JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

Modeling of Rainfall-Runoff Process and Sediment Yield using SWAT Model for Geba River Catchment, Ethiopia

By

Fikirte Seyoum Demiss

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

JANUARY, 2019

JIMMA, ETHIOPIA

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ADVISOR: Dr.-Ing. Tamene Adugna (PhD)

CO-ADVISOR: Mr. Megersa Kebede (MSc)

JANUARY, 2019

JIMMA, ETHIOPIA

DECLARATION

This thesis entitled **“Modeling of Rainfall-Runoff Process and Sediment Yield using SWAT Model for Geba River Catchment, Ethiopia”** has been approved by the following advisor(s), and department for the commencement of the required research in Hydraulic Engineering:

………………………	……………..	………………..
Candidate	Signature	Date

CERTIFICATION

I, the undersigned, certify that I read and hereby recommend for the acceptance by the Jimma University a research entitled: “**Modeling of Rainfall-Runoff Process and Sediment Yield using SWAT Model for Geba River Catchment, Ethiopia”** In partial fulfillment of a degree of Masters of Science in Hydraulic Engineering.

Dr.-Ing. Tamene Adugna	---------------------	-------------------
(Advisor)	Signature	Date
Mr. Megersa Kebede	---------------------	-------------------
(Co-Advisor)	Signature	Date

DEDICATION

I dedicate this work to my baby boy Kidus with Love

ABSTRACT

The use of rainfall-runoff modeling in the decision making process of water resources planning and management has become crucial. Extreme Runoff coupled with faulty management systems may result in high rate of soil erosion and increased sediment transport by changing the magnitude and pattern of runoff and sediment yield. The main problem in the study area is erosion, sediment transport, and sedimentations also water resource in the basin is scare due to limited rainfall, high evapotranspiration and ongoing land degradation. The aim of this study was to model rainfall runoff process and sediment yield in Geba River Watershed using Soil and Water Assessment Tool (SWAT) model. Simulation was carried out using meteorological, hydrological and spatial data that was collected from different sources. Model calibration period (2001-2010) and validation period (2011-2015) were performed for monthly flow and sediment data using Sequential Uncertainty Fitting (SUFI-2) within SWAT Calibration of Uncertainty Program (SWAT-CUP). Model performance efficiency was checked by coefficient of determination (R^2), Nash-Sutcliffe model efficiency (E_{NS}), observation Standard Deviation Ratio (RSR) and percent bias (PBIAS) indicating well performance of model estimation. For flow, the values of R^2, NSE, RSR and PBIAS were 0.71, 0.7, 0.55 and 6.7 during calibration period and 0.74, 0.7, 0.55 and 3.6 during validation period, respectively and for sediment yield 0.72, 0.66, 0.61 and -8.7 during calibration period and 0.79, 0.72, 0.53 and -11.3 during validation period, respectively. Average annual sediment yield from Geba watershed after calibration and validation at Geba gauging station was total sediment loading 18.440 ton/yr. Spatial variability of sediment yield was performed using the simulated sediment yield results. Also based on the spatial result for the critical sub-watersheds the design and development of best management practices were proposed under different scenarios. Scenarios result showed that average annual sediment yield reduction at entire watershed level after application of grassed waterway, filter strips, terracing and contouring were 20.3%, 54.7%, 78.8% and 61.57% respectively. Therefore, practicing terracing for Geba watershed should be developed and encouraged for efficient sediment reductions.

Keywords: Geba watershed, Management scenarios, Sediment yield, Stream flow, SUFI-2, SWAT model.

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Acronyms

amsl	above mean sea level
BMP	Best Management Practice
DEM	Digital Elevation Model
DMC	Double Mass Curve
HRU	Hydraulic Response Unit
GIS	Geographic Information System
GLUE	Generalized Likelihood Uncertainty Estimation
MCMC	Markov Chain Monte-Carlo
MoWIE	Ministry of Water, Irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
NMA	National Metrological Agency
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent Bias
RUSLE	Revised Universal Soil Loss Equation
SRTM	Shuttle Radar Topography Mission
SUFI-2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration of Uncertainty Program
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Project
WGEN	Weather Generator

1. INTRODUCTION

1.1. Background

Water is the most essential natural resources for living species. Since the available amount of water is limited, scarce, and not spatially distributed in relation to the population needs, proper management of water resources is essential to satisfy the current demands as well as to maintain sustainability. Understanding the basic process between rainfall, runoff, soil moisture, ground water level and land use land cover are dynamic for an effective and sustainable water resources planning and management activities with the support of hydrological models (Birhane, 2013).

Models are generally used as utility in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as, climate change, deforestation, farm practice and change of watershed management (intervention of watershed conservation practices). Land and water resources degradation are the major problems in developing country like Ethiopia. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients (Krishna.*et.al*, 2014).

Rainfall-runoff models have been under a continuous state of development. Models used in the earlier days did not integrate with different phases of hydrological cycle. Instead, they implemented simplified mathematical relationships between precipitation and catchment’s response. However, estimation of runoff is essential in different water resources studies. Runoff estimation is normally based on rainfall runoff process (Simić1.*et al.* 2009).

One of the common analyses in hydrology is runoff estimation in a watershed based on rainfall distribution. Regarding watersheds real situation due to lack of sufficient data in one hand and complexity of hydrological systems on the other hand causes inevitable use of rainfall-runoff process model. Since measurement of all parameters affect watershed's runoff is impossible, choosing a suitable model with simple structure, minimum input data requirements and reasonable precision is essential (Birhane, 2013).

The study was conducted for the Geba river basin, Northern Ethiopia, which is highly prone to changes imposing impact on hydrological processes. Excessive land degradation due to increasing population density within the watershed have created environmental changes, economic and social effects, all resulting in degradation of raw water in the basin (Abraha. ,2009). Hence, understanding process of rainfall runoff enhances the water users and managers to allocate and use the available water resources in supporting the dominant agriculture based economic and social developments. It is also used to implement techniques that control water yields, including rainfall, temperature and stream flows and, finally, to optimize the resources.

The semi-distributed Soil Water Assessment Tool (SWAT) is a hydrologic simulation model is applied in the study. Using this tool hydrological response is critically evaluated, calibrated and validated. It provides a watershed scale model that enables to conduct process studies.

1.2. Problem of the Statement

As in many parts of the world, the population in Ethiopia has also increased rapidly in the last century. This eventually resulted in large-scale land use changes, deforestation, overgrazing, expansion of crop land to marginal and steep sloping areas, poor soil management practices and unsustainable use of natural resources (Tesfahunegn *et.al*. 2012).

Soil erosion, transport and sediment yield in the watershed due to deforestation, overgrazing and poor land use practices which cause land degradation problems and a critical environmental hazard (Eckhardt et al., 2001).

For Geba watershed erosion, sediment transport, and sedimentations are critical problems also water resource in the basin are scare due to limited rainfall, high evapotranspiration and ongoing land degradation. The current level of degradation leading to erosion, and sedimentation are causing considerable loss of soil. As a consequence, the soils are becoming shallow, less fertile. In addition, water storage is declining and poor land management accelerated the rate of erosion (Abraha. ,2009).

In order to manage sedimentation problem in the Geba watershed and river, it is necessary to estimate and understand watershed sediment yield. This study has initiated to estimate the sediment yield, identify the critical source areas of sediment yield and to develop sediment yield reduction measures which can aids to the sustainable use of land and water resources in the watershed.

Therefore, this study will estimate the stream flow and sediment yield for Geba watershed using SWAT model and it will contribute in identifying strategies of sediment alleviating programs of the watershed. It can serve as a basis for developing policy interventions to understand the problems and take course of action such as soil and water conservation measures for improvement.

1.3. Objective of the study

1.3.1. General Objective

The General objective of this study was to Modeling of Rainfall-Runoff Process and Sediment Yield using SWAT Model for Geba River Catchment, Ethiopia.

1.3.2. Specific Objectives

Specific objectives of this study were:

1. To calibrate and validate the hydrologic SWAT model based on a stream flow data and sediment data.
2. To assess the spatial variability of sediment yield and identify the erosion hotspot sub-watershed.
3. To propose best management practices that can be used as mitigation measures for Sediment yield.

1.4. Research Questions

1. How to calibrate and validate the hydrologic model of SWAT was based on stream flow data and sediment data?
2. What are the erosion hot spot areas (sub basins) of the Geba watershed?
3. What are the management practices to reduce sediment yield and what amount of sediment decreased with those management practices?

1.5. Significance of the Study

Understanding the process of rainfall runoff correspondingly sediment yield is crucial indicator for resource base analysis and development of effective and appropriate response strategies. This may help stakeholders, local governments, and policy makers to design proper management strategies for sediment reduction and also to serve as an input for designers, planer and ecologists in the process of detail studies at a national level.

1.6. Scope of the Study

In this study, estimation of runoff and sediment yield from Geba watershed is near the entrance of Tekeze River but doesn’t concern Tekeze river basin. Land use/cover data and climate data is used for runoff and sediment simulation in SWAT model. However, the study will not address the impact of land use land cover and climate change on runoff and sediment yield. Also, the study emphases on sediment reduction measures for sediment prone areas but not cover the whole watershed.

1.7. Thesis Organization

In this study, estimation of runoff and sediment yield from Geba watershed using SWAT model was carry out to identify better model simulation in terms of estimating runoff and sediment yield, evaluating spatial variability and sediment management practices. Generally, the thesis is structured into five chapters, a reference list and appendices. Chapter one introduces the study with its objective, statement of the problem, the significance of the study and scope of the study. Chapter two deals about review of literatures related to the objectives of the study, hydrological models description and related previous studies. Chapter three deals the materials and methods that are used in the study. At this chapter the study area was described, the available data are collected and analyzed and the procedures to address the study objective were well-defined. Chapter four describes results and discussions and chapter five deals about conclusions and recommendations of the study. The reference list outlines the bibliography of the materials to which the respective citations refer. The Appendix provides supplementary information to the materials used and results in the study.

2. LITERATURE REVIEW

2.1. Rainfall-Runoff Process

The process including the rainfall over a catchment area and the resulting flow in a river is a fundamental problem for the hydrologist. In most countries, there are usually plenty of rainfall records, but the more elaborate and expensive stream flow measurements, which are what the engineer needs for the assessment of water resources or of damaging flood peaks, are often limited and are rarely available for specific river under investigation. Evaluating river discharges from rainfall has stimulated the imagination and ingenuity of engineers for many years, and more recently has been the inspiration of many research workers (Tewodros, 2011).

To facilitate comparisons it is usual to express values for rainfall and river discharge in similar terms. The amount of precipitation (rain, snow, etc.) falling on a catchment area is normally expressed in millimeters (mm) depth, but may be converted into a total volume of water, cubic meters (m^3) falling on the catchment. Alternatively, the river discharge (flow rate), measured in cubic meters per second (m^3s^{-1} or cumecs) for a comparable time period may be converted into total volume (m^3) and expressed as an equivalent depth of water (in mm) over the catchment area. The discharge, often termed runoff or the defined period of time, is then easily compared with rainfall depths over the same time period (Brhane, 2013).

The surface subsystem of the hydrologic cycle is where the rainfall and runoff interaction takes place. The input to this system is the rainfall and the output taken as the stream flow at the outlet of the system (Tewodros, 2011).

2.1.2. Rainfall

Rainfall is a type of precipitation that occurs when water vapor in the atmosphere condenses into droplets that can no longer be suspended in the air. The occurrence of rainfall is dependent upon several factors. Things such as prevailing wind directions, ground elevation, location within a continental mass, and location with respect to mountain ranges all have a major impact on the possibility of precipitation (Chow, 1998).

The rainfall pattern and intensity greatly influences the runoff. If the rainfall intensity is lower than the equilibrium capacity, then all the water reaching the land surface will infiltrate. If the rainfall intensity is greater than the equilibrium infiltration capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water will persist on the ground surface. Finally, if the rainfall intensity is greater than the initial infiltration capacity, some water will immediately remain on the land surface (Brhane, 2013).

Rainfall is extremely variable both in time and in space. The variation is brought about by differences in the type and scale of development of precipitation-producing processes, and is strongly influenced by local and regional factors, such as topography and wind direction at the time of rainfall. It is, however, assumed that each individual rain-gauge is representative of a very considerable area around it (Chow, 1998).

2.1.2. Runoff

When rain or snow falls onto the earth, it just doesn't sit there, it starts moving according to the laws of gravity. A portion of the precipitation seeps into the ground to replenish Earth's groundwater. Most of it flows downhill as runoff. Runoff is extremely important in that not only does it keep rivers and lakes full of water, but it also changes the landscape by the action of erosion. Flowing water has tremendous power it can move boulders and carve out canyons. There are different factors that affect run off like that of Meteorological and Physical factors. Meteorological factors that affect runoff: Type of precipitation (rain, snow, sleet, etc.), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the watersheds, Direction of storm movement, Antecedent precipitation and resulting soil moisture etc. (Brhane, 2013).

Physical characteristics that affects runoff: land use, vegetation, soil type, drainage area, basin shape, elevation, slope, topography, direction of orientation, drainage network patterns ponds, lakes, reservoirs, sink, etc.in the basin, which prevent or alter runoff from continuing downstream (Douglas *et al.*, 2005).

A considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the water that moves over the land in undecided channel is termed as runoff. During precipitation, some of the rainfall is intercepted by vegetation before it reaches the land surface. This may later fall to the ground or evaporate. Sudden water which is not intercepted by the vegetation cover falls on the ground surface, where it evaporates, infiltrates into pervious soils, lies in the ground depression or flows down giving rise to runoff. The runoff process is strongly influenced by infiltration capacity (Tewodros, 2011).

The infiltration capacity varies not only from soil to soil, but is also different for dry versus moist conditions in the same soil. After a certain time it reaches a regime value which is called equilibrium infiltration capacity. Water, which does not infiltrate, forms ponds or flows as a thin sheet across the land surface, which is called overland flow or surface runoff. The infiltrated water that percolates into the saturated zone below the water table becomes stored in the groundwater reservoirs or aquifers. This is not a static storage, as groundwater is in constant movement. While freshly infiltrated water is entering the groundwater reservoir, groundwater, known as base flow, is discharged into a stream. That infiltrates into the soil on a slope can move down slope as lateral unsaturated flow (through flow). Hydrologists refer to the water trapped in puddles as depression storage. The overland flow, sometimes called Horton overland flow, occurs only when the rainfall intensity exceeds the infiltration capacity. In areas in which soils have a high infiltration, this process may occur only during very intense storms or when the soil is saturated. Thin permeable soil overlying fractured bedrock of low permeability would provide a geological condition contributing to significant interflow (Chow, 1988).

2.2. Sediment Yield

Generally speaking, sediment yield refers to the amount of sediment transferred by a river basin over a period of time, which is also the amount which will enter a reservoir located at the downstream limit of its tributary watershed. It is also the amount of eroded sediment discharged by a stream at any given point (Abraha.2009). .

Sediment yield is the end product of erosion or wearing away of the land surface by the action of water, wind, ice and gravity. The total amount of onsite sheet, rill, and gully erosion in a watershed is known as the gross erosion. However, not all of this eroded material enters the stream system. Some of the material is deposited as alluvial fans, along river channels, and across flood plains. The portion of the eroded material that is transported through the stream network to some point of interest is referred to as the sediment yield (Arabi *et al.*, 2008).

Global estimates of erosion and sediment transport in major rivers of the world vary widely, reflecting the difficulty in obtaining reliable values for sediment concentration and discharge in many countries, the assumptions that are made by different researchers, and the opposing effects of accelerated erosion due to human activities (deforestation, poor agricultural practices, road construction, etc.) relative to sediment storage by dam construction (FAO, 1988).

Therefore the amount of sediment inflow depends on the following factors: Rainfall amount and intensity, Runoff, Soil type and geologic formation, Ground cover, Land use, Topography, Sediment characteristics-grain size, mineralogy, Channel hydraulic characteristics, Upland erosion rate, drainage network density, slope, shape, size, and alignment of channels, Erosion and Sedimentation (Abraha, 2009). .

2.3. Impact of Soil erosion and sediment load

Soil erosion and sediment yield involves the processes of detachment, transportation and deposition of sediment by raindrop impact and flowing water (Julian, 1998). Soil erosion is one of the most serious environmental problems in the world today, as it affects agricultural land and natural environment (Vrieling, 2006). The study conducted by (Deore, 2005), on global soil loss has indicated that soil loss rate in the United States is 16 t/ha/yr, in Europe it ranges between 10-20 t/ha/yr, while in Asia, Africa and South America between 20 and 40 tons/ha/yr. The average annual soil erosion in Ethiopia ranges from 16- 50 tons/ha/yr depending mainly on the rainfall intensities, land cover, and slope (Abegaz, 1995).

Forests are checkers of soil erosion. Protection is largely because of under storm vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees is usually positive. Vegetation cover can prevent the occurrence of shallow landslides (Bruijnzeel, 1990). However, large landslides on steep terrain are not influenced appreciably by vegetation cover. These large slides may contribute the bulk of the sediment, as for example in the middle hills of the Himalayas (Bruijnzeel & Bremmer, 1989).

According to (Ndomba & Griensven, 2011), sediment yield refers to the amount of sediment transferred by a watershed over a period of time, which will eventually enter a lake, reservoir or pond located at the downstream of the watershed. Sediment yield from rill through the accumulation of large quantities of runoff and channel bed material detached during gully formations has chance to join the river (USDA-NRCS, 2000). The most common discourse on sediment problems has been that of increased erosion and sediment yields from poor land use and expansion of human impacts on previously undisturbed areas (Walling, 1999).

Vegetation cover is widely accepted as a significant parameter in the erosion and sediment yield of drainage basins. Vegetation and land use are important factors with respect to the hydrology and sediment production of catchments because they are more dynamic than many other factors, with short seasonal changes as well as long- term climatic or land use management changes (Thornes, 1990).

2.4. Sediment Reduction Measures

Soil and water conservation measures are classified into structural measures (check dams, terracing, contouring, stone bunds and graded channel), agronomic measures (mulching,strip cropping, contour farming, mix cropping) and vegetative measures such as grassed waterways, filter strips and reforestation (Kruger *et al.,* 1997). According to (Douglas *et al.*, 2005) Soil and water conservation measures are classified into two groups such as structural (grassed waterways, terraces, contouring and filter strips) and non-structural (no tillage, contour farming, conservation tillage, strip tillage). For this study the selected sediment management practices and the studies conducted by different researchers were discussed below.

2.4.1. Grassed Waterways

Application of grassed waterway in critical sub basins reduces the sediment yield on the channel outlet by increasing sediment trapping efficiency and reducing flow velocity (Arabi *et al.,* 2007; Arabi *et al.*, 2008). During sediment simulation in SWAT model, the model calculates the maximum sediment yield that can be transported as a function of peak flow channel velocity (Neitch *et al.,* 2011). Studies shown that implementing grassed waterways reduce sediment yield by protecting channel erosion and intercepting the sediment particles collected and transported through channels and streams.

The study of Mwangi *et al.* (2015) reveals application of grassed waterway can decrease the sediment yield of Sasumua watershed, Kenya, at the outlet with 54%. Study conducted by Tesfu (2015), showed that introducing grassed waterway to Kesem Dam watershed, one of the tributaries of Awash River, can reduce the average annual sediment yield rate of the treated sub basins by 57.34% from the baseline condition. The study of Manawko (2017) also shows the applying grassed waterway on proposed middle Awash Dam watershed for critical sediment source sub basins reduced 76% of average annual sediment yield.

2.4.2. Vegetated Filter Strips

Vegetated filter strips should install along the edge of the channel segment to reduce the entrance of sediment, nutrients, pesticides, and bacteria in surface runoff (Arabi *et al.*, 2008). A filter strip is represented by width of the edge of field filter strips. According to USEPA (2012), vegetated filter strips are designed to treat sheet flow from adjacent surfaces and slowing runoff velocities and filtering out sediment and other pollutants.

