SEDIMENT YIELD AND INFLOW PREDICTION TO AYSERAWUM MICRO EARTH DAM, BLUE NILE BASIN, OF ETHIOPIA

MSc. THESIS

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JUNE, 2018

HARAMAYA UNIVERSITY, HARAMAYA

Sediment Yield and Inflow Prediction to Ayserawum Micro Earth Dam, Blue Nile Basin, of Ethiopia

A Thesis Submitted to Postgraduate Program Directorate Through The

School of Water Resource and Environmental Engineering

HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN IRRIGATION ENGINEERING

By

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JUNE, 2018

Haramaya University

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I hereby certify that I have read and evaluated this Thesis entitled "*Sediment Yield and Inflow Prediction to Ayserawum Micro Earth Dam, Blue Nile Basin, of Ethiopia* ", prepared under my guidance by Demisew Getu. I recommend that submitted as the Thesis Requirement.

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As member of the Board of Examiners of the MSc Thesis Open Defense Examination, I certify that I have read and evaluate the thesis prepared by Demisew Getu and examined the candidate. I recommend the thesis be accepted as fulfilling the thesis requirements for the degree of Master of Science in Irrigation Engineering.

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DEDICATION

I dedicate this thesis manuscript to my family, and my wife *Bezawit Admasu* and my brothers, for their affection, love and their generous moral support in the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born in Enewari, North showa zone, Ethiopia in January 16, 1986. He attended his elementary and junior schools Jihure and senior secondary schools from 1998 to 2002 at Debrebirhan. After the completion of his secondary school, in 2003 he joined MadaWalabu University and graduated in July 2006 with B.Sc. degree in Natural Resource Management. The author was employed in Debrebirhan Agricultural Research Center in 2009. Since then he was working as a junior researcher, in Agricultural water management researcher. In 2016, he joined Haramaya University to pursue post graduate studies in the field of Irrigation Engineering.

ACKNOWLEDGMENTS

First and above all praise to be almighty God, for endless love and gives me healthy mind to think and to complete my works and great thanks be to him forever.

I would like to express my deepest gratitude to my major advisor Dr.-Ing. Teshome Seyoum and co-advisor Mr. Shimelis Berhanu, for their valuable advice, encouragement and critical comment during the research period. I appreciate their devotion of time to me during this thesis works.

I am very grateful to Debrebirhan Agricultural Research Center for allowing me to take part in the Graduate Study Program of Irrigation Engineering and also my friends who made my dream came true with their advice and support.

I would like also to thank the Water Land Resource Center (WLRC), and National Meteorological Agency, for providing me important priceless data.

At last but not the least, I would like to extend my deepest gratitude to my friend Mr. Fikray Tesfaye, Mr. Binyam Shumeye and Mr. Belihu Negatu for their words of motivation and material support during study.

ABBREVIATIONS

ARS	Agricultural Research Services
BMPs	Best Management Practices
CFSR	Climatic Forecast System Reanalysis
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
GPS	Geographical Positioning system
ha	Hectare
HRU	Hydrologic Response Unit
LULC	Land Use Land Cover
m.a.s.l	Meter Above Sea Level
MUSLE	Modified Universal Soil Loss Equation
NRSC	Natural Resource and Soil Conservation
N_{SE}	Nash–Sutcliffe efficiency
NGOs	Non-Governmental Organizations
NMSA	National Meteorological Services Agency
AET	Actual Evapotranspiration
R^2	Coefficient of Determination
CN	Curve Number
STRM	Shutter Topography Radar Mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Educational, Social and Cultural Organization
UTM	Universal Transverse Mercator
WLRC	Water and Land Resource Center

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ABSTRACT

Estimation of runoff volume and sediment yield is a problem that directly affects the performance of dams due to the reduction in the storage capacity of their reservoirs and their effect on dam efficiency and operation schedule. The simulation models can be considered for evaluation of sediment potential if the continuous field measurements are not available. Soil and Water Assessment Tool (SWAT) was applied to estimate the annual runoff volume and sediment load for Ayserawum micro earth dam watershed area by transferring model parameter from Andit tid watershed. Six most sensitive parameters were identified for stream flow and ten for sediment load. During the course of calibration of stream flow, the performance indicators were found as $R^2 = 0.89$, $E_{NS} = 0.85$ *and* $D =+8.58$ *and for validation* $R^2 = 0.79$, $E_{NS} = 0.73$ *and* $D =+5.32$, *and for sediment load* $R^2 = 0.77$, $E_{NS}= 0.73$ *and* $D =+12$ *for calibration and* $R^2 =0.76$, $E_{NS} = 0.73$ *and* $D =+17.5$ *for validation. Simulation output of the 36 sub watersheds was contributed varying degree of average annually stream flow of 0.38* m^3*/sec to 0.01* m^3*/sec, and sediment load 297.64 to 1.85 tons/ha/yr. Based on the hydrological simulation integrated watershed management plan should be implemented for effective land and water resource development. Hence, the result of the study could help stakeholders to plan and implement appropriate soil and water conservation strategies in the hot spots area.*

Keywords:-*Arc SWAT, ArcGIS, Sediment load, Stream flow, Watershed*

1. INTRODUCTION

1.1 Background

Agriculture has a dominant feature of Nile Basin countries for centuries. Irrigated agricultural expansion over the last hundred years, has caused significant change in the use of the Nile water, and continues to be a major influence on the decisions around the Nile River use today (Awulachew, et.al., 2012) Soil erosion and loss are the major challenges for sustainable agricultural development in the upper basin. These problems are more serious in the Ethiopian highlands. Inappropriate agricultural practices, high population pressure from human and livestock, higher rainfall intensity and rugged topography have been reported as the main facilitators for having severe erosion and sedimentation (Kidane and Binyam, 2015).

Deposition of sediment in reservoirs can cause serious problems. One of the important factors in reservoirs design and operation is the sedimentation problem. Surface runoff is major cause of erosion of the earth's surface and the location of high runoff generating areas are very important for making better land management practice. Estimates produced by (Msadala, 2009)suggests that by 2050, approximately 64% of the world’s current reservoir total storage capacity will have been filled with sediment. Many dams, the design incorporates a substantial volume of dead storage explicitly allocated to sedimentation, but existing evidence suggests that the reservoir operation is likely to be seriously impacted by sediment once 70% to 80% of the original storage capacity are lost.

To reduce the severity of soil erosion and its associated effects, the Ethiopian government and NGOs have been introduced various soil and water conservation technologies though the adoption had not been satisfactory. Therefore, soil erosion has been adversely threatening the upper Nile basin particularly in the Ethiopian highlands and the effect has been both onsite and offsite to the upstream and downstream. Soil erosion/sedimentation controlling mechanisms and the mitigation measures play an indispensable role for the sustainable water resources development such as encourage tree planting as a means of reducing soil erosion, sediment load as well as increasing groundwater recharge. To implement such strategies, it is necessary to understand the magnitude of the problem and factors responsible for it. Soil erosion, sedimentation, upstream management and its associated effects are interrelated issues in the upper Blue Nile basin (Kidane and Binyam, 2015).

Heavy sedimentation has been experienced by Ethiopia's existing dams and is a very real risk to the lifespan of new hydroelectric power dams as well as dams for irrigation and water supply. The withholding of such sediment by Ethiopia's dams is likely affecting downstream ecological functions and may be impairing the rate of downstream erosion. In 2000, Addis Ababa suffered further power outages during the rainy season after turbines at the Koka Dam became clogged with sediment. According to a recent study, four irrigation dams constructed in the 1980s had to be abandoned due to sedimentation (Kidane and Binyam, 2015). Siltation had greatly reduced the lifespan of the Angereb, MelkaWakena and Tekeze dams and could greatly impair soon to be commissioned, to the others. According to the Gilgel Gibe I 1997 Environmental Assessment, a high sedimentation load was anticipated. High rates of sedimentation are also anticipated in the Gilgel Gibe III reservoir, where one-third of its space is reserved for sediment to accumulate over time (Hathaway, 2008).

