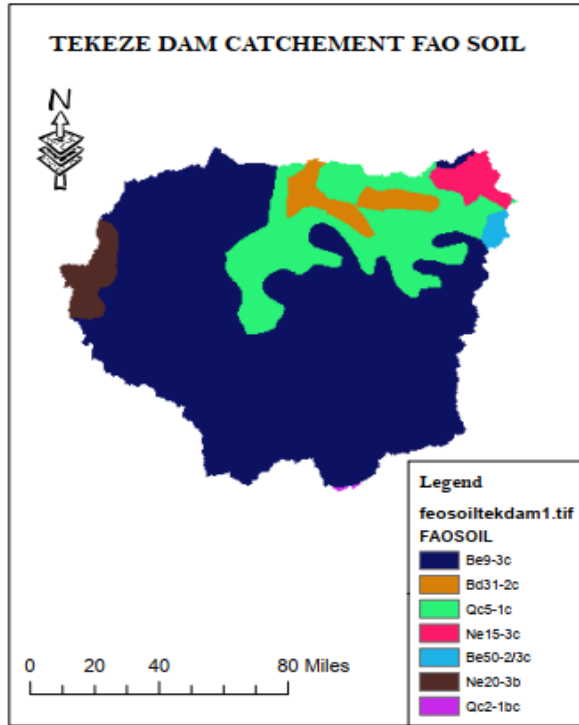


FIGURE 3.7 FAO Soil of Tekeze Dam Watershed

No	Soil type(FAO)	Description	Area (km2)	% of total area
1	Be9-3c-26	Eutric Cambisols(Clay)	2120067.533	73.316803
2	Bd31-2c-11	Dystric Cambisols(Loam)	105579.7452	3.65119
3	Qc5-1c-182	Cambric Arenosols(Sandy Loam)	500036.2149	17.2924004
4	Ne15-3c-159	Eutric Nitosols(Clay)	64365.01207	2.2258899
5	Be50-2-3c-21	Eutric Cambisols(Clay Loam)	19234.43718	0.665171
6	Ne20-3b-160	Eutric Nitosols(Clay)	80786.71524	2.7937901
7	Qc2-1bc-176	Cambric Arenosols(Sandy Loam)	1582.283605	0.054719
Total			2891653.00	100.00

TABLE 3.3 FAO Soil of Tekeze Dam Catchment

3.2.1.3. Land use/cover data

Land use land cover in a catchment can often be correlated with the amount of interception storage/loss and actual evapotranspiration in a catchment. The Land Use, Soil and Slope Definition option in the HRU Analysis menu allows specifying the land use, soil and sloping themes that will be used for modeling using SWAT. These themes are then used to determine the hydrologic response unit (HRU) distribution in each sub watershed. SWAT require land use data to determine the area of each land category to be simulated within each sub basin. In addition to land use information, SWAT relies on soil data to determine the range of hydrologic characteristics found within each sub basin. Land Use, Soil and Slope Definition option guides the process of specifying the data to be used in the simulation and of ensuring that those data are in the appropriate format. In particular, the option allows the user to select land use or

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soil data that are in either shape or grid format. Shape files are automatically converted to grid, the format required by ArcGIS to calculate land use and soil distributions within the sub basins of interest. When we select the Land Use / Soil / Slope definition option from the HRU Analysis menu. The Land Use / Soil / Slope Definition dialog box will open.

The LULC map and all datasets were obtained from the Ministry of Water Irrigation and Electric (MoWIE) as shape file format. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database. A lookup table that identifies the SWAT land use code for the different categories of LULC was prepared to relate the grid values to SWAT LULC classes.

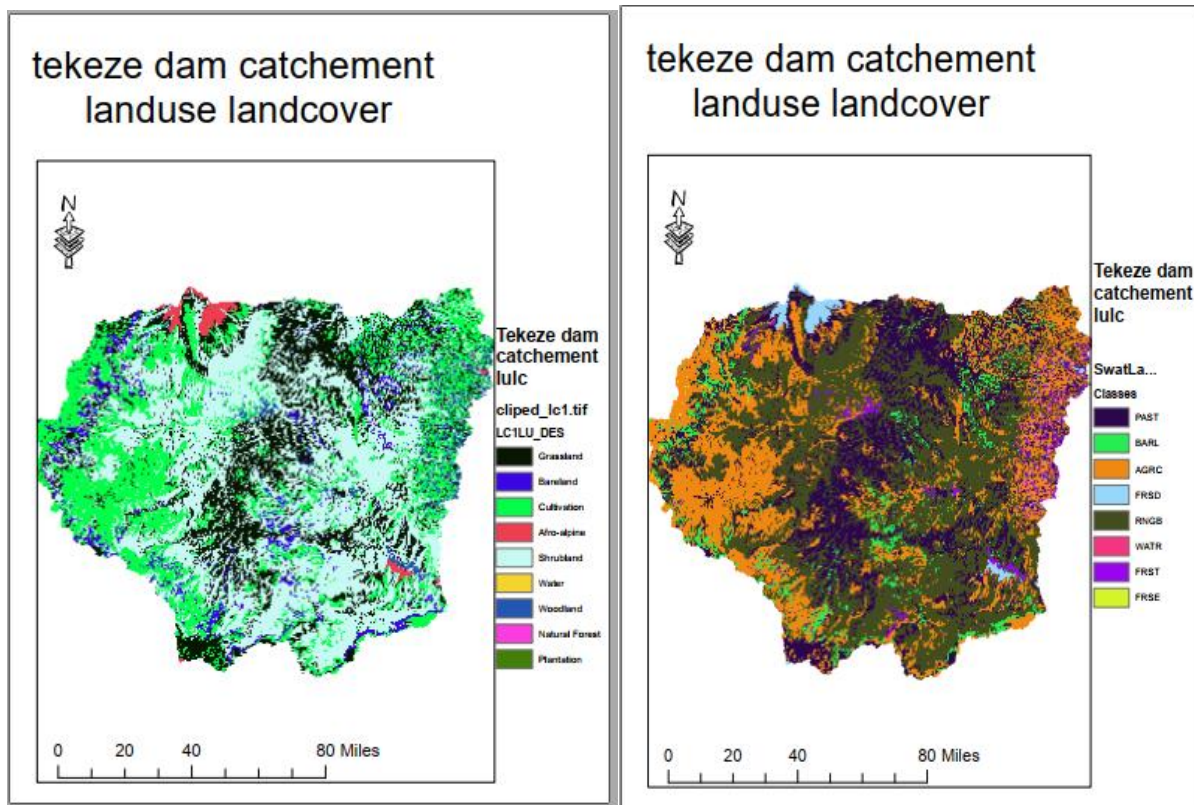


FIGURE 3.8 LULC of Tekeze Dam Watershed

No.	LULC	Description	SWAT	Area (km2)	% of total Area
1	Grassland	Pasture	PAST	658224.0634	22.7628994
2	Bare land	Spring Barely	BARL	121413.2803	4.19875
3	Cultivation	Agricultural Land Close Grown	AGRC	751054.8112	25.9731998
4	Natural Forest and Afro-	Forest-Deciduous	FRSD	32302.3665	1.11709
5	Shrub land	Range Brush	RNGB	1263369.002	43.6902008
6	Water	Water	WATR	360.7770865	0.0124765
7	Woodland	Forest Mixed	FRST	59939.05088	2.07283
8	Plantation	Forest Evergreen	FRSE	4990.47258	0.172582

TABLE 3.4 LULC of Tekeze Dam Catchment

3.2.1.4. Slope

The DEM have important use to determine the slope of the Tekeze Dam catchment to characterize the HRU definition including the land use land cover and soil properties. Due to the mean slope of tekeze dam watershed is 12.5% I have classified as shown below.

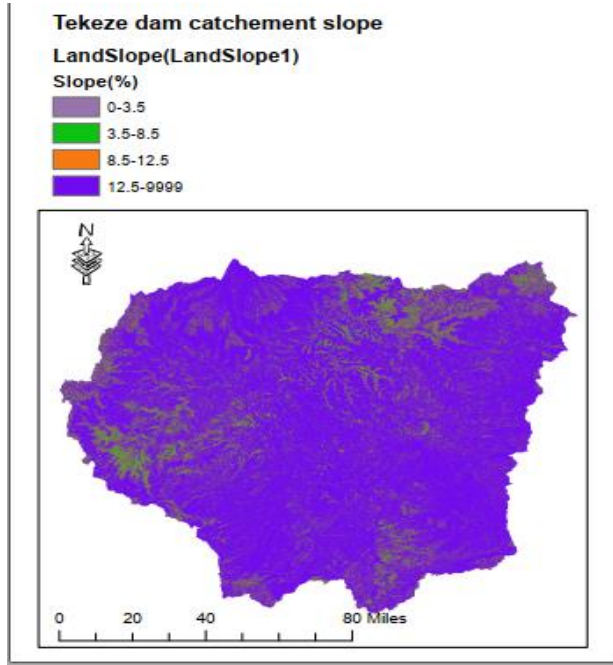


FIGURE 3.9 Slope of Tekeze Dam Watershed

No	Slope	Area contribution at outlet	
		Area (km2)	Area (%)
1	0-3.5	101207.855	3.5
2	3.5-8.5	144582.65	5
3	8.5-12.5	115666.12	4
4	12.5-9999	2530196.375	87.5

TABLE 3.5 Slope of Tekeze Dam Catchment

3.2.2. Meteorological data

SWAT need daily values of precipitation, maximum and minimum temperature, solar radiation, and relative humidity and wind speed. The weather data definition dialog is categorized in the following five list weather generator data, rainfall data, temperature data, solar radiation data, wind speed data, and relative humidity data.

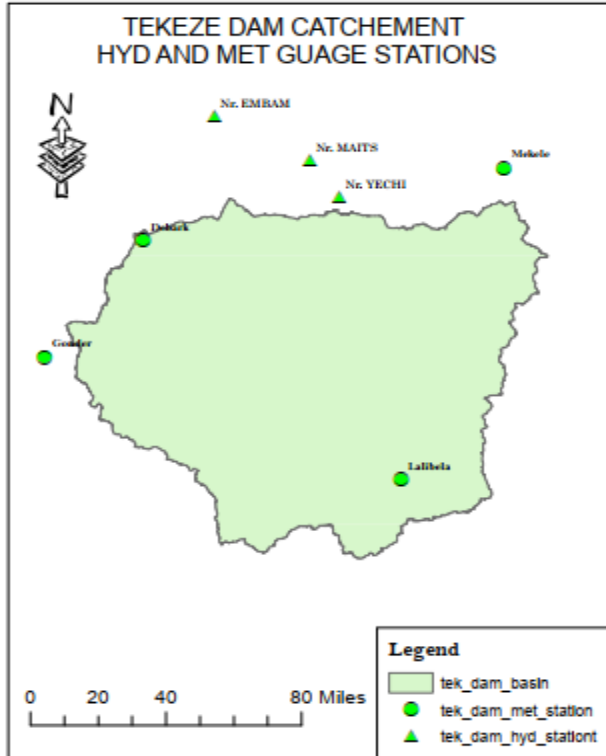


Figure 3.10 Selected Metrological and Hydrological Gauge Station of Tekeze Dam Watershed

3.2.2.1. Precipitation data

The precipitation data for the selected stations has the same duration i.e.1990-2019 with different degree of missing values. The long-term records (1986 - 2019) meteorological data was collected from six stations (Gonder, Lalibela, Mekele, Debarq, Samre, May-Tsebri, samre, Agere genet, Dabat, Ebinat, Agibe, Klumesk, Muja, Sekota) which lie inside and on the boarder of the study watershed. The observations of meteorological variables of each station were obtained from National Meteorological Stations of Ethiopia. Since relative humidity, wind speed and solar radiation data records were limited for all the stations except for the Lalibela, Gonder, Mekele and Debarq stations weather generator capabilities of SWAT model was used to generate those data by using Lalibela station records.

To check the above listed data preparation I use Excel, Rainbow, IBM SPSS(statistical model) and Hydro gnomon model and setup.to check the homogeneity, consistency, outlier and filling missed data I use the Rainbow, Hydro gnomon, IBM SPSS and Excel respectively.

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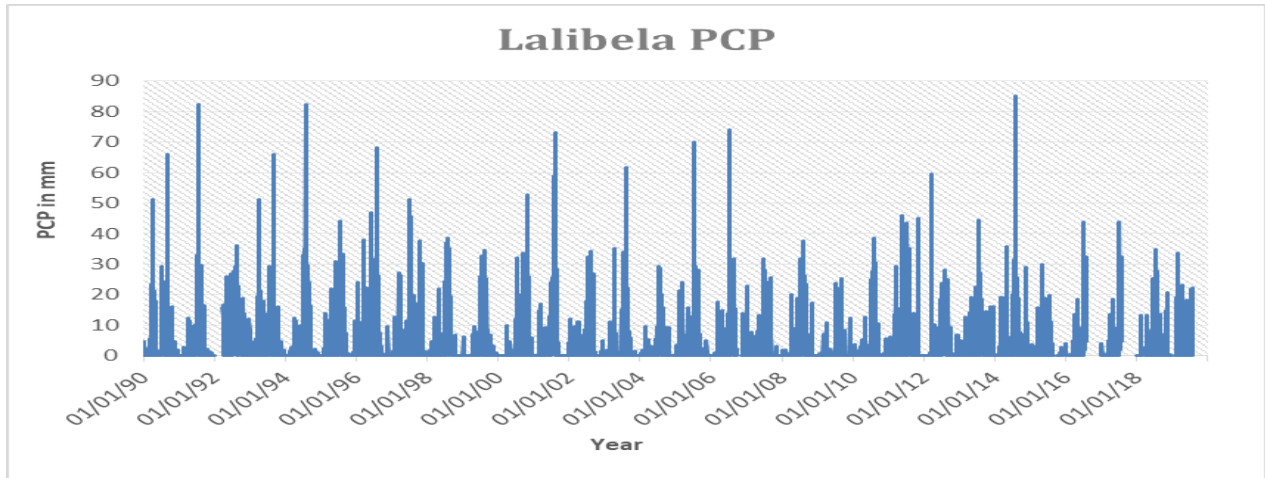


FIGURE 3.11 Lalibela Gauge Station PCP

No	Station name	Latitude	Longitude	Elevation (masl)	Observation Period (year)		
					precipitation	Max. Temp	Min. Temp
1	Lalibela	12.0386330	39.0178540	2487	1989-2019	1989-2019	1989-2019
2	Gonder	12.5968650	37.4613720	1973	1986-2019	1986-2019	1986-2019
3	Mekele	13.4933200	39.4710070	2257	1987-2018	1987-2018	1987-2019
4	Debark	13.155097	37.891539	2836	1986-2019	1986-2019	1987-2019

TABLE 3.6 Selected Metrological Stations of Tekeze Dam Catchment

3.2.2.2 Temperature data

The temperature data is needed as input to the model so the minimum and maximum average monthly temperature is collected from different station on the catchment but four of them are used on the model.

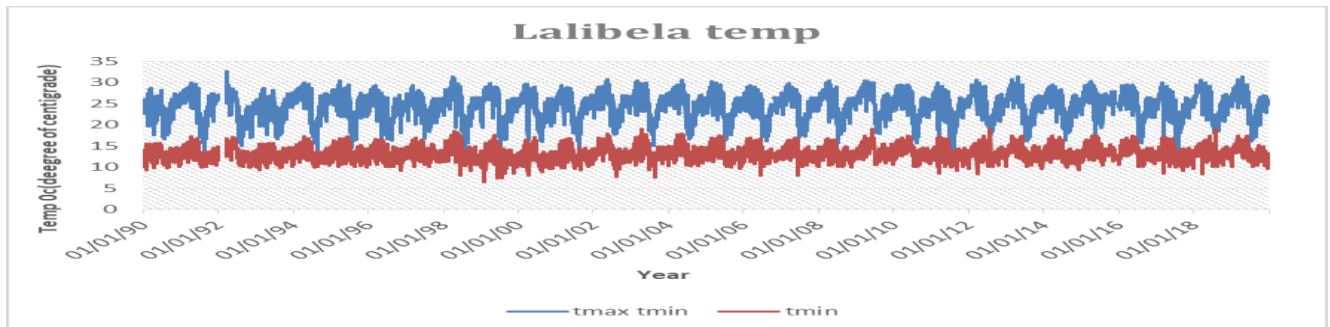


FIGURE 3.12 Lalibela Gauge Station Temp

3.2.2.3 Other climatic data

Moreover, the model needs other climate data for weather generator station such that relative humidity, solar radiation and wind speed.

3.2.2.4 Solar Radiation

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun.

3.2.2.5 Weather generator data preparation

If there are no daily values for weather, SWAT generates from average monthly values. The model generates a set of weather data for each sub basin. SWAT requires daily precipitation (mm), maximum/minimum air temperature (°C), solar radiation (MJ/m²/day), wind speed (m/s) and relative humidity (percentage).

In order to generate data, weather parameters were developed by using the weather parameter calculators pcpSTAT.exe And DEW02, which were downloaded from the SWAT website (http://www.brc.tamus.edu/swat/soft_links.html). The statistical parameters for precipitation were calculated using the programmed pcpSTAT.exe. This programmed calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (Liersch, 2003).