According to Manawko (2017), application of filter strips proposed middle Awash Dam watershed, Ethiopia using SWAT model has reduced average annual sediment yield at outlet by 25.8%. The study of Andualem and Gebremariam (2015) conducted on Gilgel Abbay watershed, Ethiopia; found that applying filter strips on the study watershed can reduce 23.74% of the average annual sediment yield at the outlet. Also, the study of Betrie *et al.* (2011) on Blue Nile Basin using SWAT model reports, applying filter strips has also reduced the average annual sediment yield at the outlet by 44%.

2.4.3. Terracing

When the slope steepness and slope length reduced by the application of terraces, the peak runoff rate and erosive power of runoff are reduced consistently (Parajuli *et al.*, 2008). A terrace is an earth embankment, constructed across the field slope usually on the contour (USDA-NRCH, 2006). To simulate terracing conservation practice in SWAT model, the SCS curve number (CN_II), USLE practice (USLE_P) factor and the slope length (SLSUBBSN) could be adjusted based on cover type, hydrologic condition and hydrologic soil groups (Arnold *et al.*, 2012).

Studies of Mwangi *et al.* (2015) evaluation of agricultural conservation practices on ecosystem services in Sasumua watershed, Kenya using SWAT model shows the application of parallel terracing reduced sediment yield for the critical affected sub basins by 85%. Study conducted by Maharjan. (1024) simulates five different land management practice cases using SWAT model. The study concluded that application of terracing on the critically affected sub basins is the most effective land management practice to reduce sediment yield with an average of 78.6%. Another study conducted by Manawko (2017) using SWAT model on proposed middle Awash Dam watershed applying terraces reduced 83.3% of average annual sediment yield for the critically affected sub basins.

2.4.4. Contouring

Application of contouring can minimize the formation of rills and reduce erosion by reducing surface runoff and giving a chance to infiltrate by impounding water in a small depression (Arabi *et al.*, 2008). According to Neitsch *et al.* (2011), contouring tillage and contour planting provides protection against erosion from storms of low to moderate intensity, but little or no protection against occasional severe storms that causes excessive break-overs of contoured rows.

The study of Czapar *et al.*, (2005) shows contouring can reduce at least 50% of average annual sediment yield for treated sub basins. The study conducted by Manawko (2017) shows applying contouring on proposed middle Awash Dam watershed can reduced 61.1% of average annual sediment yield for critical sediment source sub basins.

2.5. Hydrological Model

Hydrological models are a simplified, conceptual representation of the components of the hydrologic cycle. There are different forms of hydrological models and are primarily developed for better understanding of the hydrologic processes and prediction of hydrologic phenomena in a watershed (Beven, 2000).

2.5.1. Types of Hydrological Model

According to Chow *et al.* (1988), stochastic and deterministic models are often considered to be at the top level of the classification tree, in accordance with the way they treat the randomness of hydrologic phenomena. Stochastic models use local hydrometric data to predict flows. These models allow for some randomness that results in different outputs and based on analysis of past events, commonly rainfall and river discharge (Ahmad *et al.*, 2001). Deterministic models generally produce a single output of runoff for a given rainfall under identical physical environments. Without going to too much detail, deterministic hydrologic models can be classified into three main categories (Cunderlik, 2003).

Lumped models: lumped hydrologic model simulation evaluated only at outlet of the basin that is without explicitly accounting for the response of individual sub basins and parameters do not vary spatially within the basin. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. According to Haan et al. (1994), the impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin and the most commonly employed procedure is an area-weighted average. Lumped models are not usually applicable to event scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven K. , 2000). Water Balance model (WATBA), Snowmelt Runoff Model (SRM), Identification of unit Hydrograph and Components from Rainfall, Evaporation and Stream flow data (IHACRES) are examples of lumped hydrological models

Distributed models: distributed hydrological model parameters are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial variation of parameters together with computational algorithms to evaluate influence of this distribution on simulated precipitation-runoff behavior. Distributed models require large amounts of data for parameterization in each grid cell (Beven, 2000). However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy. For instance, HYDROTEL, MIKE11/SHE and WATFLOOD are distributed models.

Semi-distributed models: parameters of semi-distributed models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. Semi-distributed model structures are more physically based than the structure of lumped models and less demanding input data than fully distributed models. Semi-distributed model can be grouped Kinematic Wave theory models and probability distributed models. According to Beven (2000), the Wave theory models are simplified versions of surface and/or the subsurface flow equations of physically based hydrologic models. In the case of the probability distributed models, spatial resolution is considered by using probability distributions of input parameters across the basin. Examples of semi-distributed models are SWAT (Arnold *et al.,* 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), and TOPMODEL (Cunderllk, 2003).

2.5.2. Hydrological Model Selection

The choice of a suitable hydrological model depends on the function that the model needs to serve. There are several hydrological models simulating the hydrological process at different spatial and temporal scales. There are various criteria which can be used for choosing the proper hydrological model for a specific problem. Further, some criteria are also user-dependent and subjective, such as the personal preference for graphical user interface, computer operation system, input-output management and structure and clarity for users. The selection of hydrological model taking into consideration the following four fundamental selection criteria (Cunderlik & Simonovia, 2007):

- Does the model predict the variables required by the project? (Required model outputs important to the project and therefore to be estimated by the model)
- Is the model capable of simulating single-event or continuous processes? (Hydrological processes that need to be modeled to estimate the outputs adequately)
- Can all the inputs required by the model be provided within the time and cost constraints of the project? (Availability of input data)
- Does the investment appear to be worthwhile for the objectives of the project? (Price)

For this study, SWAT model was selected since it fulfills the above criteria. Besides, the model was selected because, it is physically based, semi-distributed and belongs to the public domain, computationally efficient and it requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed.

2.6. General Description of SWAT Model

The SWAT (Soil and Water Assessment Tool) model is one of the river basin or watershed scale model developed by United State Department of Agriculture - Agricultural Research Service (USDA-ARS) in Temple, Texas during the 1970's (Arnold et al., 1998). SWAT model is physically based, semi-distributed, and can continuously simulate stream flow, sediment yield, nutrient, pesticides and agricultural management in watersheds with varying soils, land use and management conditions over long periods of time (Neitsch, et al, 2011).

In SWAT model simulation, the specific watershed information such as hydrology, weather, topography, soil, vegetation, and land use practices are required. Based upon drainage areas of the attributes, the model divides the watershed in to a number of sub basins. And also, the sub basins is further divided in to a number of Hydrologic Response Units (HRUs) based on land use/ cover, soil and slope characteristics.

The hydrologic processes that can be simulated using the SWAT model contains precipitation, evapotranspiration, evaporation, surface runoff, percolation, lateral flow, ground water flow and channel routing (Arnold et al., 1998). The model routes the maximum amount of sediment in reach as a function of the peak channel velocity and estimates sediment yield for each HRU using MUSLE (Williams, 1995).

2.7. SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

SWAT-CUP software was developed to perform calibration, validation, sensitivity analysis and uncertainty analysis and also its performance was better than the auto-calibration modulus embedded in the SWAT model (Zhou *et al.,* 2014).

The SWAT-CUP program contains different algorithms such as Sequential Uncertainty Fitting (SUFI-2) (Abbaspour, 2014), Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 1992), Parameter Solution (Parasol) (Griensven and Meixner, 2006) and Markov chain Monte Carlo (MCMC) are interfaced with SWAT model. Uncertainty of the model estimation rise from model parameters, model itself and input data. Uncertainty analysis algorithms used to decrease modeler uncertainty by eliminating some probable source of modeling and calibration errors.

For this study, SUFI-2 algorithm used because of the uncertainty in SUFI-2 program considers all sources of uncertainty. According to Abbaspour (2014), these uncertainties can be quantified in SUFI-2 by a measure of P - factor and R - factor. The P-factor is the percentage of measured data bracketed by 95PPU or 95% prediction uncertainty. Whereas, R- factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. It means R-factor measures the strength of uncertainty analysis and calibration. When simulation matches with the observed, the resulting value of R- factor close to zero and P- factor close to 1 and it indicates a low level of uncertainty has contained in the simulation.

2.8. Related Previous Works Using SWAT Model

There are a number of researches have been conducted regarding to Rainfall Runoff Process, sediment yield and sediment management practice in different watersheds.

The application SWAT model was examined by calibration and validated in some parts of Ethiopia. Analyzing the impact of land use change on the hydrology of the Angereb Watershed in Ethiopia by (Melese, 2012) was concluded that a SWAT model for the Angereb watershed was Calibrated and validated for stream flow analysis and the result indicate that the hydrological model SWAT simulates the runoff in a better way with satisfactory R^2 and Nash Sutcliffe efficiency (ENS).

(Fetene, 2008) Used physically based SWAT model for developing the relationship between rain fall runoff and sediment yield for Blue Nile river basin. The main objectives of the study was to develop the relationship of the hydrological components of the river basin and for identification of governing factors of sediment yield in the basin and he conclude that SWAT model was applicable for developing the relationship, by obtaining a reasonable agreement of R^2 and Nash Sutcliffe efficiency (ENS) for both Flow and Sediment.

(Ayisheshum, 2015) Used SWAT based Identification of best management practice option for sediment yield studies of Gumera watershed, SWAT model was used to identify sensitive area to soil erosion and applying terraces, contouring and introducing Strip cropping are best management options used for reduced sediment yields both at the sub watershed and the watershed outlets. And He also conclude that SWAT model gives a good agreement for identification of best management option for sediment yield studies and obtain R^2 and Nash Sutcliffe efficiency (ENS) of acceptable limit for monthly flow and sediment yield.

(Gebrie, 2015) Has carried out the impacts of land use land cover change on stream flow and sediment yield for Gilgel Abay watershed using SWAT model and According to this study, the SWAT model performed well for estimating land use change effect on sediment yield and stream flow of Gilgel Abay watershed by obtaining a reasonable agreement of R^2 and Nash Sutcliffe efficiency (ENS) for Flow and Sediment.

Study conducted by Manawko (2017) Assessing effectiveness of watershed management options for sediment reduction using SWAT on proposed Middle Awash watershed, Ethiopia showed the model for calibration and validation in the model performance evaluation confirm the flow and sediment yield simulation of the model agreed with the actual condition on the watershed. Therefore, it provides a confidence for further application of the model for analysis of spatial and temporal variability as well as assessment and evaluation of sediment reduction options. The model result showed the implementation of BMPs has appreciable benefits in terms of sediment reduction. The annual sediment yield of the watershed at the outlet has reduced by 20.5%, 25.8%, 28.7% and 32.7% due to the application of contouring, filter strips, grassed waterways and terracing respectively.

Tesfu (2015) modeled runoff and sediment yields of Kesem Dam watershed, which is one of the sub basins of the Awash River basin using SWAT model. The model successfully calibrated the flow and sediment parameter. In addition to this, the study also simulated sediment reduction best management options (filter strip, grassed waterway, and terracing) for that specific watershed by selecting the critically eroding sub basins and the result indicated the proposed reduction options can satisfactorily reduce the sediment yield (filter strip by 59%, grassed waterway by 57.34% and terracing by 63.75%) from the existing baseline for affected sub basins, in turn, reduce the sediment yield inflow to the reservoir. The model evaluation on Nash-Sutcliffe (ENS) model efficiency was 0.86 which is within the appreciable range.

Jemal (2015) modeled stream flow and sediment yield at Gidabo watershed, rift valley basin, Ethiopia the coefficient of determination (R^2) and Nash-Sutcliffe (ENS) was used to evaluate model calibration and validation. The results found were for the gauging station for stream flow $R^2 = 0.78$ and ENS = 0.75 for calibration and $R^2 = 0.75$ and ENS = 0.74 for validation period and sediment yield flow R2 = 0.72 and ENS = 0.71 for calibration and $R^2 = 0.67$ and ENS = 0.63 for validation period. The study concluded that the performance of the model was within the acceptable range.

3. MATERIALS AND METHODS

3.1. Study Area Description

3.1.1. Location and Topography

Geba river watershed is the sub-basin of the Tekeze river Basin and situated in the northern part of Ethiopia, Tigray Regional State. This research focuses on the upper part of the watershed which covers about 3695.542 km^2. It is located roughly between 13^{0}16' and 14^{0}16' North and longitudes 38^{0}38' and 39^{0}49' East (Figure 3.1).

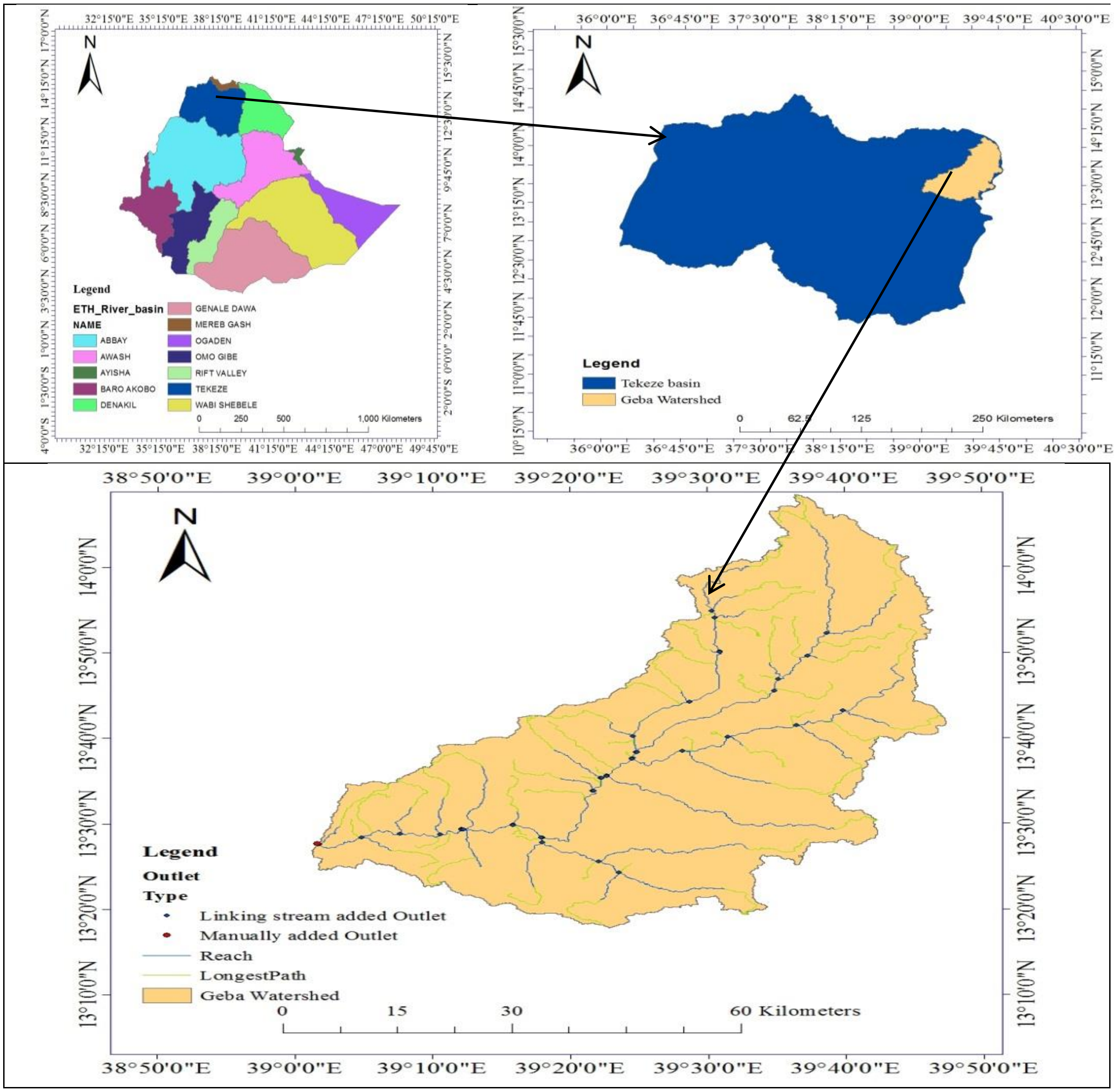

Figure 3-1 Location map of the study area

The elevation of Geba watershed ranges between 3065meter a.m.s.l in the northern and 1311meter a.m.s.l in the south with a mean elevation of 2178.32meter a.m.s.l and has maximum length of 279.24km

3.1.2. Climate

The National Meteorological Service Agency of Ethiopia (Gonfa, 1996) divides the country based on temperature into four zones; Kolla I (mean annual temperature > 20°C), Kolla II (mean annual temperature > 25°C), Woina Dega (mean annual temperature > 15°C) and Dega (mean annual temperature < 15°C). The study area is located in the Kolla II zone; here hot season mean temperatures range from between 25°C in the area close to Mekelle to about 22°C on the high plateaus. The temperature of the coldest month average less than 6°C on the high plateau and reaches 11°C near the Mekelle area. The highest mean monthly temperatures are reached just prior to the onset of the rainy season in April and May. The approximate lapse rate (decrease of temperature with altitude) averages 0.6°C /100 m (Gonfa, 1996).

3.1.3. Land Use/ Land Cover

The land use land cover is generated from LULC 2013 scheme and the land use land cover for the Geba watershed are Shurbland, Cropland, bare land, water body, forest, grass land and settlement. Among this the dominat land cover among the above are shurbland and the generated land cover is converted to SWAT data base code for running of SWAT model.

3.1.4. Soil and Geology

SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type from (Abraha, 2014). Major soil types in the Geba watershed are Calcic luvisol, Calcic vertisol, Chromic Luvisols, Eutric Cambisols,Eutric leptosol, haplic calcisol, Eutric Vertisols, etcThe geology of the study area is dominated by the Mekelle outlier, a basement complex plateau having an upper sedimentary rock layer with some doleritic intrusions and a basalt capping. Fluvial deposits occur along narrow incised river valleys (Gebreyohannes *et al.*, 2010).

3.2. Methods

3.2.1. General

In order to achieve objectives of the study the overall methodology of research study was described in the Figure 3.2 below.

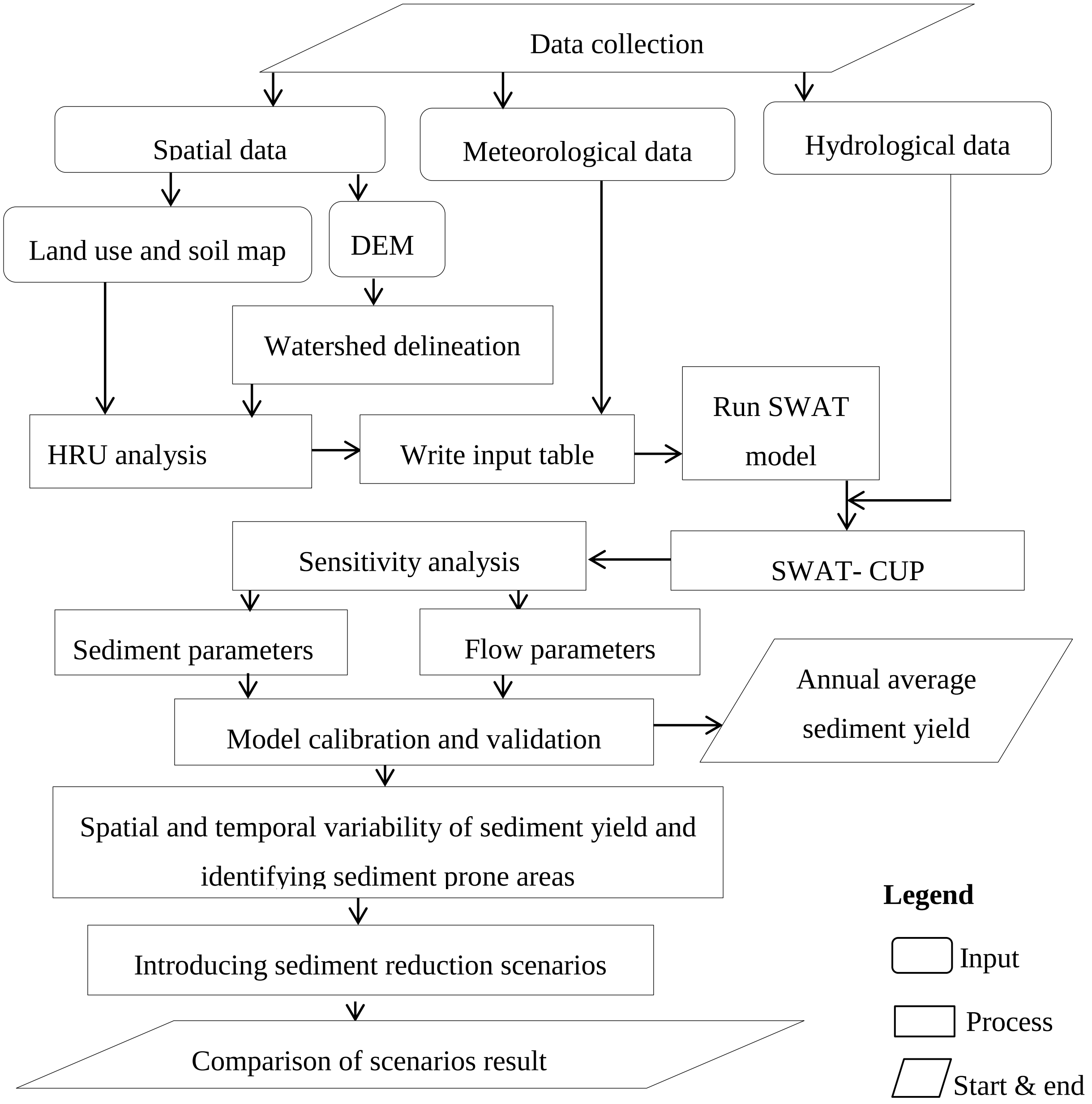

Figure 3-2 Conceptual framework of the model input data and SWAT model process

3.3. Data Collection

3.3.1. Hydro-Meteorological Data

Hydrological data

The daily flow for Geba gauged station was collected from Ministry of Water, Irrigation and Electricity from the period 1998–2015 (Ministry of Water Resource) with some missed value. The high flows concentrate on the two months of the rainy season (July, August).

