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Source Protection for Drinking Water Supply Reservoir (The Case of Geba Reservoir, Tigray)

BY
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This is certify that the thesis prepared by **Gidena Hagos**, entitled: **Source Protection for Drinking Water Supply Reservoir (The Case of Geba Reservoir, Tigray)** and submitted in partial fulfillment of the requirement for the degree Master of Science (Civil and Environmental Engineering, Major of Water Supply and Environmental Engineering) complies with the regulations of the university and the meets the accepted standards with respect to originality and quality.

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DEDICATION

I dedicate this thesis manuscript to my Mother MANA TESFAY, and to my late Father HAGOS HADUSH, for nursing me with affection, love and for their dedicated partnership in the success of my life.

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ABBREVIATION AND ACRONYM

SWAT…………..Soil and Water Assessment Tool

GIS…………….Geographical Information System

SWAT CUP………….Soil and Water Assessment Tool for Calibration Uncertainty Program

WHO…………….World health organization

TWWDSE…………Tigray Water Work Design and Supervision Enterprise

EPA………… Environmental Protection Agency

TN…………..Total Nitrogen Load

TP………….. Total Phosphorus Load

BMP…………Best Management Practice

UTM………Unified Threat Management

DEM…….Digital Elevation Model

HRU……… Hydraulic Response Unit

NPS………. Non-Point Source

SUFI2……. Sequential Uncertainty Fitting Version 2

FAO….. Food and Agricultural Organization of the United Nation

WXGEN…….Weather Generator Data Base

XLSTAT………Excel Statistical Analyst Software

LAT………….. Latitude

LONG………..longitude

NSE………….. Nash Sutcliffe efficiency

NMSA ………. National Metrological Services Agency, Ethiopian

SRTM …………Shuttle Radar Topographic Mission

M.a.s.l………… meters above sea level
MoWRE …………..Ethiopian Ministry of Water Resources, Irrigation and Electricity

SCS……………..Soil conservancy service

WMO……………World Meteorological Organization

CSA………………..critical source area

95PPU……………….95 percentage prediction uncertainty

WGS……………..world Geodetic system

SSURGO…………soil survey Geographic database

USEPA…………….United State Environmental Protection Agency

PSO………………..Particle Swarm Optimization

GLUE………………Generalized Likelihood Uncertainty Estimation

ParaSol…………..Parameter Solution

MCMC…..………..Marcov Chain Monte Carlo

WXGN…………….Weather Generator

NPS………………..Non-Point Source

ABSTRACT

Drinking water supply needs source protection to maintain high quality of water. In the current situation throughout the world the water source water quality degradation are a common problem due to environmental pollution especially in surface water resource. For this reason, the objective of this research is to study in protection of surface water resource on the proposed Geba reservoir water supply source which is located in Northern Ethiopia, Tigray near to Mekele city from pollution. The SWAT model was selected after hydrological models were reviewed using predefined criteria's. Some statistical analysis model were used to prepare temporal observed data for model simulation, calibration and validation and Arc GIS 10.3 for the spatial data preparations in this study. Among the swat model Simulation result producing Geba watersheds dominated by the highest amount of sediment, TN and TP loads. This shows the sediment, total nitrogen load (TN),total phosphorus load(TP) give the magnitude of pollutant load which are more contributing to the Geba reservoir drinking water supply. During the simulation period (1995-2015) the Monthly average in-stream loads of 37993.35, 376.068 and 17.95554 ton/ month of Sediment, TN and TP, respectively were estimated at the Geba watershed outlet. Also the total load magnitude associated with summer storms generally contribute much higher percentages to the reservoir than those from the other seasons. The steps followed to SWAT model sensitivity analysis, calibrated, validated and assessed for evaluation model uncertainty using Nash–Sutcliffe coefficient (NSE) and coefficient of determination (R^2) by the help of SWAT CUP software. The model was calibrated from 1995 to 2008 periods and validated from 2009 to 2015 for flow, sediment, TN and TP. The monthly calibration for flow (NSE = 0.75, R^2 = 0.76), sediment (NSE = 0.66, R^2 = 0.66), TN (NSE = 0.74, R^2 = 0.74), TP (NSE = 0.75, R^2 = 0.74) and validation (NSE = 0.67, R^2 = 0.70), (NSE = 0.59, R^2 = 0.61), (NSE = 0.57, R^2 = 0.64), (NSE = 0.68, R^2 = 0.73) for flow, sediment, TN and TP respectively. This study shows model efficiency greater than 0.50 and 0.60 for NSE and R^2, respectively, which are adequate for SWAT model application to select the best management practice in the watershed to protect this drinking water supply reservoir from pollution. Proper waste water treatment plant for point source pollution and soil and water conservation practice for non-point source protection were recommended as a best management practice after analyzing the risk in this study to protect Geba reservoir drinking water supply surface water resource.

Keywords: SWAT model, source protection, pollution, Geba Reservoir, water quality and Best management practice.

1 INTRODUCTION

Access to clean water for drinking purposes is a precondition for human health and well-being. Water bodies are a source of livelihood for communities and cities around the world. The fresh surface water in lakes, streams and rivers is a very important part of water which is so significant for terrestrial ecosystems, including humans. Human beings depend on surface and groundwater sources for drinking, generating energy, grow crops, harvest fish, run machinery, carry wastes to enhance the landscape and for a great deal more. Water is also vital as a habitat for plants and animals (Kraemer,2001). Water as a link it acts in connecting many things in a watershed depending on which activities are present. These sometimes opposing uses imply that water resources utilizations have to go hand in hand with management and control of water quality. Therefore, for public health reasons, it is very important that drinking water sources or public water supplies are kept clean and free of pollution (UMUHIRE, 2007).

This research provides a study on surface water resource protection in the proposed Geba Reservoir drinking water supply source, Northern Ethiopia which is highly exposed to source of pollutions due to the hydrological and environmental processes of the area. Excessive land degradation due to Rapid urbanization, change in Land use land cover and climate change associated with increased pollutions due to natural and human activities are of great concern. This impacts threaten the availability, quality, supply and sustainability of this surface water resources. Hence, understanding the impact and identifying the source of pollution in the catchment helps to implement techniques that control the surface water resource and to protect from source of pollution to meet the required water quality standards, to minimize the cost of treatment plant and to supply a reliable, safe, sufficient and adequate treated water with the same degree of purity to each consumer and to prevent the health of ecosystem.

Water resources pollution is a serious problem all over the world and has been suggested as a leading cause of death and disease worldwide. The major causes of pollution for most water bodies are the accumulation of sediment and nutrients washed off farmlands and industries. Often river basins are shared by different sub watersheds making pollution in water supply reservoirs. This calls for combined approaches to solving pollution problems in catchments. To protect water resources within a watershed context, a mix of point and non-point source discharges, ground and surface water interactions, and water quality/quantity relationships must be considered. The complexity of these issues present must considerable challenges to water resource protection programs (UMUHIRE, 2007).

Water resource protection is the major challenge in Ethiopia predominant in northern part of the country. Consequently, the Geba Reservoir is presently found exposed to source of pollution. Geba Reservoir surface water resource needs to protect from pollution source because the area is high impervious geological formations and steep slope due to during rainy season the surface runoff on the land transported with high sediment, pesticides agricultural, animal and municipal wastes.

As the capital city of Tigray state in Ethiopia, Mekelle is faced with the worsening water shortage caused by its expanding city and increasing population. Currently this city, the methods of timing water supply, interval alternative water supply or centralized point water supply are still used for reliving the water supply condition. The estimated water demand of the city in 2014 about 43,000m^3/day but the existing water supply water production is only about 28,000m^3 in which this production covers only 65% of the total water demand. In addition, the city entirely dependent on groundwater; however, with the continuous exploitation of groundwater, the output of water wells has shown a declining trend and the water quality problems have become increasingly prominent. Therefore looking for surface water sources and constructing surface water plants in order to efficiently increase the city's capability of water taking, water production and water supply has become the primary task of the local government.

Due to the nearest surface water system from Mekelle is mainly Giba River located far away from the city around 15km to North West direction. Giba River area consist of Suluh River Genefel River and Agulae River and the three branch streams successively join together at upstream of Giba Reservoir dam-site.

Therefore Geba reservoir is currently proposed for supplying water to Mekelle city for drinking water supply purpose based on hydrometric calculations, the available water quantity of Giba Reservoir solves this water supply and demand fluctuation of the city.

According to Mekelle water supply feasibility study Giba Reservoir dam is composed mainly of three parts: earth rock-fill dam with clay core wall, the tunnel for diversion, sand sluicing and flood discharge, and spillway. Upstream catchment area covers 2,540km^2 with the annual average runoff 252 million m^3. The normal water storage level of reservoir is 1,797.0m and the corresponding storage capacity is 2.95×10^8 m^3. The checking flood level is 1807.2m and the corresponding storage capacity 4.03 ×10^8 m^3, the dead water level is 1785.0m; Crest elevation is 1808.5m. It's an earth rock-fill dam with clay core wall, and the dam height is 61.5m with a dam axis of 970m long, the spillway is open style and at the right side, and tunnel for sand sluicing and flood discharge (the tunnel is constructed based on the diversion tunnel) is designed inconsideration of sediment. Average annual suspended sediment load is $3.825 \times 10^6 t$, annual position amount is about $1700t/km^2 / year$. the dead water level of Giba Reservoir is designed as 1,785.0m by considering some margin is needed in water supply and consumption . The dead reservoir water level and sediment deposition age is taken as 50 years with a permanent Reservoir sediment deposition of 18,635×10^{4}m^3.

The physical semi distributed Soil Water Assessment Tool (SWAT) is a hydrologic simulation model coupled with ArcGIS10.3 (Arc SWAT 2012.10.18) and SWATCUP 2012.5.1.6 version is applied in this study. Using this tool hydrological response is critically evaluated, calibrated and validated. This calibrated and validated model is used for watershed mangers and decision makers to identify, quantify and optimize the impact of pollutions on water resources in a watershed.

Whereas quite a number of studies have been conducted in the Geba River Basin, reviewing and skimming through some of the available research works either very general or project-specific feasibility studies in both context of surface and ground water resources development of the Geba River and its tributaries. Nevertheless, certain prevailing conditions within this study area of the reservoir noticeably suggest the need for systematic assessments of the various aspects influencing the availability and quality of the water in Geba reservoir, especially with regards to water resources technology to protect the water from pollution. (Ashenafi, 2014)

Therefore, what current conditions suggest is that there is a need for systematic estimation of the magnitude of pollutants in the watershed to protect the water resource. Such estimation should incorporate evaluations of water quality and the magnitude of pollution load entering to Geba reservoir due to agricultural practices, sediment yields, nutrients, municipal wastes as well as effects hydrogeological system as a whole. Furthermore, favorable conditions for surface water resources availability and quality have to be properly investigated, if the basin's water and soil resources are to be wisely managed i.e. utilized and protected. These study, backed up with adequate data, should help to recommend a proper water resources protection.

1.1 Statement of the Problem

Poor quality of surface water has become a threat to supplies of drinking water world-wide. Surface water resource mainly polluted by non-point source pollution as well as point source pollution. Runoff mixing with sediment, nutrient, and other human activities that travels over various land uses within a watershed is a major source of non-point source pollution and the point source pollution disposed from municipal waste to the downstream water bodies.

Reservoirs are often threatened by loss of capacity due to sedimentation and nutrient load and the point source pollution including municipal sewage treatment and industrial waste water. The range of the problems caused by reservoir upstream pollution is varied and wide. Apart from the already mentioned ones like loss of capacity, degradation of water quality, increased flood risks, downstream river bed degradation, increased complexity in reservoir operation and maintenance and consequent increase in their associated costs.

The availability of surface water resource in Ethiopia is not well protected from pollution. The water resource management practice in the country shows that there is a need of introducing integrated watershed management approaches to sustain the development according to the report of water Resource Ministry (Birhane,2010). At present Geba reservoir is one of the development corridors to supply water for Mekelle city.

The rainfall regime in Ethiopia and in Tigray in particular is irregular, unreliable and unevenly distributed and it has Sedimentary rocks like shale and sandstone which are common in the sedimentary terrain in the region are highly erodible due their inherent weakness, steep slopes of catchments. There are few perennial rivers and exploitation of groundwater remains limited. Furthermore, the country is subjected to periodic extreme events of droughts and floods; this problem is very critical in the northern part of the country (Tigray, Afar and Amhara regions). (Gebrmdihne,2016)

Geba reservoir located in Tigray region near to mekelle city which is highly exposed to surface pollution. The Geba catchment size, land use and general characteristics with a high Mesozoic sedimentation proportion of erodible rocks exhibited higher siltation risk. Large parts of the natural forest in the watershed have been removed and few scattered trees are common along inaccessible slopes and churches (Vanmaercke,2011). The upper land use of part Geba catchment is highly degraded due to a number of factors including agricultural expansion to steep slopes, population pressure, overgrazing and drought, (Kibrewossen, 2011). Hence the problem of soil erosion is straightforward and pointed out investigated siltation problems of in the reservoir threatened by massive sedimentation. It will be concluded that the reservoirs will be silted up in less their planned life time so, protection of Geba Reservoir from pollution by control the watershed sediment accumulation is required.

Fast Urbanization with increasing number of industries have had a significant negative impact on, this surface water resource and its associated ecosystem. Consequently, the water becomes polluted, lose its clarity, transparency and self-purification rate were decreasing because the Genfel and Agula perennial river in the watershed are crossed the wukro and agula town respectively. Also Genfel sub Basin River of the catchment also exposed to the Sheba Tannery Leather industry over flowed some amount waste water treatment effluent from the waste stabilization pond of the industry into the environment may pose a potential hazard during heavy rain may happen in that area especially in the summer season. This is may be a quite significant contamination of the Geba reservoir and it is only 500m far away from the Genfel River to upland areas which means this point source pollution changes in to non-point source pollution because it doesn't discharge to the river directly. (Abraha and Gebrekidan, 2010)

In general the impact of population growth, expansion of urbanization, climate change, and change in land use land cover on the Geba catchment increases from time to time. Due to this complex relationship between human development and the environment is what causes land degradation and increasing water pollution on the catchment in which the use and management of the water resources is a central issue.

1.2 Research Question

1. What are the major point sources of pollution in the watershed?
2. What are the major non-point sources of pollution in the watershed?
3. Which source of pollution contributes most to the degradation of surface water bodies in the Geba catchment and where are they degradation location?
4. What is the water quality status at Geba Reservoir in terms of key physical, chemical and biological parameters?
5. What are the magnitudes of pollutant loads from the major sources?
6. What are the appropriate surface water pollution prevention and control measures for Geba Watershed?

1.3 Objectives

1.3.1 General Objective

The overall objective of this thesis is to make a study that will contribute to protect the surface water source of Geba Reservoir.

1.3.2 Specific Objectives

- ✓ To Identify the major point and non-point sources of pollution and to locate the critical sources of surface water pollution in Geba watershed
- ✓ To Determine the major pollutant loads at the outlet of Geba watershed
- ✓ To assess surface water quality at Geba reservoir location
- ✓ To recommend best management practices for pollution protection and control in the Geba catchment

2 LITERATURE REVIEW

2.1 Introduction

Safe drinking water is essential for maintaining public health. Every effort should be made to achieve the highest quality drinking water possible. Protection of water supplies from contamination is the first step in providing clean drinking water. Source protection is one method of ensuring safe drinking water and used in conjunction with appropriate treatment and distribution procedures. For a source water protection program to be effective, pollution problems or risks within a watershed need to be identified. This is accomplished through watershed protection. This chapter provides background on source water pollutions, pollution sources impacts on water quality, methodology selection to obtain solution and methods to protect pollution sources in a watershed.

2.2 Surface Water Pollution

Surface waters can be polluted by industrial and municipal discharges as well as altercations to the natural environment, which may cause runoff of pollutants. The main sources of water pollution are from human activities and their byproducts which have the potential to pollute water. Large and small industrial enterprises, the water industry, the urban infrastructure, agriculture, horticulture, transport, discharges from abandoned mines, and deliberate or accidental pollution incidents all affect water quality. the increases in nutrient mainly from agriculture loading may lead to eutrophication, organic wastes such as sewage and farm waste impose high oxygen demands on the receiving water leading to oxygen depletion with potentially severe impacts on the whole eco-system. Industries discharge a variety of pollutants in their wastewater including heavy metals, organic toxins, oils, nutrients, and solids. Discharges can also have thermal effects, especially those from power stations, and these too reduce the available oxygen. Silt-bearing runoff from many activities including construction sites, forestry and farms can inhibit the penetration of sunlight through the water column restricting photosynthesis and causing blanketing of the lake or river bed which in turns damages the ecology (Jr. Mark and A. Elbag, 2006).

Surface water pollution is classified into two major categories: point source pollution and non-point source pollution. Non-point source pollution, often in the form of runoff, comes from diffuse or scattered sources in the environment, while point source pollution comes from a defined outlet such as a pipe. Non-point source pollution may be difficult to identify and control while point source pollution can be identified easily (Jr., Mark and A. Elbag, 2006).

2.2.1 Source of pollution

2.2.1.1 Point Source Pollution

Point source pollution, such as pipe discharges, industrial outflows, tributaries, or wastewater treatment plant outflows are relatively easy to define and regulate. This includes industrial and municipal dischargers, or any other facility that discharges wastewater to receiving water. Controlling of point source pollutants permits specify the allowable flow rate of a discharge and the maximum concentration of specific pollutants. Effluent flow disposed from municipality and industrial waste water plants which does not take into account the amount of pollutant that can safely be added to a specific water body without degrading that water.

2.2.1.2 Non-point Source Pollution

Non-point source (NPS) pollution is typically caused by runoff moving over or through the ground, picking up natural and human pollutants, and carrying those pollutants into surface waters. this Pollutants included excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas; oil, grease, and toxic chemicals from urban runoff and energy production; sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks; salt from irrigation practices and acid drainage from abandoned mines; and bacteria and nutrients from livestock, pet wastes, and faulty septic systems (EPA, 2005).

Non-point source pollution is a major problem for surface waters because it is often times difficult to identify the source of the pollution. Therefore, control of non-point sources of pollution is problematic. Often times, land use surveys and groundwater or surface water quality samples are the only ways of identifying where possible non-point sources may be located.

2.3 Water quality

Reservoir and river's water quality is important not only for protection of human and aquatic life, but it is frequently used as an indicator of the environmental health of a watershed. Often, Suspended solids and sediments in surface water bodies are contaminated by chemicals that tend to be attached to fine-grained organic as well as inorganic soil particles. The sources of such contamination can be from existing point or nonpoint sources or from historical spills or discharges. When such contamination exceeds critical levels, they pose ecological and human health risks requiring appropriate remedial actions. Such remedial actions take the form of either isolating the contaminated sediments, reducing their exposure to other parts of the ecosystem, complete removal of the contaminated sediments, or some combinations point source pollutions (UMUHIRE,2007).

River or reservoir water quality is determined by measuring three aspects of river quality: biology, chemistry and physical quality. It refers to the assessment of chemical, biological and physical properties. In the water chemical quality, nutrients are the most important matter to be taken into consideration because of its bad effect in water bodies' ecosystem (cause of eutrophication). All these determine the status and the trends in stream, lake and reservoir water quality in general. There are standards of water quality set for each of these aspects measures.

Water quality is influenced by both non-point source pollution from farming activities and point-source pollution from sewage treatment and industrial discharge as principal sources. For agriculture, the key pollutants are nutrients, pesticides, sediment and faecal microbes from the land use and Oxygen consuming substances and hazardous chemicals are more associated with point-source discharges. (WMO, 2013)

The main chemical, physical and microbial factors negatively affecting water quality include:

Suspended particles: These can be either inorganic or organic matter and originate mainly from agricultural practices and land use change such as deforestation, and conversion to pasture at steep slopes leading to erosion.

Organic pollutants: They easily decompose in water and consume dissolved oxygen, leading ultimately to eutrophication. They mainly originate from industrial wastewater and domestic sewage, as well as from seepage of old and new landfills.

Nutrients: These include mainly phosphate and nitrate and their increased concentration can lead to eutrophication. They originate from human and animal waste, detergents and run-off from agricultural fertilizers.

Toxic organic compounds: These comprise industrial chemicals, plastics, dioxins, agricultural pesticides, oil and petroleum and polycyclic hydrocarbons generated from burning of fuel. Their potential effects on humans are difficult to establish

Traces of chemicals and pharmaceutical drugs: from medical waste are hazardous substances that are not necessarily removed by conventional drinking water treatment processes. They are now being recognized as carcinogens and endocrine disrupters and pose a great threat to water quality.

2.4 Watershed system

2.4.1 Watershed definition

A watershed is an extent or area of land where surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, wetland, sea, or ocean.

A watershed is "a geographical area determined by the watershed limits of the system of waters, including both surface and underground waters, flowing into a common terminus. This watershed area of land is bounded by hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community and also come in all shapes and sizes(USEPA, 2006).

2.4.2 Watershed features

Everything that is done in a watershed affects the watershed's system. The surface water resource quality problems in watersheds were traced to the obvious causes of pollution; point source pollution and non-point source pollution. However, water quality problems from non-point source pollution are more difficult to isolate and control; these sources are often hard to identify and difficult to measure. It results from a wide variety of activities over a wide area. The watershed is considered as a complex web of natural resources - soil, water, air, plants and animals. Yet, everyday activities can impact these resources, ultimately impacting our well-being and economic livelihood. To deal with water quality problems in a watershed the need of understanding the watershed system that is the main features of a watershed is always a basic requirement; every watershed has many features that make it unique and special (UMUHIRE, 2007).

2.4.3 Watershed modelling

To support watershed studies, Modelling is one among many assessment tools used in watershed planning and management. As in general, models are representations of systems or processes.

Modelling is needed to scope or to quantify a problem and the use of a model helps to convert projections concerning some changes into a prediction of watershed conditions and water body response.

The watershed modelling encompasses the entire watershed system, from uplands and headwaters, to Flood Plain Lake, reservoir and river channels. It focuses on the processing of energy and materials (water, sediments, nutrients, and toxics) down slope through this system. This implies to watershed modelling to present like two important sections in water quality modelling for obtaining the whole representation of the ecosystem acting like a network.

2.4.3.1 Flow, Sediment and Nutrient modelling

When pollution issue is first identified, the level of understanding of the severity and sources of the problem is often limited. Modeling here is frequently used to help build understanding of pollution problems in water quality. It is used to predict how conditions are expected to change over time; it is also helpful for extrapolating from current conditions to potential future conditions. It involves the prediction of water pollution using mathematical simulation techniques i.e. use of mathematical language to describe the behavior of the water system. A typical watershed model consists of a collection of formulations representing physical mechanisms that determine fate and transport of pollutants in a water body is required. Models are available for individual components of the hydrological and environmental system such as surface runoff with pollution load addressing transportation.

2.4.4 Model choice

Numerical watershed impact simulation models are available today. It is difficult to choose the most suitable model for a particular watershed to address a particular problem and find solutions. Many of the commonly used watershed models are continuous simulation model. Those models also have strengths in certain area and weakness in others, in addressing water quantity and quality problems. It is therefore important to investigate and recognize the long term continuous storm event simulations capabilities in the model. Also important to have a clear understanding a model for its appropriate use and avoiding possible miss uses, finally the model must be thought tested by them to various watershed before using in plan and management decisions.

From the problem introduced in Geba reservoir surface water resource, SWAT model was the selected tool used for the necessary modeling tasks by integrated with Arc map GIS interface. This enables it to deal with the landscape attributes, digital elevation map and soils to distribute the entire watershed protection from pollution with required data and to divide the area into sub-watersheds within the area of interest. So, there exist available and potential model linkages between loading, hydrodynamic process and water quality models for obtaining the whole watershed functionality success to simulate and to select more recommended BMP along with development of more linkages between loadings and hydrodynamic as well as water quality models.

SWAT model incorporated with all this features, is easily linked with other water simulators tools. It can be used for the evaluation of the mentioned tasks; from the hydrology to water quality analysis and the BMP's applications and assessment in a watershed. This ability made it a promising management tool for the environmental managers taking charge of the watershed development, protection and improvement (Betrie,2011).

2.4.4.1 SWAT Model

As SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties and topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc.are directly modeled by SWAT (S.L. NEITSCH, 2010).

Physically based distributed model, SWAT can in principle be applied to almost any kind of hydrological problem. Its hydrological system is based on our understanding of the physics of the hydrological processes which control catchment's response and use physically based equations to describe these processes.

2.4.4.1.1 Application of SWAT

SWAT has built-in functionality for modeling several surface pollutant load including sediment, agricultural practices, changes in fertilizer and pesticide application, tillage operations, crop rotation, dams, wetlands, and ponds. The model also has the capacity to represent many other commonly used management practices in watershed water resource protection. SWAT will calibrated using a manual and automatic procedure across several SWAT parameters. In order to meet the Instruction's need for reservoir surface water protection, hydrological catchment models are increasingly used to predict the impact of environmental change on the flow characteristics and water quality of water bodies (S.L. NEITSCH, 2010).

2.4.4.1.2 Simulation

The SWAT model is a continuous, semi-distributed model that operates on a daily time-step and is able to stimulate and predict the movement of water and associated pollutants (microbial and chemical) in complex catchments with varying soils, land-use and management conditions over extended periods of time. The model was used with in a Geographical Information System (GIS) interface as an extension to the software Arc Map (Arc SWAT). Once the model was calibrated and validated, multiple future scenarios were run based on differing levels and intensity of precipitation, sediment yield, nutrient load, water quality and land management options (S.L. NEITSCH, 2010).

2.4.4.2 SWAT CUP

SWAT Calibration and Uncertainty Program (SWAT-CUP) is a computer program which provides the calibration, validation and sensitivity analysis of SWAT models. It involves several methods such as SUFI2, PSO, GLUE, ParaSol, and MCMC which can be chosen for the purpose of calibration and uncertainty analysis. This accesses the SWAT input files and runs the SWAT simulations by modifying the given parameters. The storage of the value of the objective function and the modification of parameters are the basis for comparison (Abbaspou,2015).

2.4.4.2.1 Sensitivity analysis

Sensitivity is measured as the response of an output variable to a change in an input parameter, with the greater the change in output response correspond to a greater sensitivity. Sensitivity analysis evaluated how different parameters influenced the predicted outputs. It supported the calibration process which means the parameters identified in sensitivity analysis were used to calibrate a model (Abbaspou,2015).

2.4.4.2.2 Calibration

A complex hydrologic model is generally characterized by a multitude of parameters. Due to spatial variability, measurements errors or incompleteness in description of both the elements and the processes present in the system, etc. the values of many of these parameters will not be exactly known. Therefore, to achieve a good fit between simulated and measured data, models need to be conditioned to match the reality by optimizing their internal parameters. The calibration incorporated function in SWATCUP 2012 uses to check the accuracy between observable and simulated results (Abbaspou,2015).

2.4.4.2.3 Validation

A calibrated model should be validated before it is recommended for use. For validation, the simulated data as predicted by the model must be computed with the observed data and statistical tests of error functions must be carried on to check the performance of calibration and validation of the model till to the values of error functions are very small then the model is validated. Finally the performance model of these parameter transfer approach was evaluated based on values of Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2).

2.4.4.2.4 Model performance

The parameter sensitivity analysis provided insights on which parameters contribute most to the output variance due to input variability. The model's accuracy with respect to measured data was evaluated according to two statistical indices:

(i) the Pearson correlation coefficient (R^2)
(ii) the Nash Sutcliffe efficiency (NSE)

During calibration, differences between observed and predicted fluxes were minimized by adjusting the selected model parameters. This was analyzed through the comparison of the computed values of these statistical indexes considered as goodness-of-fit indexes. Shown by daily hydrographs produced with the measured and the simulated series, the two statistical indices were observed at each change of parameters.

Pearson Correlation: This is a linear correlation between the measured and simulated values.

The coefficient of determination R^2 is defined as the squared value of the coefficient of correlation and is given by the equation below

$$R^2 = \frac{\left[\sum(Q_M - \overline{Q}_M)(Q_S - \overline{Q_S}\right]^2}{\sum\left(Q_M - \overline{Q}_M\right)^2 \sum(Q_S - \overline{Q}_S)^2}$$

Where, Q_m is the observed (measured) stream flow on day (m^3/s), Q_s is the simulated stream flow on day (m^3/s), and bars indicate averages.

The value of R^2 ranges from (0-1) where a value close to 1.0 indicates good performance (good correlation) of the model and the value close to 0.0 indicates poor performance (poor correlation) of the model. The main drawbacks of R^2 is that it only quantifies dispersion. A model which systematically over-or under-predicts all the time will still result in good R^2 values close to 1.0 even if all predictions were wrong (J. G. Arnold, 2012). To avoid this ambiguity, it is advisable to use additional information which can cope with that problem

Nash-Sutcliffe efficiency: This shows a good adjustment of peaks between measured and simulated Series
The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) is used to assess the predictive power of the hydrological models. The value of NS varies from 1.0 (perfect fit) to -∞. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (J. G. Arnold, 2012). The NS value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data. The major disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and simulated values are calculated as squared values. This leads to an over estimation of the model performance during peak flows and an under estimation during low flows (J. G. Arnold, 2012).

The Nash-Sutcliffe efficiency (NSE) is calculated using equation below

$$NSE = 1 - \frac{\sum (Q_M - Q_S)^2}{\sum \left(Q_M - \overline{Q}_M\right)^2}$$

For using the model with confidence for future predictions under different scenarios, the model predictive capability is demonstrated for being reasonable in the calibration and validation phase using model evaluation criteria. The goodness-of-fit of SWAT model was evaluated by the coefficient of determination (R^2) and Nash–Sutcliff coefficient (NSE) between the observations and the final best simulation. The R^2 is the square of the Pearson’s product-moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 to 1.0 with higher R^2 values indicating better agreement. The NSE ranges between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value (Nash and Sutcliffe, 1970). Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance (but NSE > 0.50 is accepted as satisfactory), whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance of model, (J. G. Arnold, 2012)

2.5 Surface water resource protection

Protecting the sources of our drinking water is a cornerstone of Drinking Water supply system. Without source protection, delivering a sustainable supply of the highest quality drinking water becomes much more difficult to achieve.

Protecting water at the source is an important way to ensure the health of humans, ecosystems and economies. Source water protection also works to ensure that a clean and safe environment is available for future generations (Holmes, 2012)

2.5.1 Human Health

Protecting sources of water is essential to ensuring human health. Preventing contaminants from entering water sources is an effective way to help ensure clean drinking water and thus prevent human disease. This is important because conventional water treatment methods cannot effectively remove many hazardous chemicals. While source water protection works to everyone's benefit, it is of particular concern for rural consumers whose geographic location may prevent them from having access to municipally treated water.