3.2.2.6 Visual inspection

Visual inspection is a common method of quality control, data acquisition, and data analysis. Visual Inspection, used in maintenance of facilities, mean inspection of equipment and structures using either-or all of raw human senses such as vision, hearing, touch and smell and/or any non-specialized inspection equipment. Inspections requiring Ultrasonic, X-Ray equipment, Infra-red, etc. are not typically regarded as Visual Inspection as these Inspection methodologies require specialized equipment, training and certification.

3.2.2.7 Filling of missing data

Fill-in or impute the missing values. Use the rest of the data to predict the missing values. Simply replacing the missing value of a predictor with the average value of that predictor is one easy method. Using regression on the other predictors is another possibility.

For this study, arithmetic mean and normal ratio method were used. According to Richard H. (1998), the two formulas are described below.

Arithmetic mean method

$$Px = \frac{1}{n} \sum_{i=1}^{i=n} Pi \dots\dots\dots 3.2$$

Where, n is the number of nearby stations, Pi is precipitation at *i*th station and Px is the missing precipitation.

Normal ratio method

$$Px = \frac{1}{N} \sum_{i=1}^{i=N} \frac{Nx}{Ni} Pi \dots\dots\dots 3.3$$

Where

- Px = the missing precipitation for any storm at the interpolation station x,
- Pi = the precipitation for the same period for the same storm at the *i*th station of a group of index stations,
- Nx = the normal annual precipitation for station x,
- Ni = the normal annual precipitation value for the *i*th station.

3.2.2.8 Checking consistency of gauging stations

3.2.2.8.1 Double mass curve

Sometimes a significant change may occur in and around a particular rain gauge station. Such a change occurring in particular year will start affecting the rain gauge data, being protected from that particular station. After a number of years, it may be felt that, the data of that station is not giving a consistent rainfall value. In order to detect such inconsistency, to correct and adjust the reported rainfall values a technique called Double Mass Curve method was adopted. In this method, groups of neighboring stations were chosen nearby the doubtful station. The yearly rainfall values reported from this group of stations was taken, and their mean yearly values are worked out for each consecutive year's available records. The mean yearly rainfall values of the selected stations are arranged in a revers chronological order (i.e. the latest year getting the first entry).

Double mass curve is based on the principle that when each recorded data comes from the same parent population they are consistent (Subramanya, 2008). If the cumulative plot of DMC shows different gradient it should be corrected as:

$$PCX = PX \left(\frac{Mc}{Ma} \right) \dots\dots\dots 3.4$$

- Pcx = correct precipitation at any time t_1 at station x
- Px = original record precipitation at any time t_1 at station x
- Mc = correct slope of the double mass curve
- Ma = original slope of double mass curve

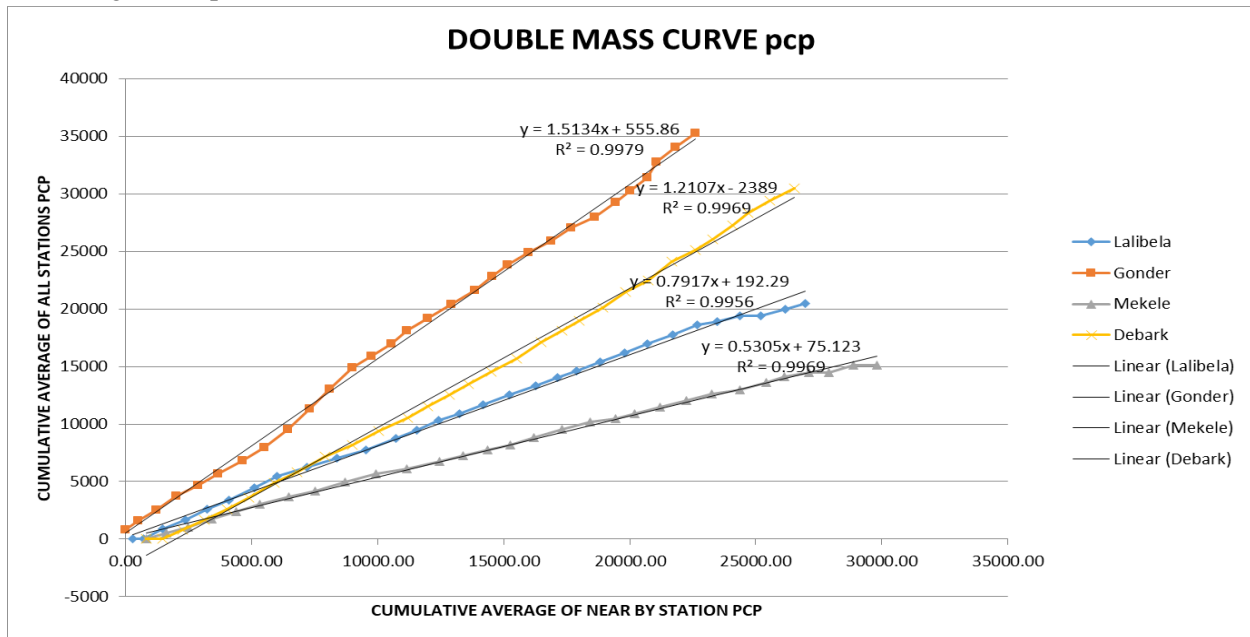


FIGURE 3.13 Double mass curve of selected meteorological Gauge Station

3.2.2.9 Checking homogeneity of selected stations by non- dimensional parameterization

Checking the homogeneity of each station data is mandatory to detected error of data due to human or natural process on the raw observed data include changing of land use and relocation of station.

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$$P_i = \frac{\bar{P}_i}{\bar{P}} * 100 \dots\dots\dots 3.5$$

Where:

P_i - is non- dimensional value of precipitation for the month in the station i

\bar{P}_i - is over year's average monthly precipitation for the station i

\bar{P} - is over year average yearly precipitation for station i

The selected stations was plotted for comparison and the stations have the same trend of the hence the group of station selected are homogeneous.

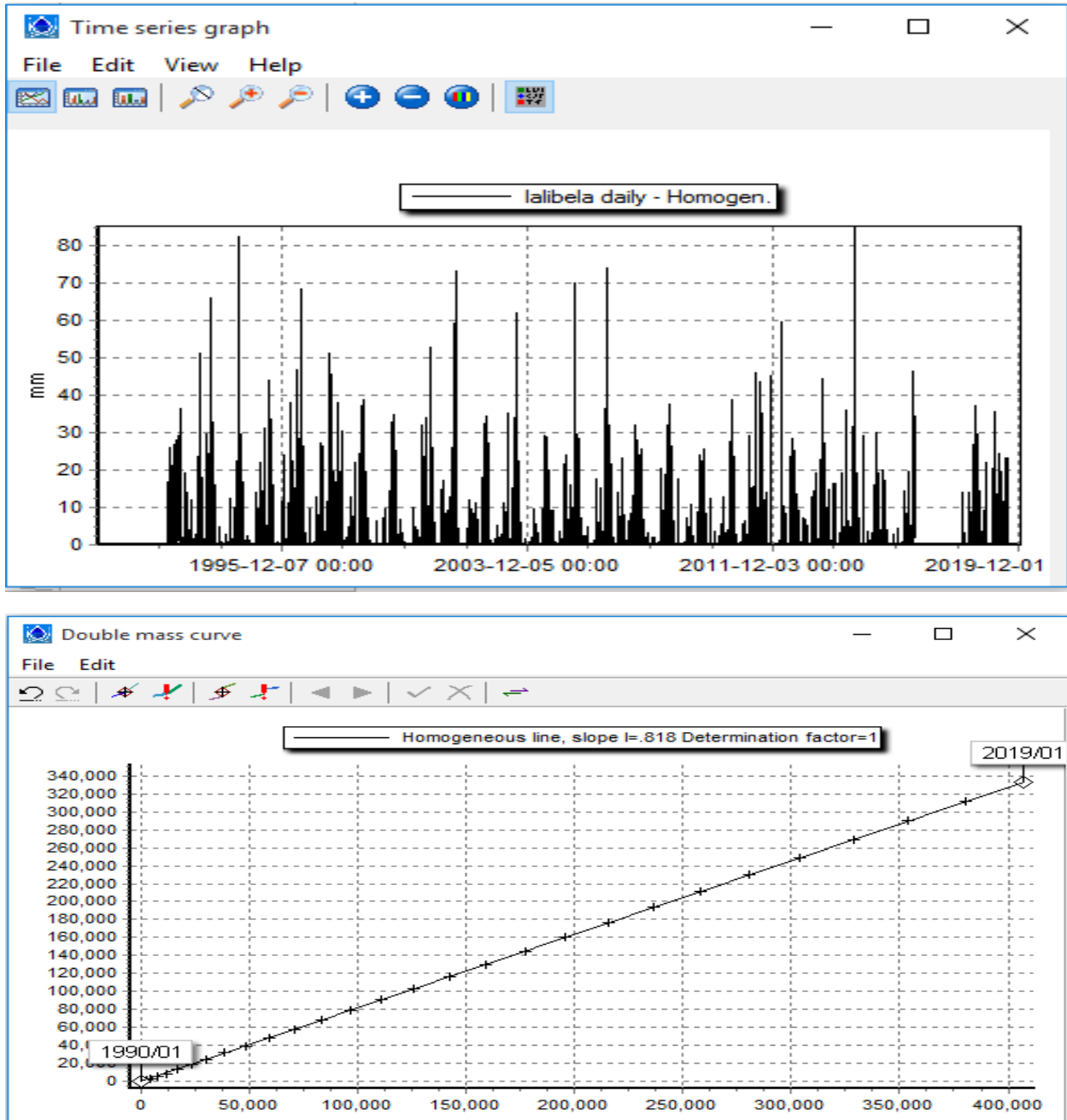


FIGURE 3.14 Homogeneity checked of Lalibela Gauge Station PCP

3.2.3. Hydrological Data

3.2.3.1. Flow Data

Flow data are collected from Ministry of Water Resource, Irrigation and Energy of Ethiopia (MoWRREE). The daily stream flow from 2014 up to 2015 record is collected for three stations for kulumesk and yechila and Embameder (Tekeze near to Embameder). After data is collected the data rearranged to make it well organized to put as input for the Soil and Water Assessment Tool (Arc SWAT) calibration and Validation. The stream data is used for calibration from 2004 to 2011 and for validation from 2012 to 2015 at the outlet of tekeze dam catchment on the gauge station of Embamedere.

The series data Stream flow of Tekeze dam catchment were checked the unrealistic data record or the outlier. An outlier is an observation that appears to deviate markedly from other observations in the sample. The monthly flow data of the Tekeze River was checked by through the steps calculating the quartiles, calculating the upper and lower boundaries and evaluating the results in excel spread sheet and there was no outlier identified.

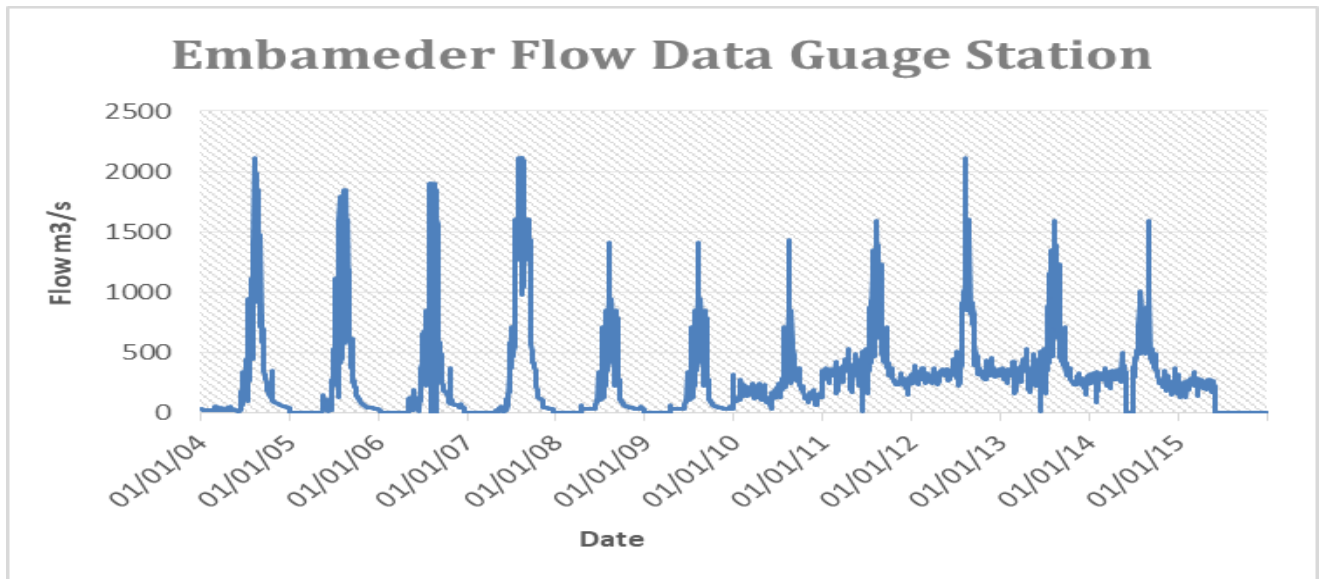


FIGURE 3.15 Embameder Gauge Station Stream Flow of Tekeze dam catchment

3.2.4 Sediment data

The sediment data is collected from Ministry of water, Irrigation and Energy (MoWIE). The data is for very short period and with monthly non-continuous and in different season sediment concentration sample record for 82 days in 2005 and 2006 at Tekeze dam site. That way the data need sediment rating curve to generate data of sediment from the short period of sediment by using developed relationship between river discharge and sediment concentration to generate daily data. Suspended sediment flux estimation was calculated using a relation of discharge to suspended sediment discharge known as a sediment-rating curve (SRC) (Khassaf and Hassan, 2014).

$$Q_s = aQ^b \dots\dots\dots 3.6$$

Where a and b are coefficient usually obtained by regression analysis. To work on the above formula, the first task was conversion of the measured suspended sediment concentration (mg/l unit) to sediment load

(ton/day unit) by using the conversion formula of the second chapter of this paper equation 2.1. (In the review part) and also the graph shows degree of quality of sediment data.

The relation of sediment load and discharge at the gauging station with R^2 value of 0.9162 was derived as: -

$$QS = 8.1956 * Q^{1.7008} \dots\dots\dots 3.7$$

Where Q_s is suspended sediment load (ton/day) and Q is stream flow (m³/s).

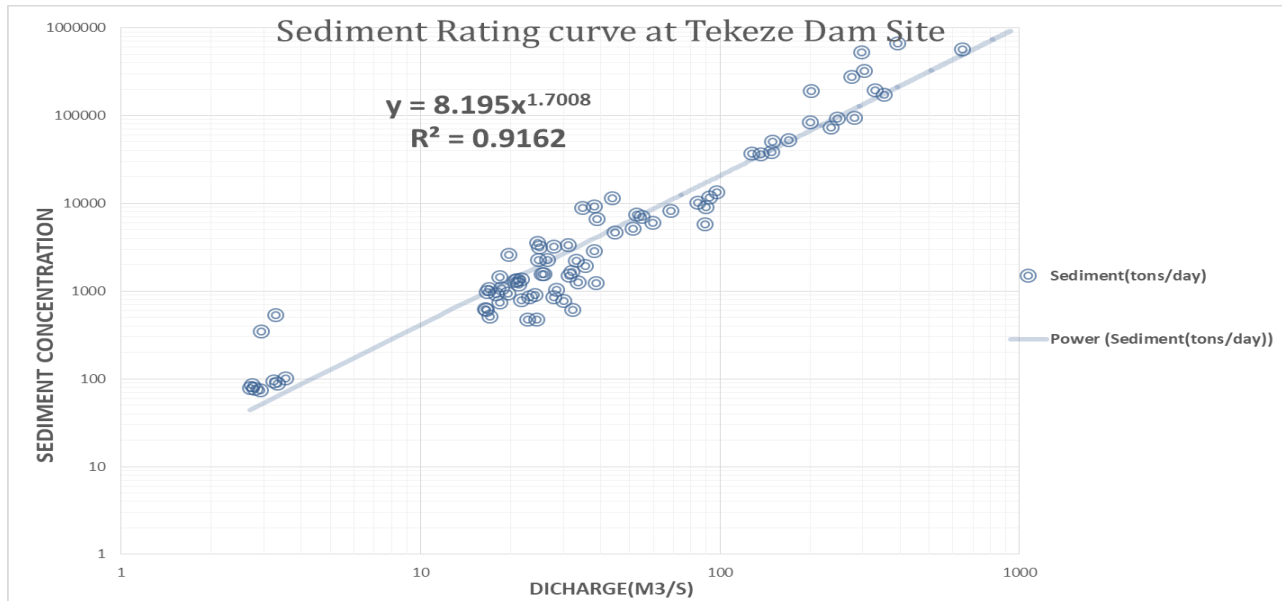


FIGURE 3.16 Sediment Rating Curve for Embameder near the Tekeze dam

3.3. Methodology

3.3.1. General

The general methodology of this study mainly depend on different secondary data from different companies or organizations to estimate the sediment yield from the catchment to the reservoir using SWAT model. The procedure of the work are listed in below including the conceptual framework to accomplish the work.

In this study, digital elevation model (DEM) 30mx30m resolution was found from ministry of water resource irrigation and electricity (MoWIE) and used to delineate the Tekeze dam watershed. The LULC map and all datasets were obtained from the ministry of water irrigation and electric (MoWIE) as shape file format. The land use classes in this study area was Spring Barely (BARL), Agricultural Land-Close-grown (AGRC), Forest-Evergreen (FRSE), Forest Mixed (FRST), Range-Brush (RNGB), Pasture (PAST) and Water (WATR). From this land use type’s major area is covered by Agricultural Range-Brush (RNGB), Agricultural Land-Close-grown (AGRC) and Pasture (PAST) with 43.73%, 26.01% and 22.75% respectively.