Meteorological Data

The only source of raw meteorological data in Ethiopia is the National Meteorological services Agency (NMA) of Ethiopia. A request for monthly rainfall and temperature, and daily: rainfall, temperature, relative humidity, sunshine hours, and wind speed data was made from the year 1998-2015.

Table 3-1 Rainfall gauging stations

S. No	Station Name	Latitude	Longitude	Recorded data years
1	Aguali	13.68	39.57	1998-2015
2	Atsebi	13.8832	39.741419	1998-2015
3	Hagere selam	13.64556	39.17372	1998-2015
4	Hawuzen,	13.97312	39.4314	1998-2015
5	Hewane	13.10788	39.49714	1998-2015
6	Mekele Airport	13.47051	39.5312	1998-2015
7	Senikata	14.06415	39.56873	1998-2015
8	Wukuro	13.78749	39.59662	1998-2015

3.3.2. Spatial Data

Digital Elevation Model /DEM/: Topography was defined by a DEM that describes the elevation of any point in a given area at specific spatial resolution. SRTM 30 × 30 DEM of Tekeze basins was collected from Ministry of Water, Irrigation and Energy of Ethiopia. Geba watershed DEM was extracted from Tekeze Basin DEM.

Land Use Land Cover data /LULC/: it was spatial dataset in the model defines the densities and types of land use found within a given area. The dominant land use condition in the Geba catchment of Tekeze basin includes mainly are Shurbland, Cropland, bare land, water body, forest ,grass land and settlement. It is estimated that 60.98% is Shurbland, 6.79% is Cropland, 17.42% is bare land, 7.27% is forest, 6.20% grass land, 0.21%and 1.13% is respectively for water body and settlement The LULC 2013 is processed and prepared as map during the image classification from Ethiopian Ministry of water, irrigation and energy MoWIE GIS department. Land use is one of the most important factors that affect runoff, Evapotranspiration and surface erosion in a watershed. Land use land cover data which is very essential for SWAT input for determining the watershed characteristics, and also used for comparison of impacts on stream flow of the catchment.

Soil map/ Soil Data: digital stream network data were collected from MoWIE. The physical and chemical property of the soil is found from (Abraha, 2014) Liticleptosol are a widespread soil type in the Geba cathment.

Topographic Data

Topography of the catchment area is defined by a DEM that express and define the elevation of any point in a given area at a specific spatial resolution. SRTM 30 × 30 DEM of Tekeze Basin was collected from Ministry of Water, Irrigation and Electricity of Ethiopia. The Geba cathment was extracted from Tekeze Basin DEM

3.4. Data Analysis

Under this sub topic all the available data and selected relevant information were checked for expected errors. The data sets are DEM, Land use and Land cover data, Soil data, hydrological and meteorological data, obtained from various organizations. All hydrological and meteorological data are vital instruments to assess the intended hydrological parameters of Geba River watershed by using SWAT model.

To make all the layers be geometrically aligned and fit to the study area, the stations were geo referenced to the corresponding coordinate projection of the study area which is North hemisphere spatial reference called WGES_UTM_Zone_37N. As far as weather data is concerned, even though it was a long time-series data, it had several gaps of missing data values.

To overcome such problem a technique that can help filling the missing data values was used in the following sections. Data like daily precipitation; maximum and minimum temperature, wind speed, sunshine hours and relative humidity were collected from National Meteorological services Agency (NMA) of Ethiopia and require filling and tests of data. After the data was filled and tested, then arranged for the SWAT daily simulation for 18 year (1998-2015 G.C).

3.4.1. Filling Missed Data

Measured precipitation data are important to many problems in hydrologic analysis and design. Because of the cost associated with data collection and time-consuming during data collection, it is very important to have complete records at every station (McCuen, 1998). Failure of the observer to make the necessary visit to the gage, destruction of recording gages or instrumental failure may result in missing data. For hydrological analysis these missed rainfall data should be first filled with an appropriate method. The simple visual inspection shows that the rainfall data available is better from 1998 to 2015.

A number of methods have been proposed for estimating missing rainfall data. For this study the missing values was estimated from other stations around the missed record station by using both arithmetic mean method and normal ratio method. Arithmetic mean method is selected when the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation of the station under consideration

$$P_X = \frac{1}{N}(P_A + P_B + P_C + \cdots + P_N) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where N is the number of index stations, PX is the precipitation for the station with missed

Records (P_{A}, P_{B}… P_{N}) are the corresponding precipitation at the index stations.

The Normal ratio method is used when the surrounding gauges have the normal annual precipitation exceeding 10% of the considered gauge.

$$P_X = \frac{1}{N}\left(\frac{N_X}{N_A}P_A + \frac{N_X}{N_B}P_B + \frac{N_X}{N_C}P_C + \cdots + \frac{N_X}{N_N}P_N\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

where, P_X is the precipitation for the station with missed record, P_A, P_B, P_C ….., P_N are the corresponding precipitation at the index stations and , N_A, N_B, N_C,………, N_N and N_X are the long term mean monthly precipitation at the index stations and at station x.

The SWAT weather generator model (WXGEN) was used to fill missing values in weather data. Since most of stations has no full weather data like that of relative humidity, solar radiation and wind speed data by selecting one synoptic station which have full weather data SWAT generates the above data by using weather generator.

3.4.2. Rainfall homogeneity test

The purpose of homogeneity test is to identify a change in the statistical properties of the time series data which is caused by either natural or man-made factors. These include alterations to land use and relocation of the observation station. The homogeneity test of time series may be classified into two groups as absolute method and relative method. In the absolute method, the test applies to each station separately. In the relative method, the neighboring stations are also used in testing (Wijngaard *et al.*, 2003). According to Peterson *et al.* (1998), the recommended method to apply homogeneity has been tested with respect to neighboring stations that is supposedly homogeneous.

The non-dimensional of the month's value is carried out as: -

$$Pi = \frac{\overline{Pi}}{\bar{p}} * 100 \quad \text{.......} \quad (3.3)$$

Where, Pi is Non-dimensional value of rainfall for month i, $\overline{Pi}$ is over year averaged monthly rainfall at the station i and $\bar{p}$ is the over year average yearly rainfall of the station.

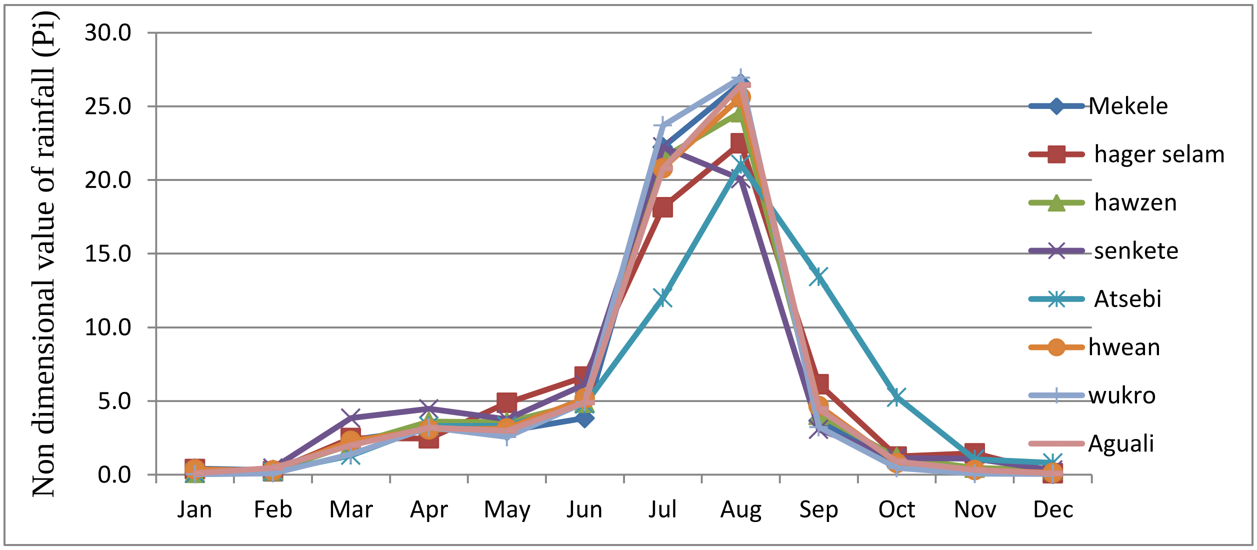

Figure 3-3 Homogeneity test for selected eight metrological stations in Geba watershed

As shown in Figure 3.3 selected rainfall stations were non-dimentionalized and plotted together to analyze their homogeneity. The maximum rainfall occurs between Jun to September in the all stations.

3.4.3. Check for consistency

A time series observational data is relatively consistent if the periodic data are proportional to an appropriate simultaneous period. This proportionality can be tested using double mass curve analysis. It is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations (Giambelluca *et al.*, 1986). A consistent record of meteorological data means that the statistical characteristics of the record like mean, variance, and higher-order moments have not changed with time.

When a significant change in the regime of the curve is observed, it reveals that rainfall data is inconsistent at that station and it should be corrected by using Equation 3.4.

$$P_{CX} = P_X * \frac{M_c}{M} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

where, P_{CX} is the corrected precipitation at any time period, P_X is the originally recorded precipitation at the time period, M_c is correct (straight line) slope of the double mass curve and M is the original slope of the double mass curve.

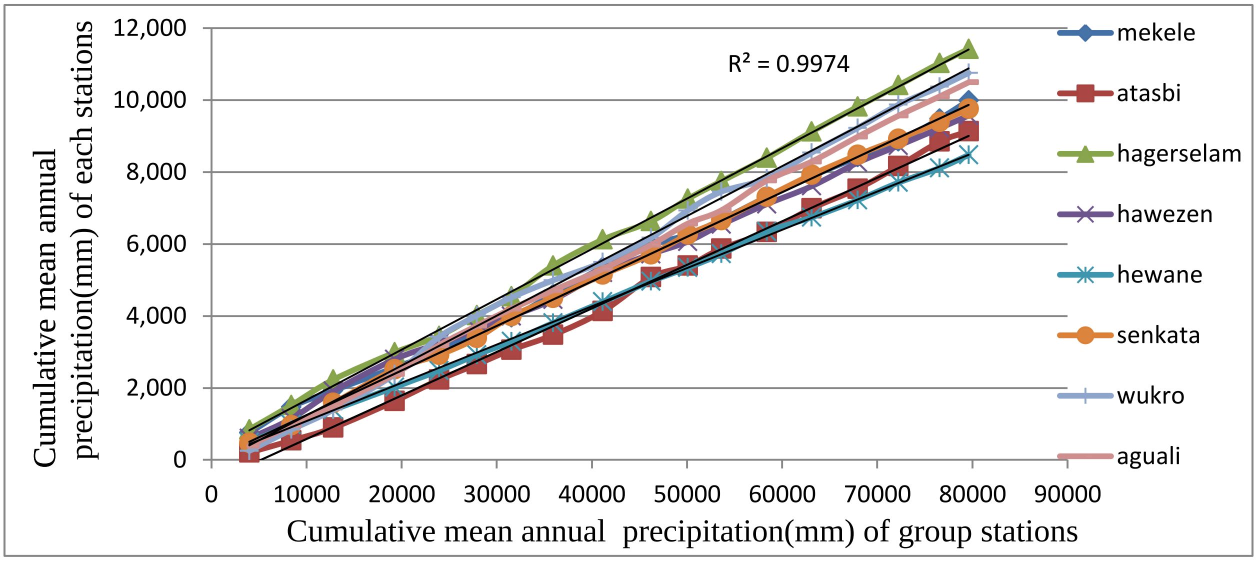

Figure 3-4 Double mass curve plot for eight stations

The double mass curve analysis (Figure 3.4) the stations used in this study have not undergone a significant change and the lines are fairly smooth with no station displaying a long-lasting break in slope.

3.4.4. Hydrological Data Analysis

Stream flow measurements were used for comparisons against the modeled stream flow in model calibration and validation. Water resource studies highly depend on stream flow data. These data should be consistent, stationary and homogenous. Monthly stream flow data from a period of 1998-2000 were used for a warm up then from 2001-2010were used for model calibration and from 2011-2015 were used for mode validation. Unlike rainfall, stream flow shows strong serial correlation; the value on one day is closely related to the value on the previous and following days especially during the period of low flow or recession. The gauging station have good stream flow records with a small number of missing data in the study baseline, especially from 2008 to 2009 which was filled by making relation within the data of the gauge itself.

3.4.5. Sediment Data Analysis

The sediment data collected from ministry of water, irrigation and electricity (MoWIE) is not in continuous time step which means they collect sediment samples and calculates the sediment concentration per three months. Therefore, it is necessary to generate the continuous sediment load by relating the stream flow with sediment load using sediment rating curve. The sediment rating curve is a relationship between the river discharge and sediment load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. A sediment rating curve may be plotted showing average sediment load as a function of discharge averaged over daily, monthly or other time periods. After the rating curve has been developed, the records of discharges are transformed into the records of sediment load and the general relationship can be written using a mathematical curve fitting method (Morris & Fan, 1998) given as:

$$S = yQ^{x} \qquad (3.5)$$

Where, S is sediment load in ton/day, Q is the discharge in m^3/s, and y and x are regression constants.

The raw data collected from the MoWIE was the sediment concentration. Thus, the data of sediment which was in concentration form have to change into sediment load in ton per day to create the sediment rating curve. This value was converted into sediment load by the time-series sediment rating curve computing technique Equation 3.6 (Morris & Fan, 1998).

$$S = 0.0864 * Q * C \quad \text{...} \quad (3.6)$$

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

Once the sediment load was calculated, the relation between the measured flow (m^3/s) and the calculated sediment load (ton/day) has been made in sediment rating curve. The relation between flow and sediment load for Geba river gauging station Figure 3.5

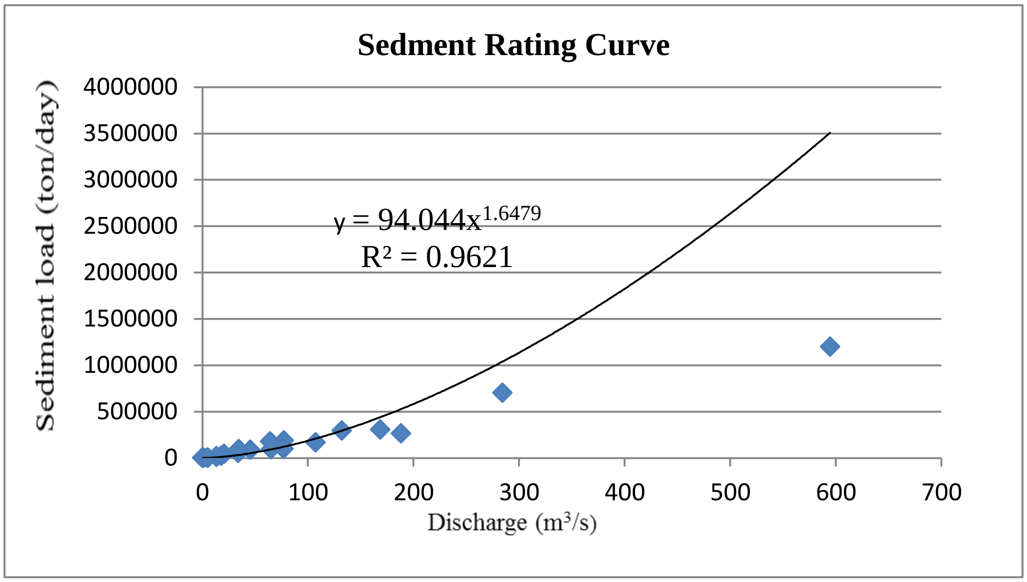

Figure 3-5 Sediment rating curve of Geba River gauging station

The continuous daily time step sediment yield for the station was generated by using the sediment rating curve equation (Equation 3.7) which has obtained from the above sediment rating curve data plot and used to sediment yield model calibration and validation processes.

$$S_{Geba\ river} = 94.044Q^{0.9621} \quad \text{..} \quad (3.7)$$

3.5. Soil and Water Assessment Tool (SWAT) Model

The large scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further divided into a series of hydrologic response units (HRUs), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated at each

HRU and then aggregated for the sub basin by a weighted average. Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. The HRUs are helpful for a better estimation of the loadings (flow, sediment, pollutants) from the sub basins.

For climate, SWAT uses the data from the station nearest to the center of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method. The water in each HRU in SWAT is stored in four storage volumes: snow, soil profile (0-2m), shallow aquifer (typically 2-20m), and deep aquifer (>20m).

Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula (Chow *et al.*, 1988).Sediment yield in SWAT is estimated with the Modified Universal Soil Loss Equation (MUSLE) developed by (Wischmeier & Smith, 1978).

3.6. SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

SWAT-CUP software was developed to perform calibration, validation, sensitivity analysis and uncertainty analysis and also its performance was better than the auto-calibration modulus embedded in the SWAT model (Zhou *et al.*, 2014).

The SWAT-CUP program contains different algorithms such as Sequential Uncertainty Fitting (SUFI-2) (Abbaspour, 2014), Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 1992), Parameter Solution (Parasol) (Griensven& Meixner, 2006) and Markov chain Monte Carlo (MCMC) are interfaced with SWAT model. Uncertainty of the model estimation rise from model parameters, model itself and input data. Uncertainty analysis algorithms used to decrease modeler uncertainty by eliminating some probable source of modeling and calibration errors.

For this study, SUFI-2 algorithm used because of the uncertainty in SUFI-2 program considers all sources of uncertainty. According to Abbaspour (2014), these uncertainties can be quantified in SUFI-2 by a measure of P - factor and R - factor. The P-factor is the percentage of measured data bracketed by 95PPU or 95% prediction uncertainty. Whereas, R- factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. It means R-factor measures the strength of uncertainty analysis and calibration. When simulation matches with the observed, the resulting value of R- factor close to zero and P- factor close to 1 and it indicates a low level of uncertainty has contained in the simulation.

3.7. SWAT Model Inputs

SWAT model input data are Digital Elevation Model (DEM), soil, land use/ cover, slope and weather data for simulation whereas Stream flow and sediment data are required for calibration and validation purposes at the outlet of the watershed.

3.7.1. Digital Elevation Model (DEM)

DEM is defining the topography of the watershed by describing the elevation of any point at a given specific spatial resolution as digital file (discussed in section 3.3.2). For this study a 30 m x 30 m resolution DEM was input for SWAT model to calculate the flow accumulation, stream networks, to delineate the watershed in to a number of sub basins based on elevation.