For long term sustainability of the reservoirs appropriate sediment control measures should be put in place. One of these measures includes accurate prediction of sediment yields in existing and under constructed reservoirs. This information is essential in the feasibility studies, planning and management of water resources with respect to sedimentation control and management (Msadala, 2009). In Tigray, 500 small dams are planned for irrigation purposes, increasing agricultural productivity such that it would be possible to feed around 4 million people more than at present (Nana-Sinkam, 1995). However, severe sedimentation has been observed in the few dams that have already been built. It is clear that if all these dams lose their capacity at such a fast rate, crop production would also decrease and food shortages might be expected. The water resources potential assessment of a given watershed is a key component in the development of micro dam irrigation projects. It has a direct impact on the economic and safety aspect of the intended project (Awulachew *et al*., 2008). Understanding water resources availability would help stakeholders and policymakers to plan and develop an area. There are various hydrological models that can estimate water resource availability (e.g., lumped models, physical distributed models, empirical models, statistical models). In the Nile countries, most of the models seem to perform quite well representing the temporal dynamics within the watershed (Betrie *et al*., 2011). Among these, distributed hydrological models can simulate water balance spatially based on various soils, land uses, topography and climate conditions. One of these hydrological models is Soil and Water Assessment Tool (SWAT)

(Gassman *et al.*, 2007), which is tested in various world climates from arid and semi-arid regions (Perrin *etal.*, 2012; Emam *et al.,* 2016) to humid and tropical areas (Roth and Lemann, 2016). Moreover, it is able to simulate water resources in large scales to regional scales. Surface runoff, soil erosion and flooding are the main issues in humid and tropical areas due to heavy rainfall (Labrière *et al.*, 2015).

SWAT interface with working under Geographical Information System (GIS) was applied to estimate the yearly runoff and sediment load (Mohammad., et,al., 2012). The model is accurate and capable of simulating surface runoff from a small watershed (Malunjkar *et al*., 2015). Various researchers have studied climate variability and human activities on soil erosion, water quality and hydrological process (Betrie *et al*., 2011; Haregeweyn *et al.*, 2005). Others also evaluated SWAT model and their findings indicated that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to all types of ungauged basins (Betrie *et al.*, 2011; Ndomba and Griensven, 2011; Prabhanjan, Rao, and Eldho, 2015). There are two basic advantages of using hydrological models, instead of relying only on collected data. Firstly, used to understand the processes that are difficult to measure due to the complexity of their temporal and/or spatial scales. Secondly, a calibrated model can be used to simulate the effects of changes in land cover, water management or climate(Kite and Droogers, 2001).

The SWAT model was applied in Blue Nile basin to model spatially distributed soil erosion/sedimentation processes at daily time step and to assess the impact of three Best Management Practices (BMPs) scenarios on sediment reductions in the Upper Blue Nile River basin. The model shows the erosion/sedimentation prone area at Hydrological Response Units (HRUs) level (Betrie *et al*., 2011). The model is also capable of identifying areas within the basin with high water and sediment yield. This provides a useful guide for formulating policies and developing plans to counteract erosion effects, to optimize land use, and to achieve sustainable land development (Huang and Lo, 2015).

1.2 Statement of the Problem

Sediment generated from catchment area causes various negative impact in Ayserawum micro earth dam. Since runoff has a capacity to erode and deposit its sediment through its path, large area in Ayserawum reservoir catchment area was affecting by excessive runoff and sediment load that generate from the upstream highland catchment area. Ayserawum micro earth dam is a newly constructed dam. The construction is completed and filled with water in summer 2015.

As indicated in the project document, the challenges during the reservoir and irrigation structure design were the availability of flow and sediment data that generates from the upstream area. Therefore, estimation of stream flow and sediment load data that generates from the upstream using hydrologic models important for preserving and operating the dam.

1.3 Significance of the Study

This study will give information about sediment load and water inflow generated from Ayserawum reservoir catchment area. A proper investigation of the sediment load and runoff yield and erosion hot spot area of the catchment is essential for management of sedimentation and utilization of water resource. In this study, stream flow rates with respect to time (i.e., month and year) and with their respective sediment deposition will be determined by using SWAT for ungauged catchment, by utilizing long-term sediment and flow data from the gauged catchment of Andit Tid watershed for calibration and validation of model.

1.4 Objectives

The general objective of this study was to investigate the sediment load and reservoir inflow to Ayserawum micro earth dam. The specific objective were as folows:

- To quantify the sediment yield and reservoir inflows of Ayserawum micro earth dam using SWAT model,
- To identify erosion sensitive areas with respect to high sediment degradation in the watershed.

2. LITERATURE REVIEW

2.1 Factors Affecting Runoff

Runoff (originating as precipitation) is part of the water cycle that flows over the land as surface water instead of being absorbed or evaporated. Apart from rainfall characteristic, there are a number of site specific factors which have a direct bearing on the occurrence and volume of runoff. The major factors are reviewed below.

2.1.1 Soil type

Soil functions essentially as medium that provides a large number of passageways for water. Water flow in soil depends on the size and permanency of the pores. The size of the conduits depends on soil texture, the degree of aggregation and the arrangements of particles and aggregates (Silveira*et al*., 2000). The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have smaller infiltration capacities. The infiltration capacity depends further more on the moisture content prevailing in a soil at the onset of a rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated (Finkel and Sergerros, 2005).

2.1.2 Vegetation cover

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. More significant is the effect of vegetation has on the infiltration capacity of the soil. Dense vegetation shields the soil from the raindrop impact and reduces the crusting effect. In addition, the root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving more time to infiltrate and to evaporate (Troch *et al*, 2003). Forests are checkers of soil erosion. Protection is largely because of under story vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees is usually positive. Vegetation cover can prevent the occurrence of shallow landslides (Arnold *et al*., 2001). However, large landslides on steep terrain are not influenced appreciably by vegetation cover. These large slides may contribute the bulk of the sediment, as for example in the middle hills of the Himalayas (Bruijnzeel and Bremmer, 1989). Afforestation normally decreases soil erosion. Splash erosion may increase substantially when litter is cleared from the forest floor(Mahmud *et al*., 2005). The spectrum for the size of the drops that are formed by the canopy varies widely among different species, resulting in large differences in the potential of splash erosion. Deforestation may increase erosion, the actual soil loss, however, depends largely on the use to which the land is put after the trees have been cleared.

2.1.3 Slope and watershed characteristics

In general, the volume and peak rate of runoff increases with watershed area. However, for the same rainfall event, a long narrow watershed would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. In the longer watershed, it takes more time for the runoff from the most remote part of the watershed to reach the outlet (Carey *et al*., 2004). The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the watershed i.e. the larger the size of the watershed the larger the time of concentration and the smaller the runoff efficiency. Investigation on experimental plots has shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it was observed that the quantity of runoff decreased with slope length to some extent (G. Setegn, *et,al.*, 2008).

2.1.4 Climate

Climatic influences on vegetation and LULC is manifested by the response in land using activities to its rainfall and temperature. In area where rainfall is adequate with good distribution and mild air temperature, people prefer to grow crops and keep livestock i.e. to undertake settled mixed agriculture (Lahmeyer *et al*., 2004).

2.2 Land use impact on hydrologic regime

The assessment of Land use and Land cover changes (LULC) on hydrology is essential for the development of sustainable water resource strategies. Specifically, understanding how change in each LULC class influences hydrological components will greatly improve predictability of hydrological consequences to LULC changes and thus can help stakeholders make better decisions (Nie *et al*., 2011). Land use change is caused by multiple interacting factors of the coupled human and environment systems (Lambin, *et al*., 2003). Basin hydrology is sensitive to changes in land cover attributes, with a general pattern of increasing unregulated runoff with migration from trees to crops due to decreasing evapotranspiration (Thanapakpawin *et al*., 2006). Conversion of natural landscapes for agricultural and urban uses often impacts soil integrity, nutrient fluxes, and native species assemblages. Such changes can affect watershed hydrology by altering the rates of interception, infiltration, evapotranspiration, and groundwater recharge that result in changes to the timing and amounts of surface and river runoff. There is conflicting evidence, however, regarding how forest conversion or a forestation in tropical regions impacts watershed hydrology. Consequences of rapid changes in the upland areas of the watershed are being felt by downstream users. Increased stream flow and flashier flows are associated with higher erosion and sediment delivery (Baker and Miller, 2013). Watershed management practices is reduce surface runoff and augment soil moisture level in the watershed (Tekleab *et al*., 2014). These practice resulted in a higher infiltration rate and a reduction of direct runoff volume by 81% which has had a positive influence on the watershed water balance (Jan Nyssen1 *et al*., 2010).