Soils in the study watershed are classified based on the FAO/Globe soil (FAO/UNESCO,) classification system. The soil of Tekeze dam watershed According to FAO, four major soils types were identified for the study area. Eutric Cambisols (clay), Dystric Cambisols (loam), Eutric Nitosols (clay), Cambic

Arenosols (sandy loam) are found in the study area. The major soil in the study area was Eutric Cambisols, Cambic Arenosols and Dystric Cambisols which has 73.32 %, 17.29% and 3.65% respectively area of the watershed.

The first step in model set up was creating the new SWAT project in Arc SWAT, then the DEM map is imported in to Arc SWAT next, the area of interest was delineated by selecting a point at the outlet of the watershed and found to be 28916.53km². The drainage network, flow accumulation and flow direction all were automatically processed in Arc SWAT. A total 35-sub basin were delineated by SWAT for tekeze reservoir watershed.

Land use and soil map in Arc shape format were imported in to the Arc SWAT model for HRU analysis. Both the maps were reclassified in Arc SWAT. A total of 202 HRUs and 35 sub catchments were defined for the whole catchment.

After HRUs are defined, the next step in model set up is importing the climate data. Climate data is one of the main sets of input for simulating the hydrological processes in SWAT. These available climate data were prepared in text (.txt) format and imported in to the SWAT model. Then the SWAT input tables were written into the model. Some SWAT input files were edited before the model was run for simulation. Soil parameters were also edited. The statistical parameters of daily precipitation and minimum and maximum daily temperature were also edited.

Hargreaves method was selected for calculating the potential evapotranspiration since it needs only daily minimum and maximum air temperature, SCS curve number was chosen to calculate surface runoff, initial curve number was estimated using soil moisture method, and Muskingum method was selected for channel routing.

Finally, The model is simulated for 30 years starting 1990 to 2019 with two years of warm up period this taken from the recommendation of warm up period for SWAT model is from two to five years.

- ❖ Data gathering
- ❖ Data organizing, processing and analysis
- ❖ Simulating and Running the model
- ❖ Selecting sensitive parameters
- ❖ Calibration and validation of the model
- ❖ Briefly discussing output of model result

The detail methodology explained in the following flow chart

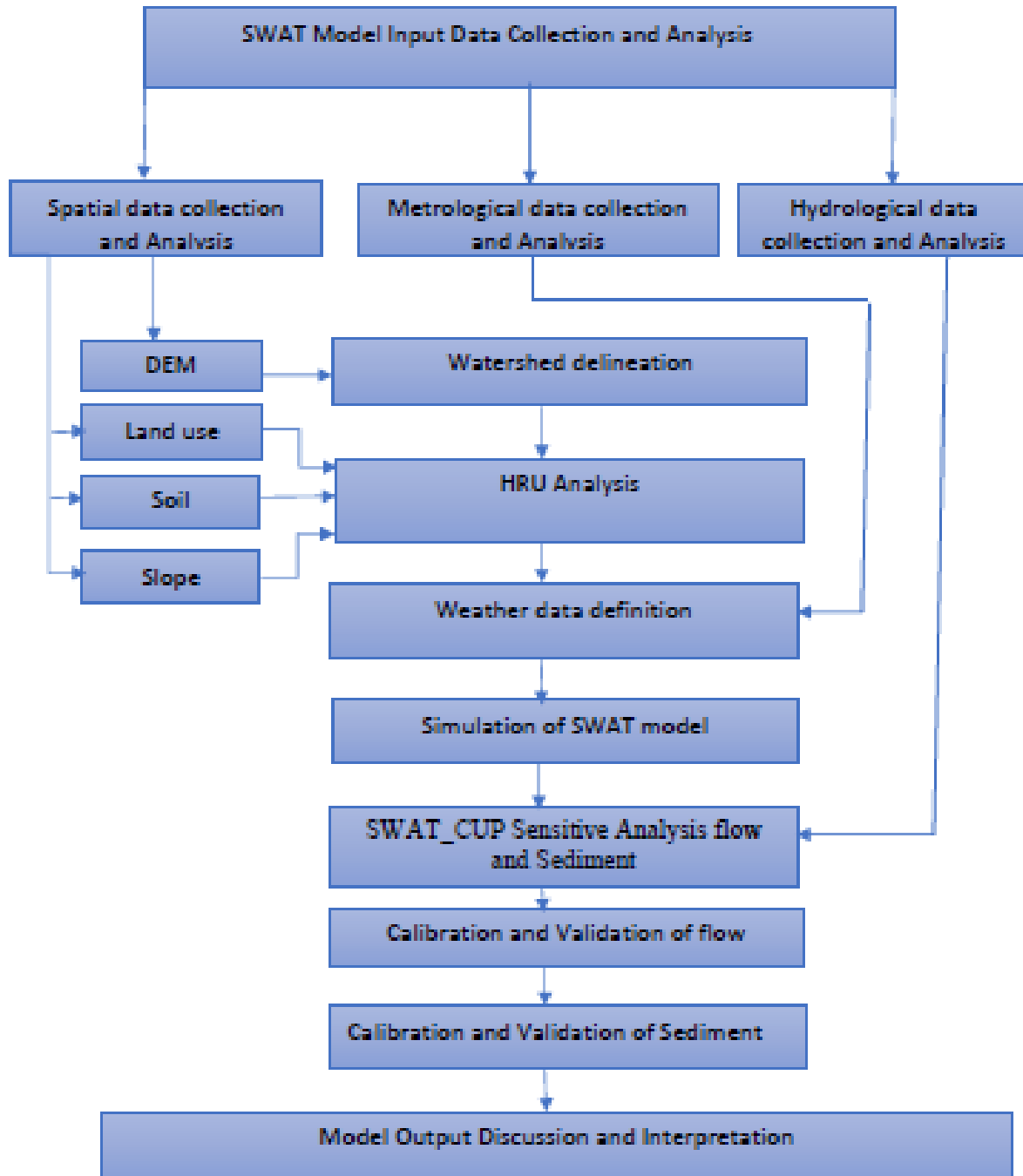


FIGURE 3.17 conceptual framework of methodology

3.4.2. Sediment modeling

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).

$$S_{ed} = 1.292E_{IUSLE}K_{USLE}C_{USLE} P_{USLE} LS_{USLE} CFRG \dots \dots \dots 3.8$$

Where, Sed is the sediment yield on a given day (metric tons/ha), E_{IUSLE} is the rainfall erosion index (0.017 m-metric ton cm/ (m²hr)), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m² hr/ (m³-metric ton cm)), is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor. The value of E_{IUSLE} for a given rainstorm is the product, total storm energy (storm E) times the maximum 30 minutes intensity (30 I). The storm energy indicates the volume of rainfall and runoff, while the 30 minutes' intensity indicates the prolonged peak rates of detachment and runoff (Neitsch et al., 2011).

$$S_{ed} = 11.8(Q_{surf} q_{peak} Area_{hru})^{0.56} K_{USLE} C_{USLE} P_{USLE} LS_{USLE} CFRG \dots \dots \dots 3.9$$

Where, Q_{surf} is the surface runoff volume (mm), q_{peak} is the peak runoff rate m³/s, $Area_{hru}$ is the area of the HRU (ha), and the other variables in the equation carries the same meaning as described in USLE equation.

3.4 Setting up Arc SWAT Model

3.4.1. Watershed delineation

The concept of a watershed is basic to all hydrologic designs. Since large watersheds are made up of many smaller watersheds, it is necessary to define the watershed in terms of a point; this point is usually the location at which the design is being made and is referred to as the watershed "outlet." With respect to the outlet, the watershed consists of all land area that sheds water to the outlet during a rainstorm. Using the concept that "water runs downhill," a watershed is defined by all points enclosed within an area from which rain falling at these points will contribute water to the outlet.

The first step in creating Arc SWAT model input is delineation of the watershed from a DEM Inputs entered into the Arc SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, Land use / land cover map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameter for Ethiopia. A watershed was divided into a number of sub-basins, for modeling purposes. The Watershed delineation process includes five major steps, DEM setup, stream definition, outlet and definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition, the threshold-based stream definition option was used to define the minimum size of the sub-basins.

3.4.2. Hydrological response units (HRUs)

Before executing SWAT, the distribution of hydrologic response units (HRUs) within the watershed must be determined based on the land use, soil and slope layers specified in the previous step. The interface allows specifying criteria to be used in determining the HRU distribution. One or more unique land use/soil/slope combination(s) (hydrologic response units (HRUs) can be created for each sub basin.

Subdividing the watershed into areas having unique land use, soil and slope combinations enables the model to reflect differences in sediment yield and other hydrologic conditions for different land covers and soils. Hydrologic response units (HRUs) are lumped land areas within the sub- basin that are comprised of unique land cover, soil and management combinations. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. The land area in a sub-basin was divided into HRUs. The HRU analysis tool in Arc SWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by Arc SWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition

to land use and soils. The multiple slope option (an option that considers different slope classes for HRU definition) was selected. The LULC, soil and slope map were reclassified in order to correspond with the parameters in the SWAT database.

After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this specific study a 5% threshold value for land use, 10% for soil and 20% for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub basin. 35-sub basin and 202 HRUs were created by integrating land use, soil and slope maps.

3.4.3. Importing climate data

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum temperature, solar radiation, wind speed and relative humidity. These climate data were loaded on the Arc SWAT model at the stage of write input table after HRU analysis is completed.

3.4.4. Sensitivity analysis

Sensitivity analysis is a technique of identifying the responsiveness of different parameter involving in the simulation of hydrological process. Sensitivity analysis was performed to choose the most sensitive flow parameters that influence the catchment represented by SWAT to be used for calibration. This was achieved using the global sensitivity approach in semi-automated Sequential Uncertainty Fitting (SUFI2) algorithm. The global sensitivity analysis method takes into consideration, the sensitivity of one parameter relative to the other in order to give their statistical significances. The t-statistics and p-values of the parameters were used to rank to the different parameters considered to influence flow and the final selection done based on the significance of the ranked values.

3.4.5. Calibration and validation of model

An important part of any modeling exercise is the model calibration and validation. Calibration is a process where in certain parameters of the model are altered in a systematic fashion and the model is repeatedly run until the simulated results match field observed values within an acceptable level of accuracy. The process of model calibration is quite complex and limited by the model itself, input, and output data. Imperfect knowledge of watershed characteristics, mathematical structures of the hydrological processes and model limitations can cause error in calibration process. Before starting model calibration, field conditions at the site should be properly characterized. Lack of proper site characterization may lead to a wrong representation of the simulated system. Model calibration can be performed either by trial and error or by automated techniques. Automated calibration can be performed by means of specifying an objective or a set of objective functions. Uncertainty in models and data leads to uncertainty in model parameters and model predictions. Automated parameter estimation techniques for model calibration are accurate and rapid. Validation of hydrologic models is a process of matching the simulated results with observed values without altering the calibrated parameters.

Calibration was accomplished by comparing the output of the SWAT model with the observed data at the same conditions. For calibration and validation, the Sequential Uncertainty Fitting (SUFI-2) calibration method within the SWAT Calibration and Uncertainty y Procedures (SWAT- CUP) was used. Figure 3.20 bellow shows the procedure of calibration using the Sequential Uncertainty Fitting (SUFI-2).

In this study, the model was calibrated with observed Monthly discharge data for the period of 2004 to 2011 and validated for the period of 2012 to 2015. The model was also calibrated for sediment for the period of 2004 to 2011 and validated for 2012 to 2015 for monthly time step. The graphical and statistical approaches were used to evaluate the Arc SWAT model performance a number of times until the acceptable values were obtained for flow and sediment independently.

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. Validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Two statistical model performance measures used in calibration and validation procedure of stream flow and sediment.

3.4.6. Evaluation of model performance

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these two numerical model performance measures are coefficient of determination (R^2 coefficient) and Nash-Sutcliffe simulation efficiency (ENS). The R^2 and ENS measures how well trends in the measured data are reproduced by the simulated results over a specified period and for a specified time step. In this study, these measures were computed of a monthly time step for both flow and sediment calibration and validation.

The R^2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results and it is calculated for n time steps using Equation 3.21 below. The model could be evaluated in order to determine the performance that how the model, simulated value fitted with the observed value. Statistical techniques like the coefficient of determination is one of the methods to assess the model performance and also estimate that at which level simulate value fitted with the observed value. It shows the best fitness and efficiency of the model. R square describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0. High values indicating better agreement. The Nash and Sutcliffe simulation efficiency indicates the degree of fitness of the observed and simulated plots with the 1:1 line (Santhi et al., 2002).

$$R^2 = \frac{[\sum_{i=1}^n (q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o)]^2}{\sum_{i=1}^n (q_{si} - \bar{q}_s)^2 \sum_{i=1}^n (q_{oi} - \bar{q}_o)^2} \dots\dots\dots 3.10$$

Where q_{si} is the simulated values of the quantity in each model time step, \bar{q}_s is the average simulated value of the quantity in each model time step, q_{oi} is the measured value s of the quantity in each model time step and \bar{q}_o is the average measured value of the quantity in each model time step.

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

ENS is computed for n time steps using Equation 3.11. It measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison.

$$ENS = 1 - \frac{\sum_{i=1}^n (q_{oi} - \bar{q}_o)^2}{\sum_{i=1}^n (q_{oi} - \bar{q}_o)^2} \dots\dots\dots 3.11$$

Where q_{oi} is the measured values of the quantity in each model time step, q_{si} is the simulated values of the quantity in each model time step and \bar{p}_o is the average measured value of the quantity in each model time step.

The Nash-Sutcliffe simulation efficiency (ENS) values range from 1.0 (best) to negative infinity. A value of 0.0 for ENS means that the model predictions are just as accurate as using the measured data average to predict the measured data. ENS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average.

3.4.7. Physical Catchment characteristics

Physical catchment characteristics has dominant influence on the dynamic property of flow and sediment. Therefore, it is important to analyze the correlation of physical characteristics and their correlation integration (Heuvelmans et al., 2006). As (Tamene et al., 2006) the physical catchment characteristics that can influence the erosion processes are listed in table 3.7 below.

Table-3.7. Physical characteristics and influence on erosion.

Watershed Attributes	Description and Relation with Erosion
Catchment Area [KM2]	Represents flow
Height difference [HD]	Runoff potential erosive power $HD = \max Ele - \min Ele$
Slope	Flow velocity and momentum of runoff
Hypsometric integral [HI]	Distribution of elevation within catchment $HI = \frac{\text{meanEle} - \text{minEle}}{\text{maxEle} - \text{minEle}}$
Relief ration [RR]	intensity of erosion process $RR = \frac{\text{maxEle} - \text{minEle}}{L}$
Drainage length (DL)	sediment transport potential DL=sum of length of all stream
Drainage density (DD)	balance between erosive forces and surface resistance $DD = \frac{DL}{A}$
Catchment shape indices Circularity index (CI) Elongation ratio (ER)	speed of sediment delivery $CI = \frac{A}{AC_p}$ $ER = \frac{D_c}{A}$

A= basin planimetric area (m²); mean Ele, maxEle, min Ele= mean, maximum, and minimum elevation of catchment (m); L= horizontal distance between the outlet of a catchment and the most remote point on the water divide (m); HD=height difference or basin relief (m), DL= drainage length (m); AC_p=area of a circle having a perimeter equal to the perimeter of a catchment (m²); DC=diameter of a circle with the same area as the catchment area(m), L=maximum length of a watershed(m).

The brief description of each group of physical characteristics are listed below-

1- Geography and Physiography

Catchment Area:

Area of the catchment is easily derived from each of the catchments. The amount of water and sediment reaching the outlet mainly depends on its area.

Length flow path:

Length of flow path is one of the out puts in the map of catchment delineation. This indirectly is indication of water to reach the gauging station.

Hypsometric integral:

This indicates the distribution of elevation across the catchment and simply calculated as:

$$HI = \frac{meanEle - minEle}{maxEle - minEle} \dots\dots\dots 3.12$$

Where *Hmean* – average altitude of the basin above sea level [m].
Hmax – Maximum attitude of the basin above sea level [m].
Hmin – Minimum attitude of the basin above sea level [m].

Average slope:

Slope is one dominant factor that controls the water flow velocity where a high slope results in high velocities that reduce the travel time of water to reach the catchment outlet. A percentage slope calculation was calculated during the HRU analysis of Arc SWAT and the catchment was classified in to five slope classes.

Catchment shape:

The physical catchment shape affects the hydrological process at catchment scale (Deckers, 2006). It is determined by the formula 3.24 below.

$$SHAPE = \frac{Hmax - Hmin}{\sqrt{AREA}} \dots\dots\dots 3.13$$

Circularity Index:

The circularity is calculated as the ratio of perimeter square to the catchment area.

$$CI = \frac{P^2}{A} \dots\dots\dots 3.14$$

Where P and A are perimeter and area in [KM] and [KM2] respectively.