3.7.2. Land Use/Cover Data

Land use/cover significantly affects surface erosion, runoff and evapotranspiration in the watershed. The land use/cover map gives the spatial extent and classification of the various land use/cover classes of the study area. For this study 2013 Tekeze river land use/cover map was from ministry of water, irrigation and electricity (MoWIE) with a 30m spatial resolution. By using Arc GIS 10.3 software Geba watershed land use/cover map was extracted from Tekeze river land use/cove map. It is one of the input data for the SWAT model with inclusive properties. The model already has predefined SWAT four letter codes for each land use/cover classification in such a way that the land use/cover classification used in study area were assigned in SWAT database.

Table 3-2 Landuse/ landcover lookup table

Original land use/cover	Redefined land use/cover according to SWAT database	Area(km^2)	%Area	SWAT code
forest	Forest Mixed	268.68	7.27	FRST
grass land	Range Grasses	229.11	6.20	RNGE
Shrub land	Range Brush	2253.43	60.98	RNGB
Cropland	Agricultural Land Row Crops	251.1	6.79	AGRR
Water Body	Water	7.67	0.21	WATR
Settlement	Residential	41.7	1.13	URBN
bare land	Barren	643.83	17.42	BARR

3.7.3. Soil Data

SWAT model requires different soil physical and chemical properties soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type.

Table 3-3 Types of soil, the SWAT code and area coverage of Geba watershed:

Original soli type	Area(km^2)	%Area	SWAT code
Calcaric cambisol	502.7	13.6	CALCAM
Calcic luvisol	74.0	2	CALCLU
Calcic vertisol	327.7	8.87	CALVER
Chromic luvisol	93.6	2.53	CROLUV
Eutric cambisol	173.7	4.7	EUTCAM
Eutric leptosol	381.0	10.31	EUTLEP
Eutric vertisol	132.0	3.57	EUTVER
Haplic alisol	26.9	0.73	HAIPCAL
Haplic arenosol	72.3	1.96	HAPARN
Haplic calcisol	77.8	2.11	HAPCAL
Haplic luvisol	243.1	6.58	HAPLUV
Lithic leptosol	596.8	16.15	LITLEP
Litic leptosol	748.8	20.26	LILEPT
Luvic calcisol	245.2	6.64	LUVCAL

3.7.4. Weather Data

Climate data required for SWAT model are daily rainfall, maximum and minimum temperature, wind speed, relative humidity, solar radiation. For this study, temperature and precipitation data were available in all meteorological stations, but Mekele gauging station has full weather data (precipitation, temperature, relative humidity, sunshine hours, and wind speed).

3.8. SWAT Model Setup

3.8.1. Watershed Delineation

Watershed delineation using DEM is the initial step in SWAT model for watershed simulation. The watershed delineation process includes five major steps: DEM setup, stream definition, outlet and inlet definition, watershed outlet selection and definition and calculation of sub basin parameters. SWAT allows the user to delineate the watershed and sub basins using DEM to carry out advanced GIS functions to aid the user in dividing watersheds into several hydrological connected sub basins for use in watershed modeling by SWAT model (Arnold et al., 2012).

The DEM of Geba watershed is loaded into ArcGIS 10.3 as grid format. The model processes DEM map grid to remove all the non-draining zones (sinks). Stream network was defined for the whole DEM by SWAT model using the concept of flow direction and accumulation. The size, number of sub basins and details of stream network depends on threshold area (Winchell et al., 2007). The user should define the threshold area to define the minimum drainage area required to form the origin of stream. The smaller threshold area gives more detail of the drainage network, large numbers of the sub basin and Hydrologic Response Unit (HRU). But this demands more processing time. The threshold area of 369,554.27 ha was taken for this study. The Geba watershed outlet point manually added and selected for finalizing the watershed delineation. Finally, the model automatically delineated a watershed area of 3695.54km^2 with 59 sub-basins.

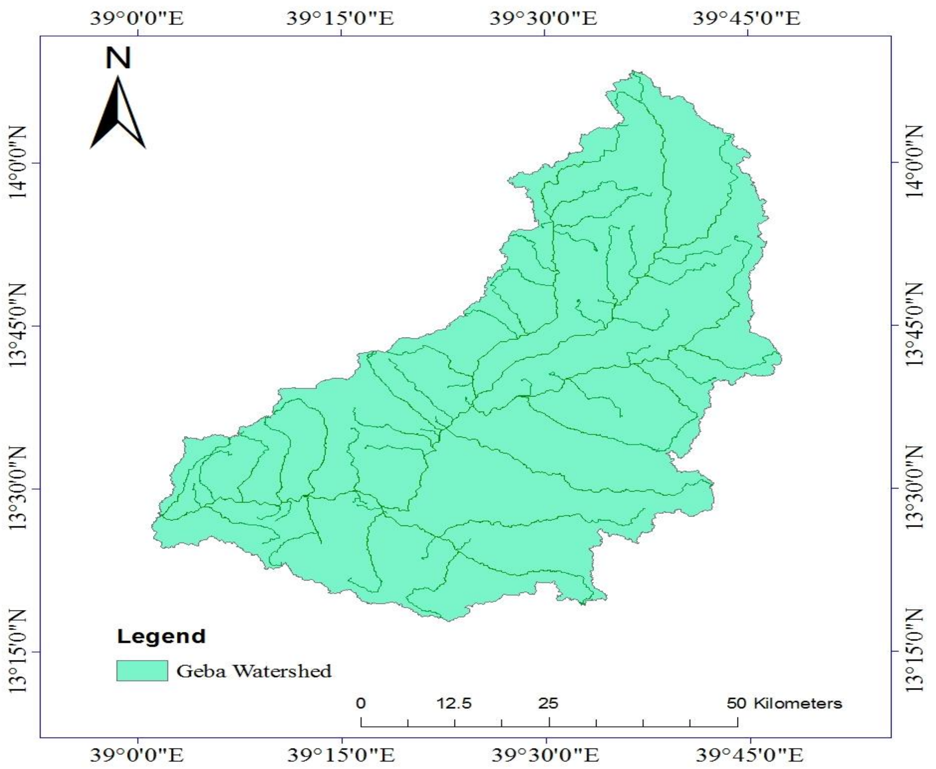

Figure 3-6 Watershed of the study area

3.8.2. Hydrologic Response Unit (HRU) Analysis

Once watershed delineated, then HRU analysis takes place. HRU analysis requires land use, soil and slope data and divides each sub basin in to number of HRU with a unique land use/cover, soil and slope combination. Produced HRU is crucial for simulation of SWAT model; because it determines how much the land use, soil and slope categorized will respond to precipitation, infiltration, runoff, sediment yield and other hydrologic processes during the simulation.

The land use, soil and slope datasets were imported overlaid and linked with the SWAT2012 databases. Delineated watershed by Arc SWAT model and prepared land use were overlapped 100%. Land use map was named into seven classes SWAT four code letter (Figure 3.10).

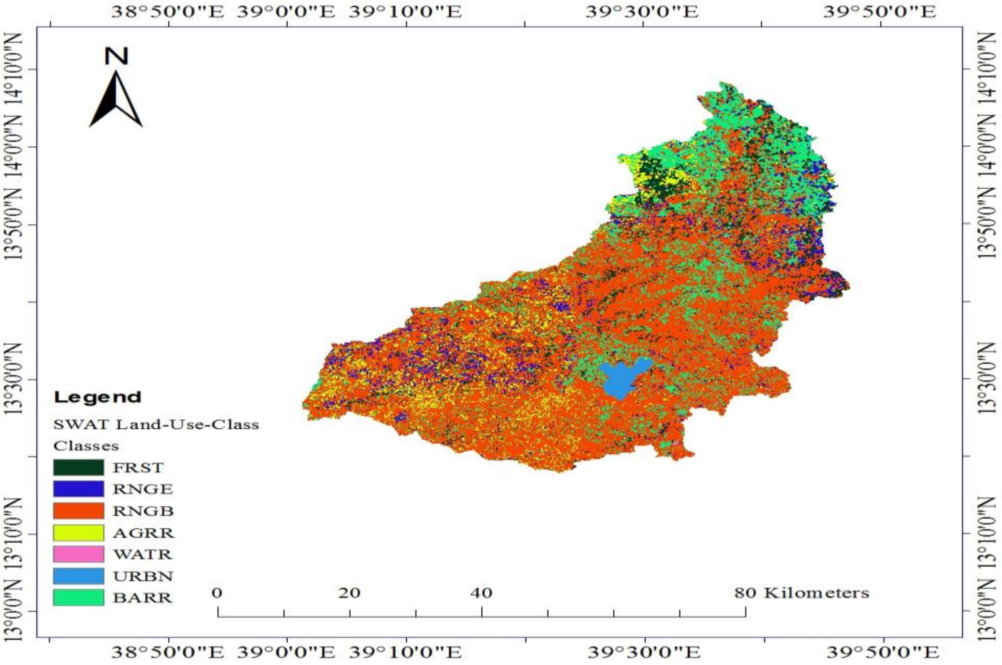

Figure 3-7 Reclassified land use four letter code by SWAT model

The delineated watershed and soil map have also overlapped 100%. The soil classes in the input soil map were decoded using soil lookup table (Figure 3.11).

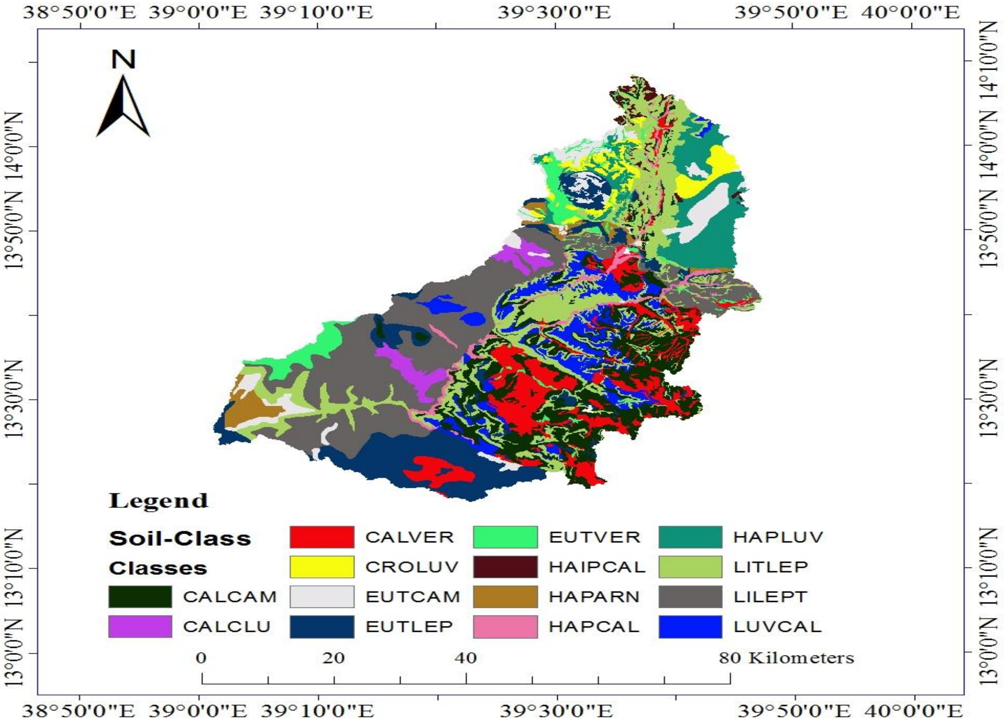

Figure 3-8 Soil Reclassified in SWAT database

Moreover, HRU analysis in Arc SWAT model includes divisions of HRUs by slope classes. Slope discretization of the watershed is 0-5, 5-10, 10-15 and >15% (Figure 3.12).

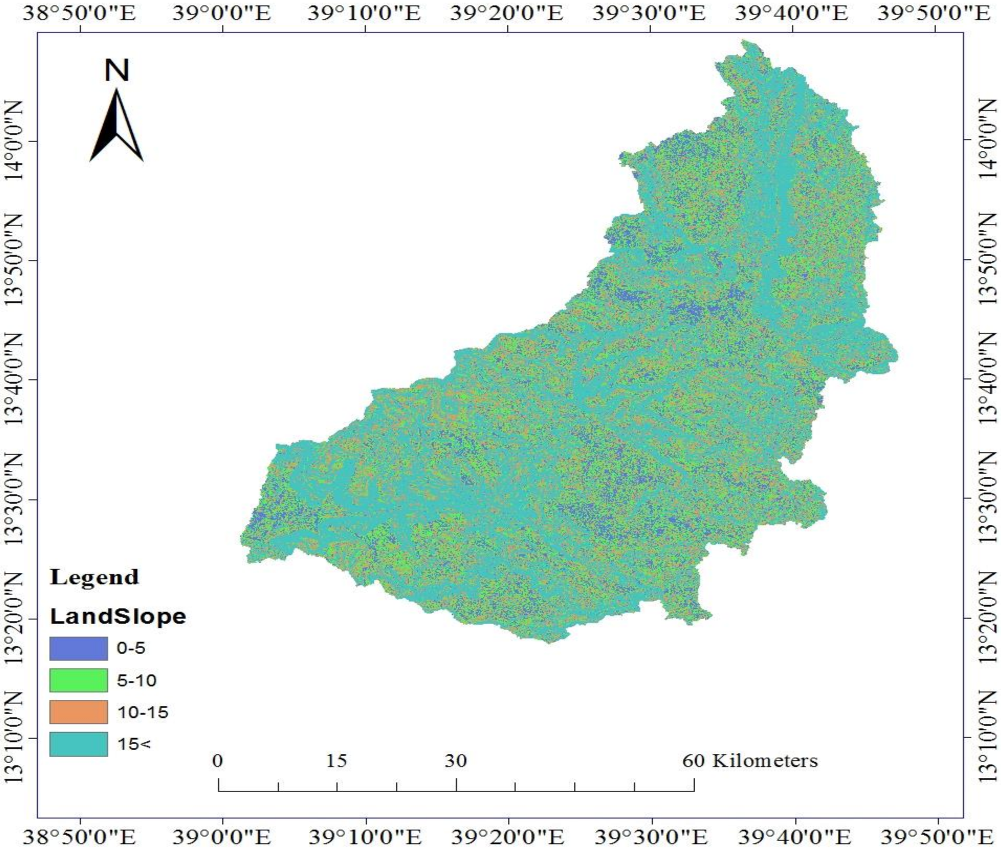

Figure 3-9 Reclassified slope for Geba watershed by SWAT model

There are two methods to define the distributions of HRUs: one can be assigning only single HRUs for each sub watershed considering the dominant land use, soil and slope. The second way is by assigning multiple HRUs for each sub watershed considering sensitivity of the hydrologic process based on a certain threshold values of land use, soli and slope combinations. For this study multiple HRUs was selected. In multiple HRU definition 20 percent land use, 10 percent soil and 20 percent slope threshold were used as an adequate for most applications. Each sub basin can then have one or more HRUs defined within it. Finally, total of 469 HRUs for 59 sub basins were created and the full HRU map of the watershed as indicated (Figure 3.13) below.

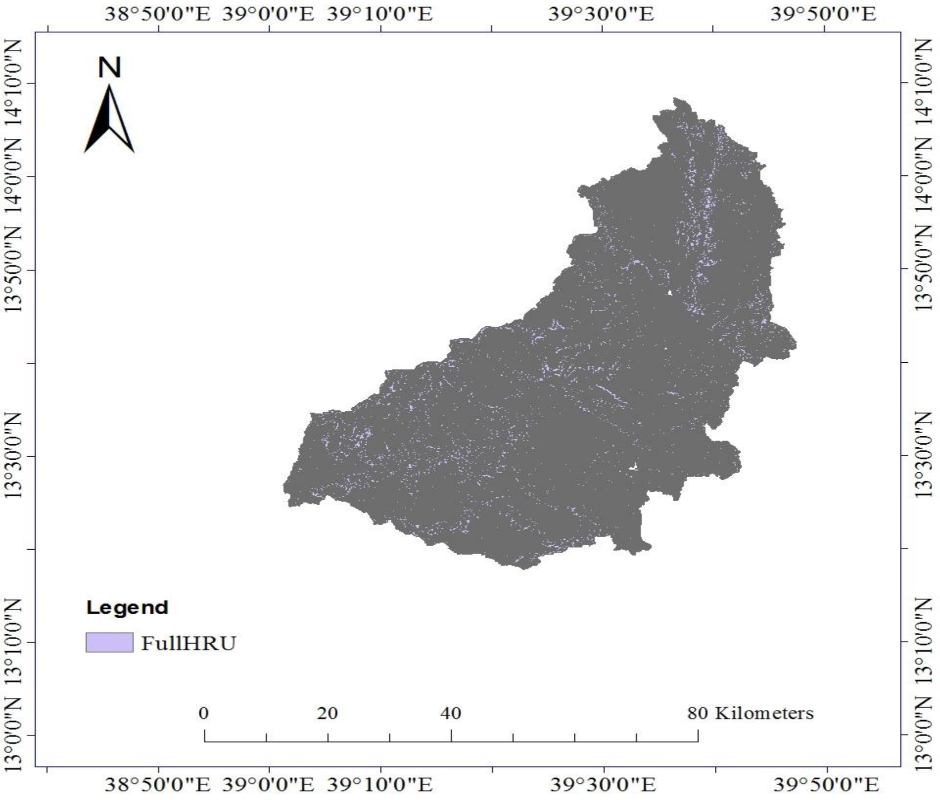

Figure 3-10 Full HRU map of Geba watershed

3.8.3. Weather Data Definition

Weather Generator

Weather generator (WGEN) in SWAT model used to generate climatic data and to fill missing values in the measured records (Sharpley *et al.*, 2003). In Geba watershed some stations have no full weather data like relative humidity, solar radiation and wind speed so by selecting synoptic station which has full weather data to generates the above data using weather generator. For this study meteorological station was synoptic station which has full weather data and generates data for the other stations having precipitation and temperature data only.

The weather generator developer called precipitation statistical analysis model (PCP STAT) was used to statistical analyzing of daily precipitation data needed to create user weather station files for SWAT model. Dew point (dew02) was additional parameter required for weather generator. It is used for generating average daily maximum and minimum temperature, humidity and dew point in month (Liersch, 2003). The available sunshine hour data was converted to solar radiation by using Angstrom- Prescott empirical equation. Weather stations geo-referenced using latitude, longitude and elevation data. Prepared weather parameters have been loaded into a WGEN user of SWAT database and weather data for the rest stations found in the study area automatically generated. The required parameters for the weather generator are listed in Appendix C.

3.9. SWAT Model Simulation

In SWAT model the default input database files are built and the required parameters values can be entered and edited manually then simulation has been taken to generate output of SWAT model. The simulated result cannot be directly used for further analysis (White & Chaubey, 2005). Therefore, the simulated result (stream flow and sediment yield) should be evaluated through sensitivity analysis, model calibration and validation.

3.9.1. Sensitivity Analysis

Watershed simulation influenced by model parameters. According to Dilnesaw (2006) sensitivity analysis is a method of identifying the most sensitive model parameters that have a significant effect in model calibration.

Model sensitivity analysis can be useful in understanding which model inputs are most important and to understand potential limitations of the model. Determination of the most sensitive parameters for watershed is the first step in the calibration and validation process. The modeler should be identifying sensitive parameters to allow the possible reduction in the number of parameters that must be calibrated afterward reducing the computational time required for model calibration (Lijalem, 2006).

In this study, stream flow and sediment yield sensitivity analysis performed by SWAT_CUP using SUFI-2 algorithm. Global sensitivity analysis uses t-stat and p-values to determine the sensitivity of each parameter (Abbaspour, 2014). The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine significance of the sensitivity. A p-value close to zero has more significance (Abbaspour, 2014).

3.9.2. Model Calibration and Validation

Stream flow and sediment data were used for calibration and validation. The model parameters were manually calibrated by using SUFI-2 algorithm in SWAT-CUP for 10 years and the sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity rank. Calibration was done by adjusting the model sensitive parameter values until the simulated results much with observed data.

Model validation is testing of calibrated model results with independent set of measured data (stream flow and sediment data) without any further adjustment of parameters. For this study five years of flow and sediment data used for validation period.