The impact of land use change is a sharp increase flow of the rivers and streams, with floods of higher magnitude, and a decrease in groundwater recharge upstream. The decreased recharge consequently gives a reduction of groundwater base flow during low flows season which is nevertheless moderated by the buffered nature of groundwater base flow (Condappa1 *et al*., 2011). Physical soil water conservation technologies used include terracing, contour bunds, check-dams, percolation pits, water retarding basins (control basins), while biological ones include planting grass, and trees (tree Lucerne). Evidences of the impact of such intervention on improved ground water recharge and reduction in soil losses have been seen in form of improved base flow down streams, prolonged retention of soil moisture, reduction in soil loss and filling up of some gullies (Ndengu *et al*., 2015).

2.3 GIS Applications in Hydrologic Analysis

Recent advances in GIS enabled planners, watershed managers, and hydrologic engineers to expand their capabilities for watershed management (DeBarry, 2004). Several advances have become apparent since the advent of computers powerful enough to run a GIS. Several procedures have been developed to incorporate GIS into watershed application (DeBarry, 2004). These GIS applications improve efficiency and accuracy and cut costs in the hydrologic parameter calculation methodology required by hydrologic models. Many subroutines have been developed to analyze the terrain and hydrologic processes from the grid cells of the DEMs. Some of the hydrologic subroutine includes: flow direction, sub watershed or drainage basin boundary determination, flow accumulation and stream channel determination. The GIS hydrologic operations are based on the premise that water flows downhill in the direction of steepest descent, and the elevations of the grid cells dictate this direction (Maidment, 2002).

2.4 Impact of Land Use on Erosion and Sediment Load

There are strong ties between land cover patterns and soil erosion and sediment yield in watersheds. The spatial configuration of land cover has recently become an important aspect of the study of geomorphological processes related to erosion within watersheds (Yan *et al*., 2013) Land use change may cause a great deal of sediment yield increase. This is mainly attributed to land degradation (conversion of forest to agricultural land) due to intense human activities, especially deforestation (Huang and Lo, 2015). In Ethiopian highlands soil erosion is a serious problem that increased sedimentation of reservoirs and lakes. Human activities (i.e. deforestation, ploughing, livestock grazing, removal of remnant vegetation, road building) led to an overall increase in erosion process intensity (Nyssen *et al*., 2008). Cultivated lands on average are five times more prone to erosion than bush–shrub lands. This emphasizes the importance of implementing appropriate soil and water conservation measures in critical sediment source areas prioritizing the steepest part of the watershed (Haregeweyn *et al*., 2013; Tibebe and Bewket, 2011). The sediment contribution of major watersheds within Lake Tana basin was estimated. On average annual sediment loss from the gauged part of the watershed is 32 t/ha. Accumulation of sediment in Lake Tana is taking place at an annual rate of 10 t/ha of watershed area with a small amount of outflow from the lake to the Blue Nile River (Zimale *et al*., 2016). To prevent or reduce land degradation, many programs have been initiated in northern Ethiopia for soil erosion control and land rehabilitation (Haregeweyn *et al*., 2012). Generally, the most important challenges related to water harvesting schemes are siltation, and less water storage in the reservoirs compared to design capacity. Lack of current data on reservoir capacity loss due to sedimentation is one of the challenges to the sustainable management of surface reservoirs (Chitata *et al*.,, 2014).

2.5 Model selection

Different simulation models are used in science and practice to estimate sediment load and water resource in ungauged basin. Various hydrological models (e.g., distributed hydrological models, lumped models, physical distributed models, empirical models and statistical models) that can estimate water resource availability. Modeling soil erosion using distributed physical models thus provides a sophisticated alternative tool for investigating the processes and mechanisms governing soil erosion at catchment or larger scales (Boggs et al., 2001).

To estimate soil erosion and develop optimal soil erosion management plans, many erosion models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Water Erosion Prediction Project (Flanagan and Nearing, 1995), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and AnnAGNPS (Bingner and Theurer, 2001) have been developed and used over many years. Among these models, the USLE has remained the most practical method of estimating soil erosion potential and to estimate the effects of different erosion factors on soil erosion. USLE has been used for more than 40 years (Dennis and Rorke, 1999; Kinnell, 2000) whereas other process-based erosion models developed afterward have limitations in applicability due to intensive data and computation requirements (Lim *et al.,* 2005). However, studies using the USLE do not consider the sediment delivery ratio to estimate the sediment delivered to the downstream point of interest (Lim *et al.,* 2005). As a result, more recent physical-models for soil erosion estimation have been developed that consider the sediment delivery process.

The application of these models is not always an easy task since they require large amounts of information which often is not available. However, models are the only current tools that enable an approximate quantification of soil erosion processes, facilitating the recognition of high-risk areas and consequently the development of efficient planning to prevent soil degradation at catchment scale (Santhi *et al.,* 2001) though such models are rarely applied in Ethiopia for reasons such as their intensive data requirements which are not available for most sites, and most models are not user friendly for operation. In this study, following a literature review of different types of erosion models, the physical-based Soil and Water Analysis Tool (SWAT) model was selected to be applied.

SWAT model is based on extensive modeling experience and also incorporates the features of several other models (Neitsch *et al.,* 2005). Identification of erosion-prone areas using a distributed physical model that estimates soil erosion rates with sufficient accuracy will have great importance for implementing appropriate erosion control practices (Shi *et al.,* 2004).

2.6 Applicability of Model

SWAT is currently applied worldwide and is considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better-informed policy decisions (Gassman *et al*., 2007).SWAT model performs better for runoff than sediment yields, and monthly simulations better than daily for both runoff and sediment yields. The model gave satisfactory results without even calibration, as observed from several simulations with default parameters and parameter regionalization for various time periods. The results improve with greater manual input into the model of parameters representative of the watershed. Hence, the SWAT model can be used in ungauged watersheds to predict the effect of land management practices on runoff and sediment (Prabhanjan,*et al*., 2015).

According to (Ghoraba, 2015) SWAT was used in order to model the hydrology of Simly Dam watershed area. Manual calibration has been performed first on annual basis followed by monthly basis. The calibration and validation of the model produced good simulation results. The efficiency of the model has been tested by coefficient of determination, Nash Sutcliffe Efficiency (N_{SE}). The model can be used successfully to predict the volume inflow to Simly Dam, facilitate the storage and release water management.

In the Nile countries on the basis of performance indicators, the SWAT models in general produced satisfying or good results (Van Griensven *et al*., 2012). SWAT model appropriate for monsoonal climates is presented as a tool to quantify the hydrologic and sediment fluxes in the Blue Nile Basin, Ethiopia. The model requires very little direct calibration to obtain good hydrologic predictions (Easton *et al*., 2010). In Ethiopia's Lake Tana Basin, with Nash-Sutcliffe model efficiency greater than 0.50, has acknowledged that SWAT has the potential for use in assessing the relative impact of land use management decision on hydrologic response. In Ethiopia's Lake Tana Basin also report Nash- Sutcliffe model efficiency greater than 0.50, acknowledging that SWAT has the potential for use in assessing the relative impact of land use management decision on hydrologic response. The performance SWAT summarized for discharge and soil loss shows very good results. With a p factor of 0.71 and an r factor of 0.53 also the Validation of discharge data showed very good results. The hydrologic model SWAT has been applied to the ungauged and semi-ungauged watershed in different part of the country gets promising results (Gebrekristos, 2015; Seyoum T. and Koch M., 2013). In Andit Tid watershed compare climatic forecast system reanalysis (CFSR) data and WLRC climatic data with SWAT model. Calibration and validation runoff and sediment yield with WLRC data yielded very good results. The CFSR generated data, which under estimated the WLRC runoff and sediment, yielded unsatisfactory results. Therefore, SWAT model shows best perform in Andit Tid by using locally collected input data(Roth and Lemann, 2016).