2- LAND USE:

The characteristic land cover is one of the most used physical catchment characteristics when establishing the model. This includes the land cover type such as forest, grass crop etc. it is a general concept deforestation increases the soil erosion, since it changes the soil properties and infiltration rates.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Sensitive parameters

4.1.1. Parameters sensitive to flow

Implementation of sensitivity analysis (SA) procedures is helpful in calibration of models and also for their transposition to different watersheds. The reported studies on SA of Soil and Water Assessment Tool (SWAT) model were mostly focused on identifying parameters for pruning or modifying during the calibration process.

Twenty hydrological parameters related to stream flow were tested. From all the sensitivity analysis result show the most sensitive parameters are seven of them so this are selected for calibration. And the list are ranked from the most sensitive to least sensitive in below table.

Table 4. 1. List of parameters and their initial ranges used for Sensitive analysis.

The SWAT model is simulated for twelve years of recording period starting from 2004 up to 2015G.C for calibration used for the more seven hydrologic sensitive parameters from the twenty one parameters according there p-value and t-value. The performance of the model is calibrated for the parameter which have p-value less than 5% and maximum t-value at Embameder gauge station for the all catchment at the outlet.

The following sensitivity analysis in the Table 4.2 was taken at Embameder at the near catchment outlet.

No	Parameters	Description of Parameters	p-value	t-stat	Range		Rank
					Min.	Max.	
1	CN2.mgt	SCS runoff curve number	0.000	-4.858	35	98	1
2	HRU_SLP.hru	Average slop length	0.000	4.019	0	0.6	2
3	ALPHA_BF.gw	Base flow alpha factor(mm)	0.000	4.010	0	1	3
4	CANMX.hru	Maximum canopy storage	0.000	-3.959	0	100	4
5	GWQMN.gw	Threshold depth of water in the shallow aquifer fore return flow to occur	0.002	-3.102	0	5000	5
6	GW_REVAP.gw	Ground water revap coefficient	0.038	-2.092	0.02	0.2	6
7	SOL_Z.sol	Depth from soil surface to bottom of layer	0.040	2.066	0	3500	7
8	SLSUBBSN.hru	Average slop length	0.137	-1.495	10	150	8
9	SOL_ALB (..).sol	Moist soil albedo	0.179	-1.349	0	0.25	9
10	CH_N2.rte	Effective hydraulic conductivity	0.214	1.246	-0.01	0.3	10
11	ESCO.hru	Soil evaporation compensation factor	0.235	1.192	0	1	11
12	SURLAG.bsn	Surface runoff lag time	0.254	-1.143	0.05	24	12

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

13	EPCO.hru	Plant uptake compensation factor	0.342	-0.953	0	1	13
14	CH_K2.rte	Effective hydraulic conductivity	0.369	0.900	-0.01	500	14
15	ALPHA_BNK.rte	Base flow alpha factor for bank of storage	0.401	-0.841	0	1	15
16	GW_DELAY.gw	Ground water delay(days)	0.457	0.745	0	500	16
17	OV_N.hru	Meaning n value for over land flow	0.479	0.710	0.01	30	17
18	TLAPS.sub	Temperature lapse rate	0.503	0.670	-10	10	18
19	REVAPMN.gw	Threshold depth of water in the	0.540	-0.614	0	500	19
20	RCHRG_DP.gw	Deep aquifer percolation fraction	0.594	0.535	0	1	20

Table 4. 1. Sensitivity rankings of stream flow parameters in the Tekeze dam catchment.

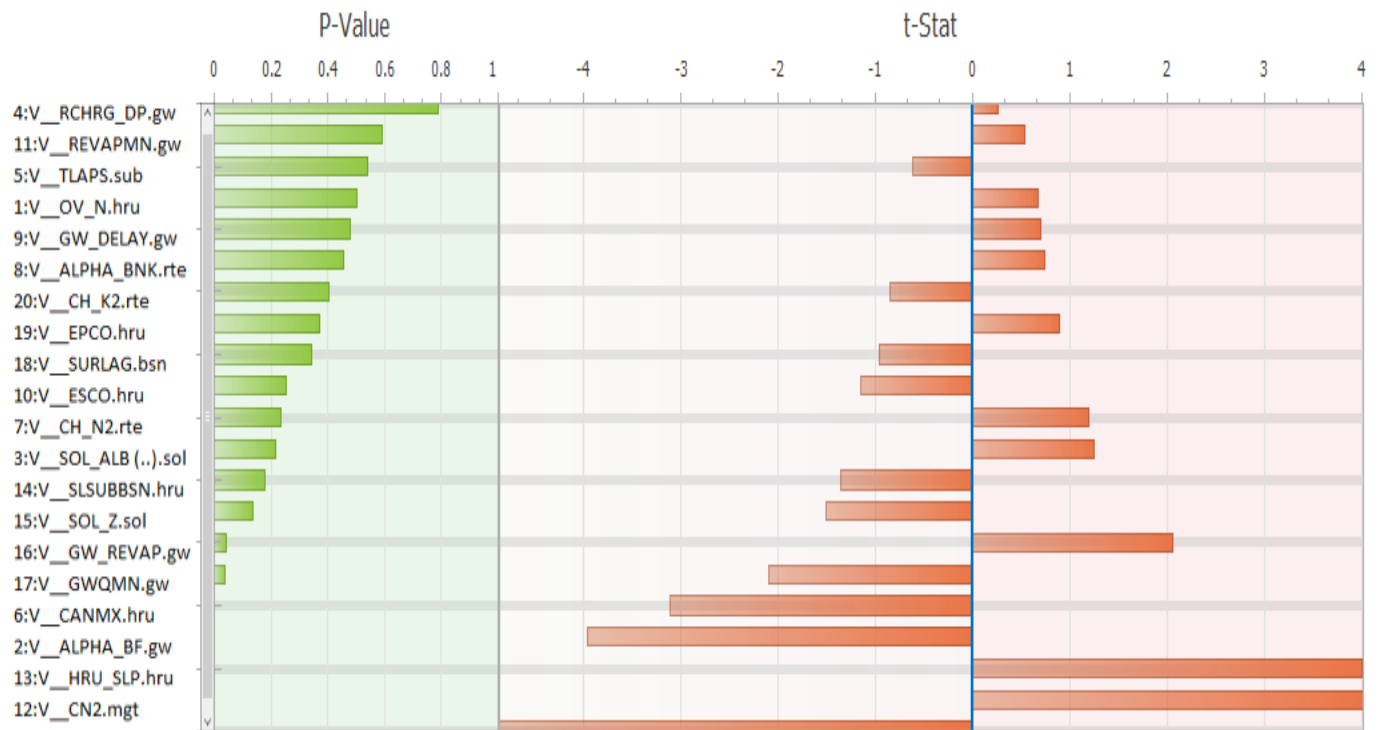


Figure 4. 1. Global sensitive parameter (p-value) and (t-stat) flow of the study area

The global sensitivity parameters are also shown on the out let gauge station of Embameder from parameters all only the seven parameters are very sensitive to flow. Accordingly the rank of the parameter are shown in the table. The seven most sensitive are the following the SCS runoff curve number (CN2), Average slop length (HRU_SLP), Base flow alpha factor (ALPHA_BF), Maximum canopy storage (CANMX), Threshold depth of water in the shallow aquifer fore return flow to occur (GWQMN), Ground water revap coefficient (GW_REVAP) and Depth from soil surface to bottom of layer (SOL_Z).The other parameters are less sensitive having p-value greater than 5%.

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

No	Parameters	Description of Parameters	Rang		Fitted value	Rank
			Min.	Max.		
1	CN2.mgt	SCS runoff curve number	35	98	74.5	1
2	HRU_SLP.hru	Average slop length	0	0.6	0.6	2
3	ALPHA_BF.gw	Base flow alpha factor(mm)	0	1	0.0001	3
4	CANMX.hru	Maximum canopy storage	0	100	100	4
5	GWQMN.gw	Threshold depth of water in the shallow aquifer fore return flow to occur	0	5000	5000	5
6	GW_REVAP.gw	Ground water revap coefficient	0.02	0.2	0.2	6
7	SOL_Z.sol	Depth from soil surface to bottom of layer	0	3500	100	7

Table 4.2. List of flow sensitive parameters, their calibrated and fitted values of the whole catchment

4.1.2. Parameters sensitive to sediment

From the twelve sediment parameters the following six sediment parameters are higher sensitive USLE equation support practice number (USLE_P), Liner parameter for calculating the maximum amount of sediment that can be reentrained during channel routing (SPCON), Channel cover factor (CH_COV2), Exponent parameter for calculating sediment reentrained in channel sediment reentrained in channel (SPEXP), USLE equation soil erodibility (USLE_K), Available water capacity on the soil layer(mm H2O/mm soil) (SOL_AWC) and Saturated hydraulic conductivity (SOL_K) .However, the other parametes also have less contribution for the sediment erosion having p-value greater than 5%.

The parameters that were used to evaluate the sensitivity to sediment are shown in Table 4.3 below.

No	Parameters	Description of parameters	P-	t-stat	Rang		Rank
					Min.	Max.	
1	USLE_P.mgt	USLE equation support practice number	0.000	10.180	0	1	1
2	SPCON.bsn	Liner parameter for calculating the maximum amount of sediment that can be reentrained during channel routing	0.000	7.675	0.0001	0.01	2
3	CH_COV2.rte	Channel cover factor	0.000	5.558	-0.001	1	3
4	SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment reentrained in channel	0.009	2.641	1	1.5	4
5	USLE_K.sol	USLE equation soil erodibility	0.028	2.213	0	1	5

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

6	SOL_AWC.sol	Available water capacity on the soil layer(mm H2O/mm soil)	0.040	-2.067	0	1	6
7	SOL_K.sol	Saturated hydraulic conductivity	0.125	-1.540	0	2000	7
8	BIOMIX.mgt	Biological mixing efficient	0.147	1.458	0	1	8
9	LAT_SED.hru	Sediment concentration in the lateral flow and ground water flow	0.216	-1.243	0	5000	9
10	RSDIN.hru	Initial residue cover	0.223	1.221	0	10000	10
11	CH_ERODMO(..).rte	Jan. erodibility factor	0.339	0.959	0	1	11
12	CH_COV1.rte	Channel erodibility factor	0.352	0.933	-0.05	0.6	12

Table 4. 3. List of parameters used in sensitivity analysis to sediment

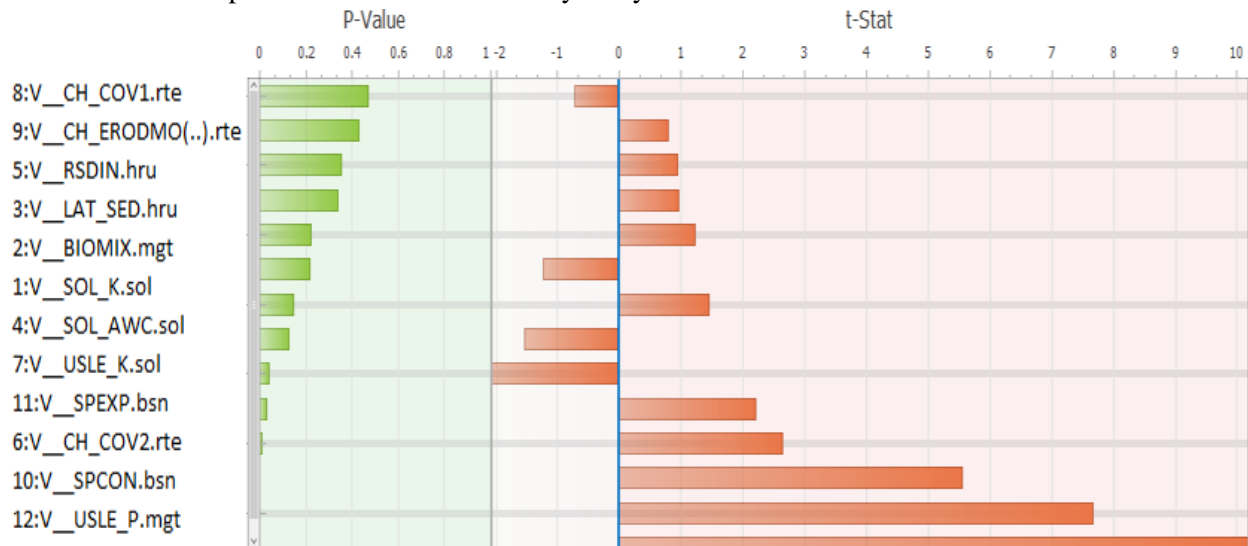


Figure 4. 2. Global sensitive parameter (p-value) and (t-stat) of the study area for sediment

To see which parameter is highly sensitive to sediment from the list of parameters in Table 4.3. Global sensitivity y analysis was applied. Six parameters that directly affect the sediment yield and sediment transport in the watershed were analysed and the result is tabulated in Table 4.4 below.

No	Parameters	Description of Parameters	Rang		Fitted value	Rank
			Min.	Max.		
1	USLE_P.mgt	USLE equation support practice number	0	1	0.0948	1
2	SPCON.bsn	Liner parameter for calculating the maximum amount of sediment that can be reentained during channel routing	0.0001	0.01	0.01	2

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

3	CH_COV2.rte	Channel cover factor	-0.001	1	0	3
4	SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment reentrained in channel	1	1.5	1.5	4
5	USLE_K.sol	USLE equation soil erodibility (k) factor	0	1	0.2	5
6	SOL_AWC.sol	Available water capacity on the soil layer(mm H2O/mm soil)	0	1	1	6
7	SOL_K.sol	Saturated hydraulic conductivity	0	2000	10	7

Table 4. 4. List of parameters sensitive to sediment.

4.2. Model calibration and validation

4.2.1. Model calibration and validation for runoff

4.2.1.1. Model calibration for flow

The model is calibrated at the out let of Embalmer Gauge station near Tekeze dam outlet of the years 2004 to 2011 for about twelve years from this the two-third data (2004-2011) used for calibration and one-third (2012-2015) for validation.

The model is calibrated and validated using auto calibration tool (SUF2 in SWAT_CUP) for the identified parameters which have highly sensitive to run off. The model performance is evaluated if it full fill the criteria and objective function (Nash-Sutcliffe coefficient of efficiency) $NSE > 0.5$ and the (coefficient of determination)² > 0.65 in SUFI-2 in observed.txt file before starting calibration. After this process the calibrated parameters were updated in the model and the final simulation was run. In general, from the result $NSE=0.73$ and $R^2=0.84$ this shows the model performs well in estimating the stream flow from Tekeze Dam catchment by. The following table and graph show the relation of simulated and observed data to compare model performance.

Time (year)	Calibration Average Flow (m ³ /s)		Model Efficiency(Monthly)	
	Observed	Simulated	R ²	NS
2004-2011	351.39	464.66	0.84	0.73

Table 4. 5. Observed and simulated flow for calibration

```

Goal_type= Nash_Sutcliff  No_sims= 200  Best_sim_no= 193  Best_goal = 7.258088e-001

Variable  p-factor  r-factor  R2  NS  bR2  MSE  SSQR  PBIAS  KGE  RSR  MNS  VOL_FR  Mean_sim(Mean_obs)  StdDev_sim(StdDev_obs)
FLOW_OUT_1  0.74  0.96  0.84  0.73  0.7798  6.9e+004  3.5e+004  -32.2  0.62  0.52  0.54  0.76  464.66(351.39)  590.88(501.46)

---- Results for behavioral parameters ----
Behavioral threshold= 0.500000
Number of behavioral simulations = 52

Variable  p-factor  r-factor  R2  NS  bR2  MSE  SSQR  PBIAS  KGE  RSR  MNS  VOL_FR  Mean_sim(Mean_obs)  StdDev_sim(StdDev_obs)
FLOW_OUT_1  0.63  0.71  0.84  0.73  0.7798  6.9e+004  3.5e+004  -32.2  0.62  0.52  0.00  0.76  464.66(351.39)  590.88(501.46)
    
```

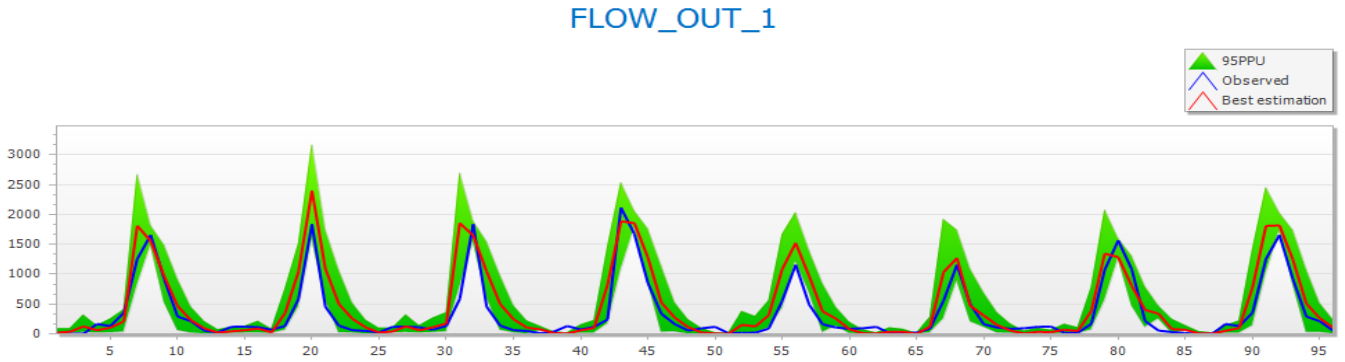


Figure 4. 3. Observed and simulated flow for calibration

4.2.1.2. Model validation for flow

The model is validated for four years(2012-2015) by re-running the model having the calibration parameters no changed to determine the model coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) for monthly stream flow at Embameder gauge station the result is good with $R^2=0.74$ and $NSE=0.71$.The observed and simulated daily stream flow for validation of the Embameder stations is shown in the table 4.7. Below