3.10. Evaluation of SWAT Model Performance

The SWAT model performance statistical measures selected for this study includes coefficient of determination (R^2), Nash-Sutcliffe modeling efficiency (E_{NS}), Root mean square error observation standard deviation ratio (RSR) and percent bias (PBIAS) which were used to check the accuracy of stream flow and sediment yield calibration and validation.

Coefficient of determination (R^2): The R^2 value is indicator of the strength of the relationship between the observed and simulated values. R^2 ranges from zero to one with higher values indicating better agreement (Legate and McCabe, 1999).

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Y_{sim} - \bar{Y}_{sim})(Y_{obs} - \bar{Y}_{obs})\right]^2}{\sum_{i=1}^{n}(Y_{sim} - \bar{Y}_{sim})^2(Y_{obs} - \bar{Y}_{obs})^2} \quad (3.8)$$

Nash-Sutcliffe model efficiency (E_{NS})

The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates that the plot of observed values to simulated values of the data fits the 1:1. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash, Sutcliffe, 1970).

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}((Yobs - Ysim)^2)}{\sum_{i=1}^{n}((Yobs - \bar{Y}obs)^2)} \quad (3.9)$$

Percent bias (PBIAS): It measures the average tendency of the simulated data to be larger or smaller than the observed values. PBIAS is expressed in percentage; the lower the absolute value of the PBIAS is the better will be the model performance (Gupta et al., 1999).

$$PBIAS = \left[\frac{\sum_{i=1}^{n} Y_{sim} - \sum_{i=1}^{n} Y_{obs}}{\sum_{i=1}^{n} Y_{Obs}}\right] * 100 \quad (3.10)$$

Root mean square error to observation standard deviation ratio (RSR): It is an error index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

$$RSR = \frac{RMSE}{STDEV_{ob}} = \frac{\sqrt{\sum_{i=1}^{n}(Y_{obs}-Y_{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Y_{obs}-\bar{Y}_{sim})^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.11)}$$

where, Y_{obs} and Y_{sim} are the observed and simulated values respectively, $\bar{Y}obs$ is the mean of n observed values; and $\bar{Y}_{sim}$is the mean of n simulated values. Model performance evaluation criteria (Moriasi *et al*., 2007; Santhi *et al.*, 2001) listed below.

Table 3-4 Model performance evaluation criteria

Rating	R^2	RSR	E_{NS}	PBIAS	
				Flow	Sediment
Very good	0.75 - 1	0 – 0.50	0.75 - 1	< 10%	< 15%
Good	0.65 - 0.75	0.50 – 0.60	0.65 - 0.75	10% - 15%	15% - 30%
Satisfactory	0.50 - 0.65	0.6 – 0.70	0.50 - 0.65	15% - 25%	30% - 55%
Unsatisfactory	< 0.60	≤ 0.70	< 0.50	> 25%	> 55%

3.11. Sediment Yield Reduction Operations in SWAT Model

In SWAT model a number of management operations which are used to reduce sediment yield in the affected sub basins. For this study as discussed in section 2.3, the sediment yield reduction methods terracing, contouring, grassed waterway and filter strip were selected and applied in the SWAT model.

According to Sharpley *et al.* (2003) and White *et al.* (2009), management practices implemented in the critical sediment source areas were more effective reduction sediment yield than randomly assigning the conservation measures spatially. SWAT model is one of the most commonly used watershed models for predicting locations of critical sediment source areas in watersheds and allows the user for evaluating the effects of management practices in improving sediment reduction (Kalin & Hantush, 2009; Singh *et al.*, 2011).In this study, identifying each sub basins sediment yield and grouped based on their sediment yield rate (ton/ha/yr). Sub basins with very high, high and moderate sediment yielding were classified as critical sediment source areas and used for sediment reduction scenario analysis.

3.11.1. Scenario Development

Baseline Scenario

Baseline scenario shows without any consideration of management practice condition observed in the watershed. The simulated result used as a reference point for understanding the effects of simulation results of the sediment reduction scenarios.

Scenario I: Grassed Waterway

Simulation of sediment yield by SWAT model with application of grassed waterway requires adjustment of grassed waterway parameters like length (GWAT_L), average slope (GWAT_S), depth (GWAT_D), average width (GWAT_W), manning's roughness coefficient (GWAT_N) and linear factor for the channel sediment routing (GWAT_SPCON). In this study, the roughness coefficient 0.35 (recommended value by Arnold et al., 2012) and average width of 30m was used. The length, average slope, depth of grassed waterway and the linear factor for the channel sediment routing were automatically adjusted by the model itself.

Scenario II: Filter Strips

Introducing filter strips on sediment source sub basins can reduce sediment yield as the width of strips reduced and increasing the width of the strip beyond 30m is not further effective (Arabi et al., 2008; Yuan et al., 2009). In SWAT model filter strip parameters such as flag for filter strips (VFSI), ratio of field area to filter strip area (FILTER_RATIO), fraction of HRU which drains to most concentrated 10% of the filter strip area (FILTER_CON) and fraction of flow within the most concentrated 10% of filter strip which is fully channelized (FILTER_CH) were adjusted. In the study, filter strips of 10m width was used to simulate this conservation practice for all HRUs of critical sub basins in the watershed.

Scenario IV: Terracing

Terracing constructed across slope on a contour with several regularly spaces. When slope length and steepness increase, there is also runoff and soil loss increase. Slope length can be changed by installing terraces. Terracing in SWAT model simulated by adjusting terracing parameters such as curve number (TERR_CN), USLE practice (TERR_P) factor and slope length (TERR_SL) to simulate the outcome of terracing. In this study, appropriate curve number (TERR_CN) and USLE practice (TERR_P) was set based on land use/cover, soil and slope (Arnold et al., 2011).

Slope length (TERR_SL) should be a maximum of the distance between terraces (Arnold et al., 2011). For this study 50% reduction slope length was used.

Scenario V: Contouring

Contour lines create a water break which reduces the formation of rills and gullies during times of heavy rainfall. These contours are oriented at the right angle to the field slope at any point. Small ridges resulting from field operations increase surface storage and roughness, reducing runoff and sediment losses. For this study, contouring simulated in SWAT model by adjusting curve number (CONT_CN) and USLE practice factor (CONT_P) to account for decreased sediment yield.

4. RESULTS AND DISCUSSIONS

4.1. Stream Flow Simulation

4.1.1. Sensitivity Analysis

Stream flow sensitivity analysis was carried out to identify which model parameter is most sensitive in the Geba watershed. It was done for a period of eighteen years, which includes three years of warm-up period (January 1, 1998 to December 31, 2000), ten years calibration period (January 1, 2001 to December 31, 2010) and five years for validation period (January 1, 2011 to December 31, 2015). Based on the results obtained from sensitivity analysis using SUFI-2, the ranks of parameters assigned depending on p-value and t-stat. P-value indicates significance of sensitivity and t- stat provides the measure of parameter sensitivity (Abbaspour, 2014). Larger in the absolute value of t-stat means the parameter is more sensitive and p-value closer to zero means parameter has more significance. Twenty seven parameters were considered for the model parameterization sensitivity analysis, only twelve of them were effective for monthly flow simulation analysis. The twelve most sensitive parameters most responsible for the stream flow assessment for the Geba catchment have been considered for the model parameterization and calibration process the remaining parameters had no significant effect on stream-flow simulations and depicted under Appendix III. Out of the twelve of the SWAT flow parameters, four parameters showed relatively high sensitivity, seven parameters showed relatively medium sensitivity and the effect of the change of the rest parameters were very small or negligible. Deep aquifer percolation fraction(RCHRG_DP) was the most sensitive of all followed by the ground water determinant parameters for flow in the watershed (GWQMN),The Ground water ‘revap’ coefficient (GW_REVAP) and Land use and antecedent soil water conditions (CN2). Deep groundwater recharge (RCHRG DP) simulates the ground water recharge that is going to deep water storage and will not discharge towards the river. This will have more significant impact on the water balance of small basins than in larger ones. For big watershed RCHRG DP will not be high value as groundwater springs off somewhere in the watershed. Considering the slopes of the basin and its size an appropriate value is calibrated. GWQMN is a threshold depth of water in the shallow aquifer that controls the recharge of groundwater when the aquifer level is higher than GWQMN recharge will occur.

Loss from shallow ground water (GW REVAP) is the water that flows to the soil above the aquifer by the process of capillary rise. These losses describe evapotranspiration from the shallow aquifer which is controlled by the potential evapotranspiration and lost from the system. This loss is high in arid and semi-arid areas and shallow depths of the aquifer.

Soil properties of the watershed (SOL_AWC), Effective hydraulic conductivity of the main channel (CH_K2), Base flow alpha factor(ALPHA_BF), Maximum canopy storage (CANMX), Manning’s roughness coefficient for main channel (CH_N2) and Average slope length (SLSUBBSN) relatively medium sensitivity and the rest parameters are insensitive to runoff simulation. The results of the sensitivity analysis gave the degree of sensitivity of 12 parameters and the parameter bound which was important for the calibration activities. Their ranking and description are exhibited in the next Figure 4-1 and table 4-1.

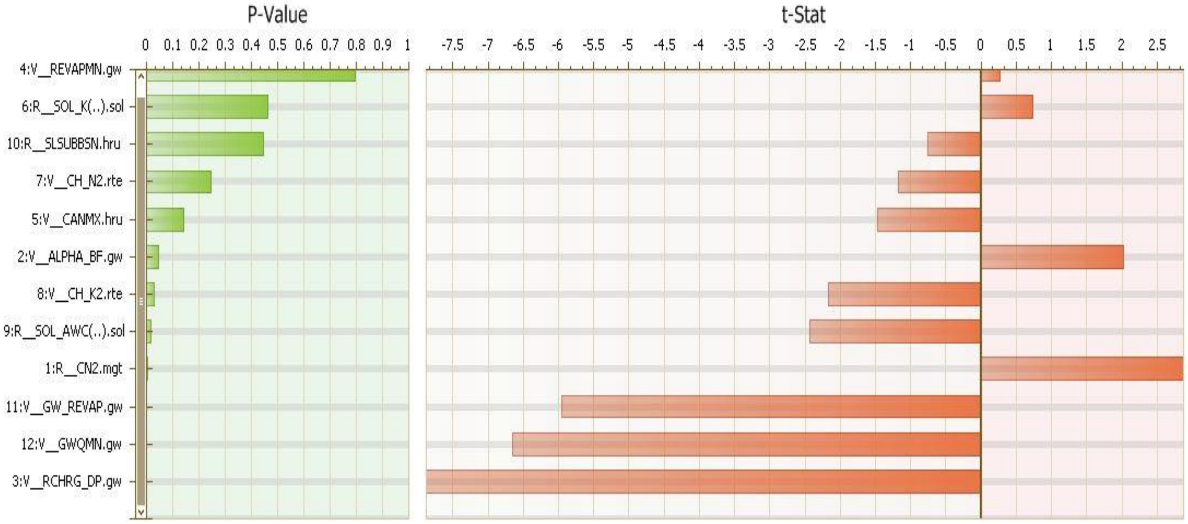

Figure 4-1 Model parameter sensitivity ranking

Note: the t Stat provides a measure of sensitivity (larger absolute values are more sensitive); the p value determines the significance of the sensitivity (a value close to zero has more significance); “R_” and “V_” means relative change and a replacement to the initial parameter values, respectively;

Table 4-1 Identified sensitive flow parameters rank in the Geba watershed

Parameters	Description	t-stat	P-value	Sensitivity	Rank
RCHRG_DP	Deep aquifer Percolation fraction	-7.88	0.00	Very High	1
GWQMN	Threshold depth of water in shallow aquifer required for return flow (mm)	-6.66	0.00	Very High	2
GW_REVAP	Ground water ‘revap’ coefficient	-5.95	0.00	Very High	3
CN2	SCS runoff Curve number for moisture condition II	2.88	0.00	High	4
SOL_AWC	Soil available water capacity (mm H20/ mm soil)	-2.44	0.02	High	5
CH_K2	Effective hydraulic conductivity of the main channel (mm/hr)	-2.17	0.03	High	6
ALPHA_BF	Base flow alpha factor (days)	2.02	0.04	High	7
CANMX	Maximum canopy storage (mm)	-1.48	0.14	Medium	8
CH_N2	Manning’s roughness coefficient for main channel	-1.17	0.24	Medium	9
SOL_K	Saturated Hydraulic conductivity (mm/hr)	0.73	0.46	Low	11
REVAPMN	Threshold water in the shallow aquifer for revap to occur (mm)	0.26	0.79	Low	12

4.1.2. Stream Flow Calibration and Validation

Calibration

The aim of calibration process is to create agreement between the simulated and observed value by adjusting the sensitive flow parameters in the recommended range. The twelve more influential flow parameters from high to medium sensitivity and which were used for further iterations in the calibration periods.

Manual calibration for 10 years’ period from 2001–2010 was performed for the simulated results based on the sensitive parameters rank at monthly time step using Sequential Uncertainty Fitting program (SUFI).

The uncertainty of the calibrated and validated model in SUFI-2, 95PPUs, is the combination of uncertainties in the input data, model structure and model parameters. Uncertainty measure of SUFI- 2 showed that P-factor of 0.51 and R-factor of 0.26 for calibration at the Geba gauging station. It means that about 51% of data of the calibration was bracketed by the 95PPU band with a better strength of estimation (R-factor <1) in this cases. This indicates the SWAT model has acceptable level of uncertainty for estimation of flow of the study watershed. The performance of the calibrated simulations was checked by NSE, R^2, RSR and PBIAS as presented below in table 4.2. And the monthly calibrated results of stream flow are presented below in Figures 4.2.

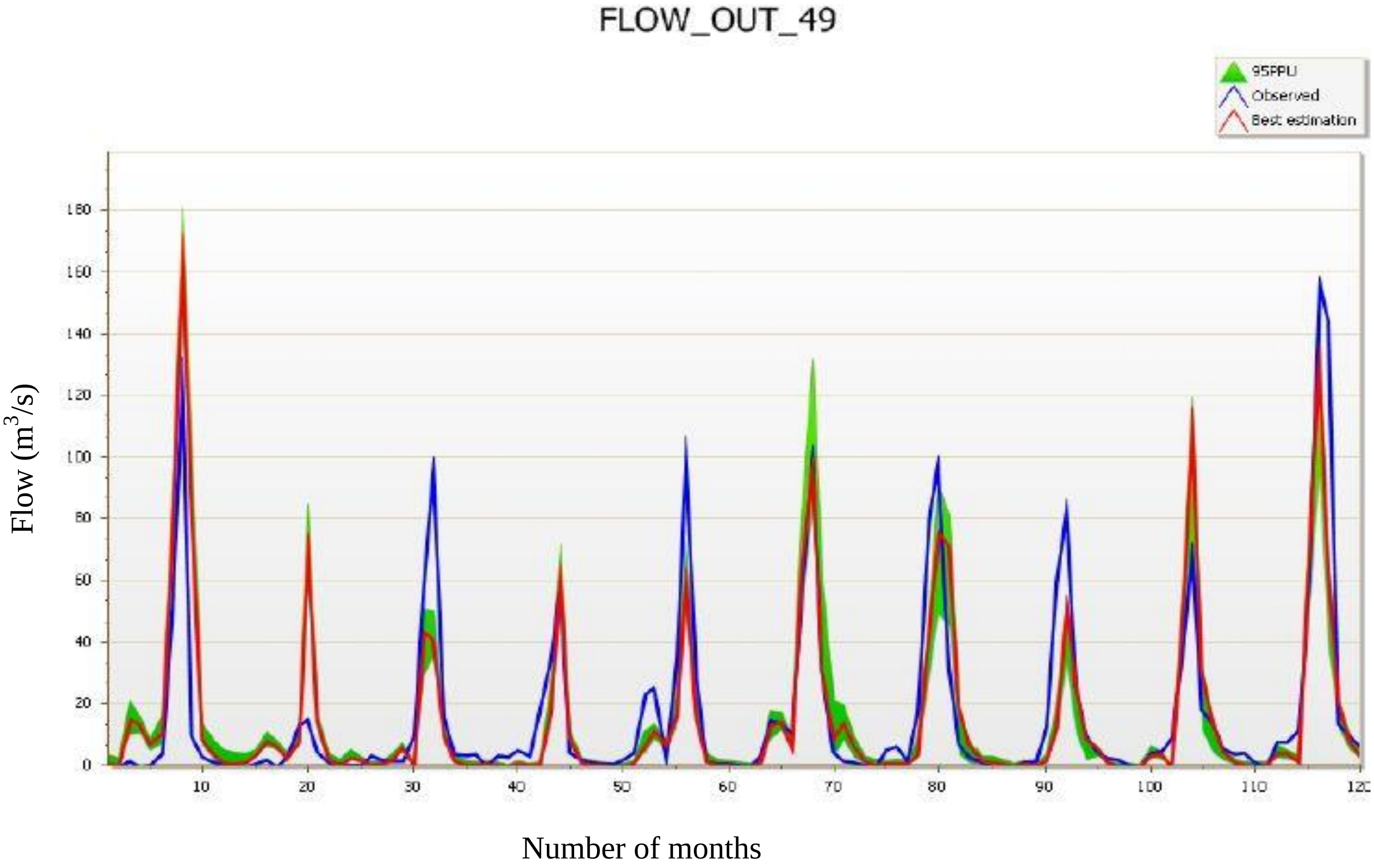

Figure 4-2 Monthly observed and simulated flow hydrograph during calibration period

Validation

Validation involves model run with unchanged flow parameters which were adjusted during calibration process. During the validation period from January 1, 2011 to December 31, 2015, the performance of the model was evaluated for the Geba watershed.

According to Moriasi et al. (2007) and Santhi et al. (2001) the model performance evaluation criteria (Section 3.10; Table 3.5), the flow validation for the Geba watershed showed a good performance with R^2 of 0.74, E_{NS} of 0.7, RSR of 0.55 and PBIAS of 3.6% for validation. The monthly validated results of stream flow are presented below in Figures 4.3.