2.7 Strength of SWAT Model

Key features that make the model applicable for a wide range of studies are modeling based on physical processes associated with soil and water interaction, flexibility to incorporate crop characteristics, cropping stage and duration, flexibility on input data requirement, capability of modeling the changes in land use and management practices, computational efficiency, capability of long-term simulations, capability of modeling watersheds areas varying between few hectares to thousands of km^2 and the model is freely available and can be easily downloaded from the internet (Eyob, 2010).

2.8 Limitation of SWAT Model

SWAT is a long term water and sediment yield model that operates on a daily time step. Daily precipitation is input to the model and an empirical (curve number) equation is applied to daily rainfall without accounting for intensity. The major limitations to large area hydrologic modeling are the spatial variability associated with precipitation. SWAT does not simulate detailed event-based flood and sediment routing. It was developed to predict agricultural management impacts on long-term (hundreds of years) erosion and sedimentation rates. In reservoir routing originally developed for small reservoirs and assumes well-mixed conditions. The reservoir outflow calculations are simplistic and do not account for controlled operation (Arnold *et al*., 1998).

2.9 Model Parameter Regionalization

In 2003, the International Association of Hydrological Sciences established a “Predictions in Ungauged Basins” that is aimed to coordinate and help the scientific community to achieve major advances in the capacity to make predictions in ungauged basins (Sivapalan, 2003).

Since then, significant progress has been made in the development of regionalization methods (Zhang and Chiew, 2009). The term regionalization was later extended to the transfer of model parameters from a gauged donor catchment to ungauged ones. In this paper, regionalization refers to the art of finding behavioral parameter sets for hydrological models run on ungauged catchments. Transferring parameters is often performed in the case of geographically close catchments. However, there is no universal method for a given region or catchment. The common approach remains the testing of various regionalization methods to identify the most appropriate for the region of interest. Different regionalization approaches have been applied to various regions with different landscapes, topography, and different basin sizes for continuous flow estimation in ungauged basins (e.g., Merz and Blöschl 2004; Parajka*et, al*., 2005; Oudin*et, al*., 2008). Three classical groups of regionalization approaches that are the most widely used, i.e., the spatial proximity, regression-based, and physical similarity approaches. These techniques are generally used to transfer model parameters from gauged basins to an ungauged basin and then, use the transferred model parameters to generate continuous flows in the ungauged basin.

The physical similarity approach is similar to the regression based in which it uses catchment descriptors to identify gauged catchments similar to the ungauged one. The methods differ in which the physical similarity uses the single (or few) most similar donor catchment(s) to transfer entire parameter sets to the ungauged basin. This method has the advantage of keeping coherent parameter sets during the transfer.

3. MATERIALS AND METHODS

3.1 Description of Study Area

The study area is found at 9° 54' 05.68" to 9° 56' 47.77" N latitude and 39° 29' 43.14" to 39° 36' 43.45" E longitude and about 2703 to 2909masl, in the upper Blue Nile basin of Ethiopia. It is located in North Shewa Zone of the Amhara National Regional State at a distance of about 223 km to the northwest of Addis Ababa on the Desse. The total watershed area is about 3,214 ha. The reservoir is found at the lower end of the watershed area at 9° 54' 45.22" N latitude and 39° 29' 55.36" E longitude about 2703m.a.s.lin Mojaworeda at EngdaWasha and Aba Bersoma kebeles.

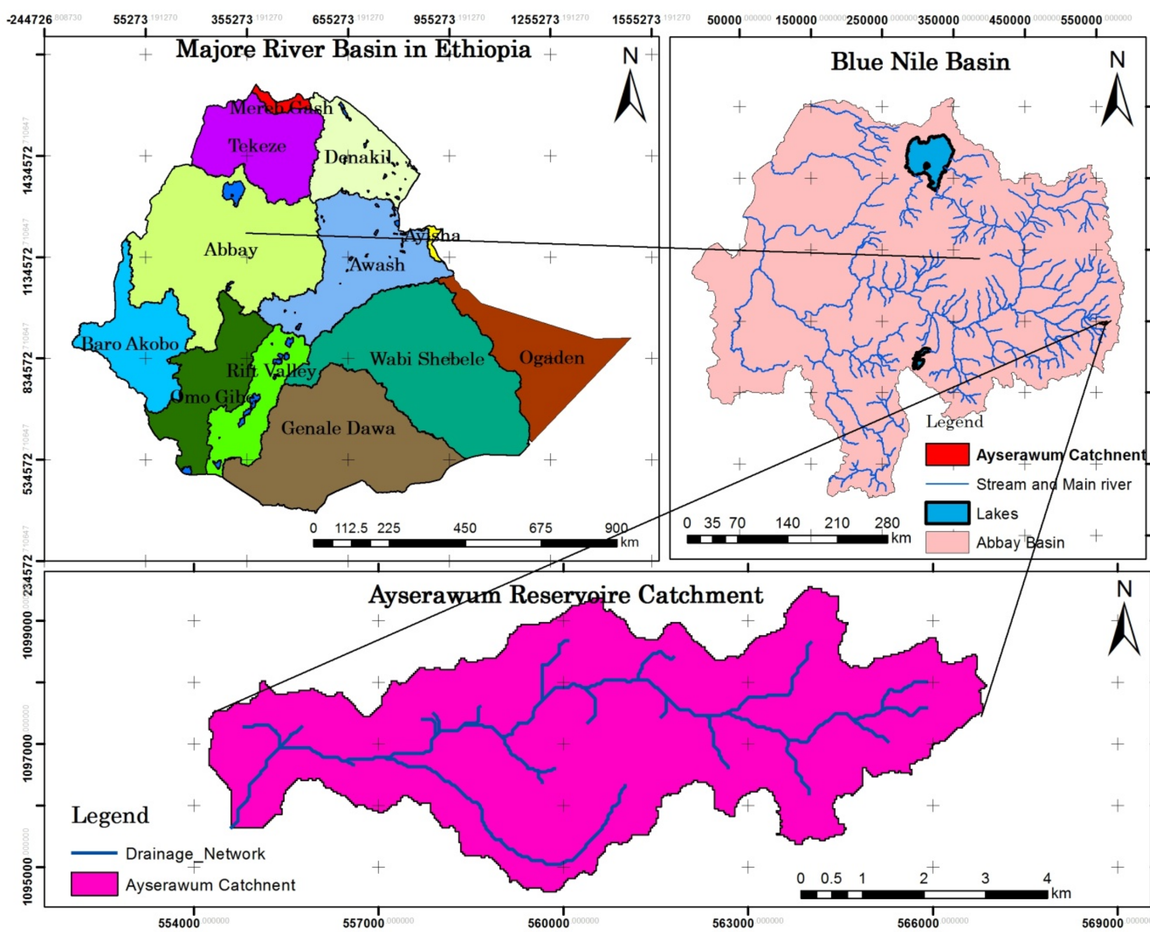

Figure 3.1. Geographical location of the study areas

3.1.1 Topography and climate

Catchment longitudinal slopes are somewhat a little flat to gentle especially around the dam location points. At far and intermediate course of the catchment at upstream, its slope becomes gentle to steep. The river is Perennial which increases its flow along its longitudinal direction because of availability of small springs and marshy area at different points along the river bank.

The mean monthly air temperature of the watershed area ranges from 11.65 to 16.1°C. The area is characterized by sharp temperature fluctuations between night and day time. During dry season, temperature would rise up and in the wet season, cools down. At higher altitude, wet season is characterized by a combination of high rainfall and occasional snow. Frosts are common. There are two rainy seasons (Kiremt) between June to September and minor rainy season (Belg) in February to April. The mean annual rainfall is ranges from 899 to 1500 mm. Most of the rainfall of the rain in area is occurred during July and August.