Time (year)	Validation Average Flow (m ³ /s)		Model Efficiency(Monthly)	
	Observed	Simulated	R^2	NS
2012-2015	340.64	293.13	0.74	0.71

Table 4. 6. Observed and simulated flow for Validation

```

Goal_type= Nash_Sutcliff No_sims= 200 Best_sim_no= 186 Best_goal= 7.138159e-001

Variable p-factor r-factor R2 NS bR2 MSE SSQR PBIAS KGE RSR MNS VOL_FR Mean_sim(Mean_obs) StdDev_sim(StdDev_obs)
FLOW_OUT_1 0.60 0.78 0.74 0.71 0.6427 5.8e+004 6.6e+003 13.9 0.80 0.53 0.52 1.16 293.13(340.64) 449.89(449.37)

--- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations= 183

Variable p-factor r-factor R2 NS bR2 MSE SSQR PBIAS KGE RSR MNS VOL_FR Mean_sim(Mean_obs) StdDev_sim(StdDev_obs)
FLOW_OUT_1 0.52 0.56 0.74 0.71 0.6427 5.8e+004 6.6e+003 13.9 0.80 0.53 0.00 1.16 293.13(340.64) 449.89(449.37)
    
```

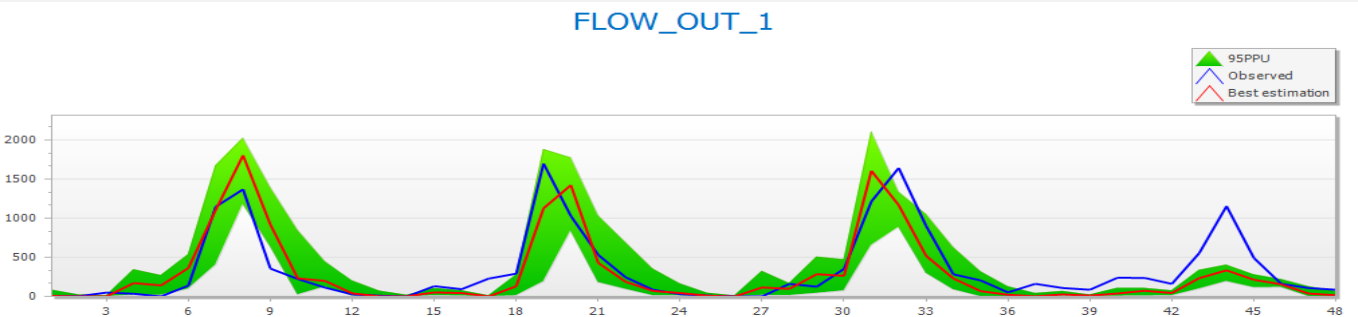


Figure 4.4. Observed and simulated flow for Validation

4.3.2. Model calibration and validation for sediment

4.3.2.1. Model calibration for sediment

The model was calibrated for sediment for the year 2004-2011.

Time (year)	Calibration Average monthly sediment (ton/month)		Model efficiency(Monthly)	
	Observed	simulated	R ²	NS
2004-2011	28.71	28.86	0.78	0.77

Table 4. 7. Observed and simulated sediment calibration.

```

Goal_type= Nash_Sutcliffe ··· No_sims= 200 ··· Best_sim_no= 188 ··· Best_goal = 7.684813e-001

Variable ········· p-factor ··· r-factor ··· R2 ··· NS ··· bR2 ··· MSE ····· SSQR ····· PBIAS ··· KGE ··· RSR ··· MNS ··· VOL_FR ········· Mean_sim(Mean_obs) ··· StdDev_sim(StdDev_obs)
Sediment_OUT_1 ····· 0.24 ····· 0.67 ····· 0.78 ··· 0.77 ··· 0.6564 ··· 1.0e+015 ··· 4.0e+014 ··· 0.5 ··· 0.87 ··· 0.48 ··· 0.69 ··· 1.00 ····· 83043032.00(83457512.00) ····· 85182784.00(88558168.00)

---- Results for behavioral parameters: ----
Behavioral threshold= 0.500000
Number of behavioral simulations = 10

Variable ········· p-factor ··· r-factor ··· R2 ··· NS ··· bR2 ··· MSE ····· SSQR ····· PBIAS ··· KGE ··· RSR ··· MNS ··· VOL_FR ········· Mean_sim(Mean_obs) ··· StdDev_sim(StdDev_obs)
Sediment_OUT_1 ····· 0.53 ····· 0.51 ····· 0.78 ··· 0.77 ··· 0.6564 ··· 1.0e+015 ··· 4.0e+014 ··· 0.5 ··· 0.87 ··· 0.48 ··· 0.00 ··· 1.00 ····· 83043032.00(83457512.00) ····· 85182792.00(88558168.00)
    
```

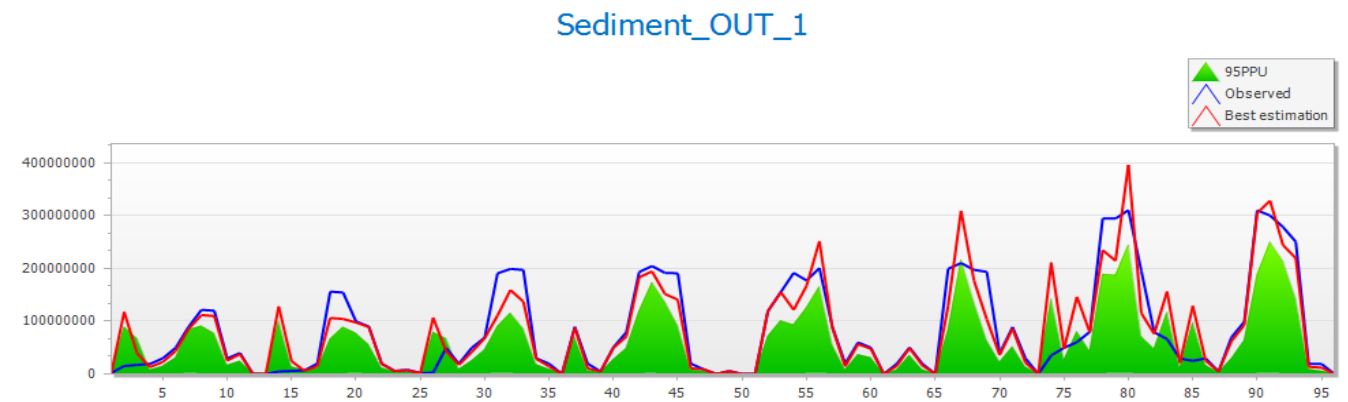


Figure 4. 5. Observed and simulated Sediment for Calibration

4.3.2.2. Model validation for sediment

The model was validated with independent validation period of 2012-2015.

Time (year)	Validation Average monthly sediment (ton/month)		Model efficiency(Monthly)	
	Observed	simulated	R ²	NS
2012-2015	12.31	12.78	0.69	0.69

Table 4. 8. Observed and simulated for sediment validation

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

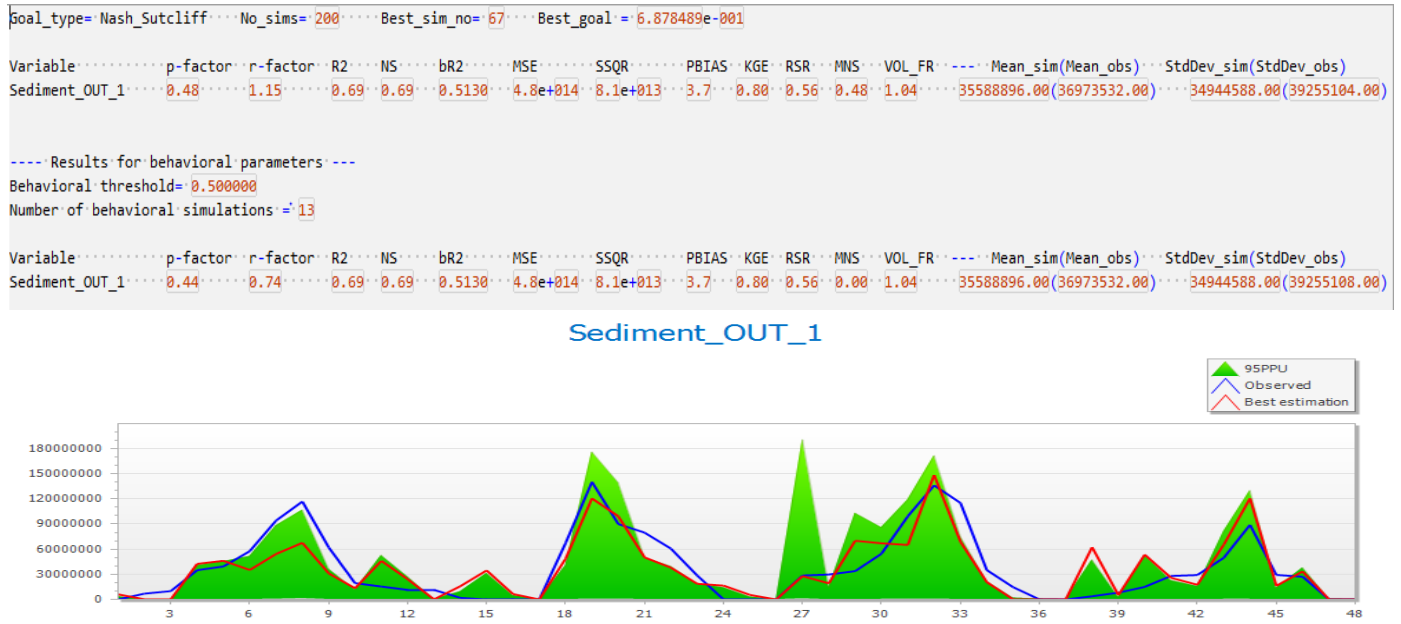


Figure 4.6. Observed and simulated Sediment for Validation

In general the model simulation result of calibration and validation at the selected gauge station Embameder for sediment yield show good relation and the result estimation is more near to the observed data. Therefore, the swat model is good for the estimation of sediment yield on Tekeze dam catchment. Accordingly The total estimated sediment entered to the reservoir after calibration and validation is 82,296,444.38 ton/year from the total catchment area of 28916.53 km² with annual specific sediment yield is 2846ton/km²/year.

4.4. Temporal variation of sediment yield

Temporal variation of sediment yield is the sediment generated on the time base especially annually. The sediment yield of the catchment depend on climate ,soil ,land use land cover, slope and catchment size.in this model the rainfall discharge from the climate type is highly proportion to the catchment sediment yield generation.

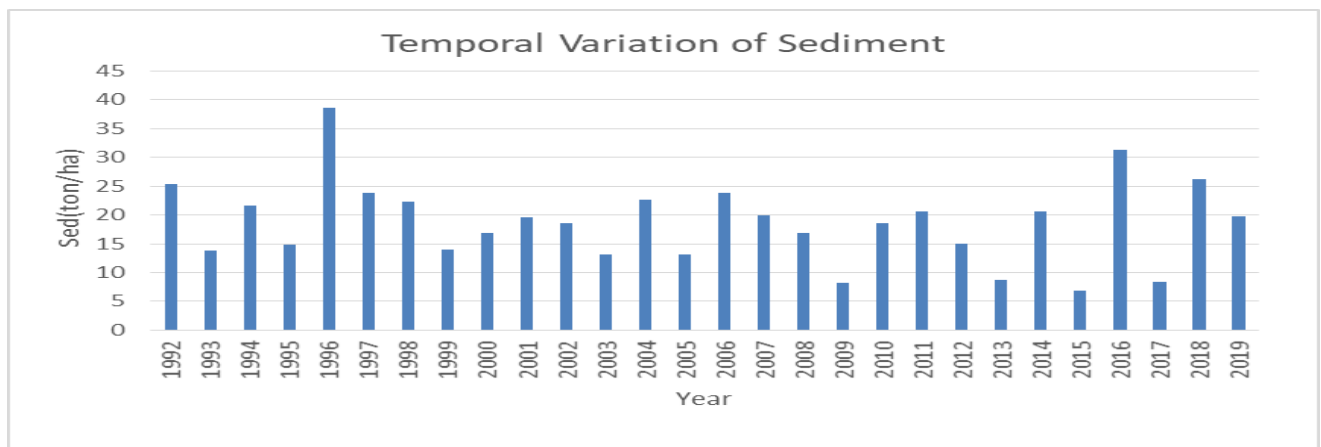


Figure 4. 7. Temporal Variation of Sediment Hectograph

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

The spatial Variation of sediment in this catchment shows variable pattern in different season and years but in general it show increasing from year to year. Table 4.09 below shows the temporal variation of sediment ranges from 8.2 ton/ha/yr. to 38.53 ton/ha/yr. in the Tekeze catchment.

No	Year	Sediment (ton/ha)	No	Year	Sediment (ton/ha)
1	1990	Warm up	16	2005	13.06
2	1991	Warm up	17	2006	23.75
3	1992	25.28	28	2007	19.94
4	1993	13.83	19	2008	16.94
5	1994	21.68	20	2009	8.2
6	1995	14.86	21	2010	18.59
7	1996	38.53	22	2011	20.57
8	1997	23.85	23	2012	15.01
9	1998	22.31	24	2013	8.72
10	1999	13.91	25	2014	20.63
11	2000	16.85	26	2015	6.86
12	2001	19.59	27	2016	31.22
13	2002	18.61	28	2017	8.3
14	2003	13.09	29	2018	26.27
15	2004	22.68	30	2019	19.77

Table 4. 9. Temporal variation of sediment.

4.5. Spatial distribution of sediment in Tekeze watershed

Spatial distribution of sediment is the digital map that shows the sediment potential of each sub basin sediment distribution on the Tekeze watershed. The SWAT model is power full on identifying the erosion prone areas on each HRU level by producing spatial visualization. The spatial visualization of sub basin wide sediment yield in tons/ha is, given in the figure the 4.8 below. Assessment of the spatial variability of soil erosion is useful for catchment management planning.

The model spatial distribution of sediment output is taken after calibration and validation. Accordingly the map shows the high erosion prone area of sub catchment 19,10,24,25 and 27 in descending order having above 65 ton/ha and the low erosion prone area of sub catchment 4,2,3,5 and 13 which are below 15 ton/ha. As general the spatial distribution of sediment in the Tekeze dam catchment varies from 4.3 ton/ha up to 79.51 ton/ha. The distribution is dependent on the combination of HRU properties. Table 4.10 below shows the spatial distribution of sediment in the Tekeze catchment.

No	Sub catchment	HRU	Sediment distribution (ton/ha)	No	Sub-catchment	HRU	Sediment distribution(ton/ha)
1	1	8	13.92	19	19	3	79.51
2	2	10	5.52	20	20	7	49.99
3	3	10	5.90	21	21	6	58.63
4	4	14	4.30	22	22	4	13.70
5	5	7	8.18	23	23	5	28.12

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

6	6	8	11.24	24	24	4	70.78
7	7	11	61.43	25	25	10	67.29
8	8	5	45.56	26	26	3	43.33
9	9	8	9.07	27	27	5	66.13
10	10	6	73.92	28	28	7	15.66
11	11	3	41.83	29	29	5	12.88
12	12	6	19.28	30	30	4	27.05
13	13	4	13.00	31	31	4	21.11
14	14	6	64.79	32	32	4	27.72
15	15	5	15.00	33	33	3	10.77
16	16	3	43.89	34	34	4	21.65
17	17	3	51.67	35	35	3	9.66
18	18	4	38.92				

Table 4. 10. Spatial variation of sediment at Tekeze catchment

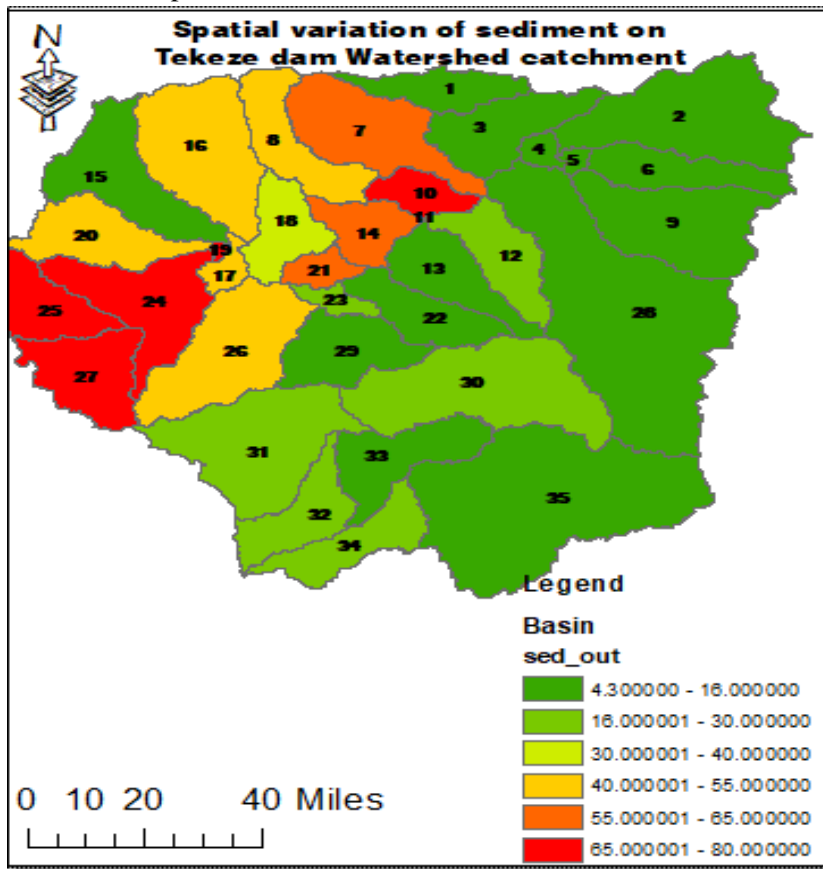


Figure 4. 8. Spatial Variation of Sediment

4.6. Mitigation measure and Scenarios development

The specific objective of this study is to mitigate sediment measure and to give different scenario development to reduce the sediment generation from the catchment by apply improved management practice and change made to the catchment land use land cover with decision making. The result of SWAT delineation process shows Tekeze watershed consists of about 43.69% of Range Brush (RNGB), 25.97% of Agricultural Land Close Grown (AGRC), 22.76% Pasture (PAST), 4.19% Spring Barely

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

(BARL), 2.07% Forest Mixed (FRST), 1.12% Agricultural Land Close Grown (FRSD), 0.17% Forest Evergreen (FRSE) and 0.012% Water (WATR).