2.5.2 Ecosystem Health

An ecosystem is a biological community consisting of interacting organisms and their surrounding physical environment. Ecosystems have four main components: air, water, land and living creatures (plants and animals including humans). Each component of an ecosystem performs or contributes to a unique service or function upon which all life depends. Every ecosystem on Earth depends on water, of varying amounts, for its survival. If either water quality or water quantity is in any way degraded, this can have a serious adverse impact on an ecosystem. Similarly, when ecosystems become degraded, this has a negative impact on water.

2.5.3 Economic Health

While there are costs associated with protecting water sources, they are investments that serve to generate economic vitality and growth. Communities with clean water sources attract human settlement, development and business Economic benefits of source water protection measures can also be measured in terms of cost savings — that is, the damage costs that may have resulted if water sources were not protected. Tangible direct costs include those associated with locating new drinking water sources, constructing new treatment systems, cleaning up contaminated sites, rehabilitating material used in the sites. Indirect financial costs include decreased property values and medical treatment of people having waterborne illnesses. More difficult to measure in economic terms, but very important, is the loss of citizens' confidence in both the safety of their drinking water and the ability of community leaders to look after their interests.

2.6 Ways of surface water resource protection

Watershed Protection methodology should be established, wherever possible, since it addresses water pollution control. This method helps to produce desired results and often lead to further water resources degradation protection. To this effect, land and water protection should be better integrated, and greater control should be exercised over land clearing activities, which impact water quality through soil erosion. In the context of integrated surface protection, water pollution control, should be re -organized and better co - ordinated in order to achieve to have control over water quality throughout the complete water cycle, thus providing an incentive for improved and co -ordinated action towards water pollution prevention (Kraemer and R. Andreas, 2001)

Ways of surface water resource protection measures are known as best management practices (BMPs). BMPs are standard operating procedures that can reduce the threat that normal activities at homes, businesses, agricultural lands or industry can pose to water supplies. BMPs have been developed for many activities and industries that store, handle, or transport hazardous or toxic substances. They can help prevent the release of these substances or control these releases in an environmentally sound manner, and encourage the adoption of voluntary design or procedural standards (DWA, 2002)

There are a number of interventions which will help to protect the quality of surface waters, principal amongst these are: land-use control within the catchment; and proper structural measures away from potential sources of pollution and preferably upstream of them; treatment of effluent and discharges leaving industrial plants and municipal sewage treatment works, regulations and permits, good housekeeping practices, public education, land management and emergency response planning, and; the establishment and enforcement of effluent quality standards (EPA, 1987).

3 MATERIAL AND METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

The research was conduct near to Mekelle city *in* Geba catchment *which* is located in the northern part of Ethiopia. The Geba watershed drains the north-eastern part of the Tekeze River Basin and the watershed has a size of 5,260 km². This research focuses on the upper part of the watershed which covers about 2,440 km². The study area is bounded between latitudes 13⁰16' and 14⁰16' North and longitudes 38⁰38' and 39⁰49' East.

The headwater area lies between altitudes of 2600 and 3300 m.a.s.l. and is bordered by higher mountains areas of Mugulat to the north and Atsbi Horst to the north east. The central plateau, which lies between 2000 to 2400 m.a.s.l and it becomes increasingly dissected by rivers flowing south west. The fault-controlled Mekelle, Wukro and Senkata areas, and the Atsbi horst, build the major plains of the Geba basin and lie between 1800 to 2400 m.a.s.l. (Ashenafi, 2014)

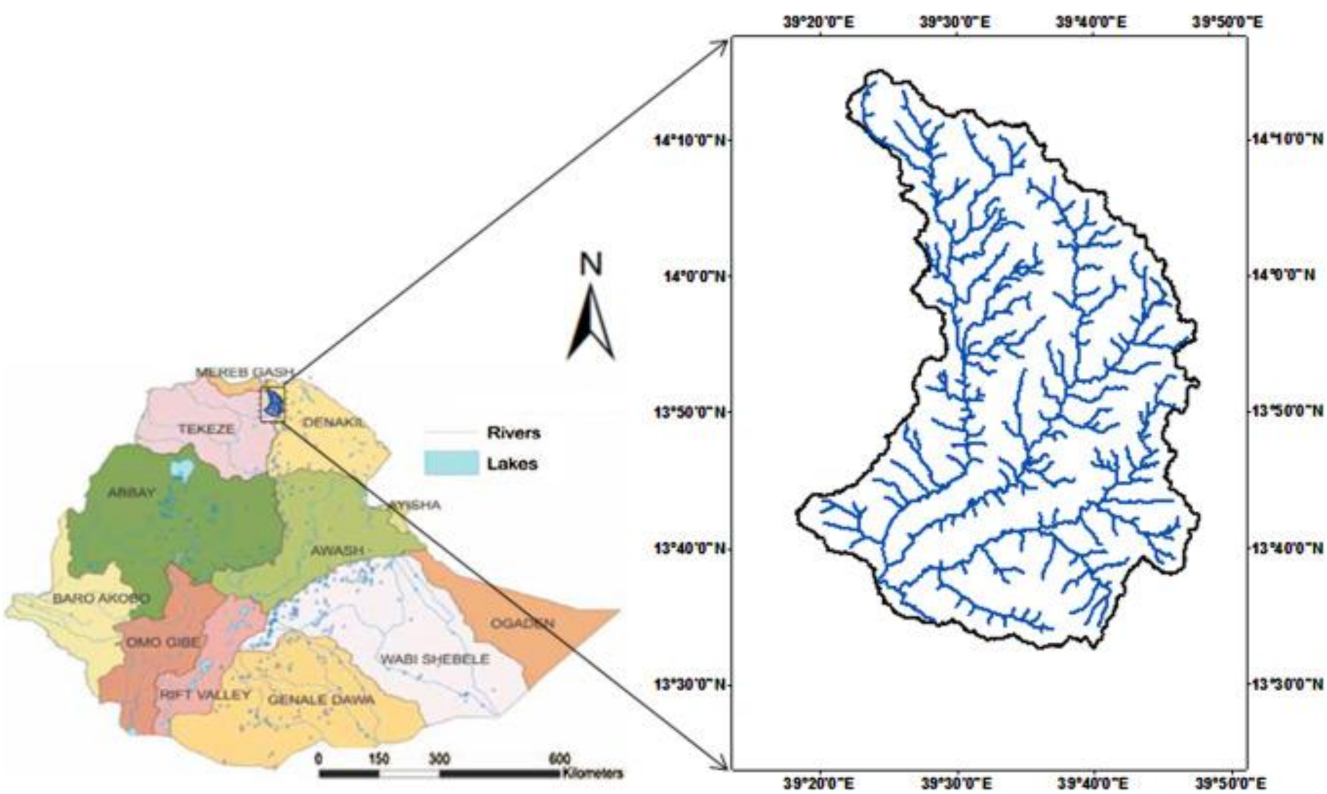

Figure 3-1:- Study area location map of Geba basin

3.1.2 Climate Condition

3.1.2.1 Rainfall

The watershed receives two rainy seasons: the main rainy season (June-September) and the small rainy season (February-May) (Ashenafi, 2014). The annual rainfall totals in average was between 500 to 800 mm. Annual rainfalls shows very pronounced annual and seasonal fluctuations. Moreover the local rainfall pattern highly depends on the topography.

In the study area around 82% of the annual rainfall occurs between July and August according to the metrological data collected for the Mekelle class I station and nearest to Geba reservoir (Figure 3.2). At all rain gauge stations in the study area annual precipitation underlies a distinct seasonality. The rainfall distribution is bimodal at all stations, with a minor peak usually in June and September and a major peak July and August.

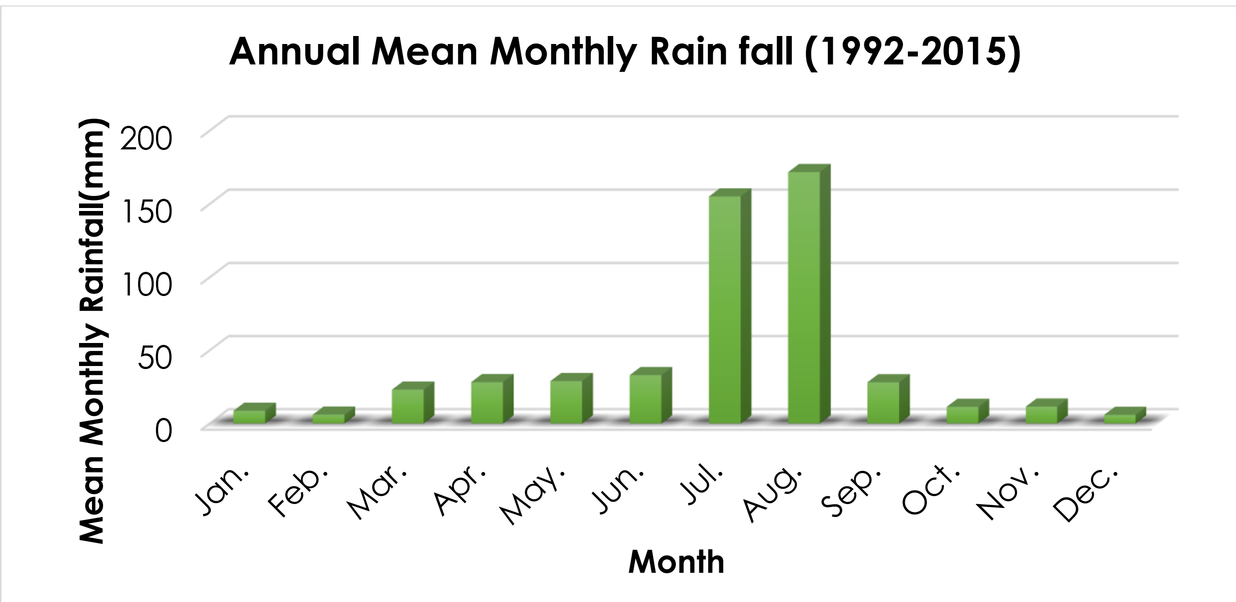

Figure 3-2:- Mean Monthly Rainfall of Mekelle Station and its surrounding (1992-2015)

3.1.2.2 Temperature

The study area is located in the winadega zone and the 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 (Figure 3.3). The highest mean monthly temperatures are reached just prior to the onset of the rainy season in April and May.

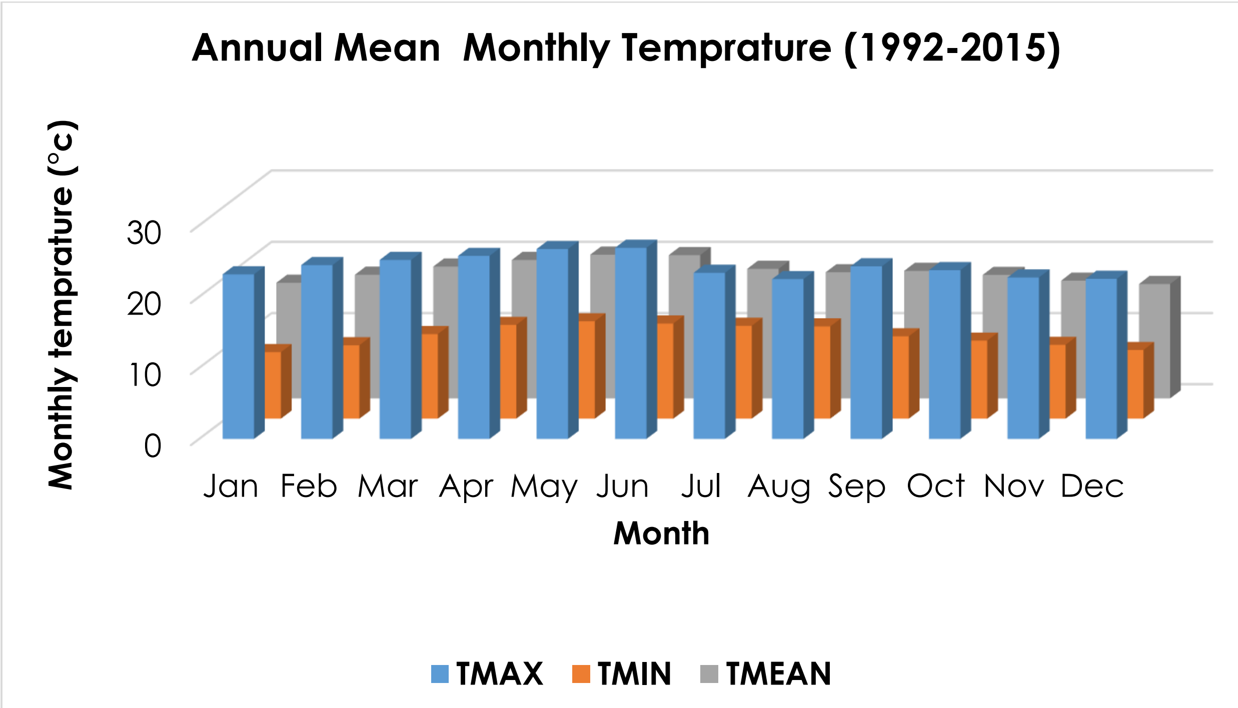

Figure 3-3:- Annual Average Monthly Temperature of Mekelle station and its surrounding (1992-2015)

3.1.2.3 Relative humidity

The mean monthly relative humidity at the Mekelle station according to the data of 1992–2015 reveal that the average humidity is highest in August (80%), and least in May (45%).

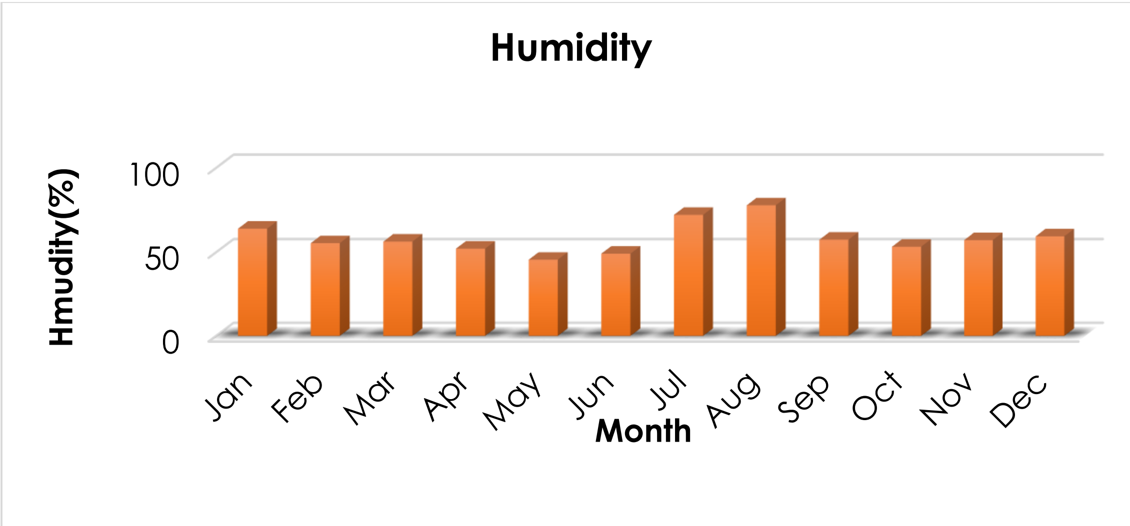

Figure 3-4:- Annual Average Monthly relative humidity (%) Mekelle station (1992-2015)

3.1.2.4 Wind Speed

Wind directions during dry season in most parts of Ethiopia is generally from the east direction (easterly or southeasterly), changing to westerly or north-westerly during the rainy season. Winds are not very strong and velocity generally averages 1.51 to 3.80 m/s based on the data obtain from the Ethiopian national meteorological agency at Mekelle station.

3.1.2.5 Sunshine

The sunshine data also available from 1992–2015 for Mekelle climate stations. The sunshine hours average around 4.6 hours/day in summer season and around 10 hours a day in winter season. Obviously the decrease in sunshine hours in July and August is due to persistent cloudiness during rain.

3.1.2.6 Geology

The 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, 2010).

3.1.3 Drainage system

The origin of the rivers that flow towards the Tekeze river catchment start from the Rift valley sub river basin that covers eastern zone part of the Tigray region. Geba reservoir mainly consists Suluh River covering an area 961km², Genfel covering an area 782 km², and Agula covering an area 735km². In which the total drainage area drain to the Geba reservoir was 2440km².

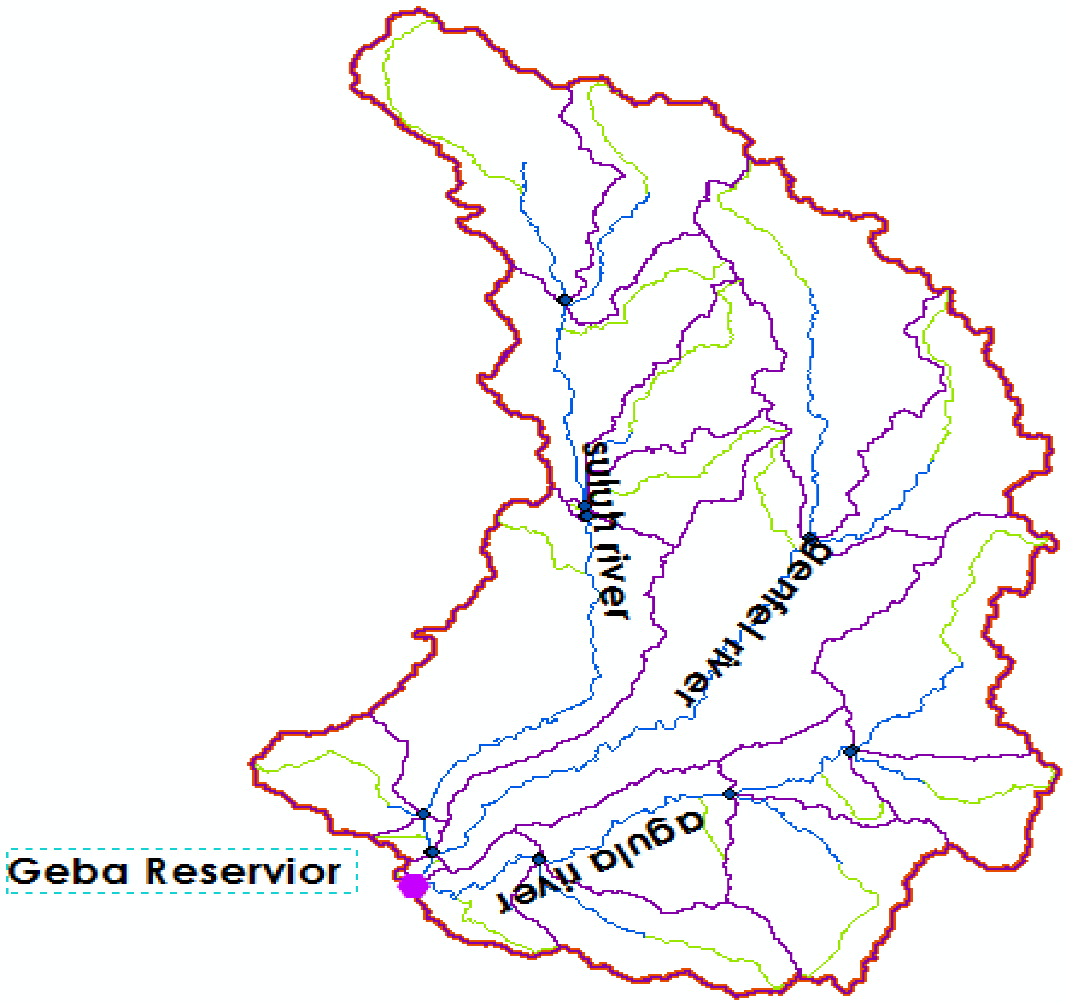

Figure 3-5:- Drainage network and river name for the upper Geba watershed.

3.1.4 Land Use/ land Cover and soil type

Geba watershed is mainly dominated by farmlands, grazing areas, residential villages, and protected areas for soil and water conservation. The geological behavior of this study area is underlain by Mesozoic – age sediments.

At a local level relief has strong influence on soil development. In the idealized sequence deeply weathered soils occur on the upper plateau, rocky or even shallow soils occur on vertical scarps, unconsolidated coarse stony soils occurs on steep debris slopes finer textured soils varying in texture occur on the undulating pediments and deep alluvial soils occur on the alluvial terraces and lower parts of alluvial deposits. Nitosols are a widespread soil type in the Geba basin (Gebreyohannes, 2010). Nitosols are very shallow soils where the unweather rock is reached within 10 cm below the surface. They occur on all rock types and, thus, include all textures. Nitosols are most common on steep land however, their distribution increases as soil erosion results in the depletion of soil depth. These soils are not suitable for crop production, but farmers use it for cultivation due to shortage of arable land.

3.2 Data Collection and Preparation

3.2.1 General

To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modelling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of Digital Elevation Model (DEM), Soil and Land use/land cover data, weather data and point source data above all other necessary data to simulate the magnitude of pollution load at the location of Geba watershed outlet and to assess the water quality status of the reservoir. The output from the SWAT model can be affected by the DEM data resolution, mask size, soil data resolution and soil map scale, length of period of weather and climatic data hydrological, nutrient, water quality and watershed subdivision. The required DEM data, soil data, land use/land cover data, flow data, climatic, point source data and sediment data was collected from different sources. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the upcoming sections.

3.2.2 Data Type

3.2.2.1 Digital Elevation Model (DEM) Data

Digital Elevation model (DEM) is one of the main inputs of the SWAT (Soil and Water Assessment Tool) model. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRUs).

For this project a digital elevation model (DEM) was extracted from the global United State Geological Survey's (USGS) in the format of SRTM (Shuttle Radar Topography Mission) with a spatial resolution of 90 m x 90 m for the Ethiopia map was download (http://usgs.gov). The DEM was imported to Arc SWAT. The projected map was used in the watershed delineation in Arc SWAT which is the interface in the Arc Map to use it in SWAT model.

3.2.2.2 Soil Data

Like the Digital Elevation Model (DEM), soil data resolution has also a significant impact on the modelling of stream flow, sediment load and nutrient content.

In this study the soil data was obtained from the harmonized Food and Agriculture Organization of the United Nations (FAO) (FAO, 1995) at a spatial resolution of 10 km. The Soil and Terrain database for Global soil data at scale 1:1 million compiled by FAO (http://usgs.gov). The spatial resolution of this soil map is very low that after it is clipped to the Geba watershed it assigns only 6 soil type for the whole watershed of about 2412 km^2. This may have very high impact on the prediction of runoff and sediment, and nutrient yield. Therefore, it should be noted that the simulation result will be subject to the quality of soil data used.
Therefore, all required soil properties were adopted from SSURGO database since there was no possibility of measuring all soil properties in the field due to time constraint. The soil map obtained from FAO was projected to WGS1984, UTM Zone 37N using the raster projection in Arc Map before it was imported to Arc SWAT. The soil map of Geba watershed and soil type database table used for HRU definition in this study was shown in below.

Table 3-1:- Global Soil type classification and their SWAT code representation naming on Geba watershed.

ID	Global Soil Name	SWAT code Name	Total area cover (km^2)	Watershed % area cover
1	Humic Cambisols	Bh13-2-3c-32	779.7996	32.33
2	Eutric Nitosols	Ne20-3b-160	26.7732	1.11
3	Cambic Arenosols	Qc2-1bc-176	33.768	1.4
4	Orthic Acrisols	Ao63-3b-6	397.7388	16.49
5	Cambic Arenosols	Qc5-1c-182	372.4128	15.44
6	Eutric Nitosols	Ne15-3c-159	801.5076	33.23
Total			2412	100

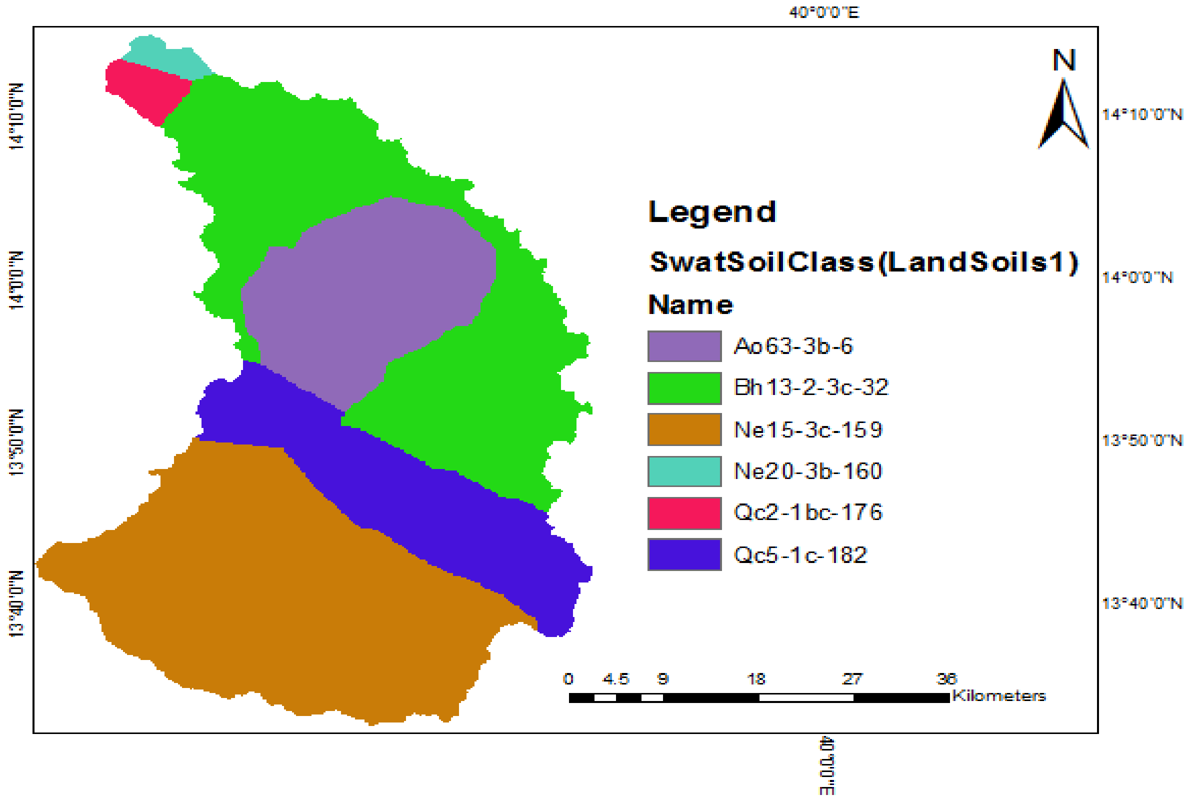

Figure 3-6 :-Soil Map of Geba Watershed

3.2.2.3 Land use/land cover Data

Land use/land cover data has also a significant effect on the hydrological modelling. Therefore, a detail analysis and mapping of the land use/land cover is crucial for proper hydrological modelling. Land use/land cover affects the runoff, nutrient and sediment transport in the watershed.

For this study land use/land cover data of Tekeze catchment was obtained from the Ethiopian ministry of water resource then clip the land use, land cover of Geba catchment from this data. The land cover data was available in the form of Binary and ESRI Grid. The ESRI Grid format with a 1 km spatial resolution was used in this study four land use/land cover types were identified for Geba watershed: Agricultural land, intensive cultivated, open bush land and dense shrub land. There were no specific crop type identified in the agricultural land use for this study. The land use for Geba watershed was projected to WGS1984 UTM Zone 37N using the raster projection in Arc Map before it was imported to Arc SWAT. The land use map of the Geba watershed data was shown in the table and figure below.

Table 3-2:- Global land use/land cover type classification and their SWAT code representation naming on Geba watershed.

ID	original land cover	Redefined land cover according to the swat database	SWAT code	Total area cover (km²)	watershed % area cover
1	Open bush land	HAY	HAY	91.4148	3.79
2	exposed sand soil surface with scats curb and grass	Barren	BARR	62.2296	2.58
3	dense shrub land	RANGE _BRUSH	RNGB	21.2256	0.88
4	intensively cultivated	agricultural land generic	AGRL	2237.13	92.75
Total				2412	100

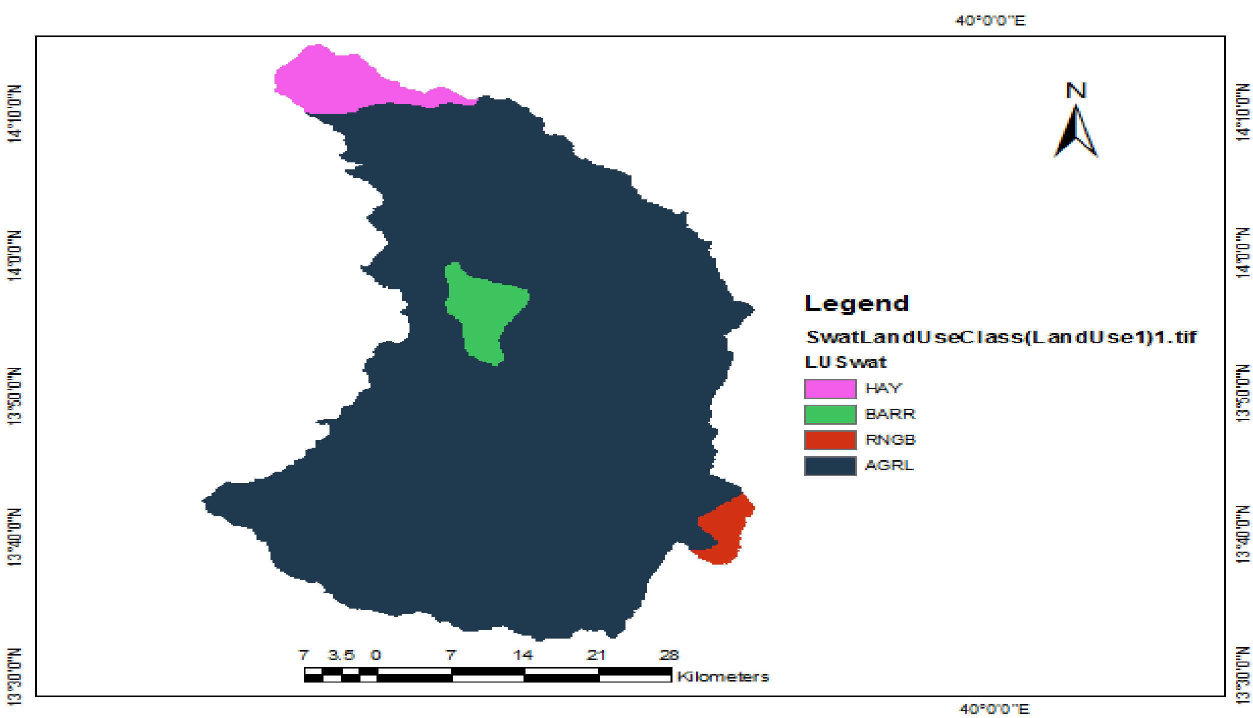

Figure 3-7 :- land use map of Geba watershed

3.2.2.4 Climate Data/Weather Data

Climatic data among the most important variables required by SWAT to model the land phase of the hydrologic cycle. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum daily air temperature, solar radiation, wind speed and relative humidity. The model allows values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed and relative humidity to be input by the user form records of observed data or generated during simulation.