3.1.2 Soil and land use

Soil in the study area is classified on the basis of the revised FAO/UNESCO-ISWC legend to soil map of the world (1998; 2002; 2005). There are two major soil types in the Ayserawum sub watershed, Eutric Leptosols and Eutric Verticsols. Out of two soil types identified in the watershed, Eutric Leptosols cover about 78.34% of the watershed area.

Soil and water conservation practice is exercised specially in the early years, but soil erosion is still the major problem. Gully is developing in the upper watershed in low slope gradients, formed by deep erosion processes typically migrating up-slopes. These indicate that the landmass is still active in surface processes which could have influence on downstream structures. The reservoir area is covered by thick layer of red brown clay loam soil texture covered with bushes and spread eucalyptus tree. The river is perennial which increases its flow along its longitudinal direction because of availability of small springs and marshy area at different points along the river bank.

Soil fertility in the area has been declining over time. In some parts of watershed areas, farmers practice soil burning (locally known as ‘Gaye’). The objective of burning soil is to minimize water logging, control insects and weeds, and to increase availability of nutrients. It is, however, a practice that reduces total productivity over the long term (Mc.Cann, 1995). The land use land cover (LULC) of the study area includes the artificial forest, cultivation landand grass land. The forest land is found in small portion in the downstream and middle part of the watershed. Cultivated land is the dominant LULC type that covers the upstream and middle parts of the watershed. Follows mixed farming system crop cultivation and raring animals, the main crops grown include barley, wheat, beans, peas, lentils and linseed. The most important are barley and beans. Sheep, cattle and equines are the major animals reared by the farmer with free grazing system.

3.2 Materials and Data

To undertake the study, ArcGIS 10.0 software, Arc SWAT 2009 Model, ERDAS IMAGINE 2010, GPS, RAINBOW, Weather generator and Microsoft excel wereused to organize and summarize the data. For this study, the following datawere collected: 30*30m resolution STRM digital elevation model (DEM), soil maps, and historical daily climatic data such as rainfall, temperature, wind speed, sunshine hour, relative humidity and stream flow. These data were required to estimate surface runoff, sediment yield and hotspot erosion area of the study area. Stream flow data was gathered from Andit tid for calibration and validation of Ayserawum watershed.

3.2.1 SWAT input data

The Arc SWAT ArcGIS extension is graphical user interface for the SWAT (Soil and Water Assessment Tool) model (Arnold *et al*., 1998) and requires detailed spatial (GIS input) and temporal input data, as a physical model. The most important spatial information needed are a Digital Elevation Model (DEM), a land use or land cover map, stream network layers and a soil map. As for temporal data, daily meteorological, sediment data and river discharge data are essential for prediction of stream flow, sediment loss and calibration purposes. The first step in initializing a watershed simulation is to partition the watershed into sub watersheds. The user has the option of allowing SWAT to automatically delineate the watershed and sub watersheds using DEM or provide predefined sub watersheds. The land area in a sub watershed is divided into hydrologic response units (HRUs). HRUs are portions of a sub watershed and possess unique land use, slope range and soil attributes (Neitsch,*et al*., 2005).

3.2.1.1 Digital elevation model

The DEM is one of the main inputs of the SWAT model. Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. Shutter Topography Radar Mission (STRM) 30*30m resolution DEM was downloaded from NASA web server (*http://earthexplorer.usgs.gov/*) and added into the Arc SWAT model to delineate the watershed of the area, and to extract information required such as slope gradient, slope length, stream network characteristics and drainage pattern of reservoir watershed area.

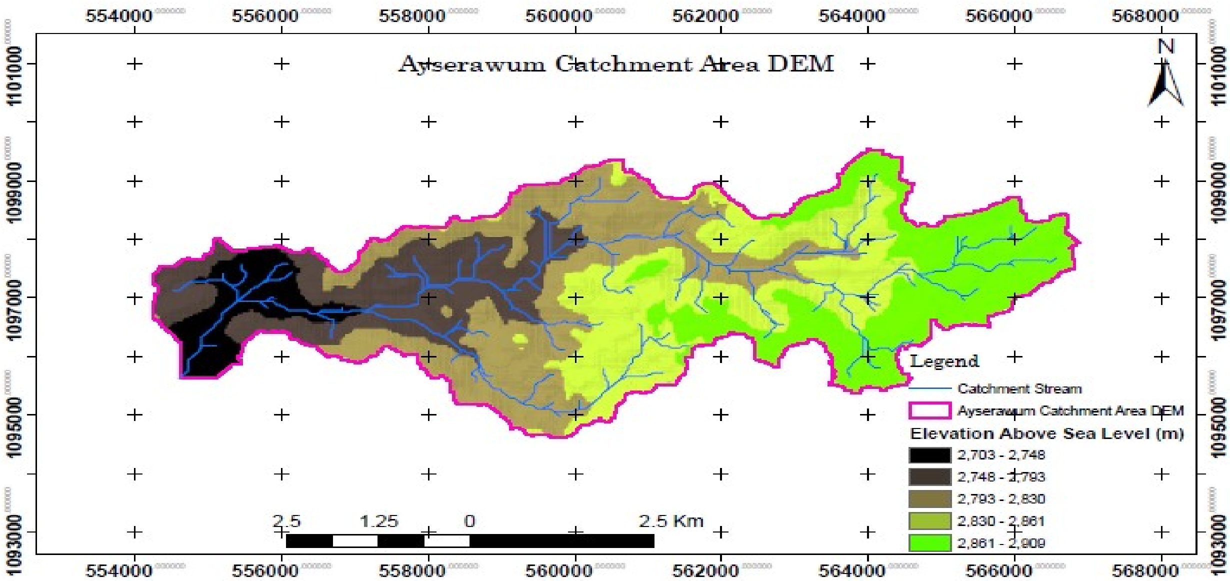

Figure 3.2. Digital Elevation model of Ayserawum Dam watershed area

3.2.1.2 Soil type and properties

SWAT model requires different soil textural and physical-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of soil. Soil data of the study areawere extracted from soil database and digital soil map was obtained from Abbay basin soil map or from FAO Afrikaner database (*http://www.africover.org./index.htm)* with the aid of ArcGIS. These data were used for further HRU analysis.

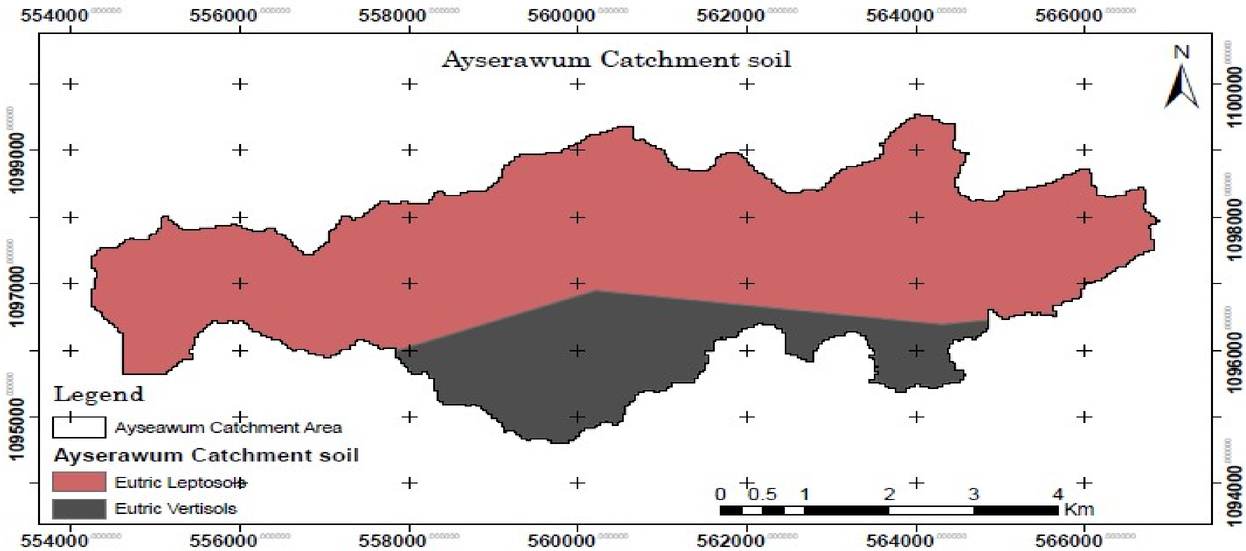

Figure 3.3. Soil Type of Ayserawum dam Watershed area

Soil Parameters in SWAT database for each soil layers are shown in Appendix Table 1. Soil Parameters presently used in SWAT model to run is given in Table 3.1.