Summary By Reported Landuse										
LULC	AREA km2	CN	AWC mm	USLE_LS	IRR mm	PREC mm	SURQ mm	GWQ mm	ET mm	SED th
PAST	6,792.32	74.50	149.76	62.19	0.00	731.47	84.60	66.51	269.16	61.07
AGRC	7,750.56	74.50	164.65	62.19	0.00	827.60	115.11	114.01	244.34	36.10
BARL	671.15	74.50	174.88	62.19	0.00	827.19	112.65	110.98	239.35	29.35
RNGB	13,119.94	74.50	162.21	62.19	0.00	779.55	91.87	81.00	273.82	8.23
FRSD	156.70	74.50	182.25	62.19	0.00	872.00	88.30	78.84	339.69	2.41
FRST	427.70	74.50	155.07	62.19	0.00	665.80	79.30	41.94	267.22	0.96

Table 4. 11. Land use summary at Tekeze catchment

The following scenario have developed by changing the pasture land and Agricultural land to Forest Mixed cover by different percent ratio. And using operational best Management Practices (OBMP): applying filter strip and terracing were also applied.

The output of the SWAT model shows land use land cover with area agricultural Land covers, Pasture land and Agricultural land are more sediment generating land use covers were us area with forest mixed, Forest Evergreen and Range-Grasses covers generate less sediment. Therefore, the solution of decreasing of sediment yield from the catchment is by interchanging the high generating sediment to less sediment yield cover, by different HRU combination and using operational best Management Practices. Accordingly, the different scenario development listed below with their results using spring barely land changed to forest mixed cover by different percent and solution is changing HRU definition at different land use, soil and slope level. The scenario is shown below as follows.

1. The first scenario Pasture land change to Forest mixed land

So = Original land

Scenario1 (S1) = 10% Pasture land change to Forest Mixed land

Scenario2 (S2) = 20% Pasture land change to Forest Mixed land

Scenario3 (S3) = 30% Pasture land change to Forest Mixed land

Scenario4 (S4) = 40% Pasture land change to Forest Mixed land

Scenario5 (S5) = 50% Pasture land change to Forest Mixed land

Table 4.12 scenario Pasture land change to Forest Mixed land

Scenario	Annul Total Sed In Ton/ha/yr	Change Of Sed In Ton/ha/yr	Percentage
s0	28.46	0	0%
s1	27.22	-1.24	-4%
s2	25.98	-2.48	-9%
s3	24.74	-3.72	-13%
s4	22.27	-6.19	-17%
s5	16.07	-12.39	-22%

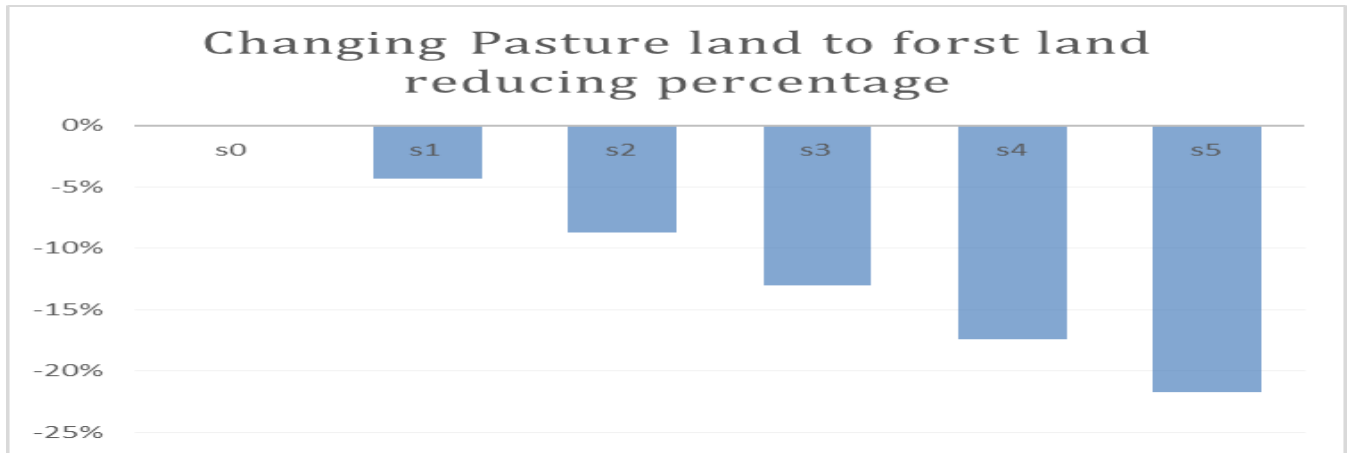


Figure 4.09 scenario of Pasture land change to Forest Mixed land

2. The second Agricultural land use change to forest mixed land

So = Original land

Scenario1 (S1) = 20% Agricultural land change to Forest mixed land

Scenario2 (S2) = 50% Agricultural land change to Forest mixed land

Scenario3 (S3) = 70% Agricultural land change to Forest mixed land

Scenario4 (S4) = 90% Agricultural land change to Forest mixed land

Table 4.13 scenario Agricultural land change to Forest mixed land

Scenario	Annual sediment in ton/ha/yr	change of sediment in ton/ha/yr	change in percentage
S0	28.46	0	0%
S1	27.01	-1.45	-5%
S2	24.84	-3.62	-13%
S3	23.39	-5.07	-18%
S4	21.94	-6.52	-23%

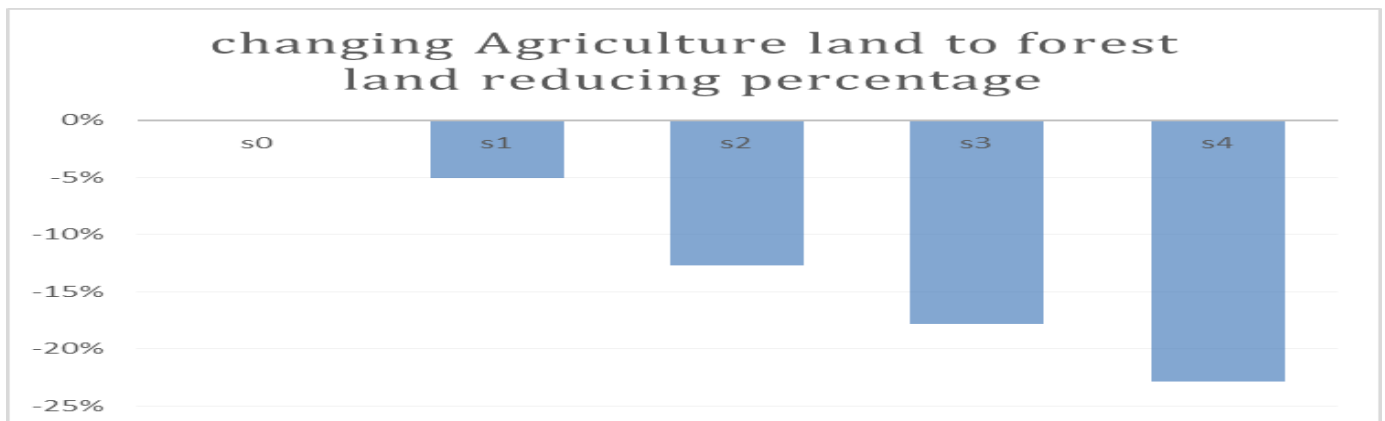


Figure 4.10 scenario of Agricultural land use change to forest mixed

3. Scenario development and analysis for HRU

HRU is the combination of land use, soil and slope, in the catchment having changing the combination from 5%, 15% and 20% to different the SWAT model reduce sediment generation as follows.

Table 4.14 Scenario Development and Analysis for HRU

scenario	% of Land use/soil:/slop percentage	Total sediment load in ton/ha/yr	sediment change in ton/ha/yr	sediment change in percentage
s0	5:10:20	28.46	0	0%
s1	5:15:20	28.06	-0.40	-1%
s2	5:20:20	27.69	-0.77	-3%
s3	22:10:20	25.24	-3.22	-11%
S4	15;10:20	20.41	-8.05	-28%

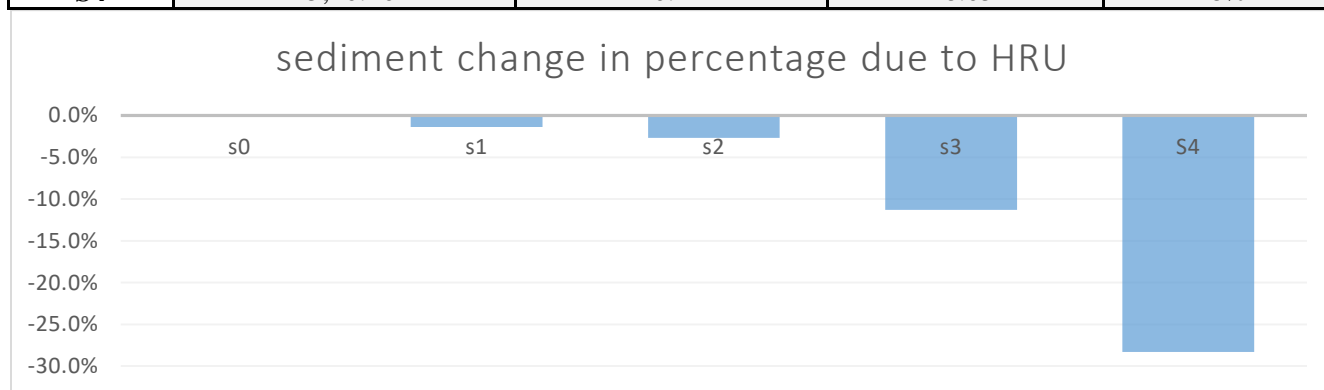


Figure 4.11 scenario of Analysis for HRU

4. Scenario development and analysis for constructing terrace

Terracing is a soil conservation practice applied to prevent rainfall runoff on sloping land from accumulating and causing serious erosion. Terraces consist of ridges and channels constructed across-the-slope.

terrace is a piece of sloped plane that has been cut into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming. This type of landscaping is therefore called terracing. Graduated terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease both erosion and surface runoff, and may be used to support growing crops that require irrigation.

Table 4.15 scenario development by construction terrace

scenario	TERR- P	TER-CN	TERR- SL	TOTAL SED IN ton/ha/yr	Reduced load ton/ha/yr	reducing percentage
s0	0.5	60	20	28.46	0	0
s1	1	60	25	27.07	-1.39	-5%
s2	0.5	70	20	26.86	-1.60	-6%
s3	1	60	20	23.61	-4.85	-17%
s4	0.5	65	25	20.55	-7.91	-28%
S5	0.5	65	20	16.54	-10.53	-37%

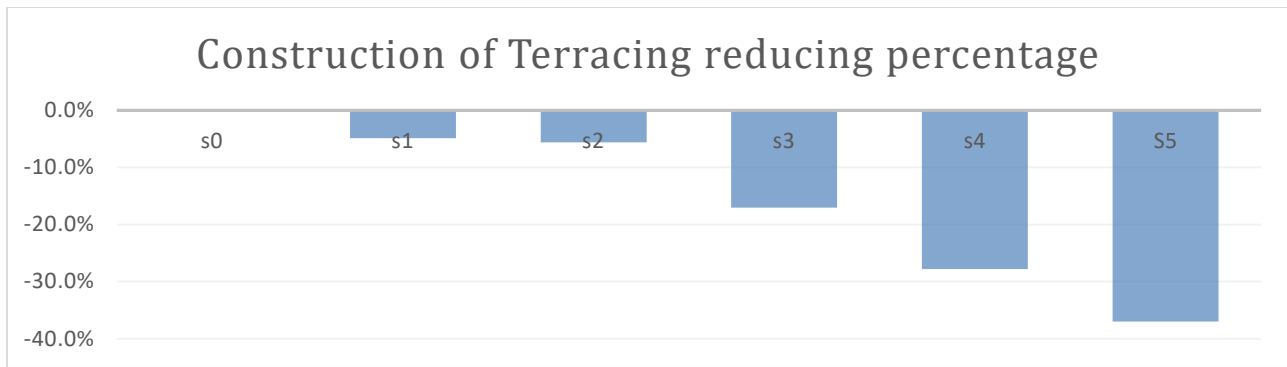


Figure 4.12 the graph shows terraces construction

5. Scenario development and analysis for constructing filter strip

Filter strips are often planted to cool-season grasses including tall fescue, Kentucky bluegrass, orchard grass, smooth brome grass, and others. A filter strip is an area of grass or other permanent vegetation used to reduce sediment, organic particulates, nutrients, pesticides, and other contaminants from runoff and to maintain or improve water quality. Filter strips intercept undesirable contaminants from runoff before they enter a water body. They provide a buffer between contaminant source, such as crop fields and water bodies, such as streams and ponds. Filter strips slow the velocity of water, allowing the settling out of suspended soil particles, infiltration of runoff and soluble pollutants, adsorption of pollutants on soil and plant surfaces, and uptake of soluble pollutants by plants.

Table 4.16 Scenario Filter Striping

scenario	VFS L	VESRA TIO	VFSC ON	VFSC H	TOTAL SEDI ton/ha/yr	Reduced Sed load ton/ha/yr	reducing percentage
s0	0	10	0.5	90	28.46	0	0
s1	0.5	20	0.75	100	27.23	-1.23	-4%
s2	1	25	0.5	90	26.51	-1.95	-7%
s3	0.5	30	0.25	80	26.02	-2.44	-9%
s4	1	10	0.25	100	25.34	-3.12	-11%



Figure 4.13 shows scenario of filter strip

The estimated SWAT model result after calibration and validation sediment yield from Tekeze dam catchment is 2846 ton/km²/year. However, using the mitigation measures the sediment generated can

reduce with good result. For example, from the above table results Scenario 1 by changing pasture land to forest mixed land the sediment reduction is 4% to 22%, Scenario 2 by changing agriculture lands to forest lands the sediment reduction 5% to 23 %, Scenario 3 by changing HRU definition at different land use, soil and slope the sediment reduction 1.4% to 28.3%, construction of terrace strip the sediment reduction 11% to 37% and construction of filter the sediment reduction 4% to 11%. Moreover, Applying and using operational best Management Practices can effectively work with small cost and difficulties to minimize the sediment yield from the catchment to Tekeze dam reservoir specially the construction of terracing. However the other solution can result good result with combination of future plan on the land use land cover of the catchment.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The general goal of this study is estimate sediment yield from Tekeze dam watershed to the reservoir, using SWAT model and to take and recommended appropriate sediment reduction measures for high sediment prone watershed areas.

The performance of the model have checked with graphical and statistical methods for the average monthly simulated and observed for flow and sedimentation and here is the result obtained for calibration and validation at the catchment outlet result with $R^2=0.84$, $NS=0.73$ and $R^2=0.74$, $NS=0.71$ for flow and $R^2=0.78$, $NS=0.77$ and $R^2=0.69$, $NS=0.69$ for sediment respectively. The result show the SWAT model has good performance on the estimation and simulation of the Tekeze catchment runoff and sediment.

The Global sensitivity analysis of the SWAT parameters of all the catchment calibrated at the outlet (Embamedere) showed that flow is most sensitive to SCS runoff curve number (CN2), Average slop length (HRU_SLP), Base flow alpha factor (ALPHA_BF), Maximum canopy storage (CANMX), Threshold depth of water in the shallow aquifer fore return flow to occur (GWQMN), Ground water revap coefficient (GW_REVAP) and Depth from soil surface to bottom of layer (SOL_Z).The sensitivity analysis of the SWAT parameters showed that sediment yield is most sensitive to USLE equation support practice number (USLE_P), Liner parameter for calculating the maximum amount of sediment that can be reentained during channel routing (SPCON), Channel cover factor (CH_COV2), Exponent parameter for calculating sediment reentrained in channel sediment reentrained in channel (SPEXP), USLE equation soil erodibility (USLE_K), Available water capacity on the soil layer(mm H₂O/mm soil) (SOL_AWC) and Saturated hydraulic conductivity (SOL_K).