All the weather data was obtained from the Ethiopian national metrological agency. There were 9 meteorological stations located inside and outside the Geba watershed. But, only six of them: Mekelle, Atsbi, Adigrat, Wukro, Agula, and Senkata were considered for further analysis. The other 3 stations: Hawzen, Haykimeshal and Hagerselam were not considered since they were a few year data recorded rather than the other station. The daily rainfall and temperature data of the six station is recorded from 1992-2015 but the other parameter of weather data like wind speed, sun shine and relative humidity is available fully only in the Mekelle station from 1992-2015. Also in all station and each parameter there are a lot of missing data was available. Due to checking consistency, data quality, fill the missing data and select the weather generator station are required.

Table 3-3 :- Meteorological stations in Geba watershed (Data base: Ethiopian National Meteorological Service Agency).

ID	Station Name	Location (UTM)		
		Latitude	Longitude	Elevation (M.a.s.l)
1	Adigrat	548379	1578542	2497
2	Agula	569390	1514714	2011
3	Atsebi	580252	1534423	2711
4	Hagereselam	518972	1508550	2608
5	Hawzen	546779	1544804	2255
6	Mekelle	557678	1489249	2257
7	Senkata	562000	1554000	2437
8	Wukro	564675	1524313	1987
9	Hyki meshal	575676	1520188	2121

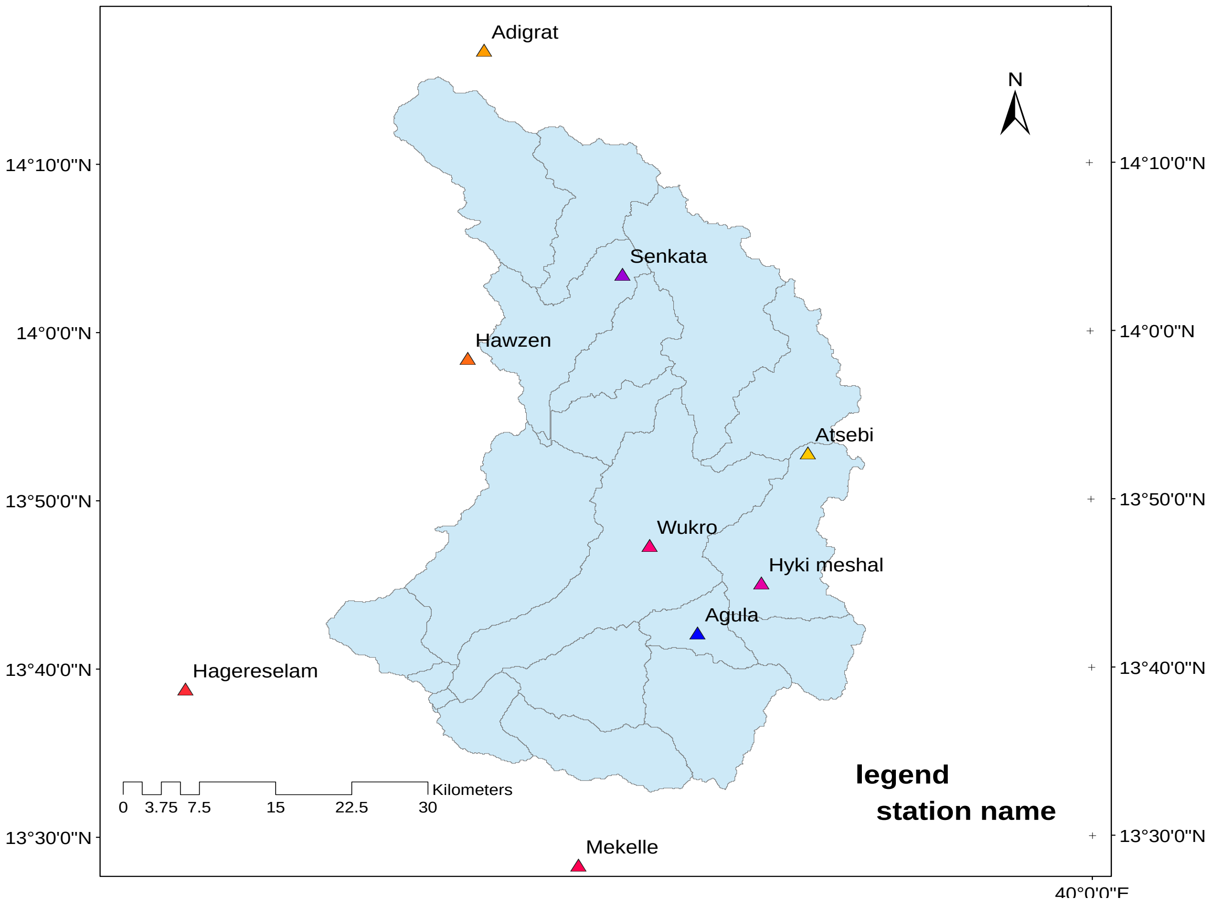

Figure 3-8 :- Metrological station name in upper Geba catchment

3.2.2.5 Flow Data

Observed flow data was required for the Soil and Water Assessment Tool (SWAT) calibration and validation. The daily stream flow data from 1992-2015 used in this study was collected from ministry of water resource. The flow hydrometric station location of Geba Reservoir which is located around the outlet of the watershed of the study area (ID Name; 121004H2). This flow data was formatted as to the requirement of the SWAT model and used for model calibration and validation.

3.2.2.6 Water quality data

Daily observed water quality data was required for the Soil and Water Assessment Tool (SWAT) calibration and validation. Normally, water quality samples measurement to get observed data are costly and time consume to collect and to analyze.

A vacant daily water quality data for nitrogen, phosphorus, and sediment were collected from the Tigray water work design and supervision enterprise of water quality section data to feasibility study of Mekelle water supply project. The water quality sample data were taken from the Genfel, Suluh and Agula main tributaries of the reservoir by selecting seven station sample and from the reservoir location at different day in the year 2014 in summer season at the maximum discharge of stream flow available and the Selected physio- chemical and bacteriological water quality analysis result at Geba Reservoir location and in the main tributaries are listed in appendix-B.

Therefore, an optional regression models are used often to estimate pollutant data for days on which water quality sample data were vacant or not measured. Pollutant load regression models were evaluated from the seven sampling frequencies for daily nitrogen, phosphorus, and sediment data. This Regression models are used extensively to interpolate intermittent water quality data and often simple linear forms using logarithmic transformations. Various water quality data sampling frequencies have been used to estimate pollutant loads with regression models and to explore what sampling frequencies are appropriate for regression model uses. Acceptable load estimates were provided by regression models with water quality data collected daily, weekly or monthly supplemented with storm samples.

So, first find the regression correlation coefficient from the suspended sediment concentration, total nitrogen and phosphorous water quality experimental results by correlating with the stream flow to provide the relationships between stream flow and concentration data. Then finally generate the whole daily water quality data in the study using the obtained correlation coefficients of regression to model display the relationships with stream flow.

3.2.2.6.1 Sediment data preparation

The measured sediment and nutrient data was required for the Soil and Water Assessment Tool (SWAT) calibration and validation but it is difficult to get those data easily due to this reason finding an optional way to solve this problem is recommended.
There is a need to estimate sediment during periods when no or few data is available. Flow is the main controlling variable to estimate sediment and nutrients. Develop a rating curve method to prepare the sediment data based on the recorded daily flow data for calibration and validation purposes of swat model was required .

Sediment rating curves are site-specific relations that give sediment daily discharge as a function of daily water discharge at a particular river location. The site-specific nature of such relations requires that field measurements of sediment discharge be made over a range of flow conditions, at the location of interest, for the development of the rating curves. Obtaining this data can be difficult and time intensive. The measured suspended sediment load is used to develop the rating curves which give suspended sediment load in tons per day as a function of mean daily flow. The effective discharge is defined as the mean of the discharge increment that transports the largest fraction of the annual sediment load .Sediment load is then computed using the historic daily mean flow data and then developed rating curves (Youn,2014).

Typically, in developing the sediment load histogram a rating curve that gives the average sediment load as a function of discharge, *Qs* verses (*Q*), is developed from historic or measured data using regression. The sediment load rating curve take the form of: The most commonly used sediment rating curves are power functions (Boukhrissal,2015)

$$Q_{s=aQ^b}$$

Where a and b are site-specific coefficients that can be obtained through regression of the *Qs* and *Q* paired data. Once *a* and *b* are obtained, the sediment rating equation can be used with the daily flow data to produce a histogram that shows the distribution of the percentage of total sediment load as a function of flow rate following equation. The effective discharge is then selected as the flow rate, Q, associated with the peak sediment loads histogram (Strom,2015).

A sediment rating curve is mainly applied to obtain the value of sediment concentration for a given discharge. Along with the flow duration curve at a given location, the sediment rating curve can also be used to estimate the amount of sediment transport over a period of time, say a year. Another important use of sediment rating curve is in estimation of the impact of land use changes and watershed management on sediment yield (Z A Boukhrissa1,2013). Once sufficient data have been collected, attention has been given to deriving the rating relationship. In the absence of actual suspended sediment concentration (SSC) measurements, hydrologists have used sediment rating curves to predict suspended sediment concentrations for subsequent flux calculations and to determine long-term suspended sediment loads (Z A Boukhrissa1,2013).

In a dataset comprising observations of Water discharge and suspended sediment concentrations at day, regression analyses were made between the daily suspended sediment concentration and the daily water discharge and a relationship of the daily suspended sediment discharge versus daily water discharge (Z A Boukhrissa1, 2013)

This Rating curve were used for sediment estimation in order to prepare the observed data for SWAT model calibration and validation. This statistical technique that can be used to determine the relation between two constituents. The use of this relation can be helpful in estimating data where one constituent was measured but the other was not (PAWEŁ MARCINKOWSKI, 2013). The rating curve was used with monthly flow data for a period from 1992 to 2015 to estimate sediment load. Also according to the general experience the bed load discharge is calculated by 20% of the suspended solid load and finally added the bed load and the suspended solid load to get the sediment load then use the regression model to get the correlation between sediment load and stream flow in Geba river .

Therefore according to the above explanations the result of the correlation coefficient from the regression model of sample date sediment concentration result with result to develop the rating curve equation was a=98.38 and b=1.7981 then the rating curve equation can be expressed as :

Sediment load:

$$Q_S = 98.34Q^{1.7981}$$

Where Qs - suspended sediment discharge load （ton/month）

Q - Flow (m^3/s)

Then the driven sediment load and the recorded monthly flow correlation using the simple linear regression according to this rating curve equation was as shown the graph below.

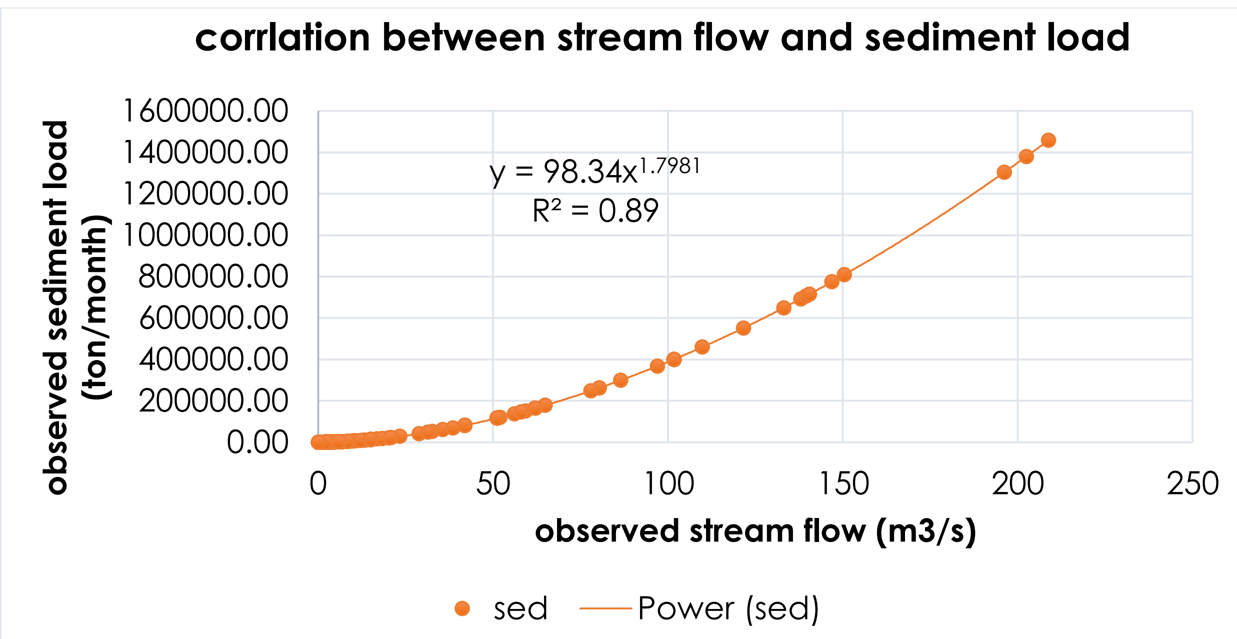

Figure 3-9 :- rating curve correlation between stream flow and sediment load

3.2.2.6.2 Nutrient data preparation

N-NO_3, N-NO_2, N-NH_4 and P-PO_4 parameters are the most dominant concentration of water quality parameters among the other nutrient loads in experimental result Geba water supply reservoirs project at the seven simple site collection results and the concentration result for each parameter are listed in Appendix B. Accordingly the concentration of the parameter was used from this laboratory result to estimate the total nitrogen and phosphorus loads using the simple trend line equation analysis.

This simple trend line equation were used for total nitrogen and total phosphorous load estimation in order to prepare the observed data for SWAT model calibration and validation. This statistical technique that can be used to determine the relation between two constituents. The use of this relation can be helpful in estimating data where one constituent was measured but the other was not. This method was used with monthly flow data for a period from 1992 to 2015 to estimate both nutrient load. The result of correlation in between must be greater than 0.65 for all nutrient loads (Scotta and Barry, 2010).

The simple trend line equation to determine nutrient load can be expressed as:

For Total Nitrogen Load

$$TN_{load} = (NO_3 + NO_2 + NH_3) * Q * 2.4466$$

Where: TN- Total Nitrogen load （ton/month)

Q- Flow (m^3/s)

NO_3- Concentration of Nitrite (Mg/l)

NO_2 -Concentration of Nitrate (Mg/l)

NH_3 -Concentration of Ammonia (Mg/l)

The estimated value of total Nitrogen load and measured stream flow correlation using simple linear regression was shown below

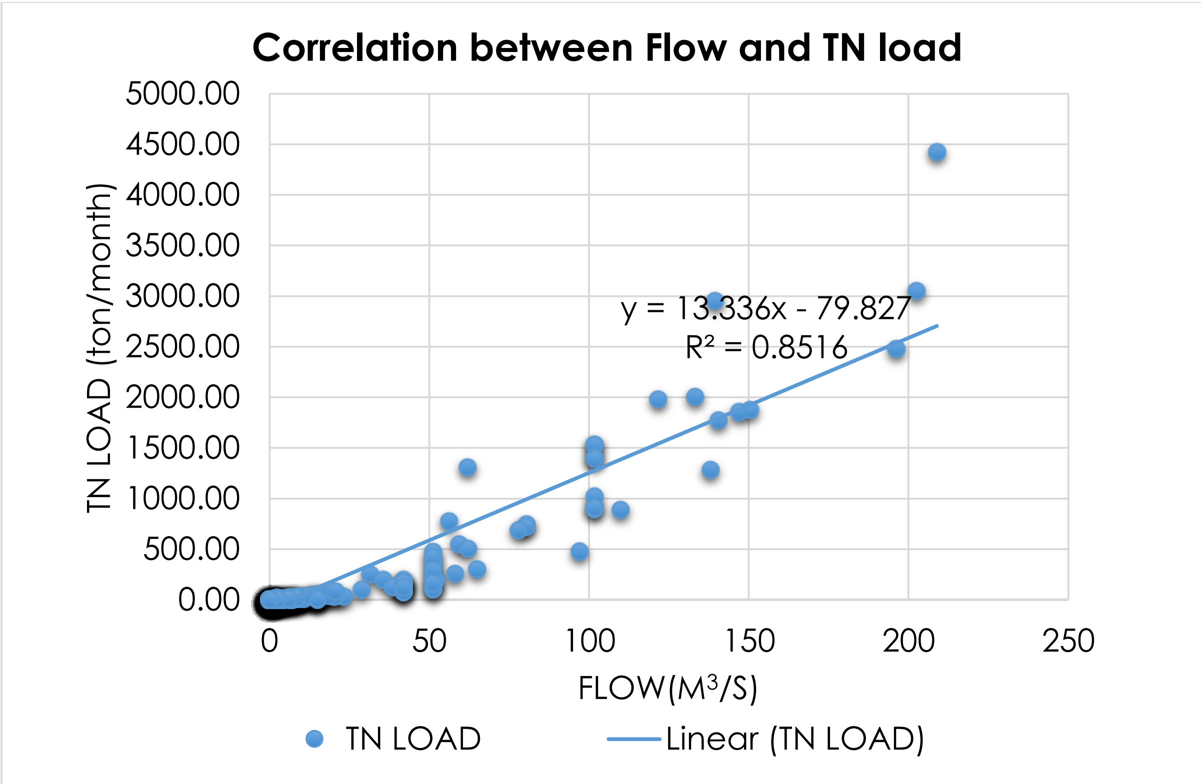

Figure 3-10 :- linear regression correlation between stream flow and TN load

For Total Phosphorus Load

$$TP_{load} = (PO_4) * Q * 2.4466$$

Where: TP - Total Phosphorus Load (ton/month)
Q - Flow (m^3/s)
PO_4 - Concentration of phosphate (Mg/l)

The estimated value of phosphorus load and measured stream flow correlation using simple linear regression was shown below.

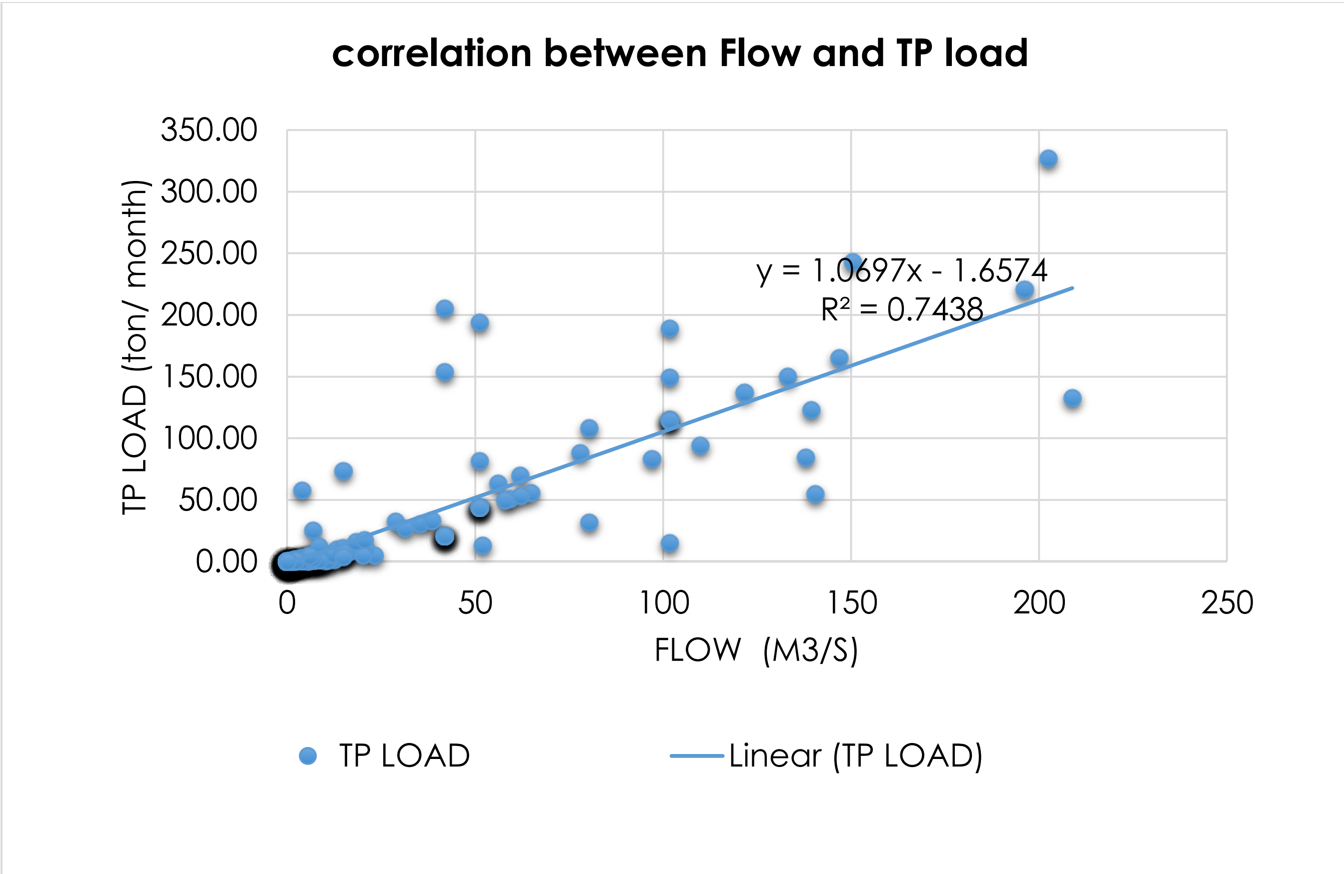

Figure 3-11:- linear regression correlation between stream flow and TP load

The computed Correlation coefficients were 0.89 for sediment concentration data, 0.85 for nitrogen concentration data, and 0.74 phosphorus for concentration data in average. Thus, sediment concentration data were most-closely correlated to stream flow, compared to phosphorus and nitrogen concentration data.

3.2.2.7 Point source data

Information on point source discharge was collected from Sheba leather industry itself. The treated waste water effluent of the industry is over flow during the heavy rain season from the waste stabilization pond sometimes to downstream land area which is far away around 500m from Genfel river sub basin of Geba reservoir. As per information of the company water quality section there was no over flow happening since three years but during over flow the sewage was entering to the water bodies mixing with the surface runoff.

3.3 Methodology

The methodology adopted for conducting the surface water source protection in Geba reservoir from source of pollution included identification of pollutant source, assessing pollutant load, estimate water quality parameter and select the best recommended water resource protection. The methodology adopted to achieve the stated objectives, applies the Soil and Water Assessment Tool (SWAT) model to simulate the stream flow, sediments load, nutrients load at the watershed outlet location entering to the reservoir, and to assess water quality status at the reservoir location within the hydrological process but before proceeding to the SWAT model fill the missing meteorological and hydrological data's, check the data quality and preparation of weather generator data were required.

3.3.1 Data Pre-Processing and Checking

The analysis will extending to hydrological and meteorological data to prepare input data for water resources assessment but the Collected data contain errors due to failures of measuring device or the recorder. So, before using the data for specific purpose, the data have to be checked and errors have to be removed. To prepare the stream flow and rainfall data for further application, their consistency was checked using double mass curve analysis and the Missing records of the rainfall stations was filled using XLSTAT 2014 method of statistical software's.

3.3.1.1 Filling of missing data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. The XLSTAT, 2014 model is used to fill the missing data. In Geba catchment the missing data were fill only when the data missing in each station is less than thirty percent using mante cruel simulation from all the neighborhood stations.

3.3.1.2 Consistency checking

After all the missing data are filled, it is important to check if the estimate was done with correct scaling. Correct scaling implies same gradient of accumulated plot of stations for long period of time using double mass curve.

The double-mass curve analysis revealed that there is good direct correlation between the cumulative rainfall records at Mekelle, Wukro, Agula Senkata, Atsbi and Adigrat gauging station with the cumulative average rainfall at the other stations (R^2 =0.9942, 0.9969, 0.9957,0.9941,0.9935 and 0.9973) respectively. This indicates that the rainfall data at all gauging station was consistent. The consistencies of their rainfall records were checked using similar procedure and it was found that no significant shift of slope was observed on their respective plots. As presented in the figure the correlation coefficients of the six stations indicated that there is good direct correlation between the stations' records and their corresponding base stations. Therefore, it was concluded that the precipitation data from all stations can be used for further application.

3.3.1.3 Data quality

The stream flow data must be checked for continuity and consistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any, accumulated plot and double mass curve. This will help identify if there are any gaps or unphysical peaks in data series and correct them before the data is used or input to the model. Otherwise, using the erroneous data as input to the model will give erroneous output from the model

Therefore, the data quality check was made by XLSTAT 2014.5.03 - Dixon test for outlier's to identify outliers to the flow data of Geba river basin after filling the missed data. The mean, minimum and maximum, standard deviation and the outlier were computed to describe the trend datasets of Geba stream flow. The resulting data set in Detail formula and description is shown below.

Data quality checking using XLSTAT 2014.5.03 - Dixon test for outlier's. The p-value has been computed using 1000000 Monte Carlo simulations and Significance level (%):5, 99% confidence interval on the p-value :(0.7900, 0.7320)

Table 3-4:- Summary statistics outlier test of annual Geba stream flow

Observations	Minimum	Maximum	Mean	Std. deviation
24	129.5416	605.6862	368.3885	134.6938

Dixon test for outliers / Two-tailed test:

R10 (Observed value)	0.1289
R10 (Critical value)	0.3257
p-value (Two-tailed)	0.7201
Alpha	0.05

Test interpretation:

H0: There is no outlier in the data

Ha: The minimum or maximum value is an outlier

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H_0. The Z- scores was that once the acceptance interval is set (typically -1.96 and 1.96 for a 95% interval). Accordingly no any value that is outside this Z-score considered suspicious for Geba annual river flow data. The risk to reject the null hypothesis H0 while it is true is 72.01%.

Table 3-5 :- Z- Score value of Outlier test Geba stream flow

year	discharge (m^3/s)	Z-score	year	discharge (m^3/s)	Z-score	year	discharge (m^3/s)	Z-score
1992	240.5	-0.784	2000	302.2167	-0.491	2008	164.7182	-1.512
1993	477.2628	0.8083	2001	411.8432	0.3226	2009	129.5416	-1.773
1994	370.1723	0.0132	2002	231.574	-1.016	2010	451.9372	0.6203
1995	544.3316	1.3062	2003	259.7932	-0.806	2011	518.6914	1.1159
1996	470.1994	0.7559	2004	331.4322	-0.274	2012	448.2922	0.5932
1997	160.1084	-1.546	2005	256.2637	-0.832	2013	215.3646	-1.136
1998	433.4129	0.4828	2006	330.1025	-0.284	2014	406.1312	0.2802
1999	417.9128	0.3677	2007	605.6862	1.7618	2015	535.9468	1.244

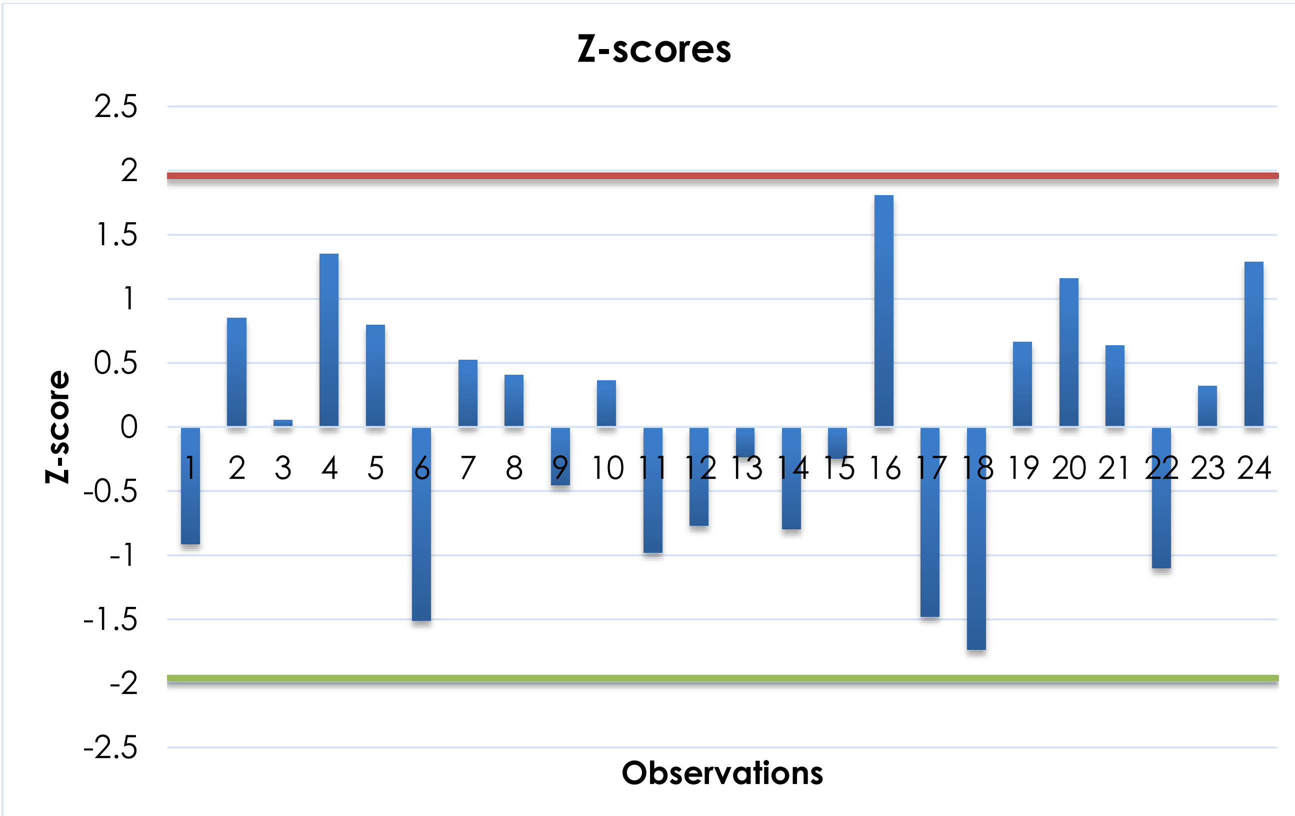

Figure 3-12:- Z- score value of outlier test Geba stream flow

3.3.1.4 Weather Generator station selection and data preparation

One of the main sets of input for simulating the hydrological processes in SWAT is climate data. Climate data input consists of precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity and the weather generator file. The climate data for study periods were prepared in dbf format files or ASCII format and then imported in the SWAT model database.