Table 3.1. Soil parameters used in SWAT

Name	Description
NLAYERS	Number of layers in the soil (min 1 max10)
HYDGRP	Soil hydrologic group (A, B, C, D)
SOL ZMX	Maximum rooting depth of soil profile
AN ION _EXCL	Fraction of porosity from which ions are exchanged
TEXTURE	Number of layers in the soil (min 1 max10)
SOIL _Z	Depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of the soil layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Clay content
SILT	Silt content
SAND	Sand content
ROCK	Fragment content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility (K) factor

3.2.1.3 Land use land cover data

Supervised classification was used to prepare the land use land cover data of the study area. The land use land cover data of the study area wereprepared from 2014 satellite image downloaded from NASA web server (*http://earthexplorer.usgs.gov/*) using ERDAS Imagine software. Preparing land use land cover data of the study area weredone by following these steps. Loading the satellite image of the study area in to ERDAS IMAGINE, ground control point was collected from each land use type by using GPS, and then the collected GPS land use type was overlaid on the satellite image. After that the recent land use land cover map was known by integrating ERDAS and GIS function. The verified land use/land covers data wereused for further HRU analysis to estimate surface runoff and sediment yield in the study area.

3.2.2 Slope

Slope was also used as input data for the model. Land use, slope and soil data used to create HRU by overlaying them together. During the creation of HRU the slope was classified to the reasonable range. Accordingly, for this work to minimize complexity and to use manageable data and also considering the steepness of the area, the slope was classified into five classes based on MoARD (2005). The classes were: 0 to 3%, 3 to 8%, 8 to 15%, 15 to 30%, and above 30%. Based on these classes the map of slopes of the area was developed.

3.2.3 Meteorological data

Climate data is one of the main sets of input data for estimating sediment and runoff yield. Meteorological data such as daily rainfall, maximum and minimum air temperatures, sunshine hours, wind speed and relative humidity werecollected from National Meteorological Agency (NMSA) of Ethiopia, and Water and Land Resource Center (WLRC) within and around the study area (i.e. Andit Tid, Mehal Meda, Debre Birhan, Enewari, Mezezo, Alem Ketema and Debre Sina). SWAT weather generatorwas used to fill missing wind speed, sunshine hour and relative humidity for Meteorological stations.

To manipulate and use point rainfall in SWAT, the missing weather data were filled negative (-99) and saved in dbf format. This negative (-99) tells SWAT to generate the missed weather data for that day (s) because SWAT has an integrated weather generator to generate missing data using the monthly weather generator parameters. The calculated values of weather generator parameters for each station were manipulated using the daily data inserted in PCP program to obtain the statistical parameters easily. After the missed data are filled, SWAT picks and uses precipitation values of stations as point rainfall based on the proximity of sub watershed to stations. The nearest and farthest meteorological were Alem Ketema and Mezezo have 59.5 and 21.5km distance from the catchment area respectively, as shown in Figure 3.4.

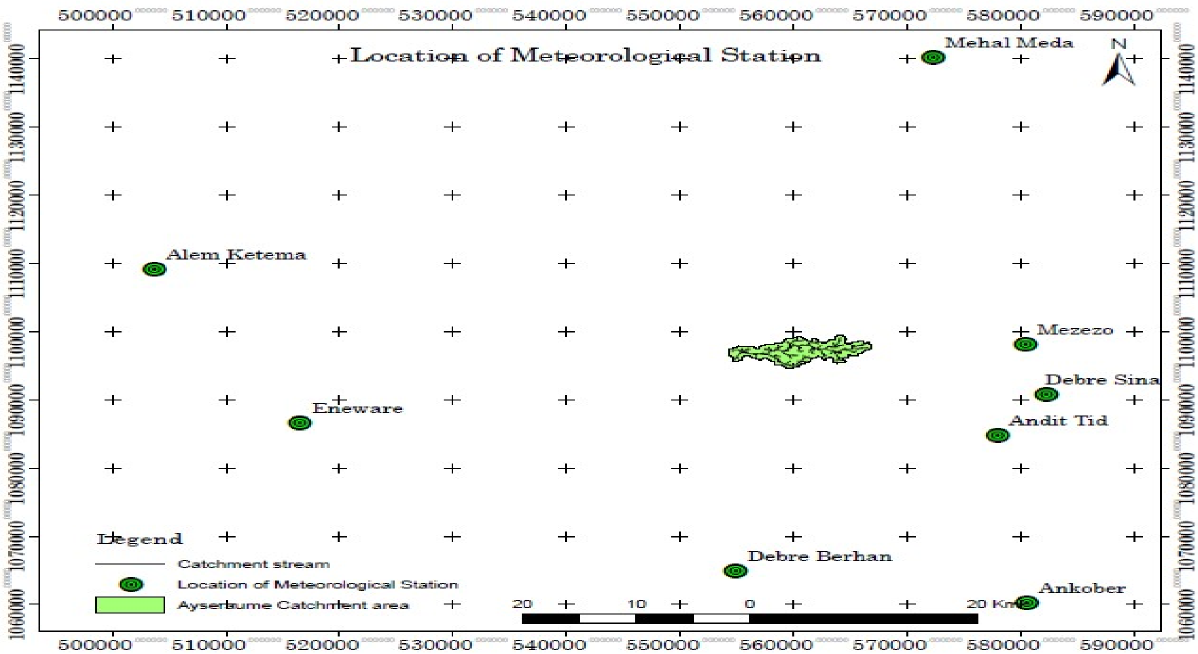

Figure 3.4. Distribution of meteorological station

3.2.4 Climatic data preparation and checking

The data collected from different meteorological station may contain errors. So, the raw data were checked and errors were corrected before using the data for estimating surface runoff and sediment yield in Ayserawum reservoir watershed areas. To prepare input data for SWAT model, data preparation and checking were made to each meteorological station.

3.2.5 Consistency analysis and homogeneity test

3.2.5.1 Consistency analysis

The consistency of the meteorological data set of the given station cheeked by the double mass curve method with in reference to their neighborhood station. Double mass curve plotted by using the annual cumulative total rainfall of the station under study as ordinate and the average annual cumulative total rainfall of neighboring station (base station) as abscissa, and checking whether they align in a single straight line or not and correlation between the variables(ADF, 2003). Double mass curve analysis is frequently used in hydro-meteorological practices to test homogeneity of precipitation (Walling, 2009). By adding successive values, it is assumed that the random error will tend to cancel each other while the linear relationship is reinforced by repetition. Significant change in the slope or trend the resulting line is a clue as to breaks in homogeneity(Shahn, 2002).

3.2.5.2 Homogeneity analysis

Homogeneity of annual rainfall and hydrological data were also tested using RAINBOW software. The results of homogeneity test are presented in a graph for cumulative deviation and probability of exceedance (Raes *et al*., 2006). Meteorological data gathered from different station should be consistent or homogeneous with the study area.

3.2.6 Hydrological and sediment data

Twenty (20) years of Hydrological data were gathered from Water and Land Resource Center (WLRC). These data were utilized for sensitivity analysis, calibration and validation of the model at the gauged point to recorded runoff and sediment load of Andit Tid watershed. Here the observed stream flow and sediment load data are recorded by automatic gauge and manually respectively. Outside the watershed there is irrigation command divert irrigation water above the gauging station. The volume of diverted irrigated water is directly added to the recorded stream flow. Automatic gauge recorder also sometimes damaged by stones and gravels deposit at the bed, to overcome these problem the recorded data is adjusted by the day to day follow up of the gauge station with respect to the gravel deposit on the gauge site and stacking of the water level redder. For sensitivity analysis, calibration and validation of stream flow and sediment twenty (20) year Andit Tid watershed adjusted stream flow and sediment recorded starting from 1989 was collected from Water and Land Resource Center (WLRC).