The total annually sediment yield in the reservoir is 28.46ton/ha and total annual sediment load from the catchment is 82,296,444.38 ton/year. Also the spatial and temporal sediment yield of the Tekeze dam catchment is analysis it show the sediment inflow increase time with time havening variable patter. The sediment prone area identified from the result of the model sub catchment 19,10,24 and 25 have high sediment generation compared to the other catchments because on this areas have more steeper or lower slope and erodible soil around there boundary. Again the model result show sub catchment 4, 2, 3 and 5 generates lee sediment relative to the other 35 sub basin in the catchment due to having low silt content and medium slop compare to the others.

The Swat model have different sediment mitigation measures accordingly in this study have five mitigation measures changing the pasture and agriculture land change to Forest mixed forest reduce the sediment inflow to the reservoir. And the operational management method such that construction of terracing and filter strip have good result on the reduction of sediment generated from the catchment.

The tekeze dam watershed generates sediment of 82,296,444.38 ton/year and it have volume of 4Billion m³ dead storage this storage will be filled with estimation of 49 years. This shows the dam service time from 50-100 year is limited only on the lower range of service life. Therefor the dam need mitigation measures to maximize the service life, by minimizing the sediment generated from the catchment.

5.2. Recommendations

- The lifetime of the reservoirs depend on the reduction of sedimentation from the watershed catchment. Therefore, sediment trap means should be exercised in upstream of the watershed. Stakeholders can achieve this through soil and water conservation program at erosion prone sub basins with vegetation screen upstream of reservoir with continuous follow up.
- For Short period of sediment yield and flow record of observation data was used in this study however having longer period of runoff and sediment data will improve the calibration result of the model.
- Using more hydrological gauging stations to improve the quality of sediment and rainfall data around critical sub-catchments.
- Administration representative's on this watershed should take decision on the sub-catchments that produce the highest by intervention strategies such as land slope stabilization, construction of terraces, filter strip in low slopes, changing the land use of steep area to forest mixed and afforestation. Sediment. On the high sediment porn sub catchments 19, 10, 24 and 25.
- All works depend on, the secondary data collected from different organizations and agencies as its input and simulation of the final model result. But using primary data is better for representativeness of these data and for better result.

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Dr K Subranlanya (2005): Engineering Hydrology

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

APPENDIX A

Metrological Gauge Station from National Metrological Service Agency

id	Met Station	PCp		Rh		SH		Tmax		Tmin		Wind		Data	
		Start-End Year	Period	Start-End Year	Period	Start-End Year	Period	Start-End Year	Period	Start-End Year	Period	Start-End Year	Period	Total	Missed
1	Lalibela	1989-2019	31	1989-2018	31	1992-2018	27	1989-2019	31	1989-2019	31	1989-2013	25		
2	Mekelle	1987-2018	32	1988-2018	31	1991-2018	28	1987-2018	32	1987-2018	32	2002-2016	15		
3	Gonder	1986-2019	34	1986-2019	34	1986-2019	34	1986-2019	34	1986-2019	34	1994-2018	25		
4	Maichew	1992-2018	27	1992-2018	27	1992-2018	27	1992-2018	27	1992-2018	27	2006-2016	11		
5	Debark	1986-2019	34	1989-2019	34	2005-2019	28	1986-2019	34	1987-2019	33	2002-2017	16		
6	Maytsibre	2005-2018	14	2011-2018	8			2005-2018	14	2005-2018	14	2005-2017	13		
7	samre	2000-2018	19												
8	Agere genet	1988-2019	32					1988-2019	32	1988-2019	32				
9	Dabat	1988-2017	30												
10	Ebinat	2000-2019	20					2015-2019	5	2015-2019	5				
11	Agibe	1997-2018	22												
12	Klumesk	1986-2019	34												
13	Muja	1986-2018	33												
14	Sekota	1995-2019	25					1995-2019	25	1995-2019	25				

id	Met Station	30 year data		PCp		Rh		SH		Tmax		Tmin		Wind	
		Total Data	Missed Data	Per. Missed data	Missed Data	Per. Missed data	Missed Data	Per. Missed data	Missed Data	Per. Missed data	Missed Data	Per. Missed data	Missed Data	Per. Missed data	
1	Lalibela	10,957.00	1682	15.35%	2174	19.84%	5791	52.85%	1750	15.97%	1529	13.95%	3250	29.66%	
2	Mekelle	10,957.00	1375	12.55%	1483	13.53%	1870	17.07%	1496	13.65%	1396	12.74%	6378	58.21%	
3	Gonder	10,957.00	377	3.44%	2054	18.75%	1073	9.79%	701	6.40%	1360	12.41%	5734	52.33%	
5	Debark	10,957.00	1080	9.86%	4932	45.01%	6055	55.26%	1982	18.09%	1449	13.22%	2521	23.01%	

id	Met Station	Rank							All Total	missed Data	Per. Missed data	Rank
		pcp	rh	sh	tmax	tmin	wind					
1	Lalibela	4	3	3	3	4	2	65,742.00	16176	24.61%	3	
2	Mekelle	3	1	2	2	2	4	65,742.00	13998	21.29%	2	
3	Gonder	1	2	1	1	1	3	65,742.00	11299	17.19%	1	
5	Debark	2	4	4	4	3	1	65,742.00	18019	27.41%	4	

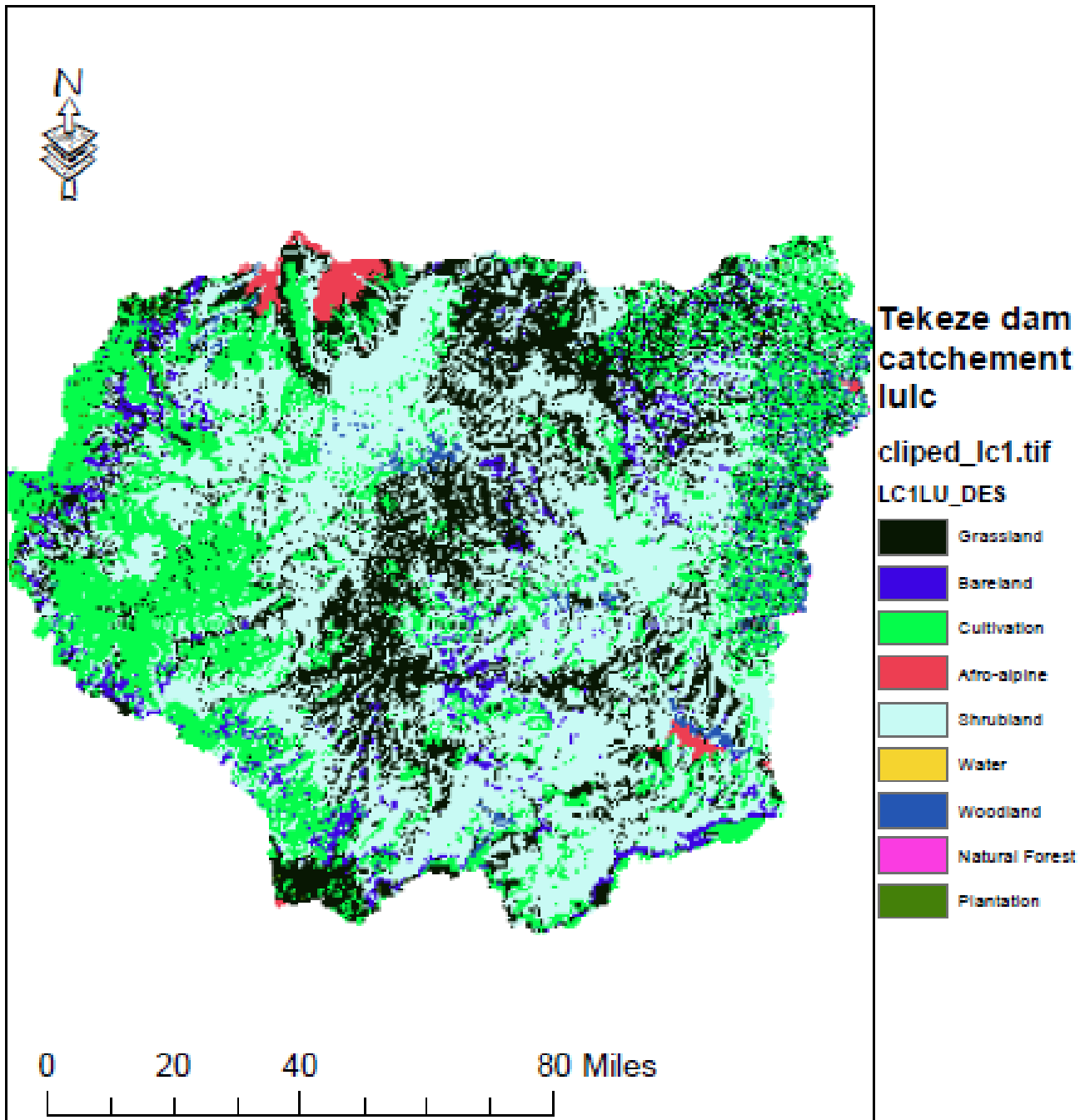
Metrological station	LAT	LONG	Elevation
Lalibela	12.0343	39.0194	2240.36
Gondar	12.5999	37.4615	2099.75
Mekele	13.4884	39.4722	2143.34
Debark	13.1491	37.8905	2844.85

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

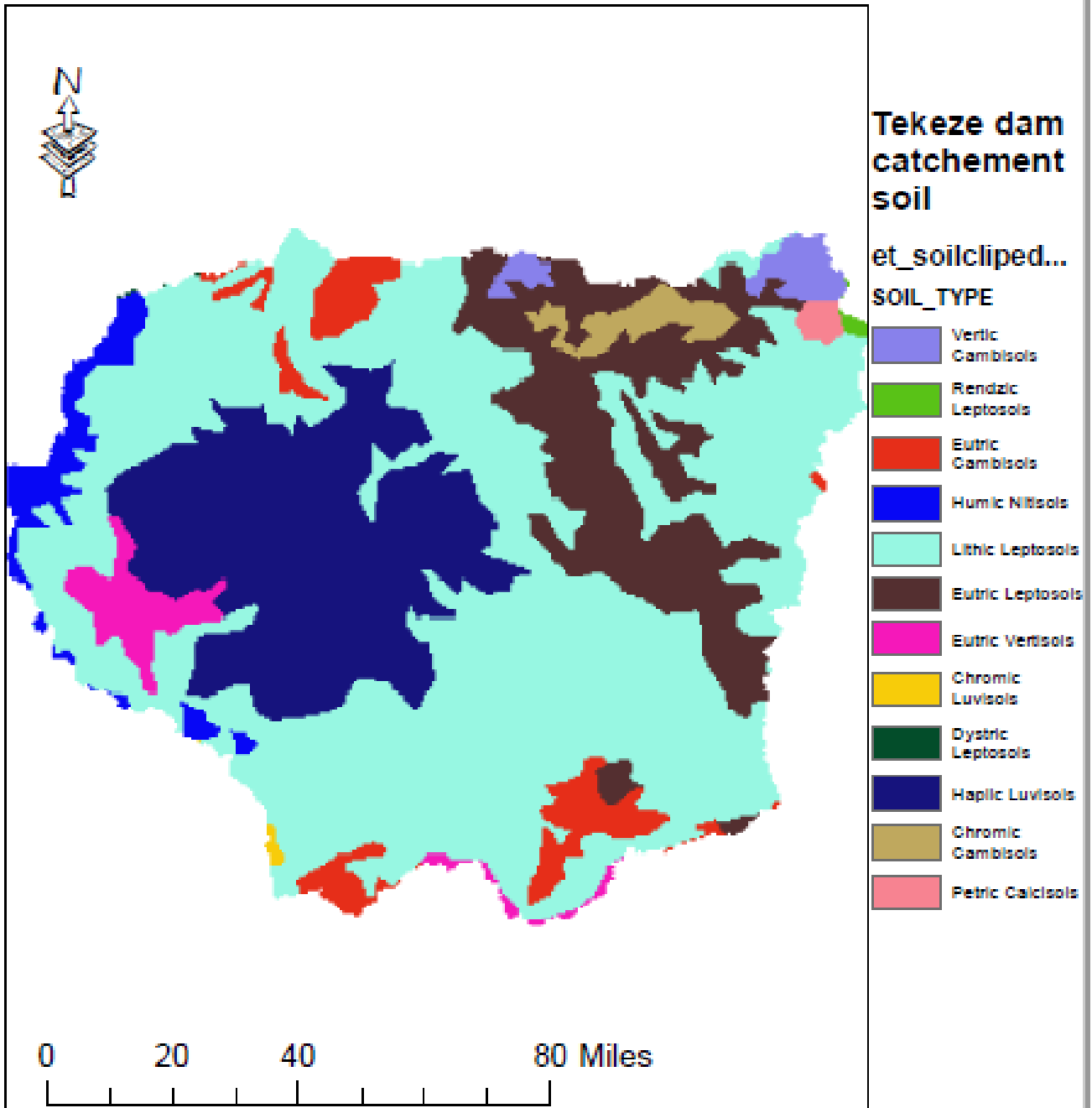
Weather generator of Lalibala gauge station

OBJECTID	STATION	WLATITUDE	WLONGITUDE	WELEV	RAIN_YRS							
1	lal	39.02	12.04	2487	30							
TMPMX1	TMPMX2	TMPMX3	TMPMX4	TMPMX5	TMPMX6	TMPMX7	TMPMX8	TMPMX9	TMPMX10	TMPMX11	TMPMX12	
25.58	26.86	26.87	26.5	26.28	25.14	20.84	21	23.14	24.66	24.95	25.03	
TMPMN1	TMPMN2	TMPMN3	TMPMN4	TMPMN5	TMPMN6	TMPMN7	TMPMN8	TMPMN9	TMPMN10	TMPMN11	TMPMN12	
13.1	13.93	14.26	14.5	14.82	14.35	12.25	12.1	12.93	12.79	12.72	12.79	
TMPSTDMN1	TMPSTDMN2	TMPSTDMN3	TMPSTDMN4	TMPSTDMN5	TMPSTDMN6	TMPSTDMN7	TMPSTDMN8	TMPSTDMN9	TMPSTDMN10	TMPSTDMN11	TMPSTDMN12	
1.071473827	1.336375384	1.517077312	1.530993485	1.5250565	1.656619284	1.1389461	1.127304437	1.183373	0.928774701	1.109243671	0.980976737	
PCPSTD1	PCPSTD2	PCPSTD3	PCPSTD4	PCPSTD5	PCPSTD6	PCPSTD7	PCPSTD8	PCPSTD9	PCPSTD10	PCPSTD11	PCPSTD12	
0.6274	0.6967	1.1554	1.2421	1.0218	1.2087	1.4534	3.1233	1.1811	0.7536	0.8566	0.6159	
PR_W1_1	PR_W1_2	PR_W1_3	PR_W1_4	PR_W1_5	PR_W1_6	PR_W1_7	PR_W1_8	PR_W1_9	PR_W1_10	PR_W1_11	PR_W1_12	
0.0468	0.0632	0.1436	0.1743	0.1257	0.1652	0.5862	0.4691	0.2214	0.0707	0.0661	0.0417	
PCPD1	PCPD2	PCPD3	PCPD4	PCPD5	PCPD6	PCPD7	PCPD8	PCPD9	PCPD10	PCPD11	PCPD12	
6.07	6.07	11.97	11.07	8.73	10.43	27.13	25.6	15.7	9.3	8.3	7.83	
SOLARAV1	SOLARAV2	SOLARAV3	SOLARAV4	SOLARAV5	SOLARAV6	SOLARAV7	SOLARAV8	SOLARAV9	SOLARAV10	SOLARAV11	SOLARAV12	
9.200239234	9.526822917	8.00864486	8.034090909	7.632673267	5.756716418	3.57527115	4.283255814	5.990570175	7.829449153	8.868052516	9.494759825	
WNDVAV1	WNDVAV2	WNDVAV3	WNDVAV4	WNDVAV5	WNDVAV6	WNDVAV7	WNDVAV8	WNDVAV9	WNDVAV10	WNDVAV11	WNDVAV12	
1.211893584	1.388926746	1.469828927	1.521613394	1.662481315	1.393290735	0.872525849	0.821418021	0.934290271	1.138461538	1.07232	1.153213752	
TMPSTDMX1	TMPSTDMX2	TMPSTDMX3	TMPSTDMX4	TMPSTDMX5	TMPSTDMX6	TMPSTDMX7	TMPSTDMX8	TMPSTDMX9	TMPSTDMX10	TMPSTDMX11	TMPSTDMX12	
1.205995982	1.333866321	1.958865244	2.122824748	2.20680381	2.508521061	2.311148747	2.017406357	1.846142169	1.487900507	1.497994514	0.960999364	
PCPMM1	PCPMM2	PCPMM3	PCPMM4	PCPMM5	PCPMM6	PCPMM7	PCPMM8	PCPMM9	PCPMM10	PCPMM11	PCPMM12	
7.22	7.8	20.68	21.83	15.02	20.4	74.37	67.85	24.79	11.2	11.59	8.4	
PCPSKW1	PCPSKW2	PCPSKW3	PCPSKW4	PCPSKW5	PCPSKW6	PCPSKW7	PCPSKW8	PCPSKW9	PCPSKW10	PCPSKW11	PCPSKW12	
3.8796	3.4041	1.7903	1.5831	2.2921	1.695	-0.5818	20.1356	1.5149	2.9528	2.8129	3.6041	
PR_W2_1	PR_W2_2	PR_W2_3	PR_W2_4	PR_W2_5	PR_W2_6	PR_W2_7	PR_W2_8	PR_W2_9	PR_W2_10	PR_W2_11	PR_W2_12	
0.7802	0.7198	0.7437	0.6627	0.6603	0.6741	0.8919	0.8646	0.7495	0.7957	0.7952	0.8511	
RAINHHMX1	RAINHHMX2	RAINHHMX3	RAINHHMX4	RAINHHMX5	RAINHHMX6	RAINHHMX7	RAINHHMX8	RAINHHMX9	RAINHHMX10	RAINHHMX11	RAINHHMX12	
3.61	3.9	10.34	10.915	7.51	10.2	37.185	33.925	12.395	5.6	5.795	4.2	
DEWPT1	DEWPT2	DEWPT3	DEWPT4	DEWPT5	DEWPT6	DEWPT7	DEWPT8	DEWPT9	DEWPT10	DEWPT11	DEWPT12	
8.71	8.66	9.97	10.26	10.75	11.14	12.75	13.18	12.06	10.33	9.59	9.03	

tekeze dam catchement landuse landcover



tekeze dam catchement soil



ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

APPENDIX B

Flow Parameters t_value and p_value

Parameter Name	t-Stat	P-Value
12:V__CN2.mgt	-4.857551221	0.000002593
13:V__HRU_SLP.hru	4.018640135	0.000086286
2:V__ALPHA_BF.gw	4.009896989	0.000089267
6:V__CANMX.hru	-3.958957375	0.000108687
17:V__GWQMN.gw	-3.102069136	0.002235262
16:V__GW_REVAP.gw	-2.091807075	0.037874721
15:V__SOL_Z.sol	2.065570772	0.040318097
14:V__SLSUBBSN.hru	-1.495415218	0.136576926
3:V__SOL_ALB (..).sol	-1.349161770	0.178998688
7:V__CH_N2.rte	1.246351909	0.214272984
10:V__ESCO.hru	1.191975088	0.234857754
18:V__SURLAG.bsn	-1.143271163	0.254461315
19:V__EPCO.hru	-0.952723014	0.342022367
20:V__CH_K2.rte	0.900348821	0.369151138
8:V__ALPHA_BNK.rte	-0.841052395	0.401447004
9:V__GW_DELAY.gw	0.744622778	0.457481747
1:V__OV_N.hru	0.710188253	0.478516791
5:V__TLAPS.sub	0.670498567	0.503409029
11:V__REVAPMN.gw	-0.614214224	0.539858018
4:V__RCHRG_DP.gw	0.534728995	0.593504584