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from satellite data. The Model requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years.

The SWAT Model contains weather generator model called WXGEN. It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters the weather generator first separately generates precipitation for the average mean monthly and total precipitation, maximum temperature, minimum temperature and humidity are then generated. The meteorological data were analyzed to determine the various statistical parameters like mean monthly maximum and minimum temperature, average monthly wind speed, number of rainy days, average daily solar radiation, standard deviation for air temperature, precipitation, and maximum half hour time probabilities required as input by the weather generator file in SWAT. The analyzed data is presented as mean monthly series.

First check the observed average value of all station its mean, standard deviation, skewers and its total precipitations and temperature with the selected weather generator data because the SWAT model is a distributed model to select the weather generator station.

For this study the Mekelle station daily measured precipitation, air temperature, relative humidity, solar radiation and wind speed data from 1992- 2015 was use as input to generate those parameters for the other stations by standing from this station by SWAT model.

Helping software's are required to prepare the weather generator data. The PCPSTAT for precipitation to calculate mean, total and standard deviation the precipitation and DEW02.exe. To calculate the temperature and relative humidity mean.

After the precipitation data was checked for quality and the appropriate station selected, the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programmer *pcpSTAT.exe*. This programmer calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model.

Table 3-6 :- Statistical Analysis of Daily Precipitation Data (1992 - 2015)

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	8.6	1.4382	13.9213	0.0262	0.7813	4
Feb.	5.97	0.7398	6.7415	0.0388	0.6941	3.54
Mar.	23.09	2.9966	7.1409	0.0818	0.6752	6.54
Apr.	28.23	4.1576	11.3411	0.1146	0.6313	7.46
May.	28.95	4.3473	7.8724	0.0851	0.5789	5.54
Jun.	33.04	3.5345	5.1216	0.1533	0.5058	7.17
Jul.	155.15	8.1714	2.8312	0.378	0.7851	20.75
Aug.	171.77	9.3006	2.742	0.3934	0.778	20.83
Sep.	28.15	2.7237	4.7451	0.121	0.662	9
Oct.	11.36	2.0119	14.341	0.0332	0.7768	4.67
Nov.	11.53	2.2052	14.511	0.0282	0.822	4.92
Dec.	5.85	0.5485	5.1605	0.0217	0.82	4.17

Where,
PCPMM: Ave amount of precipitation falling in the month (mm)
PCPSTD: Standard deviation for daily precipitation in the month
PCPSKW: Skew coefficient for daily precipitation in the month
PCPD: Average number of days of precipitation in month
PR_W1: Probability of wet day following a dry day in month
PR_W2: Probability of wet day following a wet day in month
PCPD: Ave. number of days of precipitation in the month

Also preparing the maximum half hour rain from the precipitation date were required the swat weather generator data base which is the probability distribution of maximum rainfall depth in variant of time scale. Then, hour rainfall is prepared from the one third of the precipitation data required to fill the weather generator data format. The average RHHMAX (maximum Rain half hour) value estimated are below in the table.

Table 3-7:- average half hour rain weather generator station preparation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RHHMX(mm)	10	3.6	12.3	25	18.77	11.2	19.9	25.8	7.5	13.7	14	2.6

The temperature, humidity, solar radiation and wind speed data was prepared for the weather generator station selected. The statistical model used to calculate the maximum and minimum monthly temperature and mean monthly relative humidity was the programmer *Dew02.exe*. This programmer calculates the statistical parameters of monthly humidity, temperature, used by the weather generator of the SWAT model are as shown the table below.

Table 3-8:- Daily maximum/minimum air temperature and relative humidity at Mekelle station

Month	Parameter value					
	Tmp_Max(°C)	Tmp_Min(°C)	Hmd (%)	Dewpt	Stddev of Tmax(°C)	Stddev of Tmin(°C)
Jan	23.14	9.36	63.96	10.25	2.05	1.73
Feb	24.43	10.33	55.36	8.96	1.87	1.69
Mar	25.16	11.9	56.33	10.12	1.71	1.54
Apr	25.72	13.19	52.14	9.69	1.61	1.64
May	26.68	13.7	45.52	8.3	1.75	1.41
Jun	26.86	13.39	49.15	9.22	2.01	1.48
Jul	23.35	13.07	72.16	13.5	1.92	1.32
Aug	22.47	12.98	77.78	14.15	1.67	1.13
Sep	24.26	11.59	57.44	9.98	1.36	1.38
Oct	23.73	10.98	53.25	8.42	1.14	1.71
Nov	22.7	10.39	57.19	8.66	1.26	1.60
Dec	22.51	9.66	59.42	8.89	1.69	1.62

Where,
TMPMX: Ave. maximum air temperature for month (°C)
TMPMN: Ave. minimum air temperature for month (°C)
TMPSTDMX: Standard deviation maximum air temperature for month (°C)
TMPSTDMN: Standard deviation minimum air temperature for month (°C)
The average monthly solar radiation for weather generator data base prepared from the sunshine hour data or temperatures using different forms. So, in the present study, data of daily sunshine and temperature data are available in Mekelle station from 1992-2015 and its geographical location of station are presented and the sunshine data is more vacant than the temperature data due to the solar radiation result was driven from the temperature data using the formulas below.

$$R_{S=K_{RS}\sqrt{(T_{max-T_{min}})R_a}}$$

Where

Ra extraterrestrial radiation $MJM^{-2}DAY^{-1}$

T_{max} maximum temperature (^0c)

T_{min} minimum temperature (^0c)

KRS adjustment coefficient (0.16 ... 0.09) ($^0c^{-0.5}$)

for 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, kRs ≅ 0.16; and for 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, kRs ≅ 0.19.

Table 3-9:- average solar radiation result of weather generator station

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SR ($MJM^{-2}DAY^{-1}$)	20.3	22.2	22.7	23.8	24.1	20.3	17.3	17.2	20.8	22.3	20.8	20.2

The annual average monthly wind speed value from (1992-2015) also prepared to the WXGN Mekelle station data base to finalize the rearrangement of weather generator input data.

Table 3-10:- average wind speed result of weather generator station

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind speed(m/s)	3.09	3.80	3.79	3.66	2.63	1.94	1.92	1.62	1.51	2.70	3.33	3.52

On the other hand the name of the selecting gauging and climatic stations for analysis its rainfall and temperature data table which holds the precipitation data and the rain gage location field name must be the same and save with .Dbf or ASCII format.

Six station precipitation data and data location are arranged in text format for "RFMEKELLE", "RFWUKRO","RFSENKATA","RFATSBI","RFADIGRAT" ,"RFAGULA" and their location formats as shown below.

Table 3-11:- Station Location data for precipitation data table

ID	NAME	LAT	LONG	ELEVATION (m)
1	RFMEKELLE	13.47051	39.5312	2257
2	RFWUKRO	13.7874	39.5966	1987
3	RFSENKTA	14.06415	39.56873	2437
4	RFATSBI	13.8832	39.74142	2711
5	RFADIGRAT	14.27814	39.44683	2497
6	RFAGULA	13.68	39.57	2011

Also, the name of the data table which holds the temperature data and its climate station location field name must be the same and save with a text format.

Five station temperature data table and station data location are arranged in text format for “TMEKELLE”, “TWUKRO”,”TSENKATA”,”TATSBI”,”TADIGRAT” and their location formats as shown below.

Table 3-12:- Station location data for temperature data table

ID	NAME	LAT	LONG	ELEVATION(m)
1	TMEKE	13.4705	39.5312	2257
2	TWUKR	39.5966	13.7875	1987
3	TSENK	14.0642	39.5687	2437
4	TATSB	13.8832	39.7414	2711
5	TADIG	14.2781	39.4468	2497

3.3.2 Model Development

3.3.2.1 Overview of SWAT

Soil and Water Assessment tool (SWAT) is physically based, river basin scale, computationally efficient, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in a catchment (Abbaspour, 2015), applied this models for simulate all related processes to facilitates planning for a sustainable land management in a watershed.

SWAT is developed to examine the influence of topographic, land use, soil and climatic conditions on stream flow and pollution load magnitudes. This model can be utilized either from the source code or from the Geographic Information System (GIS) interfaces, which simplifies the integration of various spatial environmental data and the use of bulk data. It is a continuous time model and allows for simulation of different physical processes in a watershed. The spatial unit for rainfall-runoff calculations is the Hydrologic Response Unit (HRU), which is a lumped land area within a sub-watershed comprised of unique land cover, soil, slope, and management combinations. It is physically-based semi distributed watershed hydrological model, requires continuous time step, readily available data for simulating stream flow, sediment load, of watershed process as a result of land use land cover change and management practice, through calibration and validation of the model parameters (DAMTEW, 2015).

Input information for each sub basin is grouped or organized into different categories: climate; hydrologic response units or HRUs; ponds/wetlands; groundwater; and the main channel, or reach, draining the sub basin. Hydrologic response units are lumped land areas within the sub basin that comprise of unique land cover, soil and management combinations. No matter what type of problem is studied with SWAT, water balance is the driving force behind everything that happens in the watershed. To accurately simulate the flow, pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle and the land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

3.3.2.2 Hydrology

Since a hydrology component is fundamental for any watershed model. It will be develop based on the water balance equation using the input data sets of precipitation evapo- transpiration, percolation, surface run off and sub-surface run off for the soil sub divide in to several columns (berihun, 2010).

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

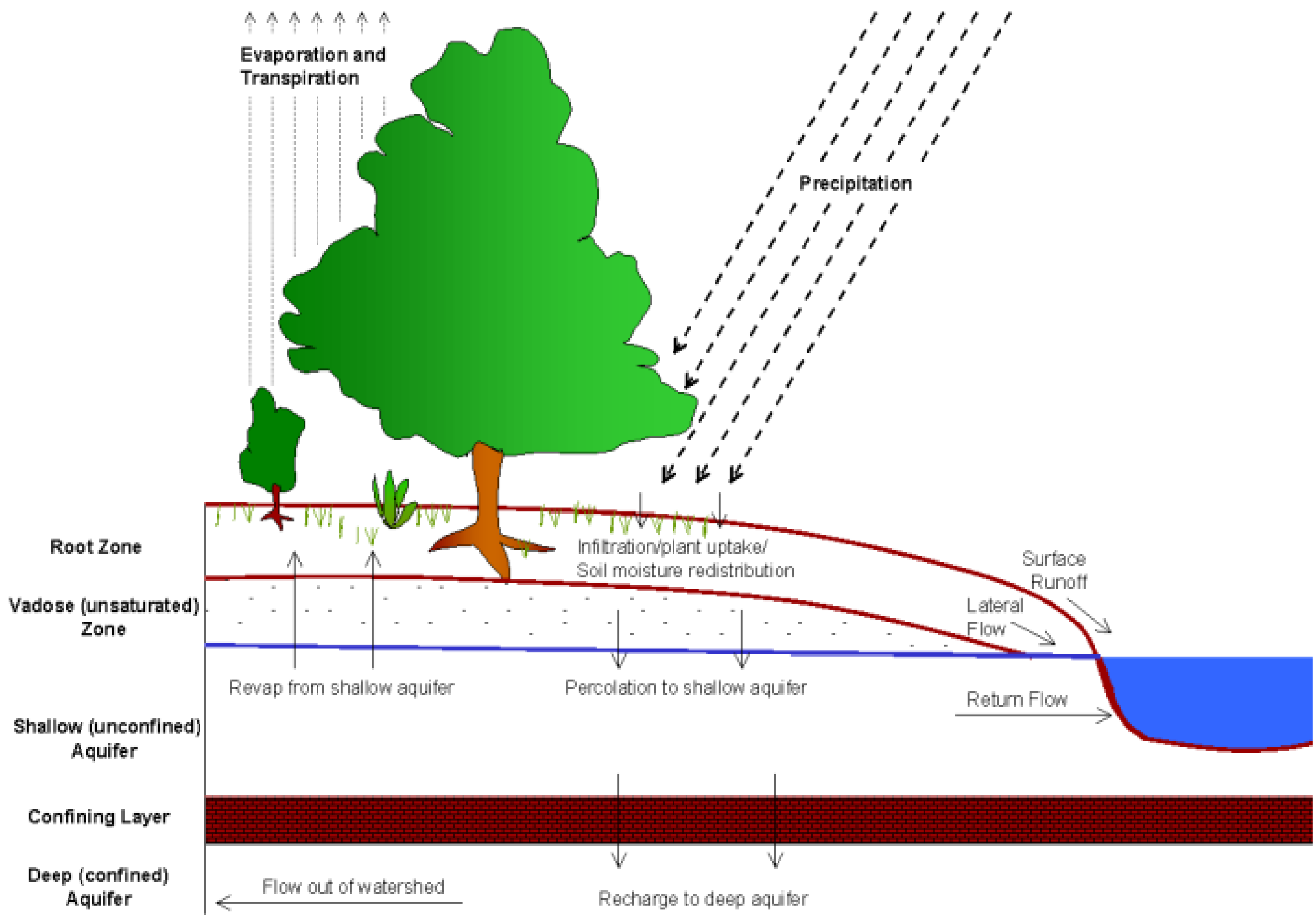

Figure 3-13:- Schematic representation of the hydrologic cycle (Neitsch et al, 2002)

3.3.2.3 Surface Run Off

Surface run off occurs whenever the rate of water applied to the ground surface exceeds the rate of infiltration. The quantity of nitrogen, phosphorus and sedimentation loss from non-point source can be determine evaluating different component of surface runoff and their temporal and spatial variations in the catchment. When the rate of the rainfall is greater than the rate at which it is able to infiltration soil the water quality constituent will be transported towards stream and the lake due to run off occur by high rain fall intensity. The transportation of pollution depends on the characteristic of the watershed which are important in determine the curve number index that expresses the catchment responses to the rain fall events such as geology soil type, vegetation cover, main precipitation, drainage area and antecedent moisture condition (berihun,2010)

3.3.2.4 Water Quality Model

Swat calculating the water quality in which the sediment, nutrient loads entering to the main channel with the surface run off.

3.3.2.4.1 Sediment

Soil erosion, especially from river channels and floodplains, provides a continuous supply for sediment transport in rivers. These sediments seasonally accumulate along the stream bed or in human-made reservoirs. Reservoir storage capacity can be classified into three types: the dead storage volume (volume below the lowest outlet level), the active storage volume (between lowest outlet and normal surface level), and the flood control storage volume (between normal and maximum surface level).

The SWAT model can be used for sediment yield predictions for planning, management and protection of water resources and reservoir sediment controls at the catchment scale. The modeling method is applicable to temporal and spatial analysis of sediment yields, of which the results are essential for reservoir management strategies.

SWAT can also be a potential tool in predicting sediment yield, especially at the catchment scale, because it considers spatial and temporal variation based on different potential physical variables. The model can also provide a better understanding of sediment transport and deposition processes by overland flow and allow reasonable prediction and forecasting. Sediment yield is the sum of the sediments produced by overland flow, gully, and stream channel erosion in a catchment. The main factor controlling sediment yield in general is the transport capacity of runoff. Sediment transport in the channel network is a function of degradation and aggradation (Neitsch, 2005). The current version of the model routes the maximum amount of sediment in a reach as a function of the peak channel velocity and estimates sediment yield for each HRU using SWAT.

3.3.2.4.2 Nutrient

Nutrient enrichment in water bodies has started to be seen as a maior problem due to different human activities experienced in the basin such as an increase human settlement in the drainage basin, clearing of forest for farming, development of urban societies and with consequential disposal of industrial and agricultural wastes. The main source of nutrient are effluent discharge from domestic and industrial source and non-point source. The non-point source are transported by run off during rainy season and by wind from the atmosphere

The fate and transport of nutrients in a watershed depends on the transformations the compounds under go in the soil environment. A certain portion of nutrients deposited in the sub basin will be lost due to various processes such as conversion to nitrogen gas, an inert form of the nutrient subsequently released to the atmosphere. The high concentration of nutrient mainly nitrogen and phosphorous increase the eutrophication in lake, reservoir and river. SWAT models the complete nutrient cycle for nitrogen and phosphorous as well as the degradation of any pesticides in a HRU. The transformation and movement of nitrogen and phosphorous with in an HRU are simulated on swat based on the cycle.

3.3.2.4.3 Nitrogen cycle

The main source of nitrogen for soil nutrient are from fertilizer added for cultivation, manure of residual applications fixation by symbiotic or non-symbiotic bacteria and rain. The different processes modeled by SWAT in the HRUs and the various pools of nitrogen in the soil are depicted in Figure below. Plant use of nitrogen is estimated using the supply and demand approach described in the section on plant growth. In addition to plant use, nitrate and organic N may be removed from the soil via mass flow of water. Amounts of NO3-N contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the layer. Organic N transport with sediment is calculated with a loading function developed and for application to individual runoff events. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil.

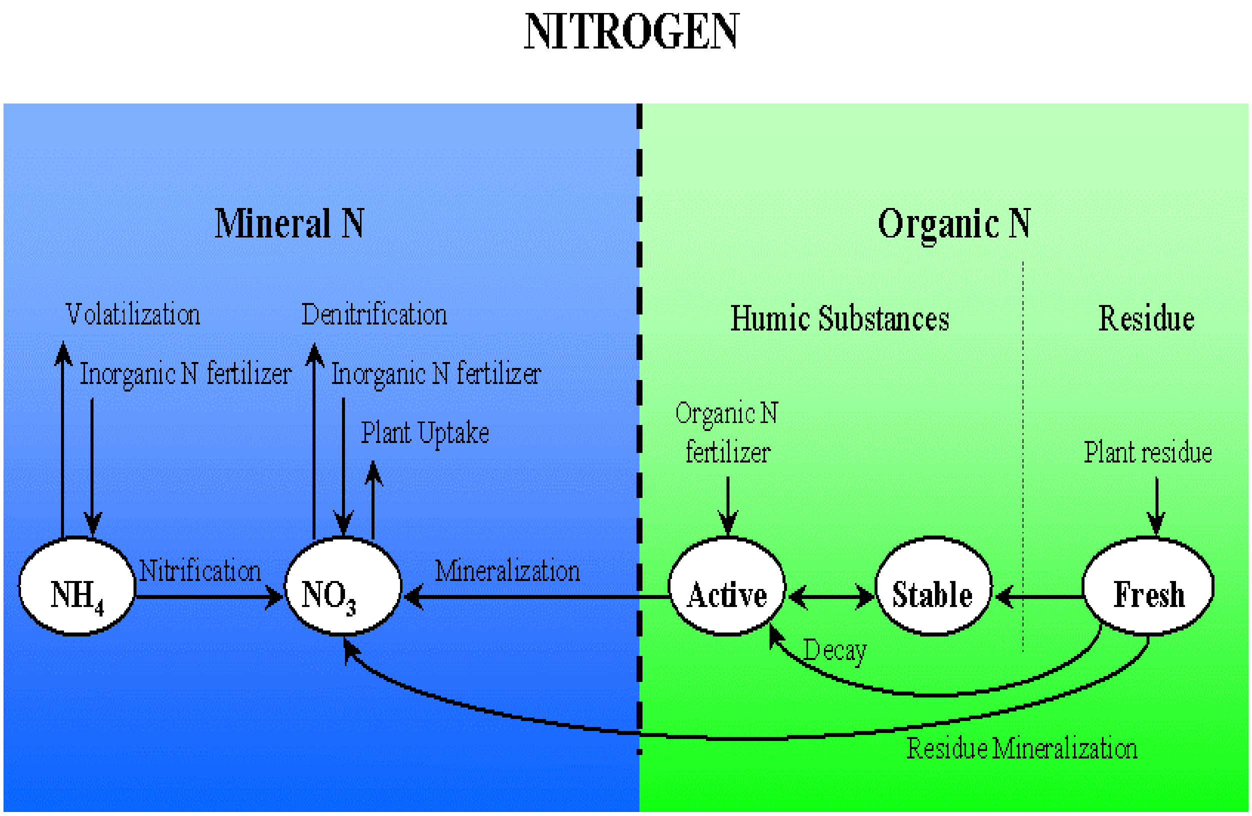

Figure 3-14:- SWAT soil nitrogen and processes that move nitrogen in and out pool (Neitsch et al, 2002)

The ability of nitrogen to vary its valance state makes it a high mobile element. Predicting the nitrogen movement between the different pools in the soil is critical to the successful management of this element in the environment. The organ and inorganic form of nitrogen are input into the soil system via commercial fertilizer, livestock manure and plant residue.

3.3.2.4.4 Phosphorous cycle

The different processes modeled by SWAT in the HRUs and the various pools of phosphorus in the soil are depicted in Figure below. Plant use of phosphorus is estimated using the supply and demand approach described in the section on plant growth. In addition to plant use, soluble phosphorus and organic P may be removed from the soil via mass flow of water. Phosphorus is not a mobile nutrient and interaction between surface runoff with solution P in the top 10 mm of soil will not be complete. The amount of soluble P removed in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport.

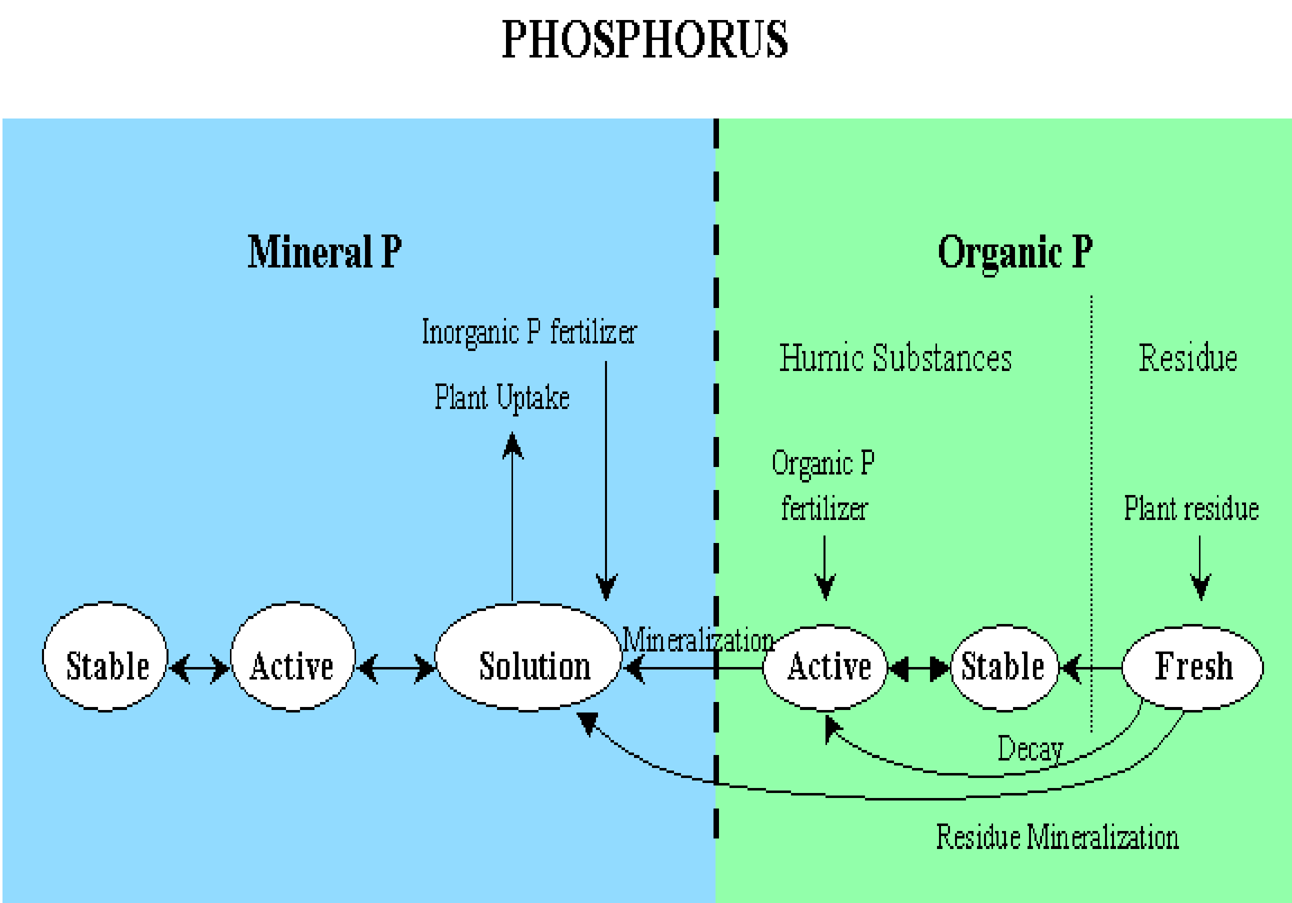

Figure 3-15:- SWAT soil phosphorous and processes that move phosphorous in and out pool (Neitsch et al, 2002)

3.3.3 SWAT Model Simulation Procedure

Before SWAT delineates streams and outlets, SWAT requires an area of flow accumulation in hectares (ha). The SWAT model can then delineate the main channel, tributaries, and outlets. The SWAT model defines the boundaries of the study area by the chosen outlet of which to define the watershed. Before HRUs could be classified, the DEM had to be separated into different slope classes. After land cover, soil data and slope classes were added to the project, a threshold percentage was needed to be defined in order to remove statistical insignificant land covers, soils, and slope classes. After the weather data definition was complete, information regarding agricultural practices and nutrient needed to be entered into the model. SWAT model its simulated result includes surface and ground water flow, pollutant (sediment and nutrient) load entering to the outlet and water quality parameter of the watershed. The general methodology procedure of swat model to stimulate runoff, sediment, nutrient load and water quality is as shown the chart below.

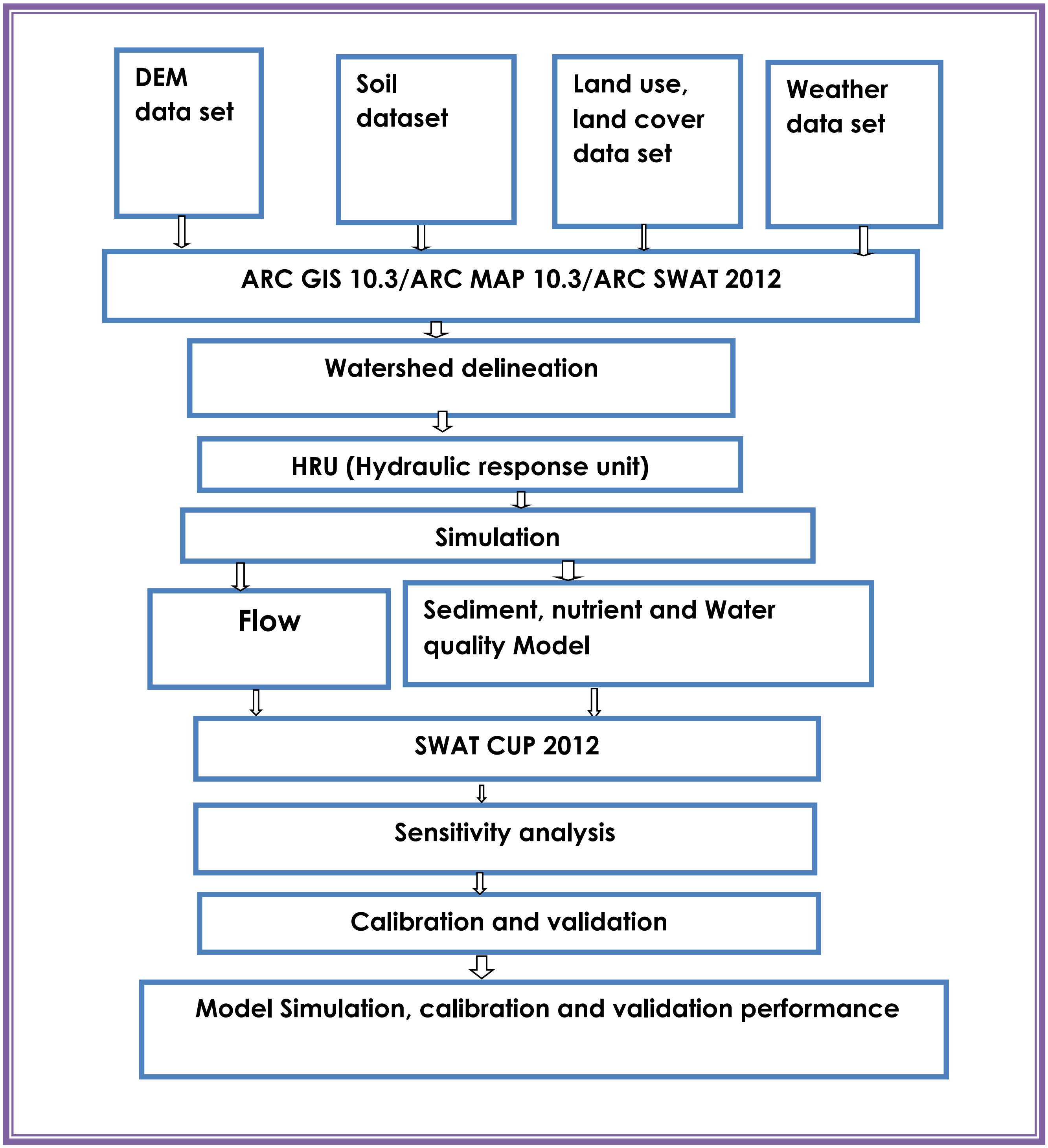

Figure 3-16 :-steps to assess flow, sedimentation and nutrient in Geba watershed using SWAT model

3.3.4 Watershed delineation

The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format. Drainage boundaries on the DEM, masking the Digital Elevation Model (DEM) with coverage of the study area to delineate watershed using Arc SWAT steps were used. The DEM of watershed was projected to UTM Coordinate system using Arc map in Arc GIS and imported to Arc SWAT to start automatic watershed delineation.