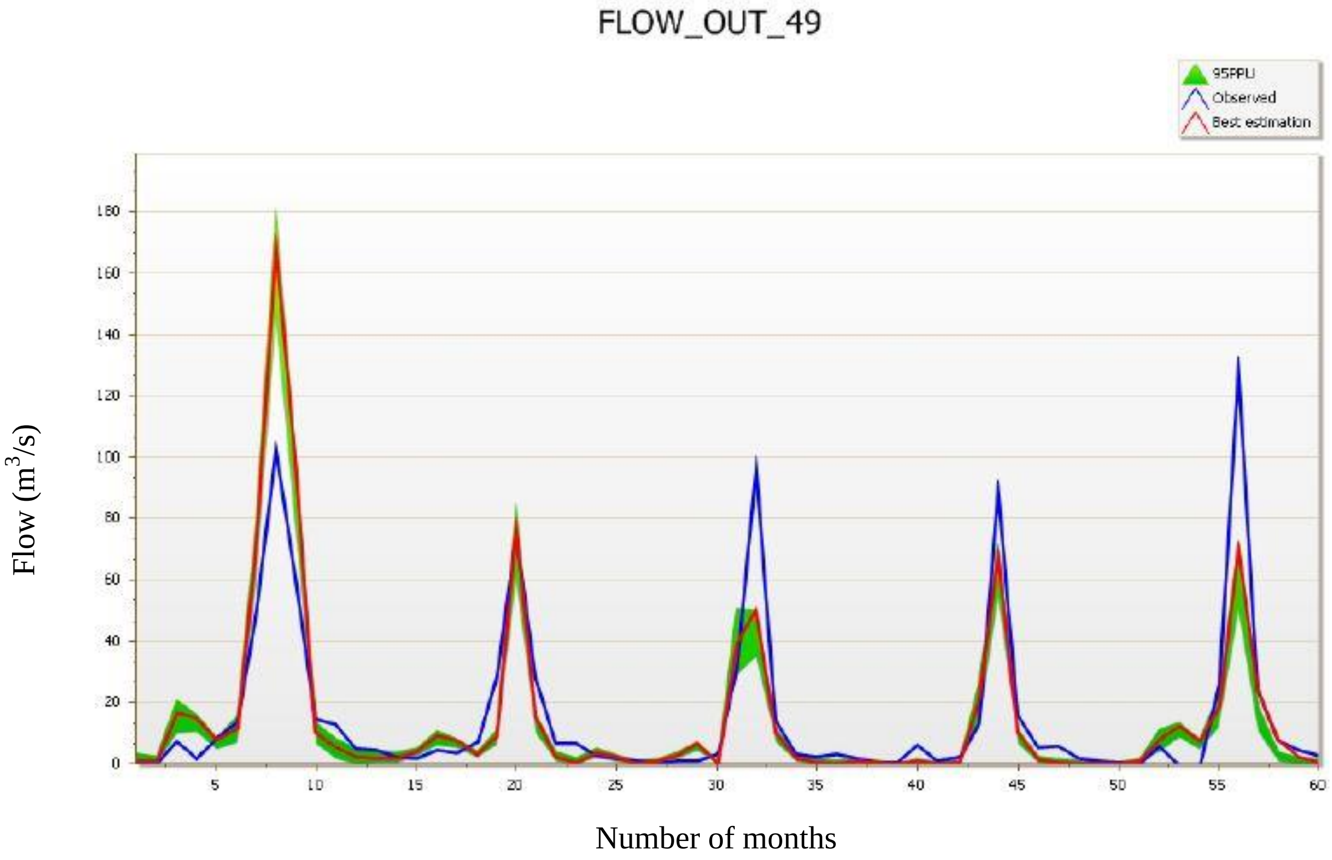

Figure 4-3 Monthly observed and simulated flow hydrograph for validation period

Table 4-2 Calibrated and validated model performance indicators value for monthly observed and simulated flow and model uncertainty measures

Gauging Stations	Simulation period	Uncertainty measures		Model performance indicators			
		P- factor	R- factor	R^2	E_{NS}	RSR	PBIAS
Outlet of watershed	Calibration (2001-2010)	0.51	0.26	0.71	0.70	0.55	6.7
	Validation (2011-2015)	0.5	0.21	0.74	0.70	0.55	3.6

From the Figure 4.2 and Figure 4.3 it was observed that for both hydrograph during calibration and validation Peak observed and simulated flow occurs in both hydrograph in (2001, 2010, 2011 & 2015) and 2011 respectively. Also the hydrographs (Figure 4.2 and Figure 4.3) showed that the model slightly overestimated flow from the watershed in some of the year and underestimated in some years.

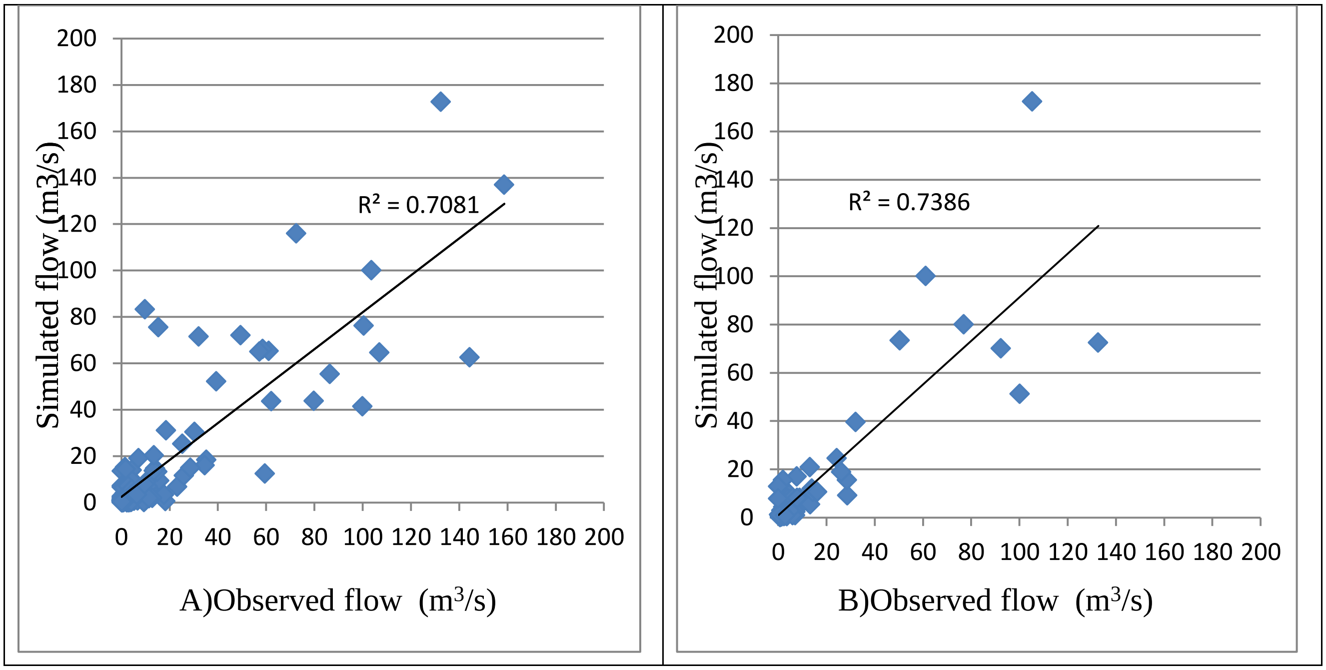

Figure 4-4 Coefficient of determination (R2) between observed and simulated flow

From the above observed versus simulated scatter plots (Figure 4.3 and Figure 4.4) A) for calibration and B) for validation it is observed that more values distributed above 45^0 (1:1) line and shows the model slightly overestimated the simulated flows.

4.2. Sediment Yield Simulation

4.2.1. Sensitivity Analysis

Sensitivity analysis was performed for the Geba watershed using the monthly observed sediment yield for identifying the most sensitive parameter and for further calibration and validation of the simulation of sediment yield. During sensitivity analysis of sediment six sediment parameters were checked for sensitivity and sensitive parameters were identified (Spcon, Ch_cov, USLE_P, Ch_erod, USLE_K, Spexp and PHOSKD). From these parameters the first three (Spexp, Spcon and USLE_P) were highly sensitive and given to high priority for calibration.

Table 4-3 Identified sensitive sediment parameters rank in the geba watershed

Parameter Name	Description	Parameter Range	Calibrated Value	t-stat	p-value	Rank
Spexp	Exponent factor for channel sediment routing	1 – 2	1.920	-0.792	0.436	1
Spcon	Linear factor for channel sediment routing	0.0001 – 0.01	0.008	-0.791	0.437	2
USLE_P	USLE support practice factor	0 – 1	0.133	-0.584	0.565	3
Ch_cov	Channel cover factor	0 – 1	0.117	0.252	0.803	4
Ch_erod	Channel erodibility factor	0 – 1	0.972	-0.071	0.944	5
PHOSKD	Phosphorus soil partitioning coefficient.	100-200	145.492	-0.056	0.956	6

4.2.2. Sediment Yield Calibration and Validation

Once the sediment sensitive parameters were identified during sensitivity analysis, calibration process took place. Similar to flow, the model was calibrated for sediment yield from 2001 to 2010. Sediment yield calibration and parameters adjustment continued iteratively until simulated and observed sediment yield fitted. Sediment yield Validation conducted with sediment data for the periods 2011 to 2015 without further adjustment of calibration fitted parameters. The model efficiency of predicting the sediment yield and uncertainty of its prediction for calibration and validation was checked through model performance evaluation criteria and model uncertainty measures.

According to model performance evaluation criteria (Section 3.10; Table 3.5) the sediment simulation result for calibration and validation at Geba gauging station showed good performance with R^2 of 0.72, E_{NS} of 0.66, RSR of 0.66 and PBIAS of -8.7% for calibration and R^2 of 0.79, E_{NS} of 0.72, RSR of 0.52 and PBIAS of -11.3% for validation.

Uncertainty measures of SUFI-2 showed that P-factor of 0.76 and R-factor of 0.36 for calibration and P-factor of 0.73 and R-factor of 0.51 for validation at the Geba gauging station. This indicated that about 76 % and 73% (Out of a perfect 100 %) of the sediment data could be bracketed by the 95PPU band with a better strength of estimation 0.36 and 0.51 (close to a perfect 0) during calibration and validation respectively. The performances of the calibrated and validated simulations were also checked by NSE, R2, RSR and PBIAS.

Table 4-4 Performance evaluation of calibrated and validated sediment yield

Gauging Stations	Simulation period	Uncertainty measures		Model performance indicators			
		P- factor	R- factor	R^2	E_{NS}	RSR	PBIAS
Outlet of watershed	Calibration (2001-2010)	0.76	0.36	0.72	0.66	0.61	-8.7
	Validation (2011-2015)	0.73	0.51	0.79	0.72	0.53	-11.3

Calibrated and validated sediment yield results were used to develop sediment yield graph (Figure 4.5 and Figure 4.6) for each gauging stations. The developed sediment graph was used to compare how much the simulated sediment result fitted with the measured sediment value.

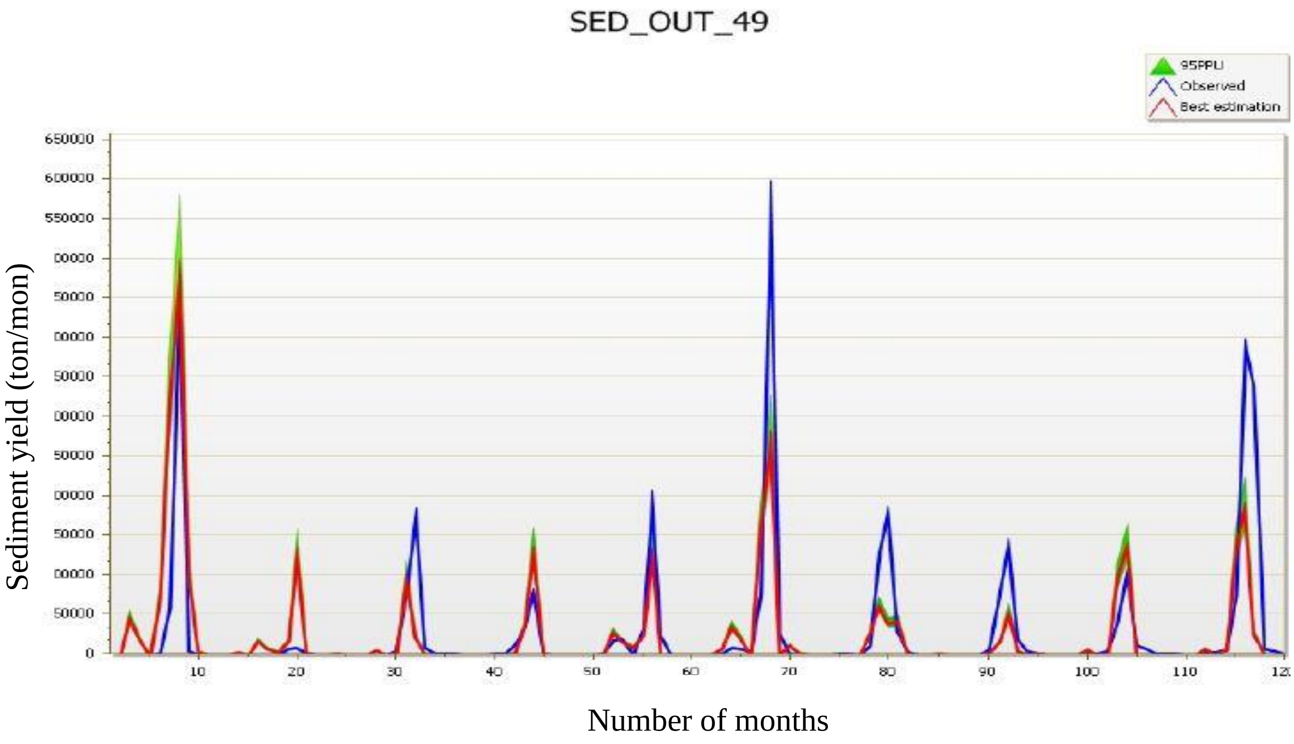

Figure 4-5 Monthly observed and simulated sediment yield graph during calibration period

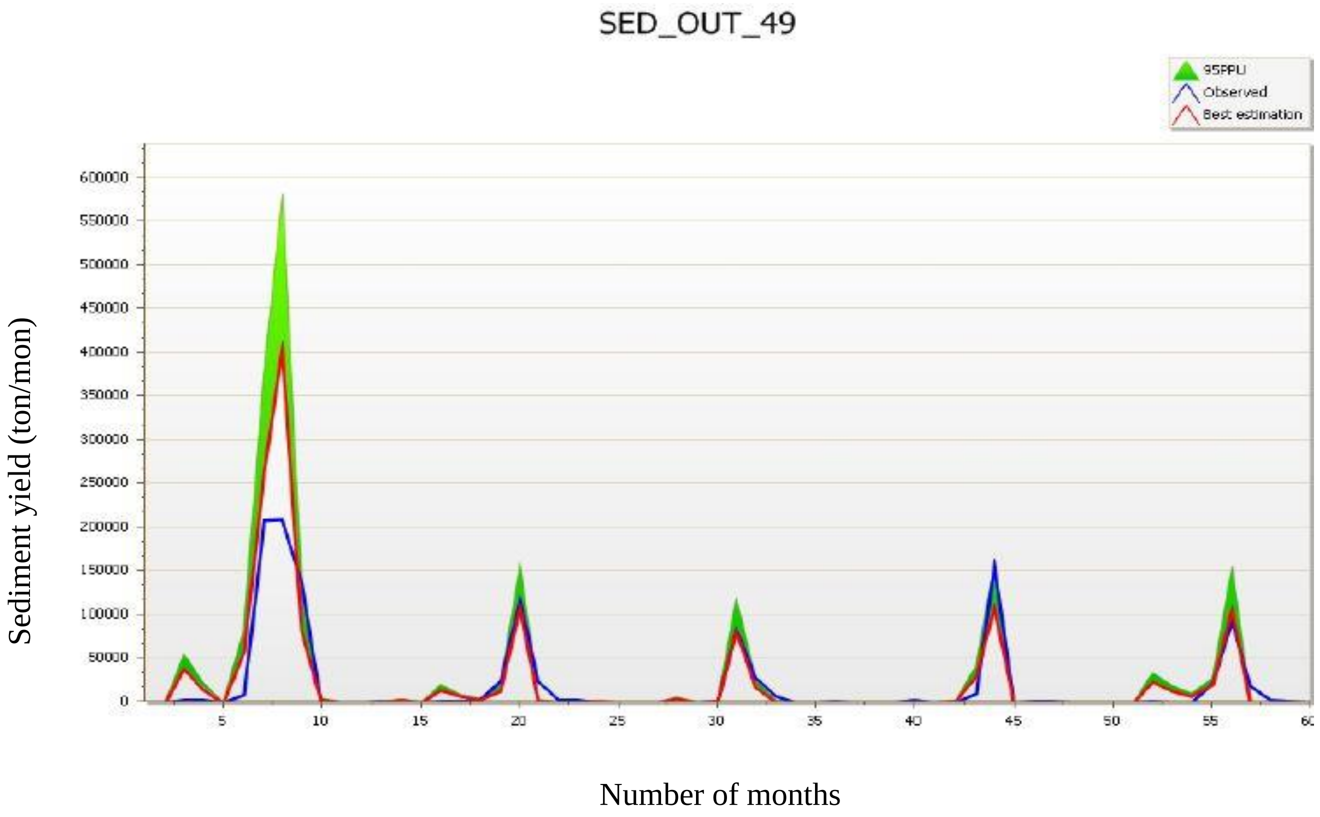

Figure 4-6 Monthly observed and simulated sediment yield graph during validation period

From Figure 4.5 and Figure 4.6 above it was observed data for both sediment graphs during calibration and validation period has the same characteristics and shape but they are different in their magnitude. Peak observed and simulated sediment yield occurs in both sediment graphs since 2010 and A2010 respectively. Also the above sediment graphs (Figure 4.5 and Figure 4.6) showed that the model slightly overestimated sediment yield from the watershed in most of the year and underestimated in some years. This is the same discussion with the flow hydrograph discussed in section 4.2.2 due to the sediment yield is direct proportional to generated erosion and flow in the river.

Average annual sediment yield from Geba watershed after calibration and validation at Geba gauging station was total sediment loading 18.440 ton/yr of 2001 to 2015.

4.3. Stream Flow

The delineation of sub-basins in SWAT is based on an automatic procedure using DEM data. This tool carries out advanced GIS functions to aid in segmenting the watershed into several hydrological connected sub-watersheds for use in modeling with SWAT. SWAT calculates the stream flow within each hydrological response units (HRU's) within each sub-basin.

The GIS tool combines the slope, land use / cover, soil and river layers as a major factor which contributes to runoff and soil erosion. Based on the model's prediction, stream flow in the sub basin varies from HRU to HRU depending on the type of soil, slope and land use in each HRU. From this stream flow was estimated (simulated) for outlet of Geba watershed is 28.04m^3/s.

4.4. Spatial and Temporal Variability of Sediment Yield in the Watershed

Spatial variability of sediment yield in the watershed of each sub basins due to the factors which affecting the sediment yield variability for instance land use/cover, type of soil, soil erodibility, rainfall distribution, topography and management practices. Thus, the sediment yield at each sub basin was not uniform.

To get average annual sediment yield spatially with sub basins level, the SWAT model was run annually (1998-2015) for eighteen years. Spatial variability of sediment yield for the Geba watershed was identified from the simulated annual sediment yield and the result shows the ranges was between 0.15 to 19.09 tons/ha/yr. with average of 5.33 ton/ha/yr for the sub-basins. Spatial variability of sediment yield from Geba watershed was identified from the sediment outputs for each of the sub-basins. Variability of sedimentation rate was also identified from the potential areas. SWAT simulated annual sediment yields for the Geba watershed for the years 1998-2015 were in the range of 0.15 to 19.09ton/ha/yr. The average annual sediment yields of each sub basins are listed in table below.

Table 4-5 Average annual sediment yield of each sub basin

Sub basin	Sediment Yield (ton/ha/yr.)	Sub basin	Sediment Yield (ton/ha/yr.)	Sub basin	Sediment Yield (ton/ha/yr.)
1	6.63	8	19.09	15	16.66
2	12.77	9	1.54	16	1.66
3	4.28	10	18.29	17	4.06
4	12.18	11	13.13	18	2.44
5	2.83	12	1.28	19	10.91
6	5.49	13	1.16	20	8.94
7	2.53	14	15.21	21	1.26
22	1.42	29	0.94	36	13.20
23	17.38	30	0.31	37	1.80
24	1.25	31	7.14	38	4.78
25	1.08	32	0.26	39	0.18
26	0.86	33	5.58	40	0.18
27	5.11	34	13.78	41	10.74
28	0.48	35	0.25	42	10.18
43	0.17	50	13.41	57	3.76
44	0.16	51	0.15	58	3.32
45	0.18	52	12.57	59	7.07
46	0.16	53	1.22		
47	0.22	54	3.30		
48	0.94	55	6.21		
49	0.15	56	2.18		

The average annual yield of sediment transport out of reach during the time step in metric tons for each sub-basin was used to generate the sediment source maps (figure4-7). The soil erosion or sedimentation levels in the basin were classified as Low (0-6 t/ha/yr), moderate (6 – 12t/ha/yr), high (12 – 18t/ha/yr) and very high (18 <t/ha/yr). The sub basins which are supplying high amount of sediment to the river system (e.g. Sub basins 2, 4, 8, 10, 11, 14, 15, etc.), have land use and soil type and slope nature that facilitate the erosion of the soil by different agents. In general the highly eroded and sediment generating sub basins are those having more of bare land coverage, 7.5% slope that accounts for more than 52% of its area and easily erodible soil type.