Sediment Parameters t_value and p_value

Parameter Name	t-Stat	P-Value
12:V__USLE_P.mgt	10.180055479	0.000000000
10:V__SPCON.bsn	7.674835257	0.000000000
6:V__CH_COV2.rte	5.558375829	0.000000094
11:V__SPEXP.bsn	2.640809837	0.008977870
7:V__USLE_K.sol	2.213220628	0.028105253
4:V__SOL_AWC.sol	-2.066906034	0.040135609
1:V__SOL_K.sol	-1.539541185	0.125380901
2:V__BIOMIX.mgt	1.457545634	0.146661213
3:V__LAT_SED.hru	-1.242555238	0.215604446
5:V__RSDIN.hru	1.221499899	0.223451092
9:V__CH_ERODMO(..).rte	0.958660382	0.338981042
8:V__CH_COV1.rte	0.932513431	0.352286655

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

Best fitted value for flow parameters

Goal_type= Nash_Sutcliffe No_sims= 200 Best_sim_no= 186 Best_goal = 7.138159e-001

Parameter_Name	Fitted_Value	Min_value	Max_value
1:V__CN2.mgt	74.500000	35.000000	98.000000
2:V__HRU_SLP.hru	0.600000	0.000000	0.600000
3:V__ALPHA_BF.gw	0.000100	0.000000	1.000000
4:V__CANMX.hru	100.000000	0.000000	100.000000
5:V__GWQMN.gw	5000.000000	0.000000	5000.000000
6:V__GW_REVAP.gw	0.200000	0.020000	0.200000
7:V__SOL_Z.sol	100.000000	0.000000	3500.000000

74.500000	0.600000	0.000100	100.000000	5000.000000	0.200000	100.000000
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v__CN2.mgt	74.500000
v__HRU_SLP.hru	0.600000
v__ALPHA_BF.gw	0.000100
v__CANMX.hru	100.000000
v__GWQMN.gw	5000.000000
v__GW_REVAP.gw	0.200000
v__SOL_Z.sol	100.000000

Best fitted value for sediment parameters

Goal_type= Nash_Sutcliffe No_sims= 200 Best_sim_no= 67 Best_goal = 6.878489e-001

Parameter_Name	Fitted_Value	Min_value	Max_value
1:V__USLE_P.mgt	0.094800	0.000000	1.000000
2:V__SPCON.bsn	0.010000	0.000100	0.010000
3:V__CH_COV2.rte	0.000000	-0.001000	1.000000
4:V__SPEXP.bsn	1.500000	1.000000	1.500000
5:V__USLE_K.sol	0.200000	0.000000	1.000000
6:V__SOL_AWC.sol	1.000000	0.000000	1.000000
7:V__SOL_K.sol	10.000000	0.000000	2000.000000

0.094800	0.010000	0.000000	1.500000	0.200000	1.000000	10.000000
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v__USLE_P.mgt	0.094800
v__SPCON.bsn	0.010000
v__CH_COV2.rte	0.000000
v__SPEXP.bsn	1.500000
v__USLE_K.sol	0.200000
v__SOL_AWC.sol	1.000000
v__SOL_K.sol	10.000000

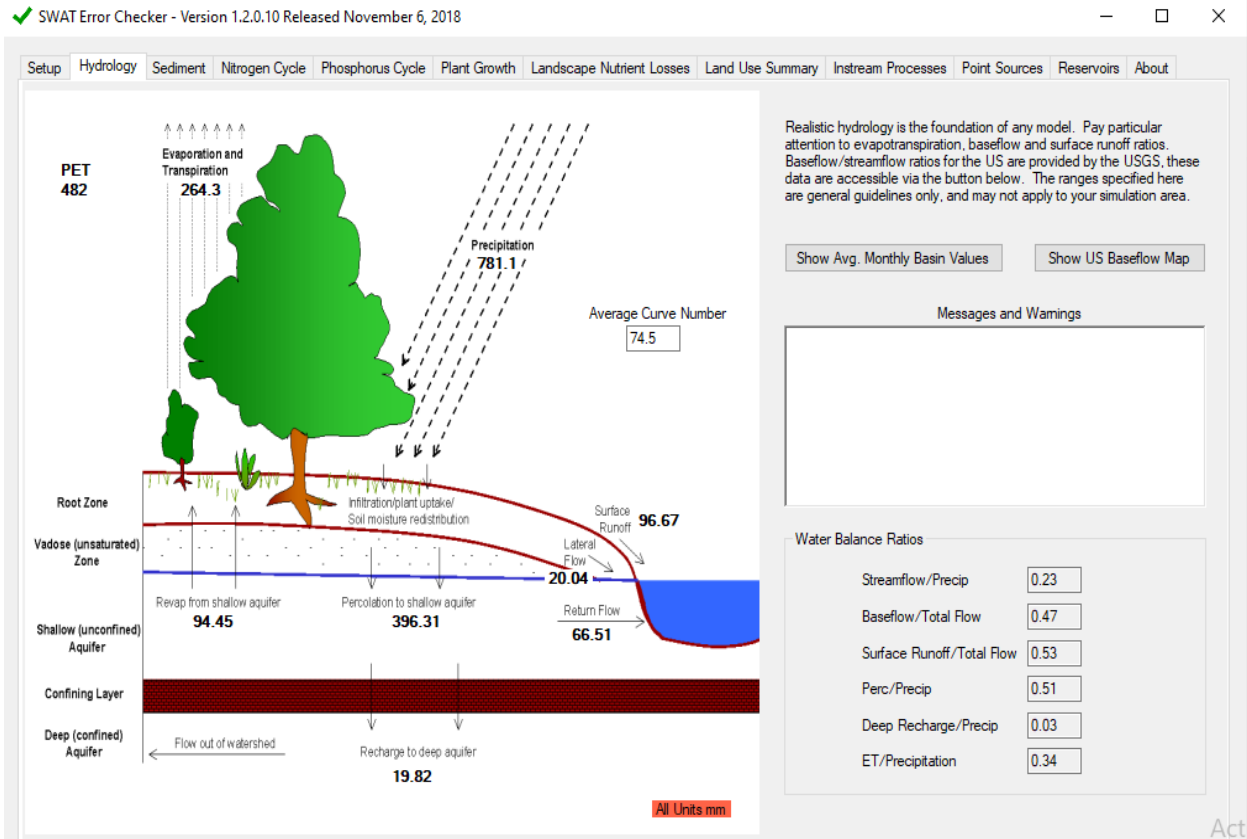
ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)

Output of Arc swat model by Arc swat model checker software

The screenshot displays the 'SWAT Error Checker' software window, version 1.2.0.10, released on November 6, 2018. The interface includes a menu bar with options: Setup, Hydrology, Sediment, Nitrogen Cycle, Phosphorus Cycle, Plant Growth, Landscape Nutrient Losses, Land Use Summary, Instream Processes, Point Sources, Reservoirs, and About. The 'Setup' tab is active, showing the 'Project Location' as 'E:\MSc Thesis\Model output\final tek res swat model\model2\Scenarios\Default\TxtInOut'. A checkbox labeled 'Already ran SWAT Check once? Leave this box checked to re-read your SWAT output files.' is checked. Below this, instructions are provided: 1. Specify your path in the text box above; 2. If you have run this version of SWAT Check before, check the box if you wish to re-read your SWAT output files; 3. Press the 'Examine Model Output' button near the top right of the window; 4. Click each tab to review related model outputs, statistics and warnings. The 'Messages and Warnings' section shows a log of the analysis process: '***** Starting Analysis *****', 'Reading output.std...', 'Finished reading output.std in 00h:00m:01.95s. Reading output.rch...', 'Finished reading output.rch in 00h:00m:03.56s. Reading output.rsv...', 'Finished reading output.rsv in 00h:00m:00.03s. Reading hyd.out...', 'Finished reading hyd.out in 00h:00m:00.20s. Computing SWAT_Check analysis...', 'Finished computing analysis in 00h:00m:00.82s.', and '***** Finished Analysis *****'. On the right side, the 'Examine Model Output' button is visible, along with 'Simulation Details' for 'SWAT Sep 7 VER 2018/Rev 670'. The simulation parameters are: Simulation Length (yrs) 30, Warm up (yrs) 2, HRUs 202, Subbasins 35, Output Timestep Monthly, Precip Method Measured, and Watershed Area km2 28,916. The SWAT logo is also present at the bottom right of the window.

Activate
Go to Sett

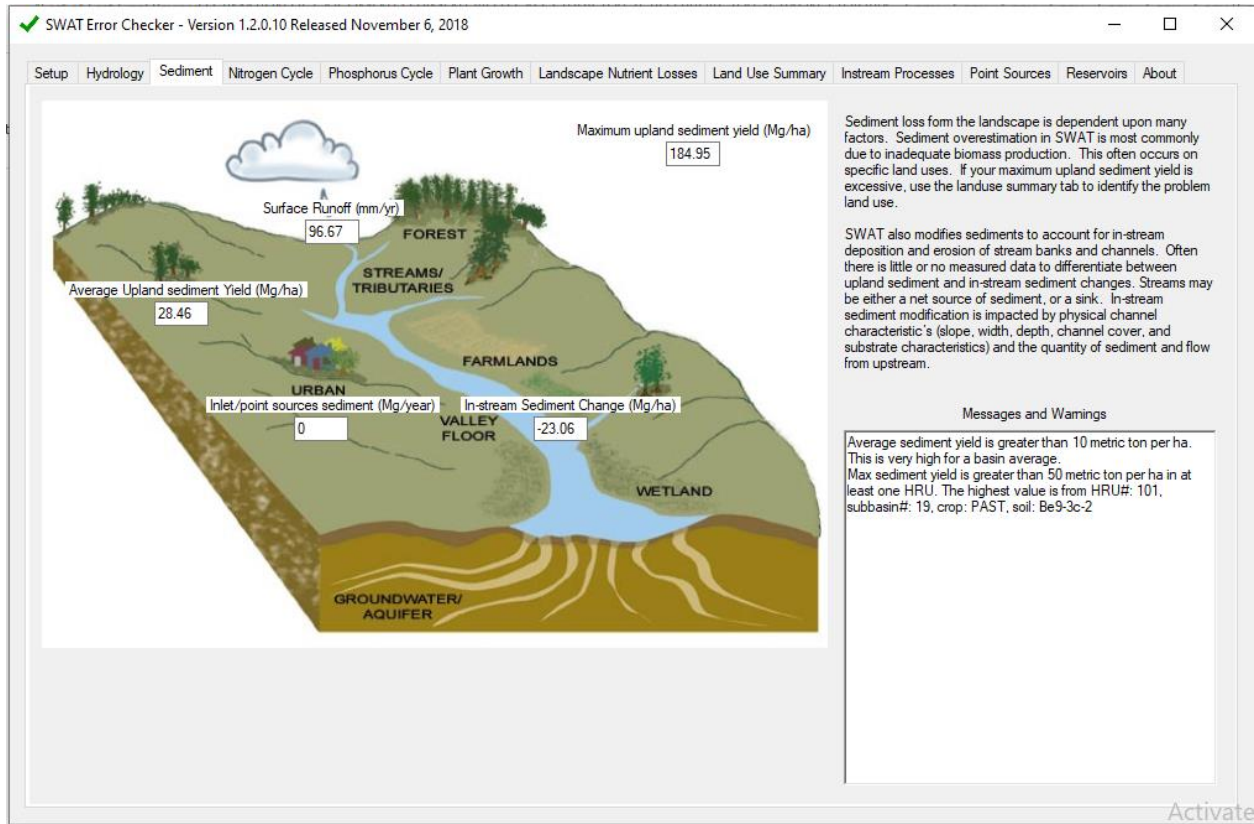
ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)



Average Monthly Basin Values

Mon	Rain (MM)	Snow Fall (MM)	SURFQ (MM)	LAT Q (MM)	Water Yield (MM)	ET (MM)	Sed. Yield (MM)	PET (MM)
1	5.60	0.00	0.10	1.35	8.71	9.21	0.06	48.69
2	8.27	0.00	0.02	1.00	7.17	10.28	0.01	47.62
3	23.83	0.00	0.88	0.92	8.28	26.10	0.79	52.22
4	33.69	0.00	0.19	0.75	6.96	34.45	0.17	46.38
5	37.75	0.00	0.66	0.67	7.34	31.70	0.23	46.26
6	88.50	0.00	8.42	0.71	14.74	23.87	3.00	31.05
7	256.51	0.00	41.91	1.66	49.23	18.87	11.92	20.77
8	219.66	0.00	35.43	3.15	46.63	20.72	9.48	22.55
9	60.80	0.00	4.80	3.30	17.06	27.41	1.33	31.79
10	25.08	0.00	3.24	2.69	15.13	26.66	1.13	41.43
11	17.21	0.00	0.88	2.09	11.49	20.87	0.28	44.08
12	4.10	0.00	0.13	1.73	10.11	14.07	0.06	48.77
*								

ESTIMATION OF CATCHMENT SEDIMENT YIELD (CASE STUDY TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA)



NB:As you see on the message and warning the average sediment yield of basin 28.46ton/ha is greater than 10ton/ha. That is why the catchment need mitigation measures to reduce the sediment yield.

SWAT Error Checker - Version 1.2.0.10 Released November 6, 2018

Setup Hydrology Sediment Nitrogen Cycle Phosphorus Cycle Plant Growth Landscape Nutrient Losses Land Use Summary Instream Processes Point Sources Reservoirs About

Summary By Reported Landuse

	LULC	AREA km2	CN	AWC mm	USLE_LS	IRR mm	PREC mm	SURQ mm	GWQ mm	ET mm	SED th	NO3 kgh	ORGN
▶	AGRC	7,750.56	74.50	164.65	62.19	0.00	827.60	115.11	114.01	244.34	36.10	0.29	
	BARL	671.15	74.50	174.88	62.19	0.00	827.19	112.65	110.98	239.35	29.35	0.36	
	FRSD	156.70	74.50	182.25	62.19	0.00	872.00	88.30	78.84	339.69	2.41	0.02	
	FRST	427.70	74.50	155.07	62.19	0.00	665.80	79.30	41.94	267.22	0.96	0.01	
	PAST	6,792.32	74.50	149.76	62.19	0.00	731.47	84.60	66.51	269.16	61.07	0.03	
	RNGB	13,119.94	74.50	162.21	62.19	0.00	779.55	91.87	81.00	273.82	8.23	0.07	

View HRU Level Warnings

Messages and Warnings

Model errors are often isolated to a particular land use type. If the land use is relatively minor, these issues may go unnoticed at the basin outlet during calibration. Often, these minor land uses are the focus of scenario development, and errors become apparent after the investment of much calibration effort.

The table above contains a few important predictions summarized by land use. These should be reviewed carefully. The button to the right provides HRU level warnings, these data are provided only to help isolate problem HRUs within a particular land use. We do not recommend that these data be used during routine checking of model output.

Output of Arc swat model tekeze dam watershed delineation