3.3 Model Set-Up

3.3.1 Watershed delineation

Automated watershed delineation in Arc SWAT interface was used to delineate the watershed. The sub watershed delineation was done using Digital Elevation Model data. DEM was imported into the SWAT model and projected to UTM zone 37N, projection area of Ethiopia. A mask was manually delineated over the DEM in order to extract the specific area, to delineate the boundary of the watershed and digitize the stream networks in the study area, which reduced the time of processing and burn in a polyline stream data set that helped the sub watershed reach to follow the known stream reach. In this study, the minimum threshold area of 10 ha was used to define the stream network and detail delineation of the watershed. This threshold area was used to define the minimum drainage area required to form the origin of a stream and to decide the number of sub-watersheds within the watershed. Outlet of the watershed was selected at the end of Ayserawum watershed. After that, SWAT was automatically delineated the watershed boundary based on sub-basin and drainage network.

3.3.2 Hydrologic response unit analysis

Sub watersheds were subdivided, after watershed delineation, into areas having unique land use, soil and slope so called hydrologic response unit (HRUs). Even if the individual fields with specific land use, soil and slope were scattered over the sub watersheds, when lumped together they form HRUs. The land use, soil and slope data sets were projected in to the same projection as DEM. Then land use, soil and slope grids were overlaid and linked with the SWAT databases and ready for HRU definition. To define the distributions of HRUs multiple HRU definition options was selected. The threshold level set for land use, soil and slope was used to define the number of HRUs within the sub watersheds. The HRUs of the watershed was derived from the combination of DEM, soil, slope and LULC data provided to the software. Most of the time the default of SWAT recommends that 10% soil, 20% LULC, and 20% slope thresholds have been used (Neitsch *et al*., 2005).

3.3.3 Sensitivity analysis

Sensitivity analysis is a test how the model output depends on model parameters. The parameter for sensitivity analysis was done using the Arc SWAT interface(Van Griens-ven *et al*., 2006) for the whole watershed. Twenty-six hydrological parameters were tested for sensitivity analysis for the simulation of the stream flow and seven for sediment loss. Hydrological parameters were used to carry out sensitivity analysis to identify sensitive parameter that significantly affects surface runoff, base flow and sediment yield. The inputs had been the observed daily flow data, the simulated annual flow data and the sensitive parameter in relation to flow with the absolute lower and upper bound and default type of change to be applied (method application) was used. After running sensitivity analysis, the sensitive parameters were categorized in to four classes based on their mean relative sensitivity Index (I).

Table 3.2.Sensitivity analysis index

Class	Index (I)	Sensitivity
I	$\|I\| \geq 1.00$	Very high
II	$0.20 \leq \|I\| < 1.00$	High
III	$0.05 \leq \|I\| < 0.20$	Medium
IV	$0.00 \leq \|I\| < 0.05$	Small to negligible

Source: (Lenhart *et al.,* 2002)

Sensitivity analysis provides information on parameters that have more effect on the model outputs. It is also used to identify which parameters are more sensitive in the watershed. Thus, using those parameters that are more sensitive during calibration reduces processing time. Among many hydrological parameters, more sensitive parameters were selected from stream flow and sediment load prediction by observing Andit Tid watershed flow and sediment data and the predicted runoff hydrograph. The most sensitive parameterswere used for further sediment calibration and validation.

3.3.4 Calibration

Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. Model calibration was undertaken manually by adjusting sensitive parameters using eleven (11) years of observed flow and sediment data hydrograph from Andit Tid watershed gauging stations from January 1, 1989 to December 31, 1999. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices, the model must be first calibrated to observed data and should then be tested without further parameter adjustment against an independent set of measured data (validation). Refsgaard and Storm (1996) categorize calibration methods as the manual trial and error method, automatic or numerical parameter optimization method; and a combination of both methods. They indicated that the manual trial and error method is most common and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite. However, it is very cumbersome, time consuming, and requires experience. Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. For this study, manual and automatic calibration methods were used. This procedure was continued until acceptable calibration statistics such as the simulated discharge and simulated sediment were match with the observed value. The standard flow chart followed for model calibration is illustrated in Figure3.5 below.

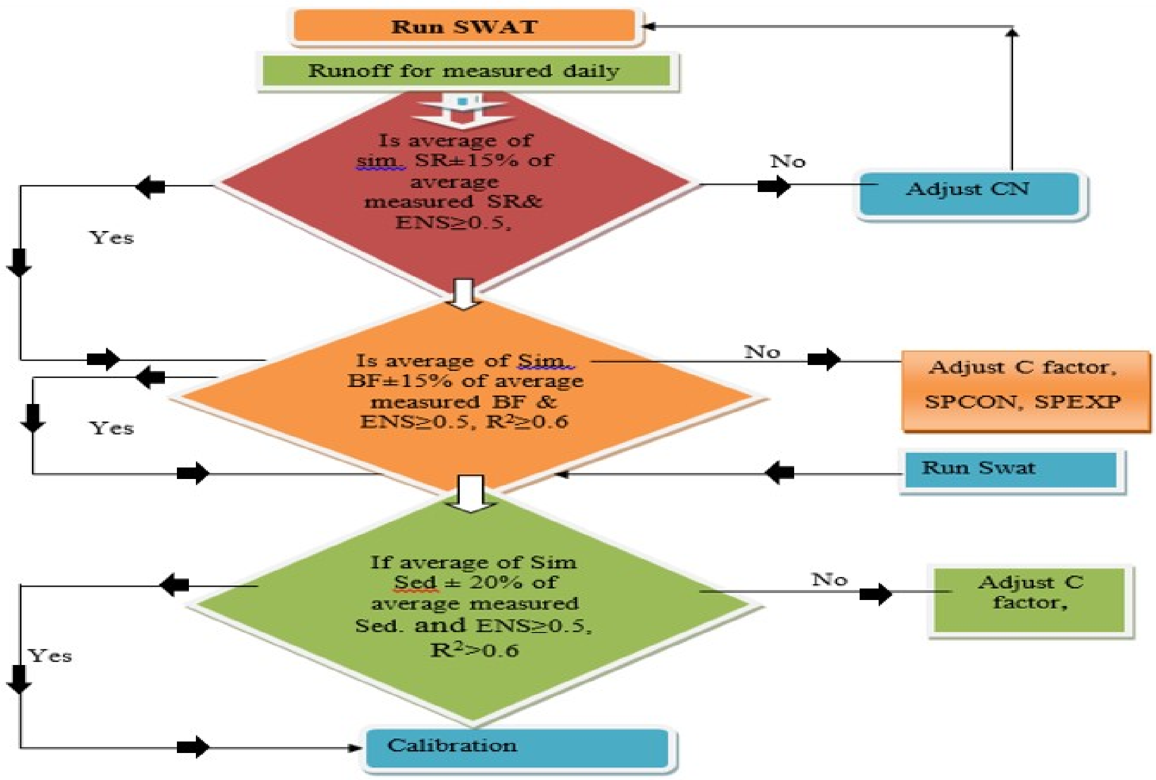

Figure 3.5. SWAT Calibration procedure for stream flow and sediment yield (Santhi, 2001)

Where E_{NS}: Nash and Sutcliffe simulation efficiency, R^2: coefficient of determination, SR: surface runoff, BF: base flow, Sed: sediment, Sim: simulated, Meas: measured, CN: curve number; C: crop cover management factor, SPCON: the linear factor and SPEXP: exponential factor.

3.3.5 Validation

After the simulation result for the calibration period had fulfilled the above statistical criteria, validation was performed for nine (9) years period of records from January 1, 2000 to December 31, 2008. Sensitive parameter that was used for calibration was used for validating the predicted runoff from Ayserawum reservoir watershed area but at different period. Nine (9) year flow and sediment data from Andit Tid watershed gauging station was used for validation in order to make the predicted result of the default value more realistic. Therefore, the results were compared against an independent set of observed discharge data and recorded sediment data.