Flow directions for individual DEM cells were created using flow direction and accumulation tool in Arc SWAT. SWAT computes flow direction for individual DEM cells and uses stream threshold area in hectares to create streams based on these directions.

An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined also create the point source inlet.

Then finally main watershed was delineated by using watershed delineator tool in Arc SWAT based on an automatic procedure using the watershed outlets created. In order to create sub-watersheds, additional drainage outlets need to be defined. After several nodes or vertices are defined into drainage outlets along the stream arcs and then create the reservoir location after the outlet of the watershed.

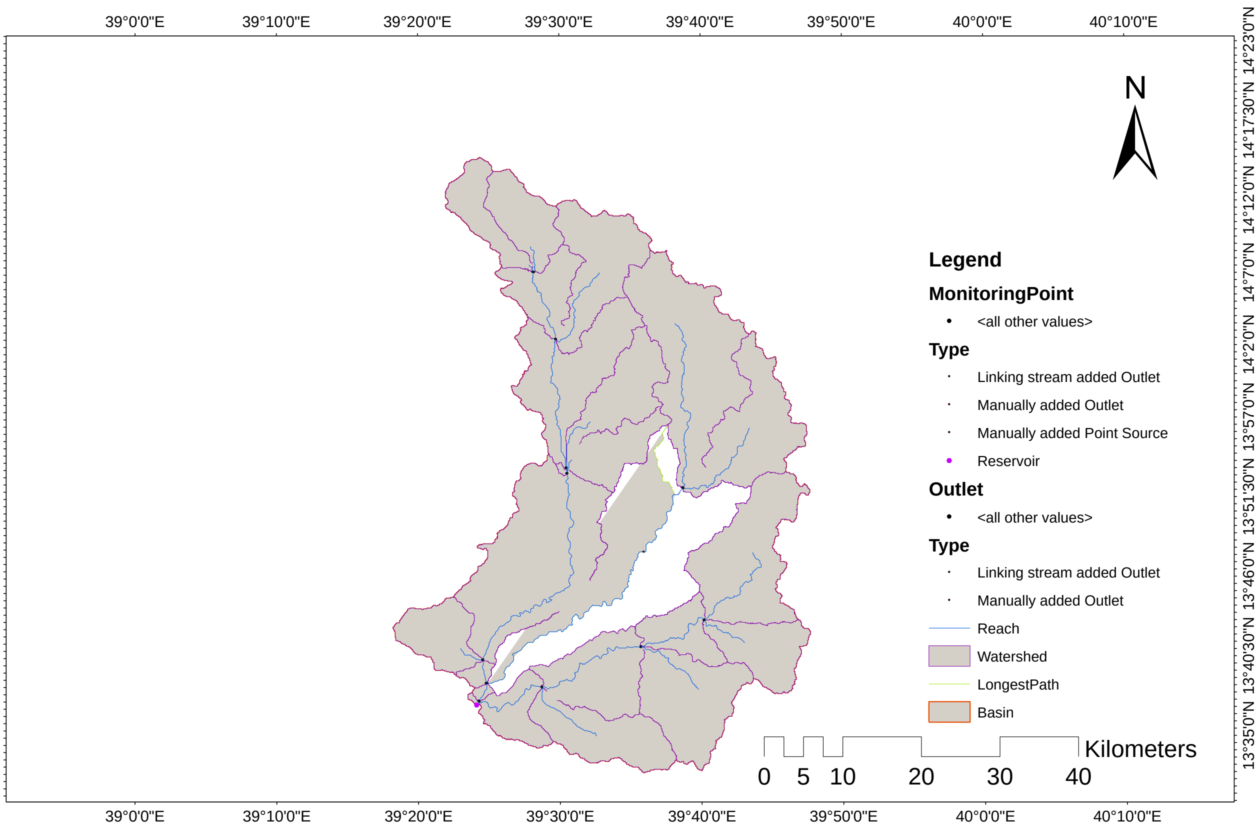

Figure 3-17 :- Geba watershed delineation

3.3.5 Hydraulic response unit (HRU)

SWAT first delineates a basin or a watershed and then, a basin is delineated into sub-basins, which are then further subdivided into hydrologic response units (HRUs). In this sub-division SWAT considers spatial variations in topography, land use, soil, slope and other watershed characteristics.

The classification of HRU is determined by soil types, land used conditions, and elements related to vegetation and landscape characteristics. Each HRU is spatially independent. Water generated from HRUs contributes to reaches through the most upstream end of the main river within the sub basin. Sub basins are spatially connected by river reaches. Water contributed to each sub basin is then conveyed through reaches along the stream network.

The land use and the soil data in a projected shape file format were loaded into the Arc SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As of the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The land slope classes were also integrated in defining the hydrologic response units. The DEM data used during the watershed delineation was also used for slope classification. The multiple slope discretization operation was preferred over the single slope discretization as the sub-basins have a wide range of slopes between them. Based on the suggested min, max, mean and median slope statistics of the watershed, five slope classes (0- 5, 5-10, 10-15, 15-20 and >20) were applied and slope grids reclassified. The generated classification of the slope in the water shed are shown in the table and figure below.

Table 3-13 Multiple slope distribution grid classification of HRU in Geba watershed

ID	Slope %	area cover	watershed % area cover
1	0_5	624.4668	25.89
2	5_10	583.9452	24.21
3	10_15	170.2872	7.06
4	15_20	687.42	28.5
5	> 20	346.122	14.35
TOTAL		2412	100

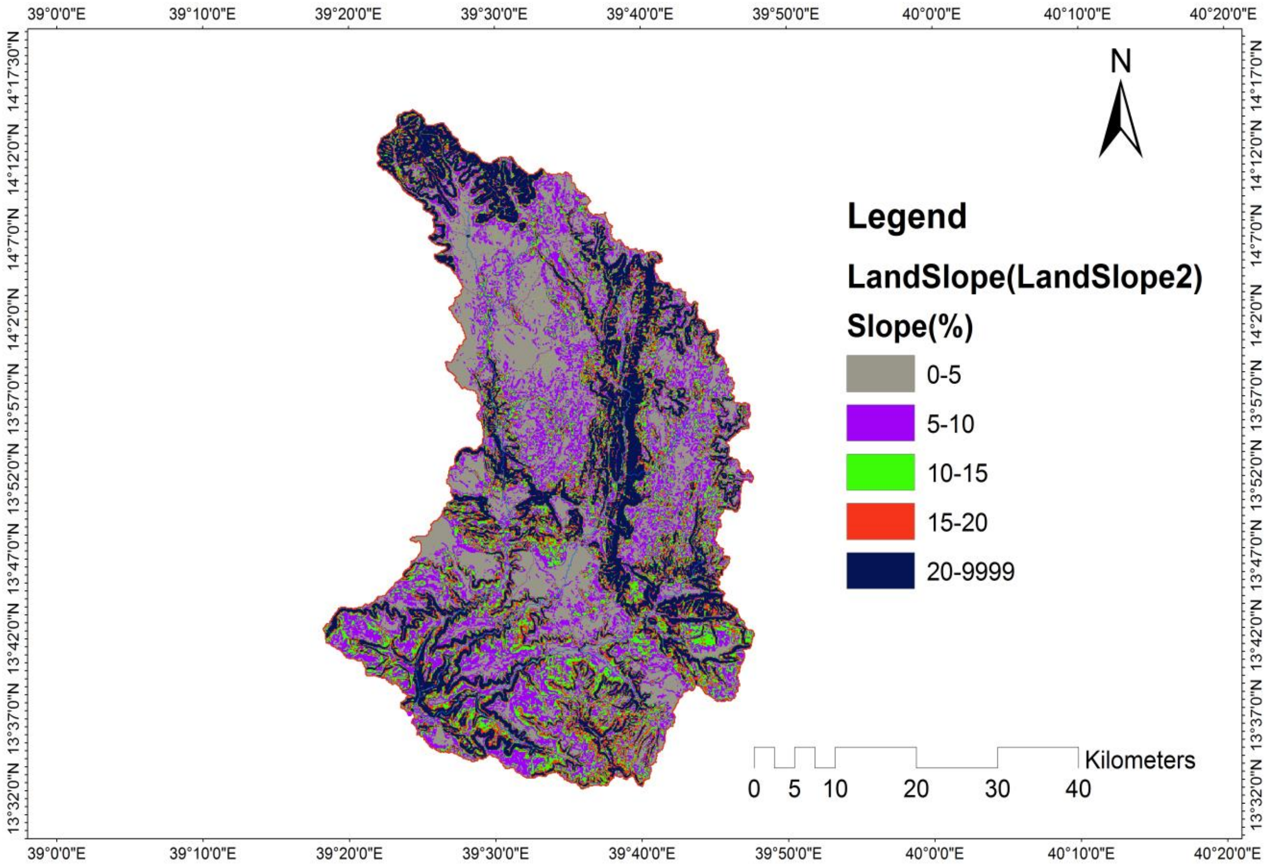

Figure 3-18 Multiple slope distribution grid classification of HRU in Geba watershed

After the reclassification of the land use, soil and slope grids overlay operation was performed. The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, soils or slope classes which cover less than the threshold level are eliminated. After the elimination process, the area of the remaining land use, soil, or slope class was reapportioned so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 10 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to consideration, 10%, 10%, and 10% threshold levels for the land use, soil and slope classes were applied, respectively so as to encompass most of spatial details.

3.3.6 Importing Climate Data

The flow, sediment and water quality of a watershed provides the climate inputs that to determine the magnitude of pollution and water quality examination. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum temperature and the weather generator data prepared form Mekelle station in the SWAT SWAT 2012 data base in WXGN users. However, the data to be used by the model depends on the type of method chosen. Due to data availability of daily precipitation, and maximum/minimum temperature in dbase format were the climatic input variables imported together with their weather generator location because observed data on max/min temperature and daily precipitation were loaded into the simulation to improve efficiency especially rainfall, have a huge effect on model performance due to the reason of rainfall is the main source of runoff. Wind speed, humidity, and solar radiation data were created by WXGEN parameters. Also added and edited the point source data and select all the write up table in order to generate the output during swat run effectively.

3.3.7 Run Swat Model

The Run SWAT icon, which is located under the SWAT simulation menu, was set to 01/01/1992 and 12/31/2015 with a monthly printout option "NYSKIP" was also set to 3 years as a warm up period for the model. The value of 3 in the NYSKIP operates the first output from the simulation as a start point of 01/01/1995. After the rest of the parameters were left as default values, the "Setup SWAT Run" icon was activated and the simulation was run.

3.3.8 Sensitivity Analysis, Calibration and Validation in SWAT CUP 2012

The hydrological system was evaluated through sensitivity analysis and calibration, the main physical processes gave corresponding parameters to be considered. The calibration was started by the sensitivity analysis taken as giving information to identify parameters that were important for the reproduction of the system response.

In order to utilize any predictive catchment model for estimating the effectiveness of future potential management practices, the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data (model validation). Model calibration determines the best or at least a reasonable parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent dataset.

3.3.8.1 SWAT CUP application

Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats.

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. SWAT model is run in ArcGIS interface for calibrating a model run, open a new project in SWAT-CUP and locate the"TxtInOut" directory of the SWAT run. Choose the program from the list provided (SUFI2, GLUE, Parasol, MCMC and PSO). After completing the inputs required, the program is executed. The output files for the best parameters and the best simulation are taken as the results.

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. A schematic of the linkage between SWAT and five optimization programs is illustrated in the Figure below.

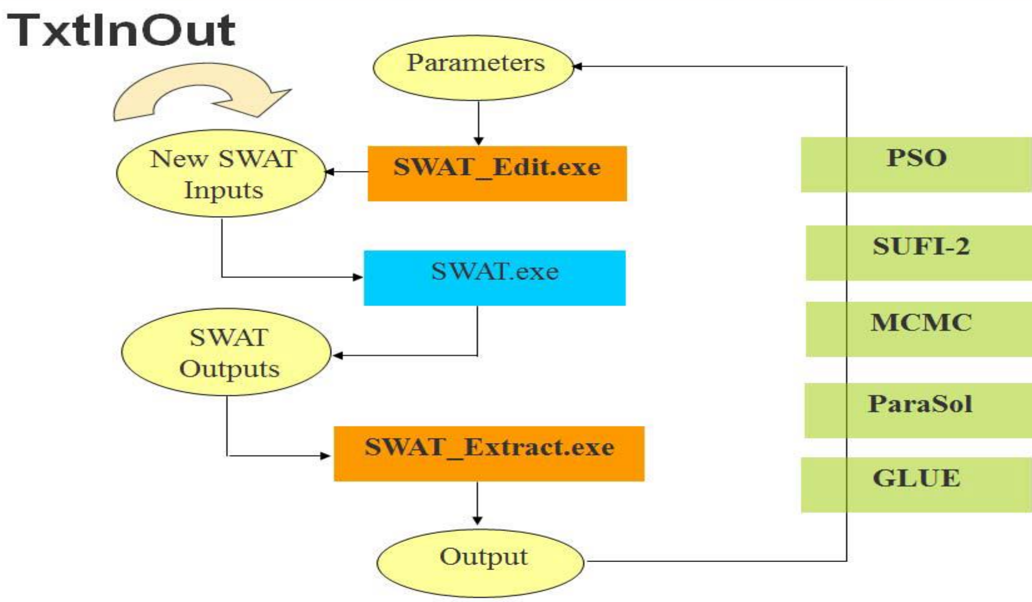

Figure 3-19 :- SWAT CUP algorithm

Among the methods offered within the SWAT-CUP package, the SUFI2 algorithm was adopted in this study for the calibration and validation purpose, since it is easy to handle; it requires a minimum of runs and thus gives comparably good results. Moreover, it is able to describe all kinds of uncertainty sources.

Following the sensitivity analysis, the SWAT Calibration and Uncertainty Procedures (SWAT-CUP 2012) version 5.1.6 was applied to calibrate, validate, and assess model uncertainty. Calibration and uncertainty analysis was performed using SUFI-2 (sequential uncertainty fitting version 2) algorithm, which is a semi-automated inverse modeling procedure for a combined calibration-uncertainty analysis

Therefore Sensitivity analysis was conducted in this study for flow, sediment, water quality and the soil nutrients (N and P) using 28 which are 18 for flow, 22 for sediment, 21 for TN and 25 for phosphorus. The flow sensitive parameters are common for all variables model parameters. The parameters associated with flow, sediment TN and TP were analyzed with a Latin Hypercube interval value of 1 and the sensitivity analysis required 500 simulations with a maximum of round four iterations. All the selected sensitive parameters for all variables are listed in appendix-C.

Parameters that have high sensitivity were chosen with care because small variations in their values can cause large variations in model output. Sensitivity analysis was run for the period 1995 to 2015. The 1992-1995 was used as a 'warm-up' period for the model and the rest of the years (1995-2015) were considered in the sensitivity analysis.

The SWAT CUP was calibrated and validated based on monthly basis for flow sediment and soil nutrients loads. Monthly Flow and sediment, TN and TP from 1995 to 2015 were used for calibration using the 1992-1995 data as 'warm-up' period for the model. The 2009 to 2015 data were used for model validation for all variables.

4 RESULTS AND DISCUSSION

4.1 SWAT Simulation

Based on the HRU definition, 21 sub-watersheds of Geba watershed are created. The total area of Geba watershed is then determined to be 2412 Km^2. Also Based on model set up with Land use, Soil and slope and minimum area threshold values set as 10%, 10% and 10% respectively, 145 Hydrological Response Units (HRU) are identified, which are unique combinations of land use, soil type and slope.

The simulation was run with three years warm up period with skewed normal distribution for rainfall data, and limited by a model boundary based on HRU, sub basin, reach, and reservoir and water quality index output data. The data on watershed statistics for flow, sediment load, and nutrient and water quality parameters were obtained through the "output.std" text file and the document in Microsoft Access format then select the major pollutant load at the out let reach 21 output result report before proceeding to the calibration and validation model process. The simulated total annual flow, sediment, TN and TP entering to Geba reservoir output result summary report are listed in appendix- A.

After generating the swat model output result the Monthly average in-stream loads of flow 16.44 m^3/s and 37993.35, 376.068 and 17.95554 ton/ month of Sediment, TN and TP, respectively were estimated at the Geba watershed outlet reach 21 during the simulation period. The monthly loads varied by several orders of magnitude. Also the total loads associated with summer storms generally contribute much higher percentages to the reservoir than those from the other seasons. The peak magnitude of in-stream monthly in August 2000 reached flow 157.9 m^3/s, 452,400, 3,321 and 218.3 ton/month of sediment load, TN and TP respectively compared many of the dry season months.

4.2 Model sensitivity analysis

The relative sensitivity value for the final best simulation value with their minimum and maximum fitted value which was ranged between the limited maximum and minimum value of goodness of fit for sensitive analysis for flow, sediment, total nitrogen and total phosphorus are listed in the table below. There were six, five, seven and ten very high sensitive parameters for flow, sediment TN and TP respectively. Those parameters was selected based on P-Value which was less than or equal 0.05 after calibrating first all the sensitive parameters for each objective variables. Also there are common parameters which shows high sensitivity to flow, sediment, soil nutrients, regardless of the differences in the sensitivity values. An example of this is that HRU_SLP Average slope steepness (m/m) Curve Number (CN2) and Slssubbsn (steep land slope sub basin) are sensitive to change these model outputs.

The results of the analysis indicate that, twelve parameters , Curve Number (CN2), Ground flow recession factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), Soil Available Water Capacity (SOL_AWC), Soil Hydraulic conductivity (SOL_K), Hydraulic conductivity in main channel (CH_K2), Threshold depth of water in the shallow aquifer for "revap" to occur (mm) (REVAPMN), base flow alpha factor for bank storage (ALPHA_BNK), over land flow (OV_N), Manning roughness for main channel (CH_N2), ground water delay (GW_DELAY), biological mixing efficiency (BIOMIX), Average slope steepness (m/m) (HRU_SLP),steepest land slope of sub basin(Slssubbsn) and are the most sensitive parameters in this study area. The sensitivity analysis indicated the overall importance of the twelve parameters in determining the stream flow, sediment TN and TP at this study area. The final best simulated result of highest sensitive parameter used for taking calibration and validation result for each object variables are listed in the table below.

Table 4-1:- the final result of SWAT CUP, SUFI 2 sensitive Parameters analysis with their Respective minimum and maximum fitted Values for flow best simulation of Calibration and validations

Par_no	Par_name	Min	Max
1	r__CN2.mgt	49.28	60.07
2	v__REVAPMN.gw	304.67981	450.151917
3	r__SOL_AWC().sol	0.615191	0.82807
4	v__ALPHA_BNK.rte	0.41932	0.727773
5	v__SLSUBBSN.hru	37.513542	46.688217
6	v__HRU_SLP.hru	0.285799	0.450955

Table 4-2 :- the final result of SWAT CUP, SUFI 2 sensitive Parameters analysis with their Respective minimum and maximum fitted Values for sediment load best simulation of Calibration and validations

par_no	par_name	Min	Max
1	r__CN2.mgt	35.5301	69.5601
2	v__SLSUBBSN.hru	133.807556	148.687073
3	v__HRU_SLP.hru	0.302	0.4452
4	r__SOL_ALB().sol	0.245458	0.8266
5	v__OV_N.hru	26.279491	26.550037

Table 4-3 :- the final result of SWAT CUP, SUFI 2 sensitive Parameters analysis with their Respective minimum and maximum fitted Values for total nitrogen load best simulation of Calibration and validations

Par_no	Par_name	Min	Max
1	r__CN2.mgt	39.653	48.067
2	v__CH_N2.rte	0.095658	0.22355
3	v__CH_K2.rte	132.006042	265.237823
4	v__ALPHA_BNK.rte	0.990372	1.213
5	v__SLSUBBSN.hru	103.000168	141.169983
6	v__HRU_SLP.hru	0.028106	0.0995
7	v__ESCO.hru	0.362565	0.668729

Table 4-4:- the final result of SWAT CUP, SUFI 2 sensitive Parameters analysis with their Respective minimum and maximum fitted Values for total phosphorus load best simulation of Calibration and validations

par_no	par_name	min	max
1	r__CN2.mgt	75.806	89.664
2	v__GW_DELAY.gw	451.991333	508.162109
3	v__CH_N2.rte	0.212803	0.341959
4	v__CH_K2.rte	-0.083874	246.980515
5	v__ALPHA_BNK.rte	0.304514	0.85828
6	v__SLSUBBSN.hru	28.5432	101.197739
7	v__HRU_SLP.hru	0.139674	0.149112
8	v__OV_N.hru	3.442299	12.14949
9	v__ESCO.hru	0.121341	0.422841
10	r__BIOMIX.mgt	0.0823	0.0877

4.3 Flow calibration and validation

After the sensitive parameters had been identified, the calibration process focused on adjusting model-sensitive input parameters determined from the sensitivity analysis to obtain best fit between simulated and observed data. Model calibration is an important step in watershed modeling studies that helps to reduce uncertainties in model predictions. The final fitted values of these parameters were included in the SWAT model so as to fine adjust the simulation to the observed data during validation and other applications.

The calibration and validation result of the simulated stream flow monthly basis perform well for the Geba watershed at the outlet location. The model goodness-of-fit NSE for stream flow calibration and validation on monthly basis was NSE= 0.75 and NSE= 0.67, respectively and the correlation ($R^{2)}$ for stream flow calibration and validation on monthly basis was R^2 = 0.76 and R^2 = 0.70· Respectively.

Therefore, SWAT model was thus calibrated and validated successfully on a monthly basis. This indicates that the final values of the model-sensitive parameters selected during the calibration represent those parameters in the study area. In addition to the statistical measures (R^2, NSE), the visual comparison of graphs also indicate the model performance during calibration and validation for stream flows as shown figure below. This is used to identify model bias and differences in the timing and magnitude of peak flows simulated.

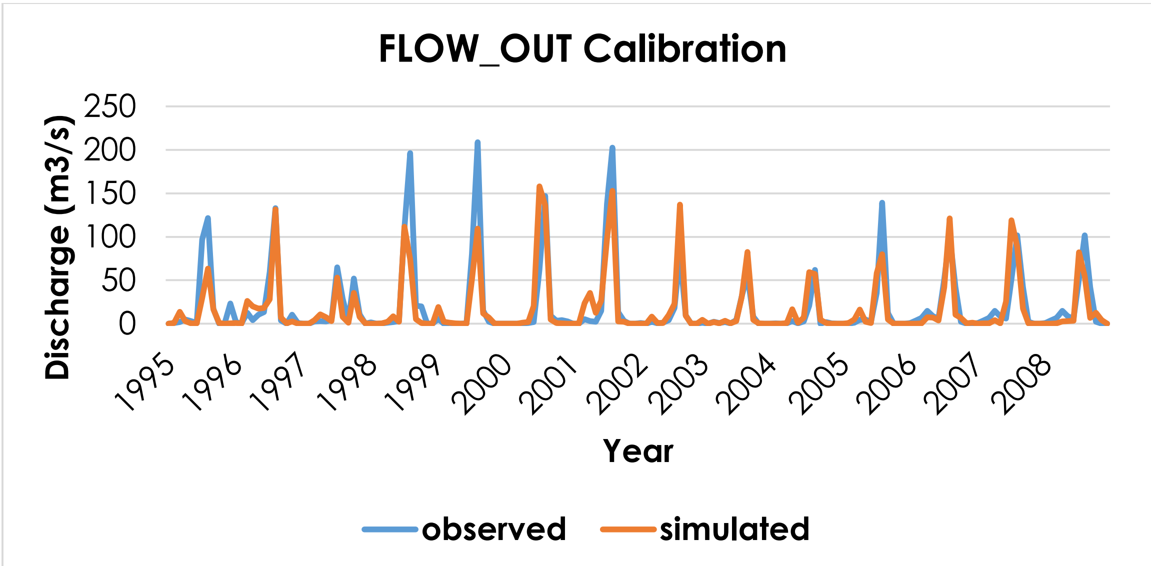

Figure 4-1:- 95ppu swat cup final best simulation result for flow calibration from (1995-2008)

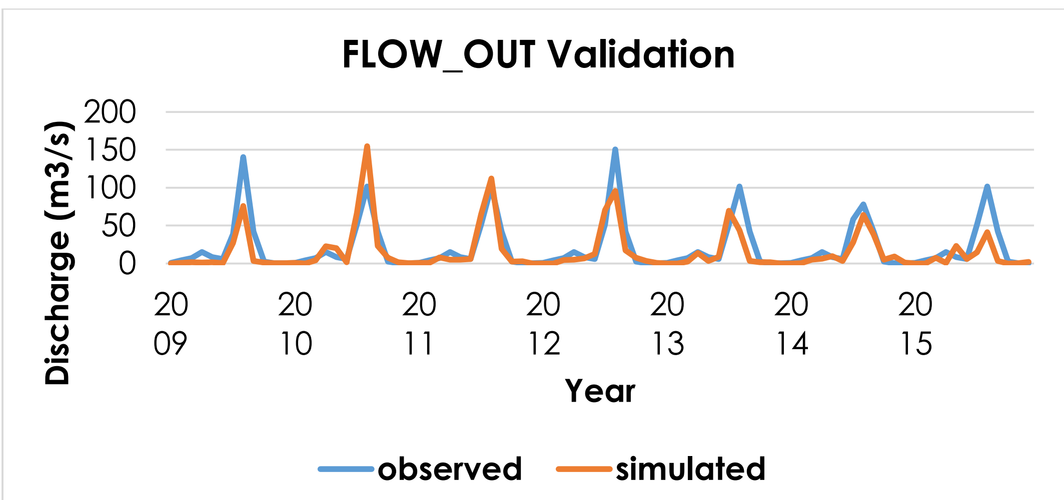

Figure 4-2 :- 95ppu swat cup final best simulation result for flow validation from (2009-2015)

In general, the SWAT model in this study provides an acceptable and better prediction efficiency of stream flow that can use in further analysis to identify and prioritize critical runoff source sites and simulate alternative best management practice strategies to protect this surface water source from pollution.

4.4 Calibration and validation of sediment and nutrients loads

The performance efficiency and their fitted values for sediment and nutrients model calibration validation processes are presented in this section. The SWAT model calibration and validation statistics for the annual sediment yield and soil nutrients show an adequate level of accuracy. The R^2 and NSE model statistic computed between the simulated and observed monthly sediment yield for the calibration period were 0..66 and 0.66, respectively. The validation of monthly sediment yield showed an R^2 of 0.60 and NSE of 0.59, which is lower than the calibration values. The calibration of monthly TN gave an R^2 of 0.74 and NSE of 0.74, while the monthly TP calibration had an R^2 of 0.75 and NSE 0.74. The efficiency for TP calibration is higher than for sediment and TN. The reason may be attributed to the uncertainty in the calculated regression analysis used as observed data, and also to the use of best fit parameters during calibration. Similarly, in the model validation R^2 and NSE for TN and TP were (R^2=0.64, NSE=0.57) and (R^2=0.73, NSE=0.68). These model efficiencies is the final improved best simulations during validation for sediment, TN and TP. The monthly validation statistics for sediment yield, TN and TP indicated a close agreement between the measured and predicted values on a monthly basis, which was explained comprehensively by NSE and R^2 for TP, sediment yield and TN. The best fit between simulated and measured values or calculated value for TP and TN other than sediment yield is likely associated with the quality of input data and the method used to prepare observed data in this study. The sources of TN, TP and sediment observed data were included in the preparation of data for calibration and validation of model; because, it was difficult to obtain measured all possible nutrient and sediment loads.

Overall model prediction capacity for the sediment yield and soil nutrients is acceptable for the study catchment as it is greater than 0.50 for NSE and 0. 60 for R^2. With regard to the observed versus simulated data for sediment during calibration and validation, results of this study reveal that the model shows under estimated result rather over estimated at most in all the simulation years.

The summarized best simulation Model Calibration and validation result at the Geba watershed outlet for both sediment and nutrient load is performed using Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP. The model is forced to run 500 times iteratively in both period (Calibration and validation). The result obtained are shown in table and figure below show that there is good agreement between monthly simulated and measured loads in both graphical and statistical comparison.

Table 4-5 :- SWAT-CUP Simulation Results during Calibration Period (1995-2008) and Validation Periods (2009-2015)

load type	evaluation parameters	simulation result		performance remark	
		calibration	validation	calibration	validation
sediment	R^2	0.66	0.6	G	G
	NSE	0.66	0.59	G	G
TN	R^2	0.74	0.64	V.G	G
	NSE	0.74	0.57	V.G	G
TP	R^2	0.75	0.73	V.G	V.G
	NSE	0.74	0.68	G	G

V.G= Very Good, G. = Good

the performance efficiency values in both calibration and validation period prove that, swat model predicted monthly soil sediment and nutrient load quite satisfactorily against the calculated load which is estimated from measured stream flow as indicated in the table 4.5, this shows very good predictive capacity of the model to reproduce loads at outlet. This graphical interpretation together with the numerical analysis gives a comprehensive measure of the agreement between measured and simulated data.