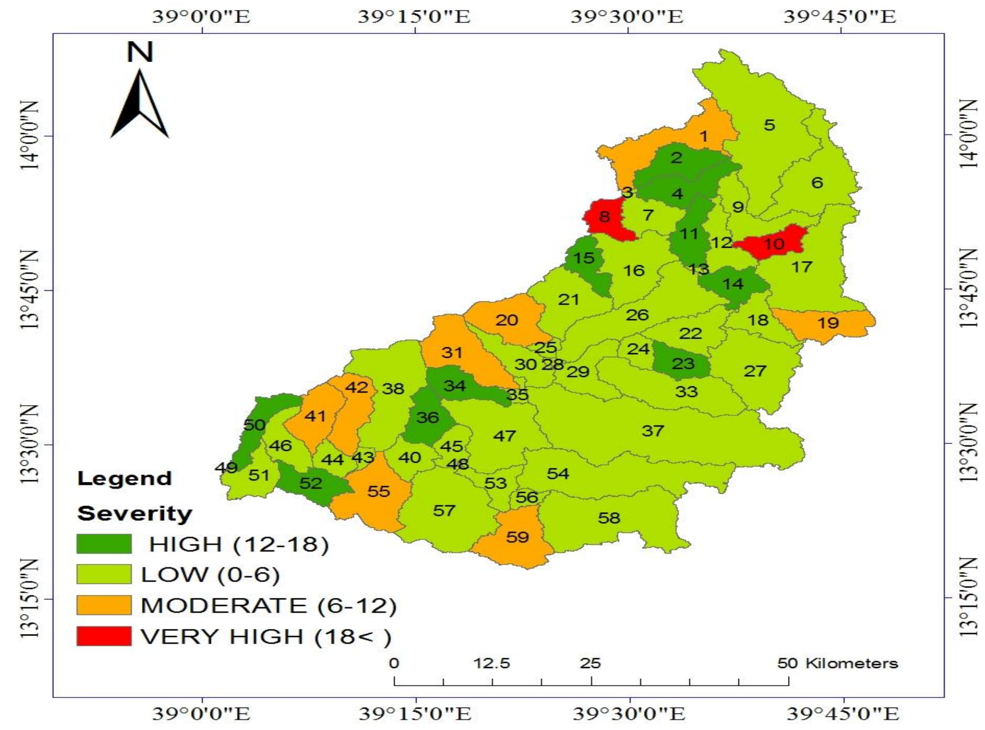

Figure 4-7 Spatial variability of sediment yield map in Geba watershed

Temporal variability

Temporal variability of sediment yield with relation to precipitation and surface runoff at Geba watershed were shown Figure 4.8 below respectively.

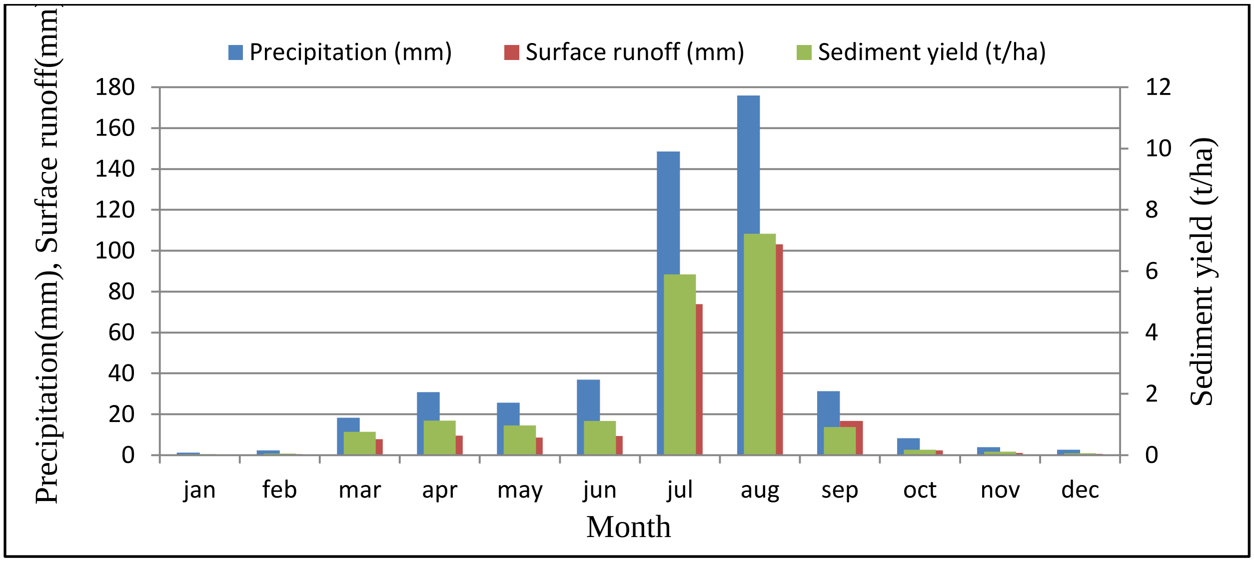

Figure 4-8 Sediment yield temporal variability with relation to precipitation and surface runoff at Geba gauging station

4.4. Sediment Yield Reduction Methods

Once the critical source areas of sediment yield identified, then it is possible to develop sediment yield reduction methods for those highly sediment producing sub basins. In this study, four management operations (scenarios) were developed and compared with baseline scenario. These scenarios were scenario I (Grassed waterway), scenario II (Filter strip), scenario III (Terracing) and scenario IV (Contouring). Baseline scenario was used as a reference for comparisons of the effectiveness of the developed sediment reduction scenarios.

Baseline scenario

The baseline scenario was assumed to reflect the current land management practices without conservation measures. In the baseline scenario, tewelve critical sediment source sub basins were identified for simulation of four selected sediment reduction scenarios. Each scenario was then run for the same simulation period (1998-2015) to provide a consistent basis for comparison of the scenario results. Out of twelve critical sub basins, two were very high (18< ton/ha/yr.), ten were high (12-18 ton/ha/yr.)

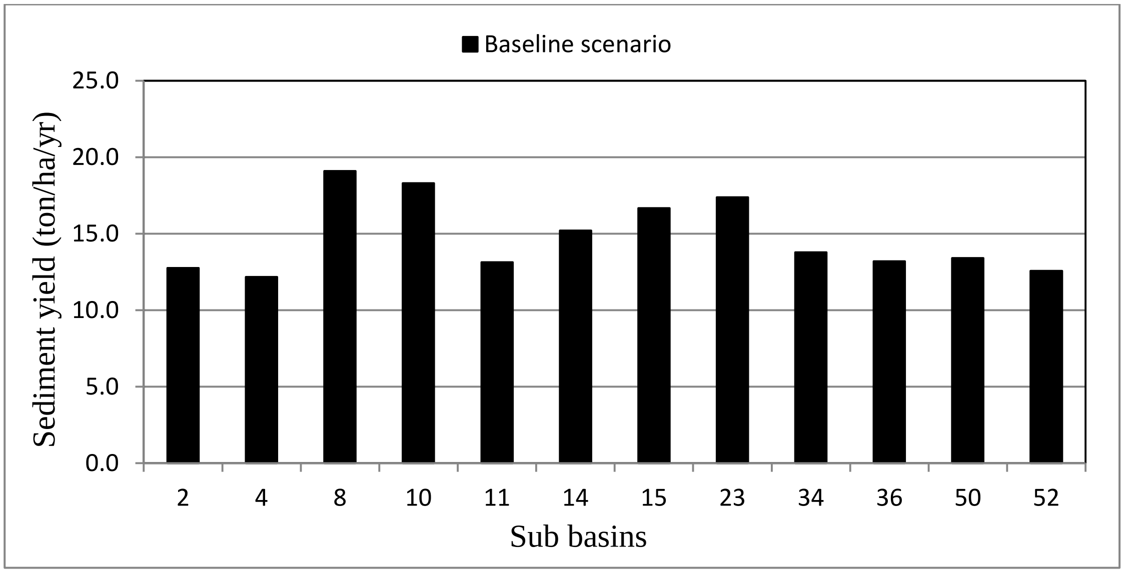

Figure 4-9 Baseline scenario (existing) sediment yield rate (ton/ha/yr)

Scenario I: Grassed Waterway

Introducing grassed waterway for sediment prone areas reduces sediment yield by protecting channel erosion, intercepting sediment particles collected and transported through the channels and used for safe disposal of water to the streams. In this study applying grassed waterways for the critical sediment source sub basins with an average width of 30m, reduced average annual sediment yield from 14.8ton/ha/yr to 11.8ton/ha/yr which accounts 20.3% of sediment yield decreased. In this scenario all treated twelve sub basins turned from the category of very high and high sediment yielding to the category of high and moderate sediment yielding (Figure 4.12).

The study conducted by Tesfu (2014), on Kesem Dam watershed one of the tributaries of Awash River introducing grassed waterway can reduce the average annual sediment yield rate of the treated sub basins by 57.34% from the baseline condition. Studies (Mwangi et al., 2015) on Sasumua watershed, Kenya, shows application of grassed waterway can reduce the sediment yield at the outlet of watershed by 54%. Also study of Manawko (2017) on proposed middle Awash Dam watershed shows applying grassed waterway with an average width of 30m for critical sediment source sub basins reduced 76% of average annual sediment yield. The result of this study also slightly agreed with the above three studies.

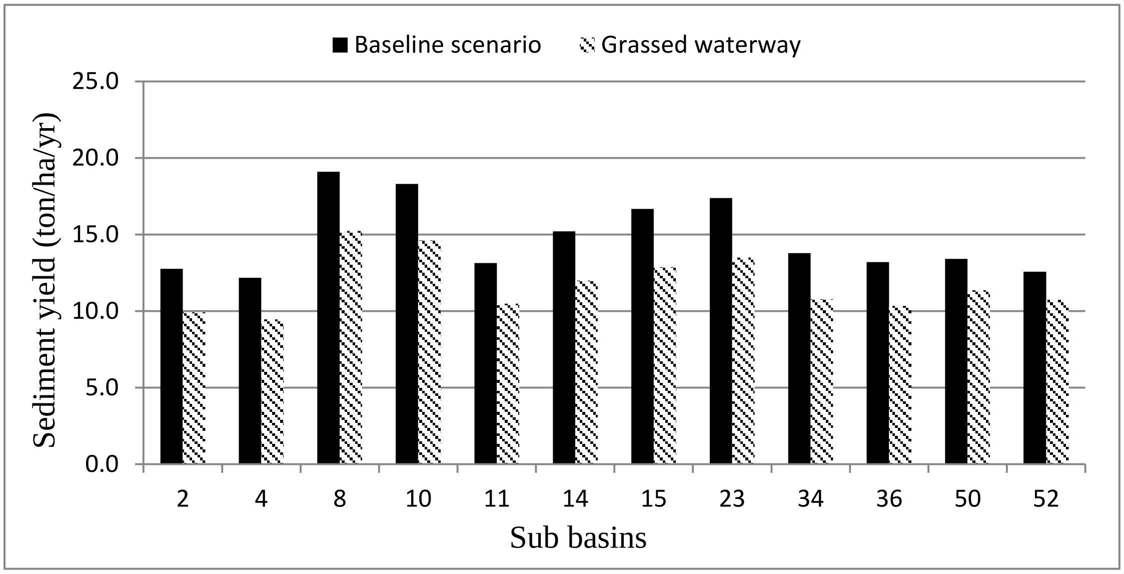

Figure 4-10 Mean annual sediment yield reduction due to application of grassed waterway

Scenario II: Filter strip

Applying filter strips with 10m width for the twelve sediment prone sub basins brought a slight reduction of average annual sediment yield by decreasing from 14.8ton/ha/yr to 6.7ton/ha/yr which accounts 54.7% reduction. After application of filter strips, eleven treated sub basins turned from the category of very high to high, moderate and low to a category (Figure 4.13).

The study of Manawko (2017) on proposed middle Awash Dam watershed, Ethiopia by applying 10m filter strips has reduced the average annual sediment yield at the entire watershed level by 25.8%. And also study conducted by Andualem and Gebremariam (2015) on Gilgel Abbay watershed, Ethiopia found that applying 10m filter strips reduced 23.74% of the average annual sediment yield at the outlet of watershed. The result of this study had some extent agreed with above studies.

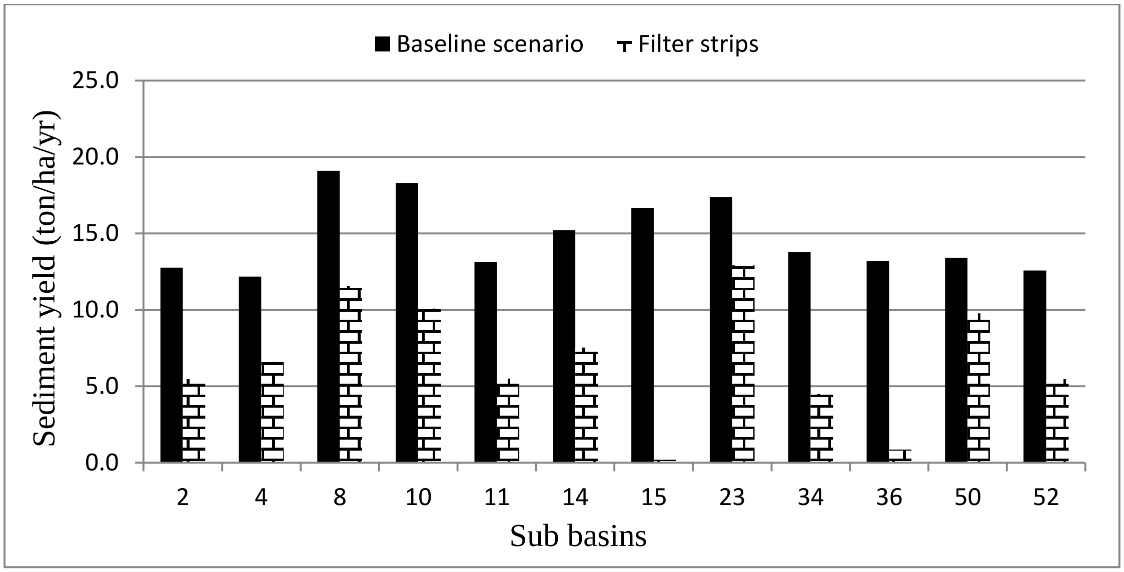

Figure 4-11 Mean annual sediment yield reduction due to application of filter strip

Scenario III: Terracing

Terracing practice used as part of a resource management system constructed to reduce erosion and sediment yield in the watershed by reducing slope length and steepness of sub basins. Simulation of terracing on the selected critical sediment source sub basins by adjusting the curve number (TERR_CN), USLE crop practice (TERR_P) and slope length (TERR_SL) significantly reduced average annual sediment yield rate by 78.8% (14.8ton/ha/yr to 3.2ton/ha/yr). After application of terraces all critical sub basins turned from the category of very high and high to category of moderate and low sediment yielding (Figure 4.14).

The studies conducted by Mwangi et al. (2015) evaluation of agricultural conservation practices on ecosystem services in Sasumua watershed, Kenya using SWAT model shows introducing terraces reduced average annual sediment yield for critically affected sub basins by 85% and concluded that application of terracing on the critically affected sub basins is the effective land management practice to reduce sediment yield. The studies of Tesfu (2015) on modeling runoff and sediment yield of kesem dam watershed, Awash basin, Ethiopia using SWAT model after application of terracing on the critically affected sub basins sediment yield reduced by 73.11%. Also the study conducted by Manawko (2017) using SWAT model on proposed middle Awash Dam watershed shows introducing terracing to critical sediment source areas reduces average annual sediment yield by 83.7%. Thus, this study result was almost agreed with those research results.

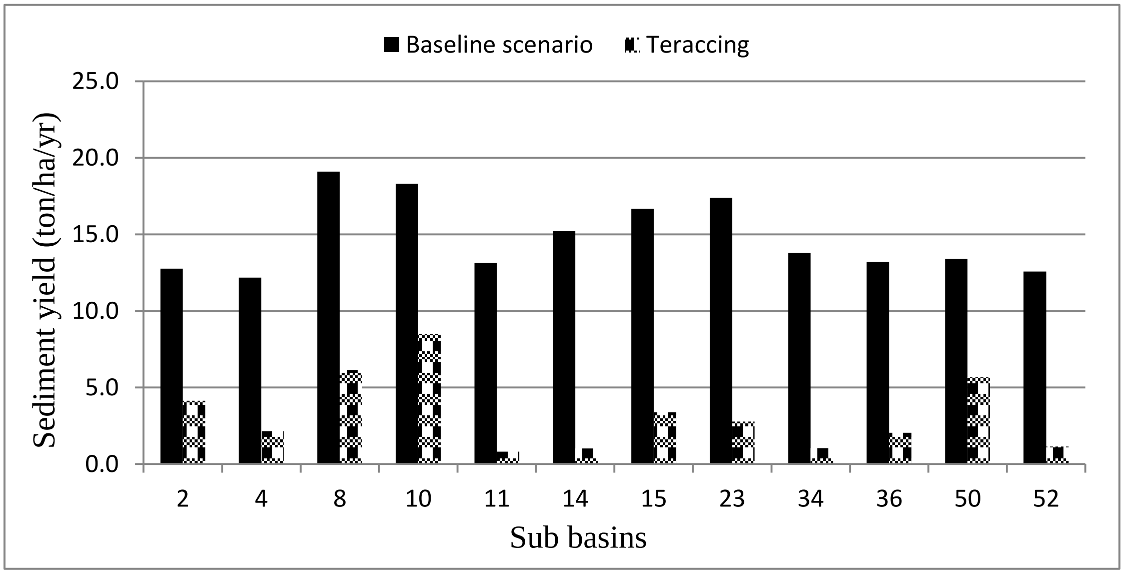

Figure 4-12 Mean annual sediment yield reduction due to application of terracing

Scenario IV: Contouring

Installing contours on agricultural lands reduces speed and erosion power of runoff by increasing surface roughness. Simulation of contouring on critical sub basins carried out by adjusting the curve number (CONT_CN) and USLE crop practice (CONT_P) parameters and reduced average annual sediment yield from 14.8ton/ha/yr to 5.7ton/ha/yr which accounts 61.57% reduction at critical sub basins level. After application of contours eleven critical sediment source sub basins turned to the category of low and very low sediment contributing sub basins (Figure 4.13).

The study of Czapar et al. (2005) shows contouring can reduce 50% of average annual sediment yield for treated sub basins. Study conducted by Manawko (2017) showed applying contouring on proposed middle Awash Dam watershed can reduced 61.1% of average annual sediment yield for critical sediment source sub basins. Also study conducted by Daggupati (2012) concluded contour farming can reduce the sediment yield rate for Black Kettle Creek watershed, Central Kansas, with an average of 62.5%. This study result also slightly agreed with those studies.

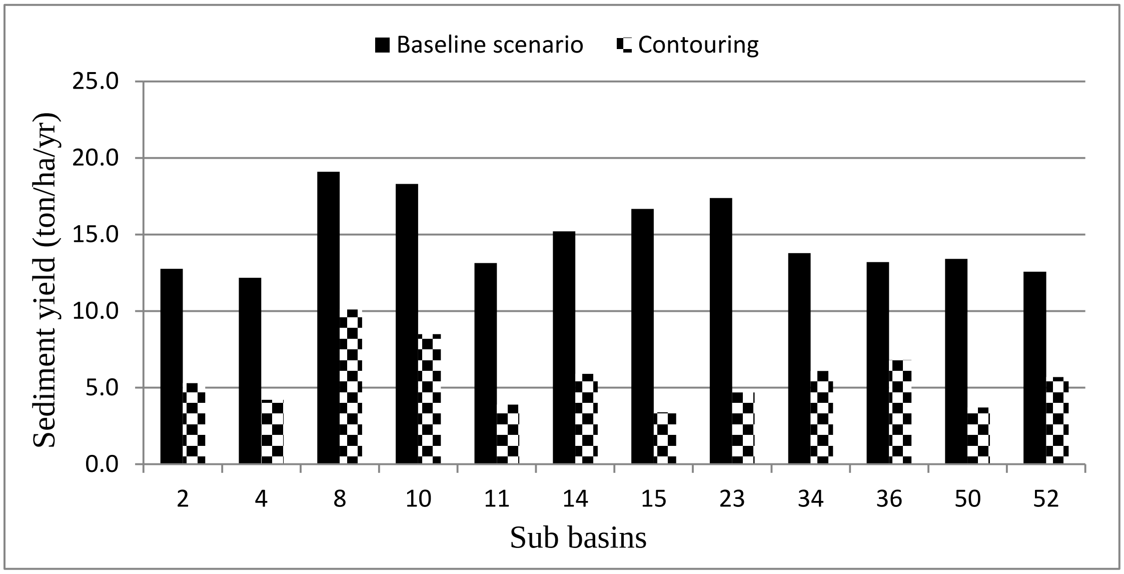

Figure 4-13 Mean annual sediment yield reduction due to application of contouring

Table 4-6 Summary of developed scenarios result for twelve sub basin

Sediment source sub basins	Baseline condition	Average annual sediment yield (ton/ha/yr.) reduction			
		Grassed waterway	Filter strip	Terracing	Contouring
2	12.8	9.9	5.5	4.1	5.3
4	12.2	9.5	6.6	2.2	4.2
8	19.1	15.2	11.6	6.2	10.1
10	18.3	14.6	10.1	8.5	8.5
11	13.1	10.5	5.5	0.8	3.9
14	15.2	12.0	7.5	1.0	5.9
15	16.7	12.9	0.2	3.4	3.4
23	17.4	13.5	12.9	2.8	4.7
34	13.8	10.8	4.5	1.1	6.1
36	13.2	10.3	0.9	2.1	6.8
50	13.4	11.4	9.8	5.7	3.7
52	12.6	10.7	5.5	1.2	5.7
Average	**14.8**	**11.8**	**6.7**	**3.2**	**5.7**
%age	**100%**	**20.3%**	**54.7%**	**78.8%**	**61.57%**

.

The developed sediment yield reduction scenarios result showed that average annual sediment yield reduction at entire watershed level after application of grassed waterway, filter strips, terracing and contouring were 20.3%, 54.7%, 78.8% and 61.57% respectively.

4.5. Comparison of Scenarios Result

Four scenarios were developed in the above section 4.5 and it is possible to compare those scenarios result to select best one for the affected sub basins. It was observed that contouring and traracing are better sediment reduction of very high sub basin 8 and 10 than the other scenarios respectively. On the other hand, filter Grassed waterway has least sediment reduction in all sub basins and terracing has best sediment reduction in all sub basins except sub basins10 and50.

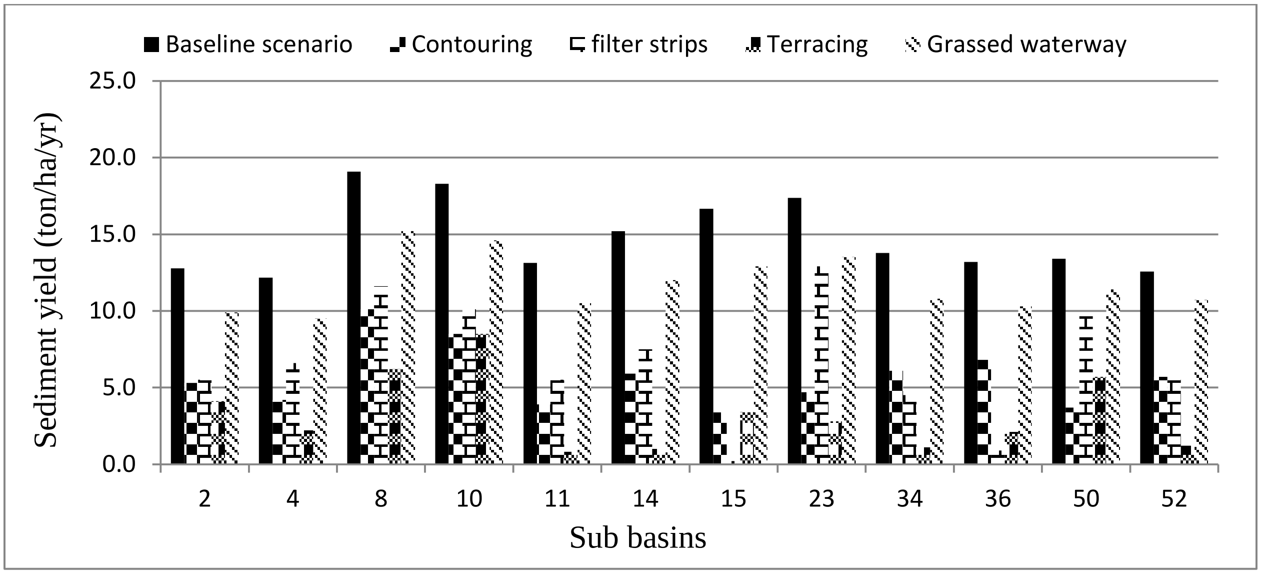

Figure 4-14Scenarios comparison with their sediment yield reduction on selected sub basin

Thus, terracing was relatively more sediment reduction practices on the majority of the affected sub basins in the study watershed.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In the study application of Arc SWAT model was applied to generate runoff and sediment under recent land use land cover, soil, metrological, hydrological and limited sediment data (used for calibration and validation) and identification of sediment prone areas, sediment reduction scenarios and comparison of scenarios result were carried out.

Based on SWAT model watershed delineation of Geba watershed the catchment area was 3690.54Km^2. Overlaying land use, soil and slope were performed to generate HRUs. Climatic data from January 1998 - December 2015 were inputs during SWAT model simulation. The calibration and validation carried out from January 2001 - December 2010 and January 2011 - December 2015 respectively on monthly basis of stream flow and sediment data using manual calibration with Sequential Uncertainty Fitting (SUFI-2) in SWAT- CUP.

The sensitive flow parameters that control runoff process and sediment yield in the watershed were found to be Deep aquifer Percolation fraction (RCHRG_DP), Threshold depth of water in shallow aquifer required for return flow (mm) (GWQMN), Ground water 'revap' coefficient (GW_REVAP) and Curve number (CN2). The sediment flow sensitivity analysis result also showed that the sediment loss from the watershed is sensitive to both HRU properties and channel properties (exponential factor for channel sediment routing (SPEXP), linear factor for channel sediment routing (SPCON) and USLE support practice factor (USLE_ P)).

In general, the model performance assessment indicated a good correlation and agreement between the monthly measured and simulated flows and satisfactory sediment. Therefore, the model is capable to estimate stream flow and sediment yield composition and contributions from the spatial data. Hence, the model simulations can be used for various water resource management and development aspects.

The developed sediment yield reduction scenarios result showed that average annual sediment yield reduction at entire watershed level after application of grassed waterway, filter strips, terracing and contouring were 20.3%, 54.7%, 78.8% and 61.57% respectively. Thus, the result indicating that terracing was relatively more sediment reduction practice than other conservation measures on the majority of the affected sub basins in the study watershed.

5.2. Recommendation

Based on results of this study, the following recommendations are drawn out for further studies:

- For this study, input data (hydro-meteorological data) collected from the concerned offices and authorities were used to simulate the SWAT model in the study watershed. In order to improve the model performance, it is highly recommended that the hydrometric and meteorological gauging stations should be improved both in quality and quantity.
- The sediment gauging stations in this watershed are recorded small number of sediment data. Hence, it is better to increase number of recorded time and number of hydrological stations to get better result.
- In this study, the amount of sediment yield was estimated with identification of sediment prone areas and management practices developed for those affected sub basins in current watershed condition. It is recommended that for the future study, estimating the amount of sediment yield under changing climate and land use land cover is possible in the study watershed.
- Sediment reduction practices such as grassed waterway, filter strips, terracing and contouring were developed in this research work. In order to improve the sediment reduction in the Geba watershed additional management practices should be established from SWAT model management operation or other soil and water conservation measures should be introduced.
- The developed and evaluated management scenarios showed as effective for sediment yield reduction. Therefore, the study was paramount important to different stakeholders for plan and implementation of erosion and sediment yield reduction on the Geba watershed.

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APPENDICES

Appendix A: Monthly measured flow (m^3/sec) at Geba gaging station (1998 – 2015)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	0.81	0.33	8.21	5.87	11.86	7.74	69.11	94.38	18.60	4.04	2.08	1.53
1999	0.86	0.33	0.16	3.66	0.91	3.14	23.86	61.42	12.68	5.41	2.24	1.48
2000	0.75	0.33	0.29	1.44	1.34	3.59	19.66	30.71	4.94	1.74	1.39	0.51
2001	0.20	0.20	1.60	0.20	0.30	4.10	49.40	132.40	9.80	3.10	1.50	0.80
2002	0.50	0.20	1.00	2.40	0.20	3.10	13.20	15.40	4.40	1.40	0.70	0.30
2003	0.30	3.40	2.00	1.80	1.60	9.90	62.10	99.90	15.70	4.10	3.70	3.90
2004	0.50	3.30	3.20	5.30	3.50	18.30	35.30	61.10	4.50	2.10	1.20	0.90
2005	0.70	2.30	4.40	23.20	25.90	4.40	34.60	106.90	28.60	1.60	0.90	0.70
2006	0.40	0.20	3.70	14.90	14.00	11.00	58.60	103.70	30.30	4.40	1.90	1.10
2007	0.30	0.10	5.30	6.70	2.20	17.70	79.80	100.40	32.10	7.10	2.90	1.40
2008	0.20	0.10	0.20	1.10	1.80	12.80	59.50	86.40	25.30	10.30	4.40	2.70
2009	2.20	0.60	0.20	4.50	5.00	9.40	39.30	72.50	18.50	13.50	5.90	4.00
2010	4.20	1.10	0.20	7.80	8.10	11.50	57.30	158.70	144.40	13.50	9.60	6.50
2011	1.10	0.60	7.70	2.00	8.90	14.00	50.40	105.40	61.20	14.70	13.30	5.10
2012	5.00	2.70	2.10	4.70	4.10	7.40	28.70	77.00	28.60	7.20	7.10	2.90
2013	2.00	1.20	0.80	1.40	1.20	3.60	32.10	100.20	14.30	3.30	2.70	3.60
2014	2.40	0.80	0.80	6.70	1.50	2.60	13.20	92.30	16.20	5.80	6.00	2.40
2015	1.20	0.80	0.40	6.00	0.10	0.10	26.20	132.70	24.30	7.80	4.80	3.00

Appendix B: Monthly measured sediment (ton/month) at Geba gaging station (1998 – 2015)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	66.0	15.0	3020.1	1739.9	5540.5	2742.3	101080.1	168939.6	11619.0	938.1	315.6	188.7
1999	73.5	14.8	4.7	797.0	80.7	621.2	17522.7	83229.4	6185.9	1518.1	356.1	179.7
2000	58.9	15.2	12.5	171.7	153.3	773.5	12739.3	26558.9	1309.1	234.2	161.4	31.5
2001	6.6	6.6	204.0	6.6	12.9	961.9	58133.1	295114.3	4043.6	606.8	183.4	65.1
2002	30.0	6.6	94.0	398.0	6.6	606.8	6605.8	8516.2	1080.6	163.7	52.2	12.9
2003	12.9	706.6	294.7	247.7	204.0	4111.9	84755.3	185530.4	8791.3	961.9	812.2	885.8
2004	30.0	672.7	639.4	1468.5	741.1	11316.8	33412.5	82517.9	1121.4	319.4	127.0	79.1
2005	52.2	371.0	1080.6	16730.9	20058.9	1080.6	32327.7	207435.7	23619.8	204.0	79.1	52.2
2006	20.8	6.6	812.2	8065.4	7278.4	4891.5	77028.2	197302.6	25977.7	1080.6	270.8	110.0
2007	12.9	2.1	1468.5	2160.8	344.8	10711.9	128127.3	187063.1	28569.4	2377.5	543.6	163.7
2008	6.6	2.1	6.6	110.0	247.7	6279.2	78987.4	146053.5	19298.9	4389.2	1080.6	483.3
2009	344.8	40.5	6.6	1121.4	1334.0	3775.3	39877.7	109391.1	11521.4	6855.0	1752.3	923.6
2010	1000.9	110.0	6.6	2776.0	2954.1	5263.3	74232.5	397797.3	340472.4	6855.0	3908.6	2055.6
2011	110.0	40.5	2717.6	294.7	3450.1	7278.4	60085.0	202661.0	82740.6	7887.8	6688.5	1378.3
2012	1334.0	483.3	319.4	1204.7	961.9	2545.3	23756.1	120803.4	23619.8	2432.9	2377.5	543.6
2013	294.7	127.0	65.1	163.7	127.0	776.4	28569.4	186449.4	7537.2	672.7	483.3	776.4
2014	398.0	65.1	65.1	2160.8	183.4	454.1	6605.8	162849.7	9257.4	1703.7	1801.6	398.0
2015	127.0	65.1	20.8	1801.6	2.1	2.1	20443.2	296217.1	18058.1	2776.0	1247.2	574.9

Appendix C: Weather generator (WGEN) parameters used by the SWAT Model

TMPMX	23.4	24.7	25.4	26.2	27.3	27.2	23.6	22.6	24.5	24.0	22.9	22.5
TMPMN	9.3	10.4	11.9	13.2	13.8	13.4	13.1	13.1	11.8	10.8	10.2	9.4
TMPSTDMX	1.8	2.2	1.6	1.4	1.5	1.9	1.9	1.7	1.3	1.1	1.2	1.8
TMPSTDMN	1.9	1.7	1.6	1.8	1.5	1.5	1.4	1.1	1.5	1.7	1.7	1.7
PCPMM	3.4	2.6	19.5	25.9	24.7	32.0	185.2	221.1	30.6	5.9	4.0	0.4
PCPSTD	0.9	0.7	2.8	4.4	3.6	3.5	9.2	9.5	3.1	1.5	1.5	0.2
PCPSKW	9.8	11.1	6.1	11.4	6.6	5.5	2.7	1.9	4.4	11.1	17.6	17.7
PR_W1	0.0	0.0	0.1	0.1	0.1	0.2	0.6	0.6	0.2	0.1	0.0	0.0
PR_W2	0.4	0.4	0.3	0.3	0.4	0.4	0.7	0.7	0.5	0.1	0.1	0.1
PCPD	1.2	1.1	3.6	4.3	4.4	7.1	22.5	22.9	8.3	1.9	0.8	0.5
SOLARAV	20.7	21.9	22.7	22.9	22.2	18.4	15.8	16.6	20.7	21.8	20.2	19.6
DEWPT	9.3	8.3	9.5	9.9	9.3	10.2	14.5	15.0	11.3	9.6	8.7	8.3
WNDAV	1.9	2.1	2.1	2.4	2.1	1.8	1.5	1.3	1.6	2.3	2.3	2.1

Appendix D: Symbols and description of weather generator (WGEN) parameters

Symbol	Description
TMPMX	Average or mean daily maximum air temperature for month (^{0}C)
TMPMN	Average or mean daily minimum air temperature for month (^{0}C)
TMPSTDMX	Standard deviation for daily maximum air temperature for month (^{0}C)
TMPSTDMN	Standard deviation for daily minimum air temperature for month (^{0}C)
PCPMM	Average or mean total monthly precipitation (mm H2O)
PCPSTD	Standard deviation for daily precipitation for month (mm H2O/day)
PCPSKW	Skew coefficient for daily precipitation in month
PR_W1	Probability of a wet day following a dry day in the month
PR_W2	Probability of a wet day following a wet day in the month
PCPD	Average number of days of precipitation in month
SOLARAV	Average daily solar radiation for month (MJ/m^{2}/day)
DEWPT	Average daily dew point temperature in month (^{0}C).
WNDAV	Average daily wind speed in month (m/s)

Appendix E: Sensitivity analysis parameters of flow in Geba watershed

Parameters		
NO.	**Name**	**Description**
1	CN2.mgt	SCS runoff Curve number for moisture condition II
2	ALPHA_BF.gw	Base flow alpha factor (days)
3	GW_DELAY.gw	Ground water Delay (days)
4	GWQMN.gw	Threshold depth of water in shallow aquifer required for return flow (mm)
5	GW_REVAP.gw	Ground water ‘revap’ coefficient
6	ESCO.hru	Soil evaporation compensation factor
7	CH_N2.rte	Manning’s roughness coefficient for main channel
8	CH_K2.rte	Effective hydraulic conductivity of the main channel (mm/hr)
9	ALPHA_BNK	Base flow alpha factor for bank storage
10	SOL_AWC.sol	Soil available water capacity (mm H20/ mm soil)
11	SOL_K.sol	Saturated Hydraulic conductivity (mm/hr)
12	SOL_BD.sol	Moist bulk density
13	SFTMP.bsn	Snowfall temperature (oC)
14	BLAI.crop.dat	Sub-maximum potential leaf area index
15	SLSUBBSN.hru	Average slope length (m)
16	REVAPMN.gw	Threshold water in the shallow aquifer for revap to occur (mm)
17	SOL_Z.sol	Soil depth (mm)
18	SOL_ALB.sol	Moist soil albedo
19	SMFMX.bsn	Melt factor for snow on June 21 (mm H20/ oC-day)

20	SMFMN.bsn	Melt factor for snow on December 21 (mm H20/ ^{o}C-day
21	SMTMP.bsn	Snow melt base temperature (oC)
22	TIMP.bsn	Snow pack temperature lag factor
23	SURLAG.bsn	Surface runoff lag time (days)
24	CANMX.hru	Maximum canopy storage (mm)
25	SLOPE. hru	Average slope steepness (m/m)
26	TLAPS.sub	Temperature lapse rate (oC/Km)
27	BIOMIX.mgt	Biological mixing efficiency

Appendix F: Soils parameter values used in SWAT model database

No.	SOIL TYPE	No. of Layer	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z	SOL_BD	SOL_AWC	SOL_K	SOL_CBN	CLAY	SILT	SAND	ROCK	SOL_ALB	USLE_K
1	CALCAM	1	A	1000	0.5	0.5	S_L	100	1.55	15	1.8	0.3	12	12	76	5	0.23	0.1
2	CALCLU	1	B	1700	0.5	0.5	LS	900	1.05	0.12	25	2.5	38.6	40	21.1	0.01	0.13	0.2
3	CALVER	1	B	1000	0.5	0.5	L	100	1.4	15	1.8	0.8	24	28	48	1	0.2	0.1
4	CROLUV	1	A	100	0.5	0.5	S_L	10	1.59	50	1.8	1.4	9	18	73	2	0.23	0.1
5	EUTCAM	1	D	1000	0.5	0.5	C	100	1.22	12	0	1	56	25	19	4	0.23	0.1
6	EUTLEP	1	D	1000	0.5	0.5	C	100	1.25	50	0	1.1	48	29	33	1	0.23	0.1
7	EUTVER	1	D	1800	0.5	0.5	C	500	1.04	0.11	25	2.3	51	22	27	0	0.13	0.2
8	HAIPCAL	1	A	300	0.5	0.5	S_L	30	1.61	15	0	0.6	8	16	76	2	0.23	0.1
9	HAPARN	1	A	1000	0.5	0.5	S	100	1.71	10	3.6	0.4	5	5	90	4	0.37	0.1
10	HAPCAL	1	B	1300	0.5	0.5	C	900	1.35	0.14	15	0.29	72	8	20	0	0.13	0.28
11	HAPLUV	1	C	1000	0.5	0.5	L	100	1.6	10	3.6	0.4	9	10	81	1	0.23	0.1
12	LITLEP	1	B	1000	0.5	0.5	L	100	1.4	15	1.8	0.7	22	37	41	4	0.2	0.1
13	LILEPT	1	D	1000	0.5	0.5	C	200	1.1	0.11	25	2	50	34	17	0	0.13	0.22
14	LUVCAL	1	B	1000	0.5	0.5	L	100	1.39	10	1.8	1.1	23	27	40	8	0.23	0.1

Appendix G: Soils parameters description

Parameters	Description
NLAYERS	Number of layers in the soil (min 1 and max 10)
HYDGRP	Soil hydrographic group (A, B, C, D)
SOL_ZMX	Maximum root depth of the soil profile (mm)
TEXTURE	Texture of the layer
SOIL_Z	Minimum depth from soil surface to bottom of layer (mm)
SOL_BD	Moist bulk density (g/cm3)
SOL_AWC	Available water capacity of soil surface to bottom of the layer (mm/mm)
SOL_K	Saturated hydraulic conductivity (mm/hr)
SOL_CBN	Organic carbon content (%)
CLAY	Clay content (%)
SILT	Silt content (%)
SAND	Sand content (%)
ROCK	Rock fragmented content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility factor (K)