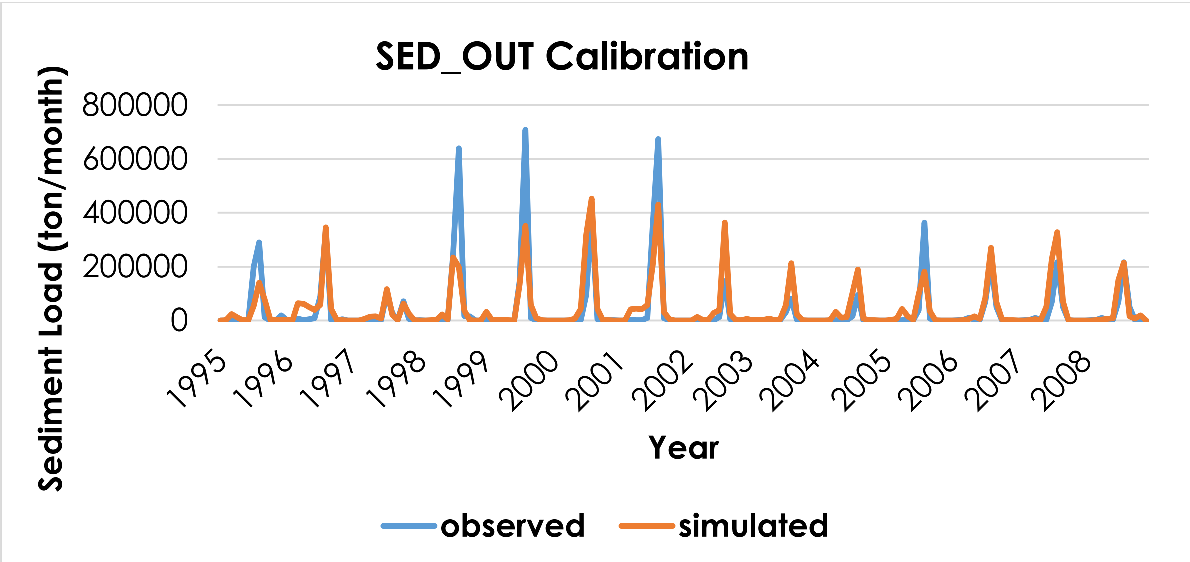

Figure 4-3 :- 95PPU swat cup final best simulation result for sediment calibration from (1995-2008)

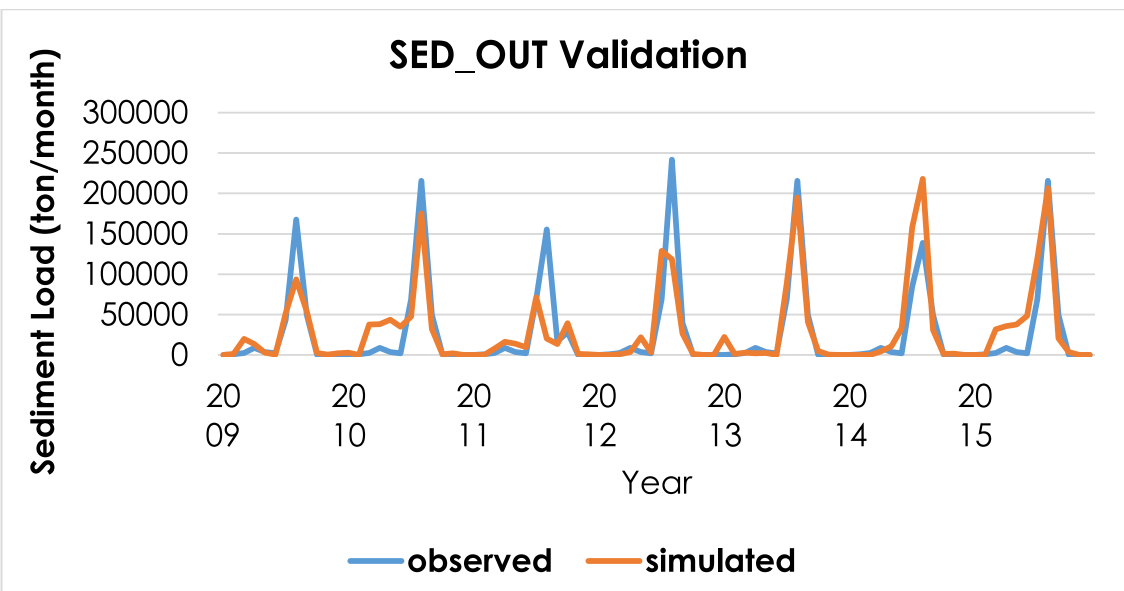

Figure 4-4 :- 95PPU SWAT CUP final best simulation result for sediment validation from 2009-2015

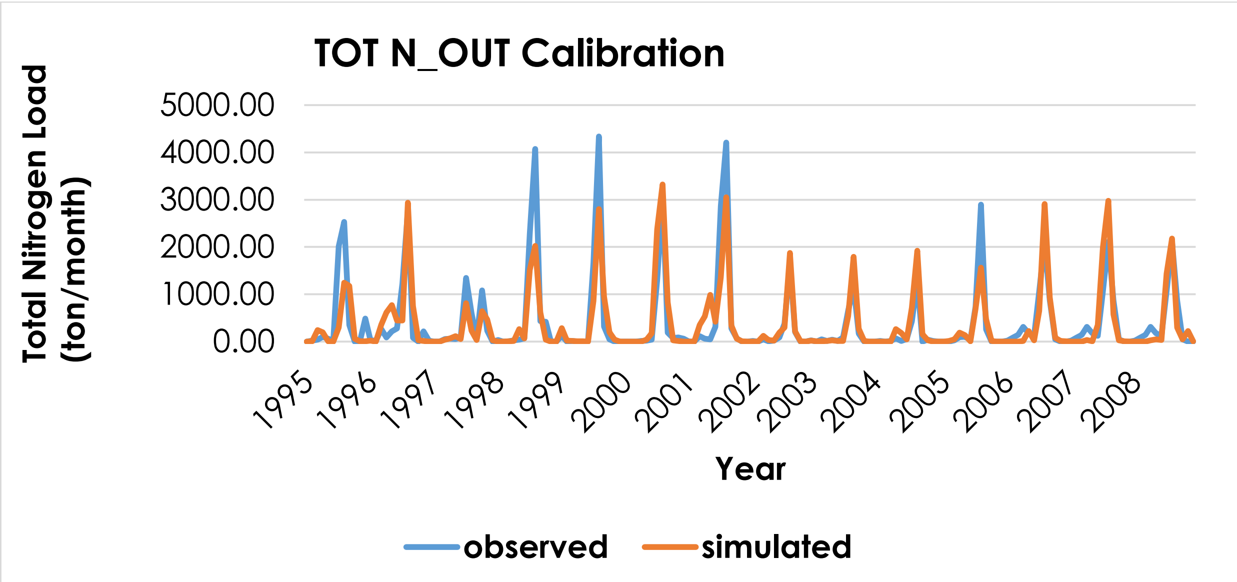

Figure 4-5:- 95PPU swat cup final best simulation result for total Nitrogen load calibration from (1995-2008)

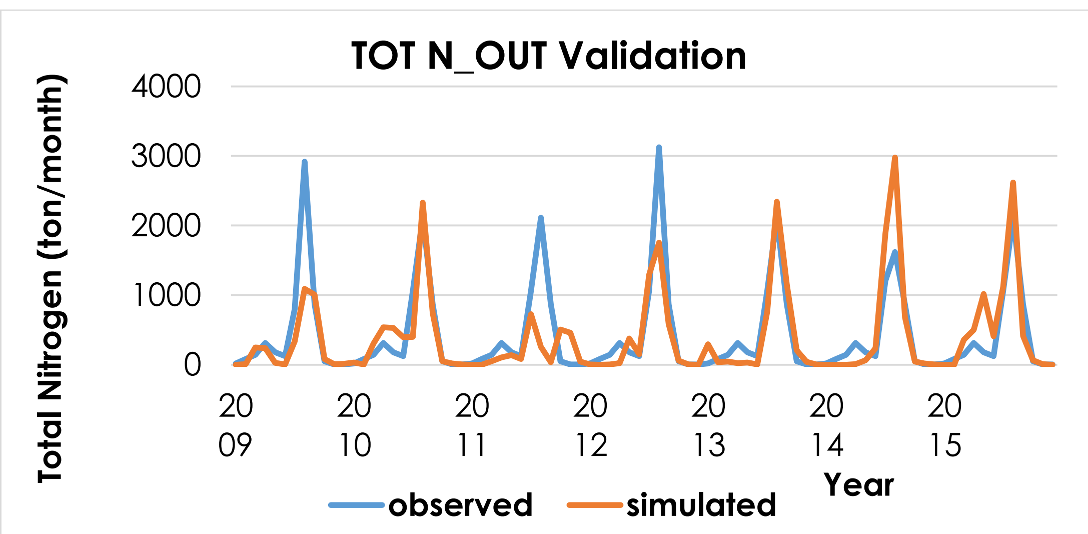

Figure 4-6 :- 95PPU swat cup final best simulation result for total Nitrogen load Validation from (2009-2015)

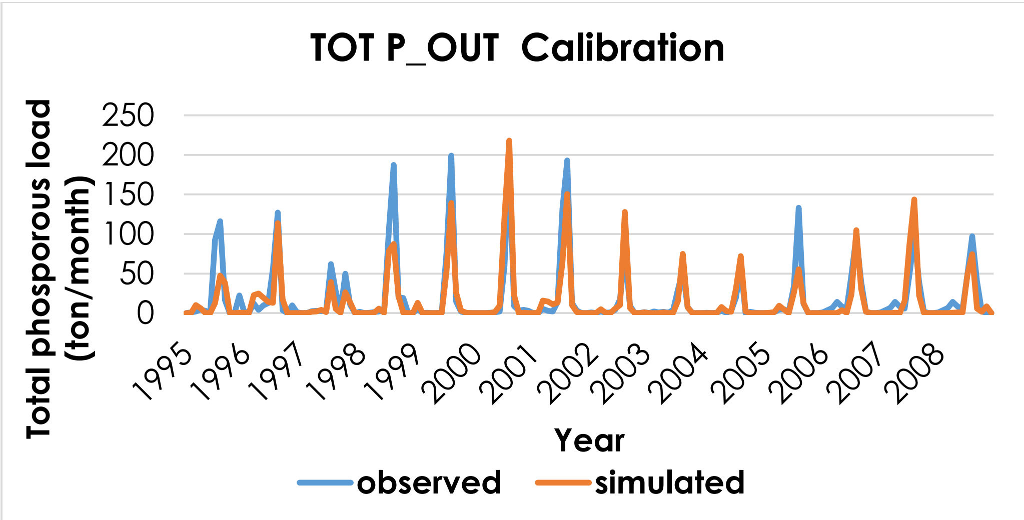

Figure 4-7 :- 95PPU swat cup final best simulation result for total phosphorous load calibration from (1995-2008)

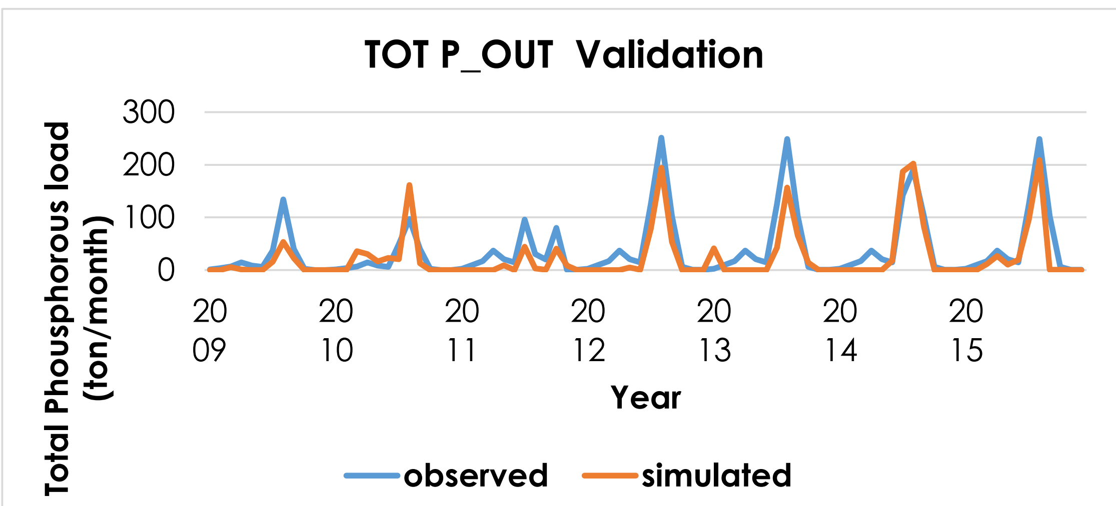

Figure 4-8 :- 95PPU swat cup final best simulation result for total Phosphorous load Validation from (2009-2015)

4.5 Major Pollution Identification and their Critical Source Area

While point source pollution s can be identified easily in general, the non-point sources are harder to find. The major point source pollution in the Geba watershed is treated wukro town Sheba tannery effluents, which is located at the upper part of Genfel sub basin of the Geba reservoir. The increased concentrations of waste water effluent during heavy rain in summer season were overland flow from the waste stabilization pond waste water treatment plant of the industries discharging to Genfel sub Basin Rivers but it doesn.t get directly because the river is far away around 0.5km from the industries which means this point source changes into non-point source pollutions. And also there is a new industries established in 2015 which is the Semayata dimension stone factories inside the watershed located at near Genfel sub basin watershed but till to day it doesn't affect the downstream land and water bodies due to its waste is crushed stone and required less amount of water for productions but may be a pollution for the future. The other one is the Nile steel fabrics and the mekelle branch mesfin industrial engineering fabric constructed in wukro town which are not functional still due to they aren't affect the downstream Genfel river stream of Geba reservoir sub tributaries.

Also, Wukro, Atsbi, Agula, Haykimeshal and Senkata small town are a critical source areas expected for the future which dispose a point source pollutions and their solid waste in this catchment because their population, commercial activities and urban infrastructure increment due to the Geba reservoir may be degraded its water quality.

The major non-point source pollution is the sediment yield and nutrient loads entering to the reservoir due to the upper land use is highly exposed to soil erosion and highly degraded area. Also, Agricultural land has expanded at the expense of natural vegetation, including forests, grazing land and shrub lands. In many parts of the highlands of the catchment, agriculture has gradually expanded from gently sloping land into the steeper slopes of the neighboring mountains (Vanmaercke,2011). On the other hand in the Geba catchment, solid waste disposal and sanitary swage disposed to the fertile area, animal waste, urban infrastructure, Modern-day agricultural practices often require high levels of fertilizers manure are common which leading to high-nutrient (nitrogen and phosphorus mostly) supplies to Geba reservoir drinking water supply through various non-point source of pollution movement processes. Excessive nutrient concentrations in this catchment, however, cause adverse effects by promoting eutrophication, with an associated loss of plant and animal species in Geba reservoir.

The verified model was then applied for the CSAs identification. The SWAT model generates the spatial distribution of sediment yield, TN and TP on sub-basin-level. This level was used sediment yield, TN and TP to identify CSAs because significant detailed distribution of critical source areas could be captured using sub basin predictions.

In line with the above pollution identifications Geba watersheds dominated by the highest amount of sediment, TN and TP loads, and thus identified as CSAs, among the swat model Simulation result producing. This shows the sediment, total nitrogen load (TN),total phosphorus load(TP) give the magnitude of pollutant load which are more contributing to the Geba reservoir drinking water supply.

Identification of critical source areas (CSAs) (areas contributing most of the pollutants in a watershed) is important for cost-effective implementation of best management practices. Identification of such areas is often done through watershed modeling. The Soil and Water Assessment Tool (SWAT) were used to identify CSAs of sediment and nutrients in the Geba watershed. The total sediment load, total nitrogen (TN) and total phosphorus (TP) were identified based on the average annually time scale of sub basin total load from their contributing sub watershed in the watershed using spatial analyst tool by exporting the sub basin shape file in to the ARC GIS 10.3 interface. Also a threshold unit load was required to identify CSAs. Most this threshold unit load have been categorized as CSAs depended on the characteristics of watershed. An appropriate threshold should be defined by ranking each discrete unit within a watershed based on the estimated pollution loads contributing to the sub basin.

So, the average annual sediment load per unit area in each sub basin is shown below in the map. The maximum sediment load contributing was sub basin 7 with a total load of 23.899 kg/ha based on the load per area proportion and the minimum load In sub basin 16 with its total load of 6.466 ton/ha at the end of the catchment towards the highest elevation. Also the sediment load was highest in the early rain season and lowest in the dry season and at the wet season, along Geba River system from upper to lower downstream end the total sediment load transportation was exceeded due to the surface runoff increment based on the result generated from swat model.

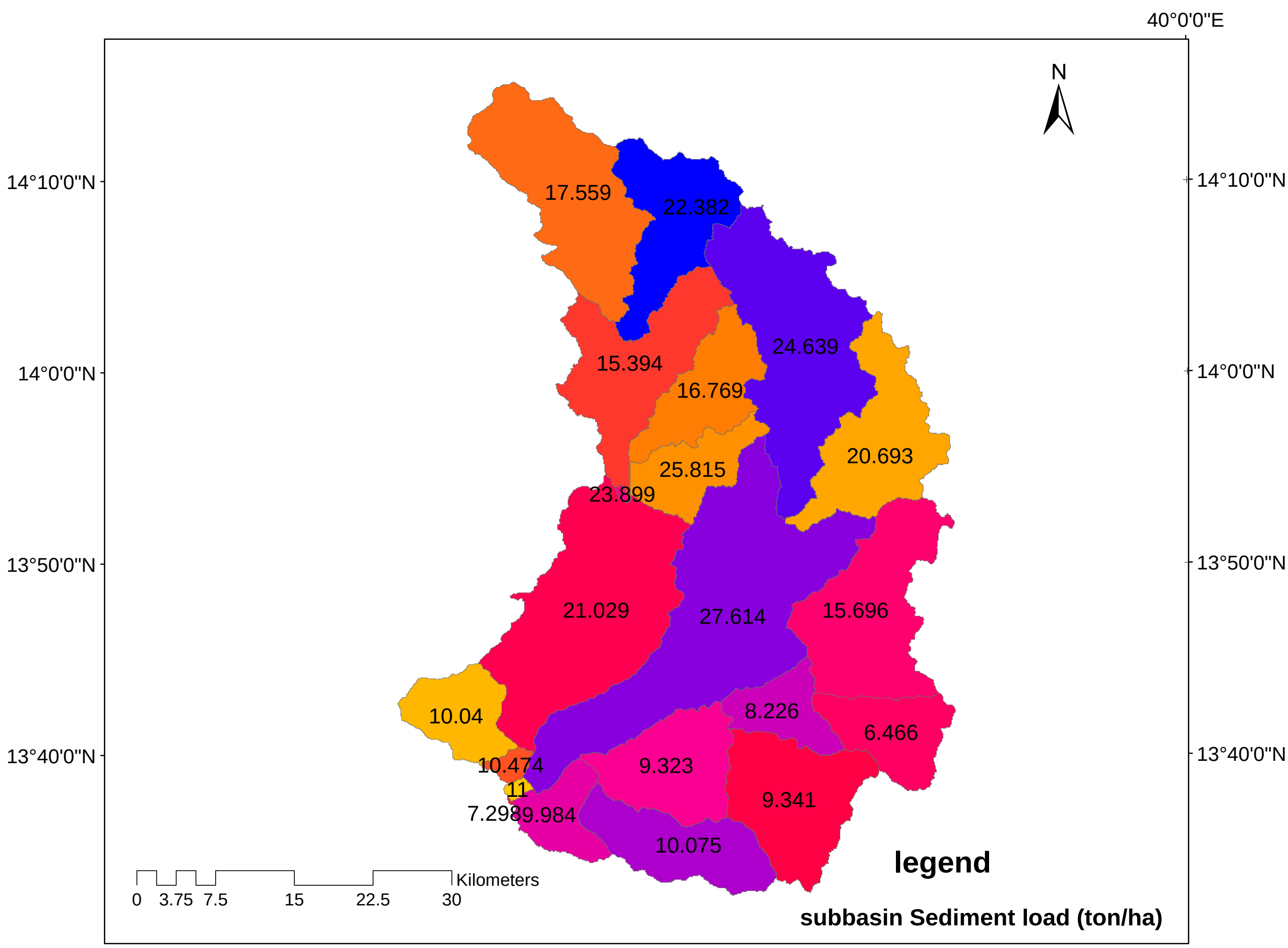

Figure 4-9:- critical source area Identification Map of Sediment load per area based on sub-basin Criteria at Geba watershed.

Therefore, sediment load critical area identification have a distinct potential for soil erosion control and should be considered as the priority for placement management practices in this study area. For conservation practices, it might be impractical to make decisions directly on sub basins as some of them are very small. However, the identified CSAs could be reprocessed to facilitate decision making. For example, the sub basins which are adjacent to each other can be treated with one conservation practice and the sub basin which are separated and very small can be ignored when designing conservation practice.

Similar to sediment obtained the average annual total nitrogen load per unit area in each sub basin was below in the map. The maximum load contributing was sub basin 9 which was a total load of nitrogen with 3.468 kg/ha based on the load per area proportion and the minimum in sub basin 16 with its total load of 0.827 kg/ha at the end of the catchment towards the highest elevation. Also the total nitrogen load was highest in the early rain season and lowest in the dry season and at the wet season, along Geba River system from upper to lower downstream end the total nitrogen load transportation was exceeded due to the surface runoff increment based the result generated from swat model.

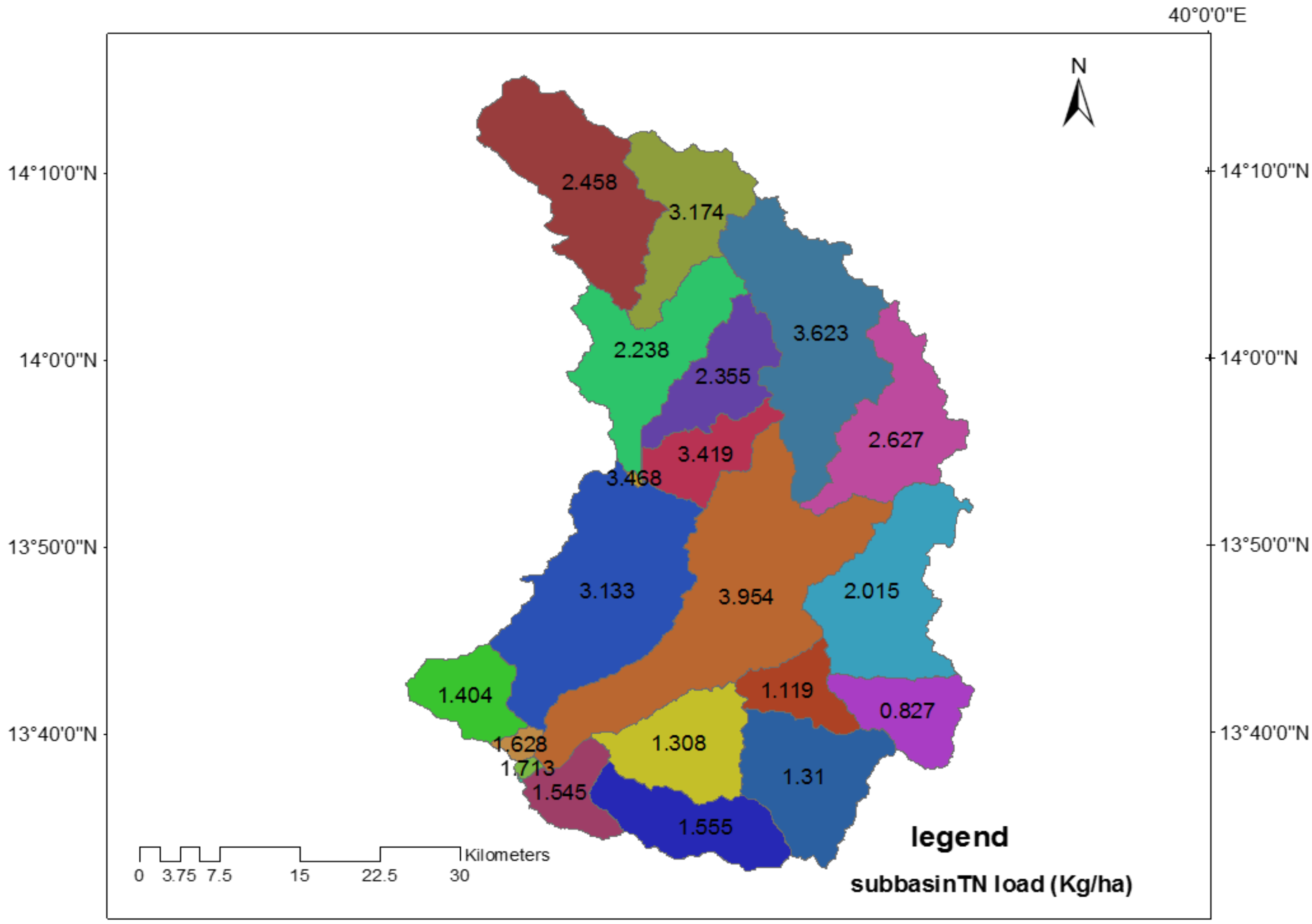

Figure 4-10:- critical source area Identification Map of TN load per area based on sub-basin Criteria at Geba watershed

The average annual total phosphorus load per unit area in each sub basin is as shown below in the map. Comparing to the sediment and TN load the TP load contribution is very small in each sub basin. the maximum load contributing was sub basin 9 which was a total load of phosphorus with 1.136 Kg/ha at the middle of the catchment and the minimum load available was In sub basin 16 with its total load 0.013 Kg/ha at the end of the catchment towards the highest elevation. Also the total phosphorous load was highest in the early rain season and lowest in the dry season and at the wet season, along Geba River system from upper to lower downstream end the total phosphorous load transportation was exceeded due to the surface runoff increment based the result generated from swat model.

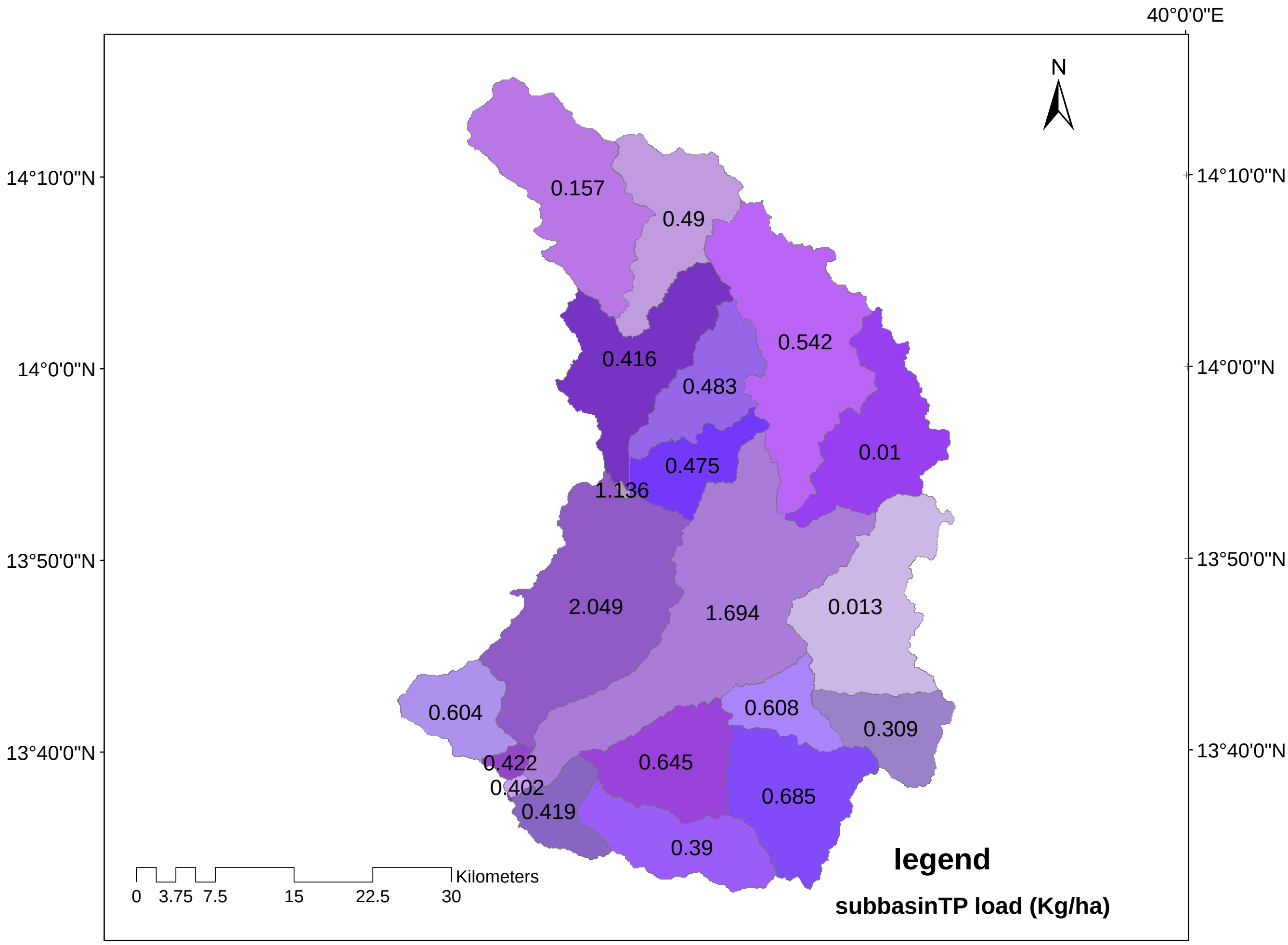

Figure 4-11:- critical source area Identification Map of TP load per area based on sub-basin Criteria at Geba watershed

The CSAs identified in this study which occupied more of the watershed, contributed by sediment load to the watershed rather than the nutrient load. Such a trend is more obvious under larger storms, large agricultural practices and steep slope areas according to the spatial analysis detail result of sub-basin level. This leads to a conclusion that CSAs identification on moderate fine spatial detail scale (sub basin level) is suitable for selection of best management practices in the watershed. This study also confirms that CSAs identification could be a potential approach in assisting water quality control in Geba Reservoir tributaries.

4.6 Key Water Quality parameter assessment at Geba reservoir location

The daily water quality assessment is completed in a step-wise procedure using ARC SWAT model and finally compare it with the water quality laboratory result at the reservoir location. On the periods observed data available were adopted the % error difference estimation method to compare the key water quality parameter simulated and observed results at Geba reservoir location.

Errors of estimation (E) have been calculated and expressed as percent errors of the estimated key water quality parameter value from the observed key water quality parameter value (Denver,2010).

$$\boldsymbol{error}(\%) = \left(\frac{\boldsymbol{estimated\ result}}{\boldsymbol{observed\ result}} - \mathbf{1}\right) * \mathbf{100}$$

The key water quality parameter was calibrated by comparing SWAT model output with laboratory result for Water Temperature, TSS, DO, NH_4-N, NO_3-N, NO_2-N, and PO4-P at Geba Reservoir locations. To assess the predictive capability of the model on water quality, the final output was compared to experimental data result on the time period of 09/07/2014 which was done by the Tigray water work design and supervision enterprise water quality section for the water supply feasibility study in this source of water by taking the sample at the peak flow from Geba reservoir and the concentration result recorded of those parameter are listed in the appendix-B. Then the % error difference comparisons and quantitative analyses were performed based on the key water quality parameter samples taken result.

Table -4.6 presents the error analysis performed on the water quality parameter. The quality parameter comparisons was at that the model performs reasonably well during summer season peak flow experimental result of the key water quality parameters on 09/07/2014. The water quality simulations were not satisfactory in reproducing the simulated water quality parameters concentrations results due to lack water quality data. After comparing the results of key water quality parameters categorized their percentage difference accuracy. A general statistical study and analysis on the biological, physical and chemical parameters using % error difference method comparison of their percentage error difference between the observed and the simulation categorized as <15 very good, 15-25 good, 25-35 fair and >35 poor according to USGS water quality regulations.

Table 4-6 :- some of the key water quality parameter calibration at Geba reservoir location.

Parameter	simulated	observed	% error difference	Rank
Water Temperature (^{0}c)	14.20	12.95	9.653	good
NO3 (mg/l)	4.93	7.50	-34.240	fair
NO2 (mg/l)	0.34	0.33	1.198	very good
NH4 (mg/l)	0.62	0.66	-6.606	very good
DO (mg/l)	10.19	10.00	1.900	very good
BOD (mg/l)	6.39	4.01	59.352	poor
PO4 (mg/l)	0.24	0.39	-37.692	poor
TSS (mg/l)	1208.69	980.00	23.336	good

The performance efficiency values of one day comparison period prove that SWAT model daily simulation result on water quality was good against the experimental result of key water quality parameters but it may increase when the availability of observed data collected are good enough. The positive percent error represented an overestimation result and the negative percentage represented an underestimation of the value.

4.7 Recommended protection measures

Geba drinking water supply reservoir is particularly vulnerable to the agricultural waste, sediment, solid and liquid municipal waste source of pollutions in coming from the upland catchment. As a result, this surface waters require protection before they enter the pollutants to the reservoir.

The objective of this section was to select the surface water protection measures for the identified major pollutants to both point and non-point source pollutant by estimating first the risk analysis.

For surface water supplies that use water from upstream watersheds, evaluating threats to water quality and implementing a watershed remedial measures are crucial for the protection of drinking water safe for humans and the environment. The aim of this section is to establish a risk assessment model that provides basic information for selection of remedial measures and to control areas at high risk for degraded water quality.

Quantitative and qualitative risk assessments have been applied to prepared watershed management plans in order to acquire priority information for implementing drinking water supply protection actions. Quantitative risk is often used for pollutants with complete information on hazard threshold values. On the other hand, qualitative risk assessment is often used for pollutants without specific threshold values for negative effects on human and environmental health, such as nutrients in the watershed. The application of such qualitative models for pollutant management is often used to identify the greatest potential pollutant which is a high risk in this surface water source. To fill the gap in watershed management, an integrated model of qualitative risk event analyses were implemented to provide complete information for watershed management and protect source water. Development this model helps to evaluate the risk of the pollutant to humans, environment and local economy through this drinking water supplies.

In this study, a qualitative risk model were applied to evaluate the relative risk level of potential pollution events in order to characterize the current condition and potential risk of Geba watersheds providing drinking water. In this case study of Geba water source Area the total sediment, TN and TP were the top three major non-point source pollutants of concern based on the SWAT model result and the wukro town sheba leather industry and upland municipal waste are also identified as source of pollution.so, based on this the risk exposure were assessed and finally select the recommended remedial measures to protect this surface water source.

A qualitative risk assessment model was developed to identify sub-watersheds within the study area that were at greatest risk of impaired water quality. The model required information on watershed attributes and land use.

The qualitative risks were analyzed using a matrix that considered the consequences of a hazardous event and the likelihood of identified hazards causing harm in exposed areas over all the watershed. During the risk analysis the Pollutant Source characteristics, Proximity of pollutant to water and land use activity of the catchment were considered to frame the assessment matrix.

Qualitative risk assessment is the impact probability matrix. The two variables such matrices are in fact risk component. Actual technique of this method is the assignment of scores (values) for likelihood and impact of risk categories for the identified major pollutants in the catchment. The product of the two variables will give risk exposure. The steps to analyze the risk were below in the table but first step was to set the impact and probability on a scale of 1 to 5 score for both.

Table 4-7:- Impact Analysis set

Magnitude of impact	Impact definition	Score	Rating
High impact/ High probability	**Very high**: They are the biggest risks that pollutant should require protection	**5**	**A**
High impact / Medium probability Medium impact / High probability	**High** These risks have either a high probability of occurrence, or a significant impact	**4**	**B**
Medium impact / Medium probability	**Medium** There is a medium chance that the risks appear noticeable impact.	**3**	**C**
Medium impact / Low probability Low impact / Medium probability	**Low** These risks can occur in some situations and have a low to medium impact.	**2**	**D**
Low impact / Low probability	**Insignificant** There are risks with low probability of occurrence and low impact. Can therefore be neglected.	**1**	**E**

Table 4-8 :- Likelihood of occurrence risk set

Likelihood Level	Occurrence	Value
Very low	Un likely possible to occur in the next 4-5 years	1
Low	likely to happen in the next 4-5 years	2
Medium	Probable expected to happen in the next 4-5 years	3
High	Is expected to happen in the next 4-5 years	4
Very high	Almost certain Confident this will happen at least once in the next 4-5 years	5

Table 4-9:- Calculation of the degree of risk exposure

No	Risk Type		Occurrence likelihood		Impact		Degree of risk exposure	
			Probability	Score	Probability	Score	Rating	Score
1	non-point source pollution	sediment load	Very high	5	Vary low	5	A	25
2		Total Nitrogen load	High	4	low	4	B	20
3		total Phosphorous load	Medium	5	Medium	2	C	10
4	point source pollution	wukro town Sheba leather industry	Very low	1	high	3	D	3
5		Upland municipal waste dispose	low	2	Very high	4	E	8

Table 4-10:- the assessed risk matrix result

Impact				
Likely hood		**Low** (insignificant, just note)	**Medium** (reasonable impact, to be monitored)	**High** (will have a significant impact)
	Low (unlikely to occur)	**D**	**E**	**C**
	Medium (may occur at a time)	**E**	**C**	**B**
	High (likely to occur)	**C**	**B**	**A**

As seen from the above matrix assessment table the risk lies in the range 1 to 5 and reflects the degree to which the system is exposed to vulnerabilities as a high, medium and low risk which require corrective action as soon as possible and helps to make decision what corrective measures are applied to minimize the risk in this watershed.
Ranking potential total sediment load sources by applying qualitative risk analysis were greater as the estimated exposures matrix above. Sediment related impacts on water bodies are a major environmental and economic problem and are manifested as an increase suspended solid load at the reservoir location.

Upon completion of the source water risk assessment it should proceed to develop a remedial measure action plan aimed at reducing all significant risks to an acceptable level. The important point is to get to a level of consensus regarding risk assessment and management actions. It is important to note that not all risks can be eliminated. The number and the extent of remedial measures will vary depending upon the final risk ranking. Depending on where they rank on the list, some risks may warrant multiple management actions, whereas others may require only minimal control efforts.

Control measures should be based on a ranking of risks associated with the occurrence of each hazardous event. The basis on which control is assured and therefore they should always function reliably. Control measures are activities and processes applied to prevent hazard occurrence within the water supply chain or at the pollutant source.

There are many remedial measures for the protection of source water from both point and non- point source of pollutions. A list of remedial measures based on the risk exposure to Geba reservoir drinking water supply source were provided in table below for convenience. The correct remedial measure will depend on the specific site and situation.

Table 4-11 :- recommended risk remedial measures to protect Geba reservoir water supply source

pollutant	Source	Remedial Measures
Sediment load	soil erosion	soil and water conservation system, planting, fast-growing vegetation, such as grasses and wild flowers, constructing sediment traps basins, sediment fences to encourage filtration, infiltration or settling of suspended particles
Nutrient load	agricultural waste, pesticide, fertilizer and urine disposals	chemical and nutrient control constructions like buffer zone, filtration and infiltration process and it needs education and regulation
Industrial waste	the wukro town Sheba leather and the wukro town dimensional stone industries	efficient mechanism of industrial waste water treatment
Solid waste	upland town municipal solid waste disposal	Prepare proper land fill site, applying solid waste management at the waste generation level. awareness and regulation
Municipal waste water	upland town residential and commercial waste water effluent discharges	waste water treatment, awareness and regulation
Urban waste transportation	high runoff due to pavement, roof and impervious geological land formation of the catchment	urban green infrastructures

In general, in order to protect drinking water quality and quantity, governments, local water organizations and communities are designing and adopting source protection plans. A source protection plan is a management strategy designed to minimize the impacts that human activities and natural events have on water sources. Such a plan should take a comprehensive ecosystem approach to water management to recognizing the need for clean drinking water sustainable services for human uses and protecting the integrity of ecosystems.

5 CONCLUSION and RECOMMADATION

5.1 Conclusions

This study was aimed at the major pollution source identification, pollution load estimation, water quality status and recommendation on best management practices to Protect Geba reservoir surface water supply. The results obtain from this study the support conclusion listed below.

In this study some statistical models to prepared temporal data and GIS interface to prepare and process a geospatial data required was used to run the model. SWAT 2012 was used to simulate the magnitude of pollution load at Geba watershed outlet locations. Automatic calibration of SWAT model using Sequential Uncertainty Fitting version two was used together with enormous support of manual calibration to summarize the best simulated output result of calibration and validation of the model.

Sediment, TN, and TP were identified as a major pollution contributing high load to Geba reservoir. The swat 2012 monthly average in-stream load magnitude of 37,993.35, 376.068 and 17.95554 ton/ month of Sediment, TN and TP, respectively were estimated at the Geba watershed outlet during the simulation period (1995-2015).

The sensitivity analysis, calibrated, validated of SWAT model was assessed for evaluation model uncertainty using Nash–Sutcliffe coefficient (NSE) and coefficient of determination (R^2). The model was calibrated from 1995 to 2008 periods and validated from 2009 to 2015 for flow, sediment, TN and TP. The monthly calibration for flow (NSE = 0.75, R^2 = 0.76), sediment (NSE = 0.66, R^2 = 0.66), TN (NSE = 0.76, R^2 = 0.75),TP (NSE = 0.75, R^2 = 0.74)and validation (NSE = 0.67, R^2 = 0.70), (NSE = 0.59, R^2 = 0.61), (NSE = 0.57, R^2 = 0.64), TP (NSE = 0.68, R^2 = 0.73) for flow, sediment, TN and TP respectively. This shows SWAT model efficiency is adequate to select the best management practice in the watershed to protect this drinking water supply reservoir from pollution.

In general, Calibration and validation of the SWAT model show that the simulated monthly stream flow and sediment yields, TN and TP were in reasonable agreement with measured values and calculated values. In addition the simulation of flow was better than that of sediment, TN and TP because of the observed data for calibration and validation is derived from the recorded flow data.

On the basis of the results obtained in this study, SWAT may be believed to be a reasonable selection for the simulation of the magnitude of pollution loads entering to Geba reservoir from the upper Geba watershed. The model evaluation results thus confirm that the SWAT model can be applied to simulate runoff, sediment yield and nutrient losses from the study catchment condition so as to identify the major pollution critical areas. Therefore, the model simulation results helps to select the best management practice to reduce and control the pollution problems in Geba watersheds to make source protection of proposed Geba reservoir drinking water supply.

The increased transport of sediment and nutrient pollution from the upper Geba catchment contributes to degrade the water quality of the reservoir and reduces the lifespan of the reservoir due to sediment deposition and eutrophication after some years. Therefore applying proper best management practice at the watershed was required to reduce the sediment load and nutrient load based on the risk exposure analysis. So, efficient mechanism of waste water treatment for Sheba leather industries for point source protection and increasing vegetation cover and strengthening on-going soil and water conservation measure helps protect Geba reservoir drinking water supply from non-point source pollutions.

5.2 Recommendation

As the SWAT model result shows in some objective variables the simulation was not good to reduce the burden as such issue for further research and development the following points are recommended.

Climate data was available only for some station with poor data. Recording reliable climate data could have required to increase the accuracy of the simulation result.
Land use/land cover and soil map was also of poor quality. Therefore, this might greatly affect the water balance, water quality and pollution load estimation and representative and high resolution geospatial data is recommended to improve the result.

Calculated value of sediment and nutrient data derived from stream flow was used as observation data to calibrate the model. The unreliability of the calculated data greatly affect the result of the calibration.

Some of the water quality parameters and targeted placement of BMPs like filter strips, grassed water ways, riparian buffer zones, wetlands, grassland or other land use within a given sub watershed is not adequately treated by the model.

Lack of long-term sediment load data has represented key constraints on such work, but surrogate data on past sediment obtained from the monitoring station and from reservoir sediment deposits and through space–time substitution clearly could possess considerable potential in such work.

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APPANDIX

Appendix –A

Table 0-1:- the simulated SWAT model monthly l stream flow, sediment, TN and TP load result entering to Geba reservoir.

Month	Year	Flow (m^3/sec)	Sediment (ton/month)	TN (ton//month)	TP (ton/month)
1	1995	0.04	0.31	0.18	0.00
2	1995	0.91	716.10	4.37	0.10
3	1995	13.61	3120.00	244.00	9.98
4	1995	3.04	1010.00	198.50	6.17
5	1995	0.46	890.60	7.61	0.04
6	1995	0.42	318.90	1.13	0.02
7	1995	29.52	54030.00	295.60	12.60
8	1995	63.46	140500.00	1247.00	47.20
9	1995	16.57	78480.00	1179.00	38.29
10	1995	0.74	1675.00	58.74	0.55
11	1995	0.08	193.30	4.00	0.03
12	1995	0.57	1488.00	7.64	0.29
1	1996	0.78	2292.00	20.14	0.60
2	1996	0.3	45.39	1.58	0.02
3	1996	26.11	4210.00	358.50	22.55
4	1996	20.00	1070.00	616.50	24.76
5	1996	17.42	9050.00	773.50	19.54
6	1996	18.26	39280.00	445.80	14.04
7	1996	27.98	57280.00	446.50	13.06
8	1996	131.50	345300.00	2940.00	113.80
9	1996	6.94	42470.00	751.20	17.48
10	1996	0.36	447.80	28.86	0.17
11	1996	2.62	1155.00	11.60	0.05
12	1996	0.05	87.77	1.90	0.01
1	1997	0.03	0.46	0.13	0.00
2	1997	0.01	0.00	0.06	0.00
3	1997	4.23	5906.00	38.88	1.52

4	1997	10.71	4160.00	65.05	2.25
5	1997	7.44	5080.00	114.70	4.25
6	1997	3.02	6751.00	53.13	1.21
7	1997	53.10	115600.00	809.50	39.41
8	1997	7.91	20380.00	226.90	5.21
9	1997	1.38	1970.00	32.40	0.54
10	1997	35.34	310.00	41.80	26.38
11	1997	7.81	230.00	68.70	13.40
12	1997	0.29	534.40	29.32	0.26
1	1998	0.12	73.65	0.90	0.00
2	1998	0.00	0.46	0.12	0.00
3	1998	0.58	407.90	9.06	0.12
4	1998	2.24	2210.00	12.29	0.26
5	1998	8.62	1980.00	265.60	5.83
6	1998	2.31	3511.00	66.70	0.55
7	1998	111.50	233700.00	1515.00	78.35
8	1998	73.99	198700.00	2022.00	87.32
9	1998	5.39	36340.00	617.70	21.42
10	1998	0.77	803.20	40.10	0.40
11	1998	0.2	4.48	1.13	0.00
12	1998	0.001	0.03	0.14	0.00
1	1999	19.33	390.00	84.10	13.16
2	1999	2.43	874.10	18.99	0.23
3	1999	1.07	1698.00	13.62	0.03
4	1999	0.46	1376.00	4.51	0.03
5	1999	0.20	1196.00	5.52	0.04
6	1999	0.02	19.05	0.31	0.00
7	1999	51.06	134200.00	858.80	52.92
8	1999	109.60	351400.00	2800.00	139.20
9	1999	11.71	57600.00	953.40	26.02
10	1999	7.21	7854.00	193.10	3.23
11	1999	0.03	921.10	43.01	0.49
12	1999	0.001	5.58	1.28	0.00
1	2000	0.001	0.03	0.13	0.00
2	2000	0.001	0.00	0.07	0.00

3	2000	0.001	0.00	0.06	0.00
4	2000	1.17	1240.00	1.69	0.03
5	2000	2.08	6163.00	38.22	1.15
6	2000	20.44	42030.00	172.70	9.24
7	2000	157.90	318300.00	2367.00	121.10
8	2000	136.00	452400.00	3321.00	166.40
9	2000	4.77	42620.00	831.90	22.66
10	2000	0.66	955.20	29.41	0.23
11	2000	0.30	850.70	10.35	0.25
12	2000	0.01	5.78	0.54	0.00
1	2001	0.02	0.03	0.15	0.00
2	2001	0.0001	0.00	0.00	0.00
3	2001	23.83	630.00	351.60	15.75
4	2001	35.35	510.00	530.90	14.48
5	2001	12.52	810.00	989.20	10.84
6	2001	26.62	56730.00	418.70	13.21
7	2001	97.30	207000.00	1361.00	63.41
8	2001	153.00	430300.00	3051.00	150.50
9	2001	2.86	30940.00	336.50	9.95
10	2001	2.29	878.00	58.35	1.30
11	2001	0.03	88.63	4.13	0.03
12	2001	0.02	9.88	0.22	0.00
1	2002	0.06	22.84	0.11	0.00
2	2002	0.01	9.96	0.10	0.00
3	2002	8.02	2340.00	123.90	4.71
4	2002	0.83	2179.00	30.21	0.51
5	2002	0.75	1210.00	17.18	0.07
6	2002	10.09	28000.00	186.50	5.73
7	2002	23.06	37780.00	297.80	10.30
8	2002	137.00	363300.00	1871.00	127.90
9	2002	9.41	23760.00	216.40	6.37
10	2002	0.23	246.20	8.64	0.06
11	2002	0.21	155.90	0.93	0.00
12	2003	4.43	5542.00	18.70	0.94
1	2003	0.11	250.60	3.08	0.06

2	2003	1.82	1936.00	9.17	0.23
3	2003	0.57	1331.00	14.17	0.22
4	2003	3.55	6666.00	24.93	0.88
5	2003	0.47	1212.00	9.55	0.17
6	2003	2.93	4641.00	12.16	0.48
7	2003	30.76	57190.00	543.40	15.27
8	2003	82.47	212200.00	1794.00	74.95
9	2003	4.69	22990.00	273.20	7.17
10	2003	0.61	300.90	12.12	0.06
11	2003	0.001	2.13	0.67	0.00
12	2004	0.04	0.31	0.11	0.00
1	2004	0.13	36.84	0.91	0.00
2	2004	0.04	47.69	0.52	0.00
3	2004	0.91	729.30	1.88	0.00
4	2004	16.71	2190.00	262.50	7.89
5	2004	1.32	936.00	178.90	2.29
6	2004	7.09	1850.00	48.56	1.82
7	2004	59.21	101700.00	716.30	30.79
8	2004	57.05	188900.00	1921.00	71.87
9	2004	4.38	6633.00	157.50	2.17
10	2004	0.73	712.80	25.55	0.10
11	2004	0.20	150.20	1.45	0.00
12	2004	0.03	0.98	0.20	0.00
1	2005	0.17	0.00	0.12	0.00
2	2005	0.69	1740.00	14.15	0.34
3	2005	4.71	6025.00	47.14	1.44
4	2005	16.48	2060.00	188.40	9.19
5	2005	2.20	5140.00	135.40	4.55
6	2005	1.02	1492.00	7.05	0.13
7	2005	58.21	97570.00	686.90	25.48
8	2005	80.16	181200.00	1561.00	55.30
9	2005	4.83	34560.00	473.90	12.47
10	2005	0.13	262.80	15.22	0.08
11	2005	0.01	1.38	0.54	0.00
12	2005	0.4	0.01	0.15	0.00

1	2006	0.001	0.00	0.10	0.00
2	2006	0.03	0.00	0.07	0.00
3	2006	0.42	214.00	1.27	0.02
4	2006	7.41	4484.00	10.42	0.18
5	2006	6.97	5290.00	225.30	3.79
6	2006	3.78	5400.00	23.56	0.61
7	2006	42.15	83390.00	647.10	23.71
8	2006	121.10	269300.00	2910.00	104.70
9	2006	10.48	66870.00	933.70	30.76
10	2006	6.85	4577.00	78.96	1.47
11	2006	0.34	328.70	14.75	0.19
12	2006	1.13	823.90	8.73	0.06
1	2007	4.00	9.33	0.56	0.00
2	2007	0.35	134.40	0.26	0.00
3	2007	0.63	761.10	1.62	0.04
4	2007	4.04	4547.00	33.45	0.49
5	2007	0.45	393.10	4.66	0.05
6	2007	25.64	50370.00	351.10	15.36
7	2007	119.00	227900.00	1986.00	87.11
8	2007	88.40	328200.00	2978.00	143.50
9	2007	17.23	69180.00	577.00	22.21
10	2007	0.31	737.40	24.70	0.25
11	2007	0.08	29.63	2.51	0.01
12	2007	1.00	0.22	0.50	0.00
1	2008	0.05	0.00	0.40	0.00
2	2008	0.01	0.00	0.29	0.00
3	2008	0.43	330.30	1.84	0.00
4	2008	2.73	3259.00	27.51	0.38
5	2008	3.10	5562.00	48.68	0.87
6	2008	3.37	7468.00	29.86	0.93
7	2008	82.20	149900.00	1436.00	48.51
8	2008	54.55	215000.00	2177.00	74.32
9	2008	6.65	14740.00	294.00	5.66
10	2008	12.73	6606.00	44.99	1.51
11	2008	4.24	18330.00	225.00	8.67

12	2008	0.04	127.00	7.70	0.06
1	2009	0.01	1.03	0.10	0.77
2	2009	0.63	1355.00	5.96	0.41
3	2009	1.39	19890.00	249.50	345.00
4	2009	1.22	3520.00	239.50	322.00
5	2009	1.48	2828.00	26.39	0.57
6	2009	0.42	538.70	2.89	0.54
7	2009	27.05	51820.00	332.90	15880.00
8	2009	75.94	93720.00	1092.00	53430.00
9	2009	3.40	54200.00	1005.00	22530.00
10	2009	1.16	2570.00	80.28	16.13
11	2009	0.32	419.40	7.02	1.00
12	2009	0.39	2202.00	11.88	0.64
1	2010	0.57	2982.00	29.26	0.41
2	2010	0.04	116.30	3.47	0.48
3	2010	4.05	7830.00	301.50	530.00
4	2010	22.62	8320.00	537.80	305.00
5	2010	19.91	3640.00	529.30	400.00
6	2010	1.39	4820.00	395.30	920.00
7	2010	66.46	47850.00	400.70	580.00
8	2010	154.80	175400.00	2329.00	1500.00
9	2010	22.90	32080.00	741.90	390.00
10	2010	7.33	778.60	47.82	0.99
11	2010	1.63	2005.00	16.12	0.41
12	2010	0.33	250.10	3.78	0.51
1	2011	0.64	4.06	0.21	0.22
2	2011	0.82	0.05	0.05	0.00
3	2011	7.77	8047.00	47.61	139.00
4	2011	5.03	6560.00	105.70	83.92
5	2011	5.10	4170.00	136.20	181.00
6	2011	5.76	9604.00	79.83	46.08
7	2011	64.94	71450.00	724.20	420.00
8	2011	112.10	20380.00	254.80	2802.00
9	2011	19.21	3607.00	36.06	237.50
10	2011	2.28	240.00	506.10	40730.00

11	2011	2.95	290.00	461.30	8534.00
12	2011	0.8	1083.00	45.20	5.00
1	2012	0.2	286.60	2.56	0.75
2	2012	0.01	6.16	0.17	0.63
3	2012	4.53	899.70	4.70	0.38
4	2012	4.73	3694.00	23.78	0.20
5	2012	6.81	740.00	374.50	5003.00
6	2012	12.54	3443.00	149.40	441.70
7	2012	70.28	128700.00	1292.00	810.00
8	2012	95.86	118500.00	1753.00	4300.00
9	2012	17.07	26530.00	581.30	3100.00
10	2012	7.26	1191.00	60.14	71.70
11	2012	3.29	18.39	2.68	0.75
12	2012	0.58	0.28	0.19	0.62
1	2013	0.02	2160.00	295.40	230.00
2	2013	0.03	1425.00	33.23	0.35
3	2013	2.40	3100.00	46.28	0.15
4	2013	13.66	2255.00	19.65	0.15
5	2013	3.09	2392.00	31.58	0.14
6	2013	8.67	116.90	1.71	0.15
7	2013	69.58	88700.00	762.10	710.00
8	2013	43.80	195200.00	2344.00	600.00
9	2013	3.22	40800.00	1157.00	620.00
10	2013	1.56	5090.00	208.00	700.00
11	2013	1.60	663.40	40.31	63.05
12	2013	0.05	10.04	1.96	0.40
1	2014	0.01	0.13	0.13	0.00
2	2014	0.06	0.00	0.05	0.00
3	2014	4.76	0.00	0.04	0.00
4	2014	6.01	4394.00	9.73	0.00
5	2014	9.76	1750.00	61.31	18.25
6	2014	3.09	33140.00	233.50	480.00
7	2014	27.72	158100.00	1886.00	900.00
8	2014	64.18	218100.00	2980.00	2100.00
9	2014	38.28	30870.00	684.20	640.00

10	2014	5.08	1478.00	42.67	13.02
11	2014	9.29	1801.00	15.80	3.93
12	2014	0.96	53.23	0.95	0.36
1	2015	0.54	1.55	0.11	0.51
2	2015	0.04	0.00	0.05	0.14
3	2015	7.30	3180.00	356.90	470.00
4	2015	0.65	3720.00	502.60	240.00
5	2015	3.24	3770.00	1017.00	480.00
6	2015	25.80	48660.00	410.40	170.00
7	2015	14.56	119400.00	1121.00	570.00
8	2015	41.02	206700.00	2620.00	700.00
9	2015	3.10	2730.00	414.90	463.60
10	2015	1.52	885.00	561.33	464.40
11	2015	0.20	213.70	6.04	0.00
12	2015	1.88	65.75	0.45	0.00

Appendix-B

Table 0-2:- Physio- chemical and bacteriological water quality analysis laboratory result at Geba Reservoir location

NO	date Sample taken	9/7/2014
	location of laboratory	TWWDSE water quality section
	parameter	giba reservoir water quality result
1	taste	tasteles
2	odour	odourless
3	turbiduty(NTU)	417.5
4	total solid 105 0c (mg/l)	980
5	total dissolved solid 105 0c(mg/l)	330
6	electric conductivity(µs/m)	480
7	PH	7.35
8	Water Temprature (^{0}c)	12.95
9	ammonia (mg/l NH3)	0.66
10	sadium (mg/l Na)	18
11	potessium (mg/l K)	7.2
12	total hardness (Mg/l caco3)	212
13	calicium (mg/l ca)	62.4
14	magensium (mg/l Mg)	13.44
15	total iron (mg/l Fe)	0.2
16	fuloride (mg/ l F)	0.59
17	chloride (Mg/l cl)	18.64
18	dissolved oxgen (mg/l DO)	10
19	nitrite (mg/l NO2)	0.334
20	nitrate (mg/l NO3)	7.5
21	alkalinity (Mg/l caco3)	117.8
22	bi caribonate (mg/l HCO3)	143.72
23	sulphate (Mg/l SO4)	131.52
24	phosphate (Mg/l PO4)	0.39
25	copper (Mg/l CU)	0.145
26	zinc (mg/ l Z)	0.141

Table 0-3:- Physic- chemical and bacteriological water quality analysis laboratory result at Geba Reservoir location

No	date Sample taken	8/28/2014		8/26/2014	
	location of labraatiry	**TWWDSE water quality section**			
	parameter	**result agula river 1**	**result agula river 2**	**result agula river 3**	**result agula river 4**
1	taste	tasteless	tasteless	tasteless	Tasteless
2	odour	odourless	odourless	odourless	Odourless
3	turbidity(NTU)	2460	509	1960	2920
4	total suspended solid 105 ^{0}c (mg/l)	4020	636	2452	3612
5	total dissolved solid 105 ^{0}c(mg/l)	175	170	122	117
6	electric conductivity(µs/m)	366	354	256	246
7	PH	7.98	8.18	7.94	7.96
8	ammonia (mg/l NH3)	0.02	0.01	0.01	0.02
9	Water Temperature(T^0C)	15.6	12.9	16.7	14.5
10	total hardness (Mg/l $caco_3$)	166	145	158	192
11	calcium (mg/l ca)	116	122	106	110
12	magnesium (mg/l Mg)	52	26	52	82
13	fluoride (mg/ l F)	0.71	6.7	0.64	0.6
14	chloride (Mg/l cl)	12.5	11.5	5	6.5
15	Dissolved oxygen	13.9	12	10.9	13.1
16	nitrite (mg/l NO2)	0.21	0.15	0.25	0.26
17	nitrate (mg/l NO3)	0.98	0.7	0.8	0.84
18	alkalinity (Mg/l caco3)	134	156	188	256
19	bi carbonate (mg/l HCO3)	134	156	188	256
20	sulphate (Mg/l SO4)	16	14	25	23
21	phosphate (Mg/l PO4)	0.2	0.06	0.41	0.05
22	copper (Mg/lCU)	0.0014	0.0014	0.0014	0.0014
23	Chromium Cr (mg/ l)	0.006	0.006	0.006	0.006

Table 0-4:- Physio- chemical and bacteriological water quality analysis laboratory result at Genfel Reservoir location

NO	date Sample taken	28/8/2014
	location of labraatiry	**TWWDSE water quality section**
	parameter	**result**
1	taste	tasteles
2	odour	odourless
3	turbidity(NTU)	1620
4	total solid 105 ^{0}c (mg/l)	1670
5	total dissolved solid 105 ^{0}c(mg/l)	96
6	electric conductivity(µs/m)	202
7	PH	7.91
8	ammonia (mg/l NH3)	0.03
9	water Temperature (T^{0}C)	13.95
10	total hardness (Mg/l $caco_3$)	104
11	calcium (mg/l Ca)	84
12	magnesium (mg/l Mg)	20
13	dissolved oxygen (DO)	11.3
14	fluoride (mg/ l F)	105
15	chloride (Mg/l cl)	6.5
16	nitrite (mg/l NO2)	1
17	nitrate (mg/l NO3)	0.3
18	alkalinity (Mg/l caco3)	68
19	bi carbonate (mg/l HCO3)	68
20	sulphate (Mg/l SO4)	Nil
21	phosphate (Mg/l PO4)	0.08
22	copper (Mg/lCU)	<0.0014
23	Chromium Cr, Mg/L	<0.006

Table 0-5:- Physio- chemical and bacteriological water quality analysis laboratory result at suluh river location.

NO	date Sample taken	8/26/2014	
	location of labraatiry	**TWWDSE water quality section**	
	parameter	**result suluh river 1**	**result suluh river 2**
1	taste	tasteles	tasteles
2	odour	odourless	odourless
3	turbidity(NTU)	2020	670
4	total solid 105 ^{0}c (mg/l)	3192	472
5	total dissolved solid 105 ^{0}c(mg/l)	103	102
6	electric conductivity(µs/m)	218	215
7	PH	7.69	7.89
8	ammonia (mg/l NH3)	0.03	0.02
9	Water Temperature (T $^\circ$ c)	15.5	16.3
10	total hardness (Mg/l caco$_3$)	122	96
11	calicium (mg/l ca)	88	66
12	magensium (mg/l Mg)	34	30
13	fuloride (mg/ l F)	0.48	Nil
14	DISSOLVED OXGYEN	9.88	12.3
15	chloride (Mg/l cl)	10	10
16	nitrite (mg/l NO_2)	Nil	
17	nitrate (mg/l NO_3)	0.47	0.51
18	alkalinity (Mg/l caco$_3$)	82	74
19	bi carbonate (mg/l HCO^3)	82	74
20	sulphate (Mg/l SO_4)	1	Nil
21	phosphate (Mg/l PO_4)	0.36	0.15
22	copper (Mg/l CU)	0.0014	0.0014
23	Chromium, Cr (mg/ l Cr)	0.006	0.006

Appendix- c

Table 0-6:- Selected parameters used for sensitivity analysis in swat cup for calibration and validation of all objective variables

Par ID	Parameter	Definition	MIN	MAX	Fitted value
1	r__CN2.mgt	SCS runoff curve number	35	98	70.7
2	v__ALPHA_BF.gw	Baseflow alpha factor (days)	0	1	0
3	v__GW_DELAY.gw	Groundwater delay (days)	0	500	132
4	v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H2O)	0	5000	533
5	v__GW_REVAP.gw	Groundwater revap coefficient	0.02	0.2	0.058
6	v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0	500	200
7	v__RCHRG_DP.gw	Deep aquifer percolation fraction	0	1	0.6
8	r__SOL_AWC().sol	Soil available water storage capacity (mm H2O/mm soil)	0	1	0.025
9	r__SOL_K().sol	Soil conductivity (mm/h)	0	2000	500
10	r__SOL_ALB().sol	Moist soil albedo which is the ratio of the amount of solar radiation	-0.25	0.25	0.1
11	v__CH_N2.rte	Manning roughness for main channel	-0.01	0.3	0
12	v__CH_K2.rte	Effective hydraulic conductivity in the main channel (mm/h)	-0.01	500	9.9
13	v__ALPHA_BNK.rte	Baseflow alpha factor for bank storage (days)	0	1	0.45
14	v__SLSUBBSN.hru	steepness slope differnce of the sub basin	10	150	80
15	v__HRU_SLP.hru	Average slope steepness (m/m)	0	0.6	0.416
16	v__OV_N.hru	over land flow characterstics	0.91	31	19
17	v__ESCO.hru	Soil evaporation compensation factor	0	1	0.094
18	v__EPCO.hru	Plant evaporation compensation factor	0	1	0.898

	SEDIMENT and phosphorus only				
19	r__SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channelsediment routing	0	0.002	0.002
20	r__SPEXP.bsn	Exponent parameter for calculating sediment re-entrained in channel sediment routing	1.35	1.47	1.43
21	r__CH_COV2.rte	Channel erodibility factor	0.2	0.25	0.22
22	v__SURLAG.bsn	Surface runoff lag coefficient	0.05	24	12
	phosphorous only				
23	r__PSP.bsn	Phosphorus availability index	0.5	0.7	0.65
24	r__ERORGP.hru	Phosphorus enrichment ratio for loading with sediment	1.1	5	2.75
25	BIOMIX	Biological mixing efficiency	0.08	0.1	0.09
	Nitrogen only				
26	r__RCN.bsn	Concentration of nitrogen in rain fall	0	1.3	0.75
27	r__ERORGN.hru	Nitrogen enrichment ratio for loading with sediment	1.1	5	2.75
28	BIOMIX	Biological mixing efficiency	0.08	0.1	0.09

Appendix -D

Rain fall consistency checking using double mass curve for the six selected station used in the analysis.

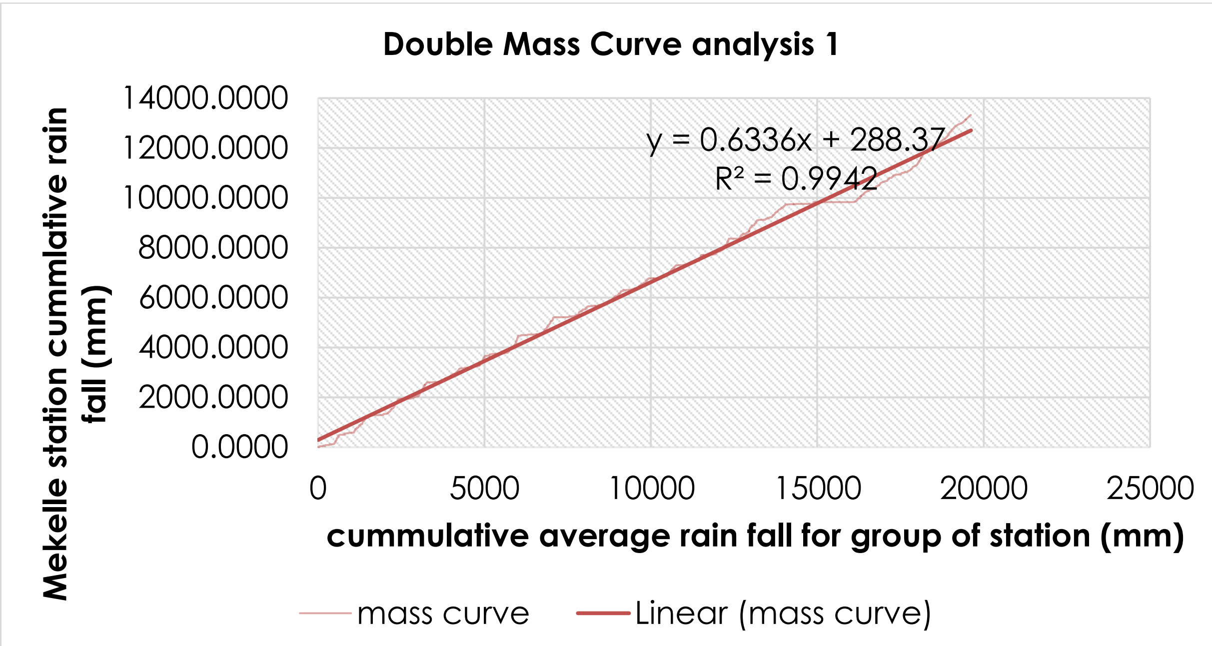

Figure 0-1:- Double mass curve for Mekelle station (1992-2015)

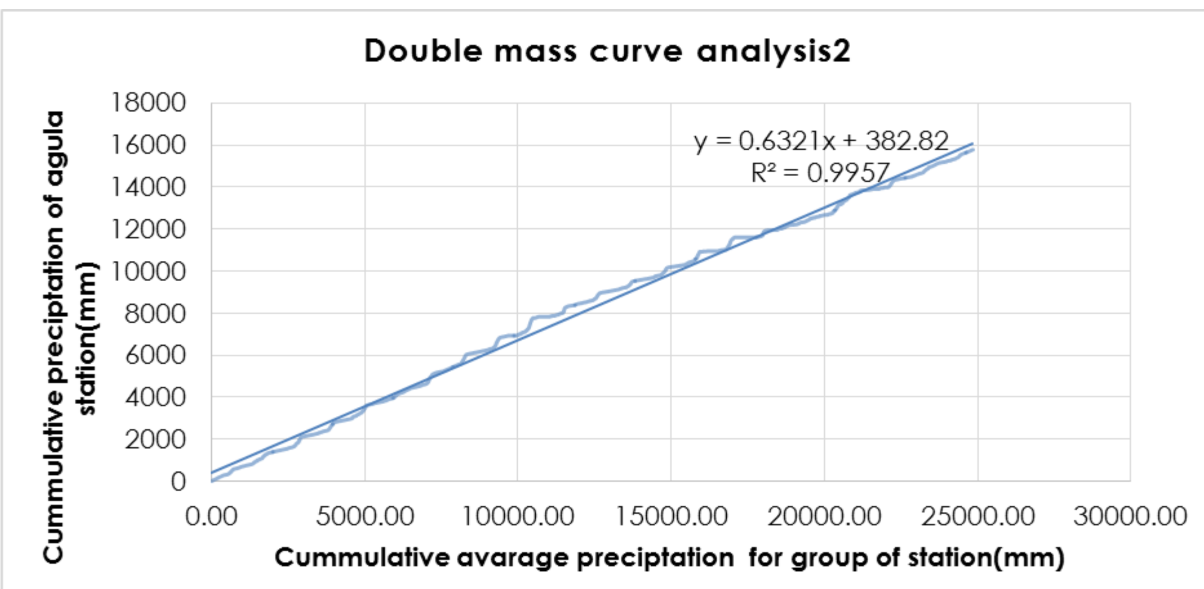

Figure 0-2:- Double mass curve for Agula station (1992-2015)

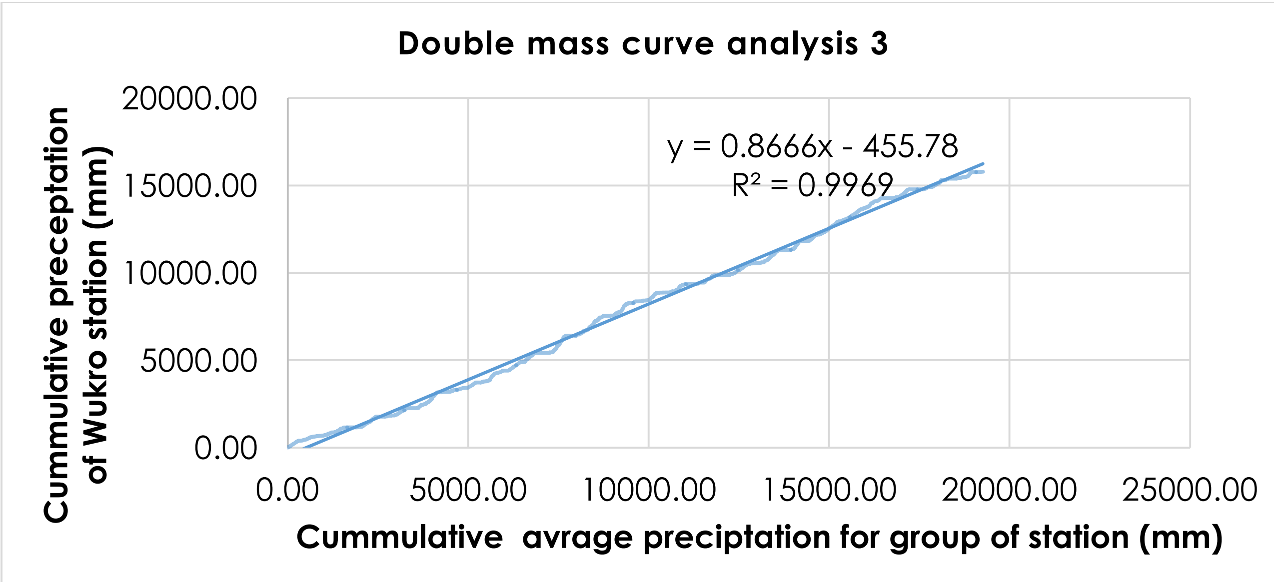

Figure 0-3:- Double mass curve for wukro station (1992-2015)

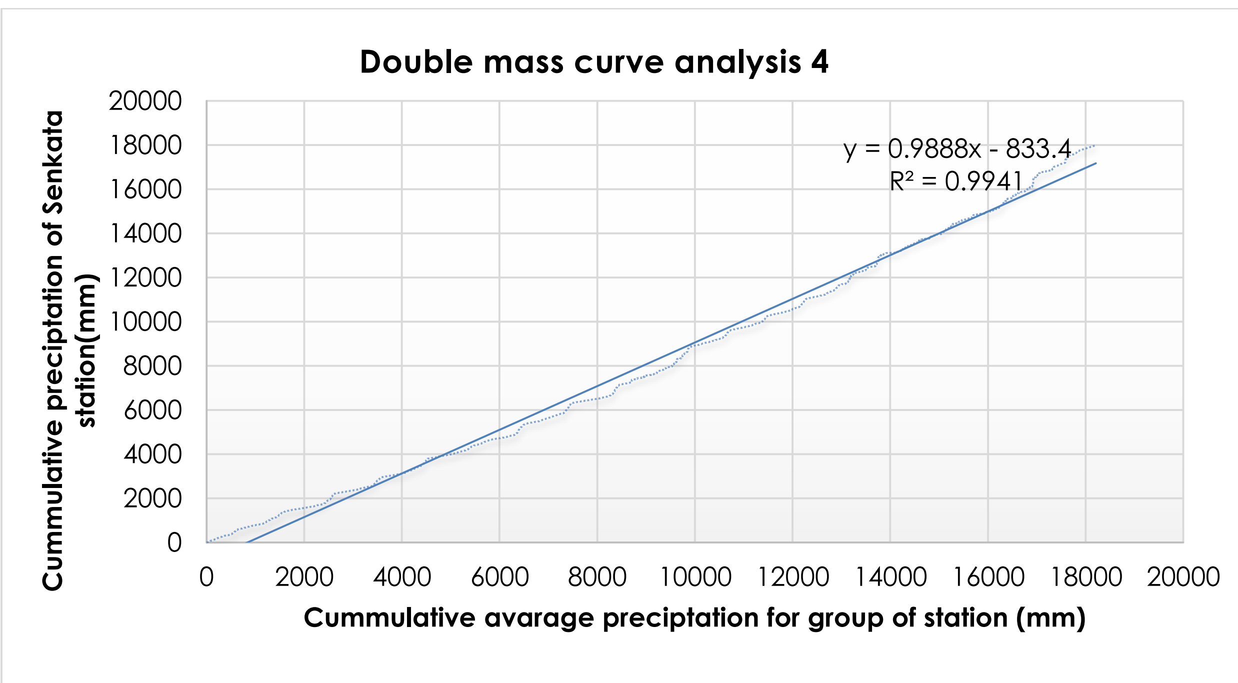

Figure 0-4:- Double mass curve for Senkata station (1992-2015)

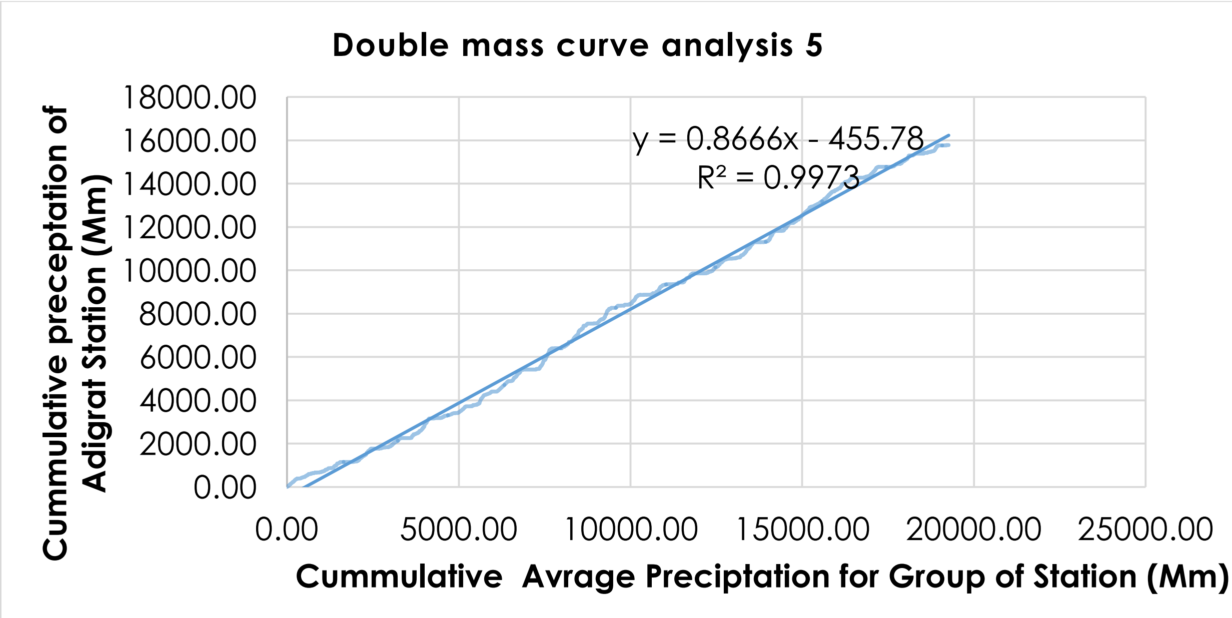

Figure 0-5:- Double mass curve for Adigrat station (1992-2015)

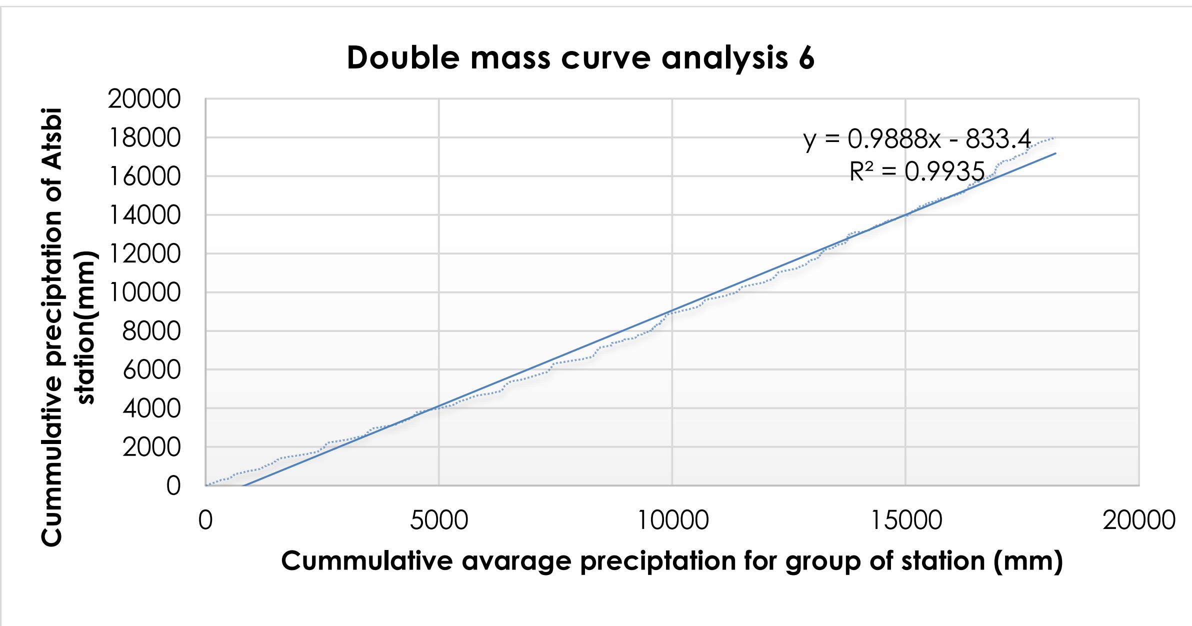

Figure 0-6 :- Double mass curve for Atsbi station (1992-2015)

Appendix –E

Table 0-7:- Total annual precipitation (mm) for the six station used in the analysis

Year	Wukro	Agula	Adigrat	Mekelle	Atsbi	Senkta
1992	664.6	729.5	645.0	563.5	790.5	655.4
1993	491.5	555.9	941.5	720.9	1102.0	682.0
1994	615.2	807.9	747.9	657.5	1073.5	655.5
1995	486.4	859.7	948.6	663.2	889.0	672.6
1996	925.3	558.9	932.4	586.3	882.9	984.0
1997	541.0	813.5	1007.1	550.7	457.6	673.9
1998	686.9	714.0	960.1	753.3	880.1	676.5
1999	1010.6	855.2	415.9	717.1	900.0	664.1
2000	984.0	845.2	905.1	455.6	911.3	908.1
2001	1136.8	815.0	1013.1	649.2	905.3	921.8
2002	825.4	661.0	572.2	456.9	886.8	553.3
2003	505.7	839.0	548.2	526.8	906.0	795.1
2004	486.3	1093.0	438.9	421.5	932.3	775.6
2005	501.6	812.3	497.9	642.5	884.2	751.8
2006	681.0	835.4	716.5	755.2	915.4	688.2
2007	757.8	851.7	691.1	619.3	912.2	561.8
2008	523.4	817.7	735.7	420.5	894.3	550.1
2009	366.2	437.9	383.3	371.1	437.9	285.0
2010	766.7	1147.6	576.3	668.0	867.8	651.6
2011	683.9	530.0	573.9	571.1	530.0	611.3
2012	639.6	986.1	543.9	533.2	986.1	629.6
2013	500.0	428.7	593.2	685.2	877.9	445.7
2014	609.0	841.4	583.0	856.1	860.8	656.2
2015	395.6	828.9	641.6	855.1	928.8	628.9

Table 0-8:- Annual average maximum and minimum temperature (°c) for the five station used in the analysis

Year	Mekelle Station		Adigrat Station		Atsbi Station		Senkata Station		Wukro Station	
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
1992	23.18	11.68	23.79	6.45	19.99	7.98	24.16	8.74	26.70	11.27
1993	22.80	11.57	23.81	8.40	19.98	7.97	24.18	8.73	26.54	10.84
1994	23.05	11.67	23.82	5.42	19.97	7.98	24.17	8.76	27.72	10.14
1995	23.90	11.79	23.78	6.43	19.95	8.01	24.18	8.73	28.13	9.80
1996	23.81	11.75	23.81	9.43	19.99	8.02	24.18	8.76	27.58	10.73
1997	24.30	12.17	23.47	7.22	19.99	7.98	24.15	8.71	28.50	11.01
1998	24.31	12.22	23.91	7.24	19.99	8.01	24.17	8.71	28.88	11.22
1999	24.16	11.71	23.47	6.24	19.97	7.95	24.15	8.74	27.62	10.05
2000	24.27	11.86	23.93	5.46	19.98	8.02	24.16	8.75	27.76	11.34
2001	24.26	11.90	23.49	6.35	19.97	7.98	24.02	11.20	28.68	10.04
2002	25.03	12.13	24.11	8.72	19.96	8.01	24.81	12.02	27.48	7.29
2003	24.64	11.97	23.76	10.09	20.00	7.98	24.21	12.03	28.43	12.13
2004	24.66	11.63	23.87	9.09	19.98	7.96	24.00	11.57	27.95	11.39
2005	24.46	11.51	23.94	7.85	19.99	7.98	24.06	11.48	28.03	11.97
2006	24.29	11.49	23.81	7.98	19.99	8.86	23.86	11.97	27.79	11.40
2007	24.25	11.46	23.74	7.91	19.69	8.26	23.81	11.37	28.24	10.99
2008	24.76	11.38	23.99	9.18	20.11	9.16	23.87	11.82	27.30	10.07
2009	25.12	11.64	24.39	9.43	20.21	9.81	24.41	12.30	28.23	11.11
2010	24.40	11.87	24.02	8.89	19.69	9.67	23.88	11.91	28.27	12.00
2011	24.05	11.14	23.58	7.38	19.77	9.49	23.50	10.56	27.66	10.70
2012	24.39	11.32	23.83	7.38	20.30	9.39	24.24	9.39	27.20	11.19
2013	24.20	10.60	23.96	5.90	19.91	9.25	25.09	7.89	28.06	9.64
2014	24.38	10.19	24.00	5.65	20.14	9.74	24.59	7.56	28.14	9.63
2015	23.21	9.78	22.85	7.43	19.99	7.97	24.18	8.74	28.07	7.77

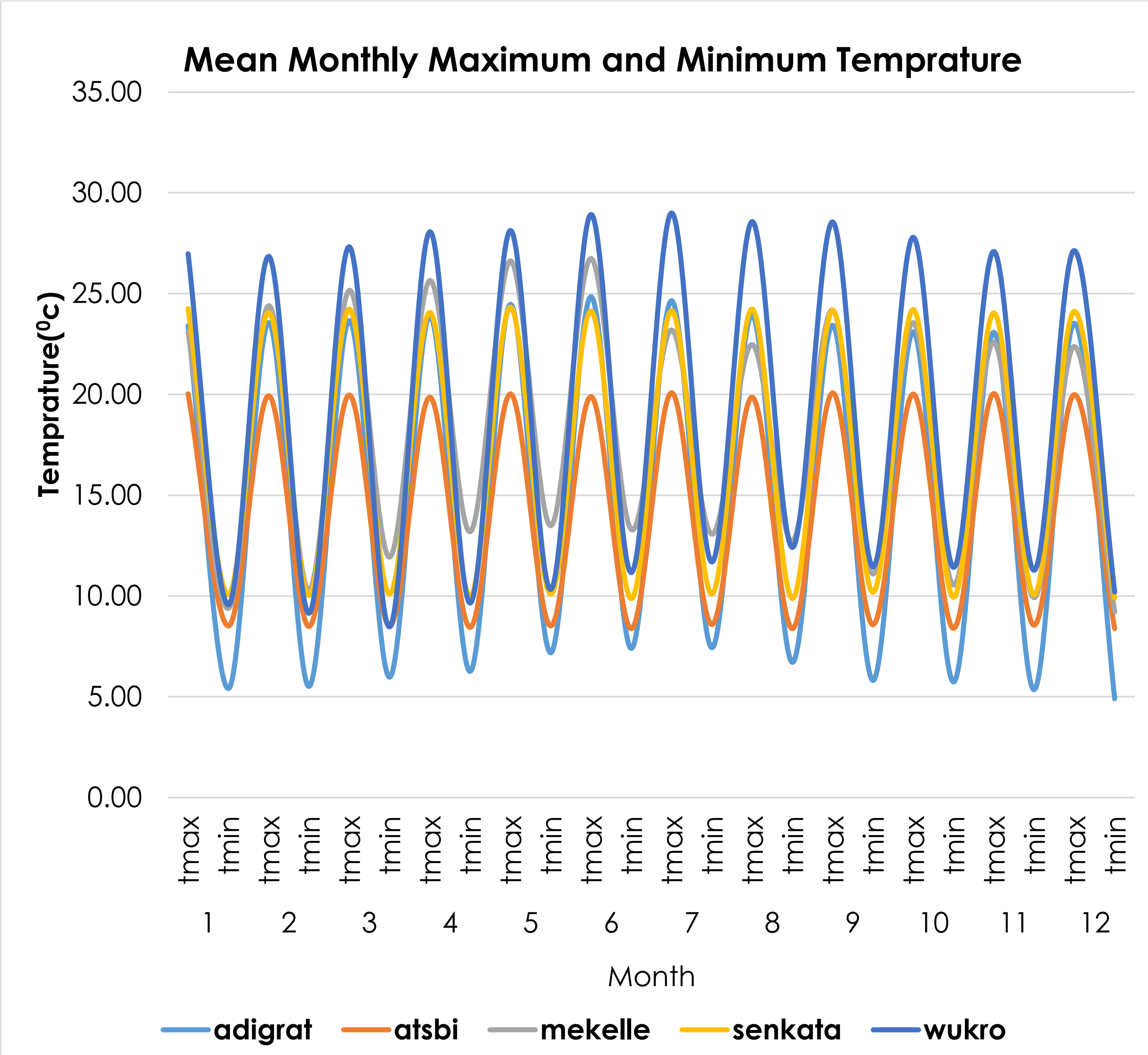

Figure 0-7 :- Average monthly Maximum and Minimum temperature for the selected station used in the analysis from 1992-2015

Table 0-9:- Annual monthly flow data which is entering to Geba reservoir (10^6 M^3)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1992	2.7	0.08	4.71	1.37	2.46	0.71	22	69.57	1.58	3.26	22.3	7.61
1993	2.9	1.58	7.5	41.8	18	21.5	100	53.23	9.46	13.4	0.09	0.08
1994	0.1	0.51	0.35	2.37	0.36	11.3	52	205	42	0.1	6.53	1.5
1995	0.1	0.78	1.99	4.86	2.91	0.67	97	121.6	16.9	0.1	0.09	23.3
1996	1.7	0.65	12.6	4.25	10.3	13.3	59	133.1	3.71	0.09	10.3	0.96
1997	0.1	0.08	2.52	3.01	2.61	4.02	65	28.8	2.71	52	10.9	0.09
1998	1.6	0.08	0.36	1.24	2.03	3.15	110	196.2	20.9	20.1	0.09	0.09
1999	5.7	0.08	0.66	0.08	0.08	0.32	80	208.9	15.2	2.31	0.09	0.08
2000	0.1	0.08	0.08	0.59	1	1.98	62	146.9	9.22	3.54	4.25	2.84
2001	0.1	0.08	5.35	2.93	2.17	14.9	138	202.5	13.3	3.27	0.09	0.08
2002	0.7	0.08	2.28	0.41	1.07	4.18	18	80.37	9.74	0.09	0.08	1.23
2003	0.1	2.28	0.76	1.94	0.59	4.15	31	56.08	8.2	0.09	0.08	0.08
2004	0.6	0.08	0.62	3.14	0.6	2.57	21	61.96	0.09	1.9	0.62	0.08
2005	0.1	0.08	1.11	4.56	4.98	1.86	36	139.4	12.2	0.09	0.09	0.08
2006	0.08	0.64	0.88	1.42	0.51	7.51	71.7	167.19	63.59	0.1	0.09	1.24
2007	2.1	0.08	0.76	8.44	1.12	5.47	167	156.33	16.9	20.27	0.09	2.47
2008	0.1	0.08	1.85	2.06	2.25	1.45	174	187.8	26.6	10.9	5.68	1.72
2009	1.02	3.6	3.5	6.24	5.17	0.81	221	354.24	52.03	0.11	0.1	0.09
2010	0.08	0.6	1.14	11.15	4.03	66.96	164	338.85	39.19	8	4.45	1.77
2011	0.08	0.08	10.8	12.58	47.03	30.32	64.3	207.21	25.05	2.39	0.09	0.09
2012	0.1	0.09	16.7	31.48	3.29	0.08	83.4	207.03	38.77	0.1	0.09	1
2013	0.08	0.86	0.28	1.51	17.4	1.22	92.7	139.6	25.47	2.26	7.64	0.09
2014	0.08	0.31	0.95	8.13	0.84	22.11	74.8	27.82	13.63	2.49	16.64	0.07
2015	3.26	0.08	31.6	10.39	10.38	0.08	56.8	81.36	17.59	0.09	0.09	0.08