3.3.6 Regionalization of SWAT model parameters

Regionalization of model parameters was, based on physical and hydrological similarity measured between Andit tid and Ayserawum watershed characterstics.It is a popular methodology for discharge prediction in ungauged basins. The advantage of transferring the entire model parameter set is that it does not interfere with the integrity of model parameters as a set (Oudin *et al.*, 2010). Physical similarity approach regionalization technique which uses catchment attributes to find out similarity between donor and receiver catchments (Nathan and McMahon, 1990; Parajka *et al.,* 2005; Samuel *et al.,* 2011). The advantage of physical similarity approach over regression technique is that it does not take the assumption of linearity (Samuel *et al.,* 2011). The idea behind this method is to recognize similar catchments according to their attributes where one may be the receiver catchment and other catchments are the donors (Parajka *et al.,* 2005; Oudin *et al.,* 2008; Samuel *et al.,* 2011; Razavi and Coulibaly, 2013).

Catchment similarity assuming that the physical and climatic characteristics are likely to be relatively homogeneous within a region, and it has been widely used for parameter regionalization (Merz and Bloschl, 2004; Oudin *et al.,* 2008). In this study regionalization was done by using DEM, land use land cover map, settlement, soil texture, area coverage, mean elevation and slope; similarly used by Samaniego and Bardossy (2005).

Select catchment attributes which are most relevant for determining catchment similarity. Then determine physical similarity regions. Model parameters in ungauged basins are estimated by using the physical similarity approach for only the similar-attribute sites. Several similarity indices, computed from watershed attributes, have been used in regionalization studies (Oudin *et al*., 2008). This study used the similarity index from Nathan and McMahon (1990). Assess watershed similarity by calculating the cosine measure of pattern similarity (SI_{td}) between the target watershed and gauged watershed as follows:

$$\boldsymbol{SI_{td}} = \frac{\sum_{i=1}^{n}(\boldsymbol{CD_{d,i}})(\boldsymbol{CD_{t,i}})}{\sqrt{(\sum_{i=1}^{n}\boldsymbol{CD_{d,i}^2}).(\sum_{i=1}^{n}\boldsymbol{CD_{t,i}^2})}} \quad (2)$$

Where *CD* is the watershed descriptor, *d* is the donor watershed, *t* is the target watershed, *n* is the total number of watershed descriptors. The SI_{td} values vary between -1 and +1, and perfect agreement is indicated by a value of +1 gauged basin is the most similar attributes to the ungauged basin. The estimated model parameters are then used to simulate flow time series in the ungauged basin. The watershed descriptors used in the study are summarized in Table 3.3.

Table 3.3. The watershed descriptors used in the study

Watershed descriptors	Andit tid	Ayserawum
Mean slope (%)	19.70	28.96
Agriculture (%)	57.83	70.33
Forest (%)	3.78	2.01
Grassland (%)	37.89	24.9
Residential (%)	0.49	2.02
Water body (%)	0	0.73
Silt clay (%)	24.49	0
Clay loam (%)	75.50	78.33
Clay (%)	0	21.66

The next step is to transpose the parameters of the donor catchment upon the receiver catchment. The attributes of the ungauged catchments which bear similarity with the gauged catchments and the model parameter value of the gauged catchment to get the value of ungauged catchments.

The river discharge data at the outlet of the Ayserawum watershed was predicated on the observed data from Andit Tid station, 25 km away. Data was available at daily scale from 1989 to 2008 at Andit Tid station.

3.3.7 Model evaluation

In order to evaluate the performance of SWAT model to determine the quality and reliability of prediction compared to the observed values the following methods for goodness of fit measures of model predictions had been used during the calibration and validation periods. These numerical model performance measures are coefficient of determination (R^2 coefficient), Percent difference between simulated and observed data (D) and the Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe 1970). The determination coefficient (R^2) is the square of the Pearson product–moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to 1, the higher is the agreement between simulated and measured flows and was calculated as:

$$R^2 = \frac{(\sum_{i=1}^{N}(O_i - O_{av})(P_i - P_{av}))^2}{\sum_{i=1}^{N}(O_i - O_{av})^2 \ \sum_{i=1}^{N}(P_i - P_{av})^2} \tag{3}$$

Nash–Sutcliffe (1970) coefficient calculated as

$$N_{Es} = \frac{\sum_{i=1}^{N}(O_i - O_{av})^2 - \sum_{i=1}^{N}(P_i - O_{av})^2)}{\sum_{i=1}^{N}(O_i - O_{av})^2} \tag{4}$$

Where is the number of observations during the simulation period, O_i and P_i are the observed and predicted values at each comparison point i, O_{av} and $P_{av}$are the arithmetic means of the observed and predicted values. The value of E_{NS} ranges from 1.0 (best) to negative infinity. The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the observed value is the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between observed and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe 1970).

The percent difference (D) measures the average difference between the simulated and observed values for a given quantity over a specified period (usually the entire calibration or validation period) was calculated as follows:

$$\mathbf{D} = 100(\frac{\sum_{i=1}^{N} Pi - \sum_{i=1}^{N} Oi}{\sum_{i=1}^{N} Oi}) \tag{5}$$

Where: O_i is observed value, P_i is simulated value. A value close to 0% is best for D. However, higher values for D are acceptable if the accuracy in which the observed data gathered is relatively poor.

Table 3.4. Performance evaluation of monthly flow and sediment

Performance Rating	E_{NS}	R^2	D
Very Good	0.75 - 1.00	> 0.7	< ±10
Good	0.65 - 0.75	0.6 - 0.7	±10 - ±15
Satisfactory	0.50 - 0.65	0.5 - 0.6	±20 - ±25
Unsatisfactory	<0.50	0.0 - 0.5	> ±25

Source: (Moriasi *et al*. 2007)

SWAT model predict runoff yield if properly calibrated and validated for gauged watershed and transferring the calibrated parameters to the ungauged watershed. Therefore, despite the data scarcity, the SWAT model is a potential tool to simulate the hydrology of ungauged watersheds in Ethiopia that have similar hydro meteorological conditions with those of the gauged watershed (Ehitaferahu *et al*., 2010).

3.3.8 Identifying hotspot area

The evaluated model was applied for identifying and prioritizing critical hot-spots of runoff and soil losses in the catchment. Hot spot area was known after knowing sediment and runoff amount, land use land cover map, and slope of each sub-watershed in Ayserawum reservoir watershed area. Since SWAT overlay and divide the watershed in to a number of sub-watersheds had its own runoff and sediment yield. Then, the runoff and sediment yield of each sub-watershed with their area coverage in the watershed was known from SWAT output.

Sub-watersheds which weresmaller area, steep slope and higher value of runoff and sediment yield was considered as most severe area (hotspot area). Based on runoff and sediment amount, area coverage and slope steepness ranking was done. Sub-watershed which have smaller area, steep slope and higher value of runoff and sediment load was considered as most severe area (hotspot area).

4. RESULTS AND DISCUSSIONS

4.1 Watershed Characterization

The watershed delineation and HRU definition in the Ayserawum micro earth dam watershed area gave watershed area of 3214.11 ha which resulted in 36 sub watersheds with 200 HRUs. As it was observed in table 4.1 and figure 4.1 in the watershed, most portion of the watershed is covered with cultivated land and grass land, which accounts for 69.47% and 25.7% respectively. The value of the land use presented in table 4.1 was after the definition of HRU but Figure 4.1 was inputs before the definition, for that reasons they are different.

Table 4.1. Area coverage by each land use type of the study area

Land use	SWAT code	Ayserawum micro earth dam watershed	
		Area in ha	Area in %
Cultivated land	CULT	2232.95	69.47
Artificial plantation forest	PLFO	65.12	2.03
Grass land	GLAS	825.92	25.7
Residential area	URLD	66.89	2.08
Water body	WATE	23.23	0.72
Total		3214.11	100.0

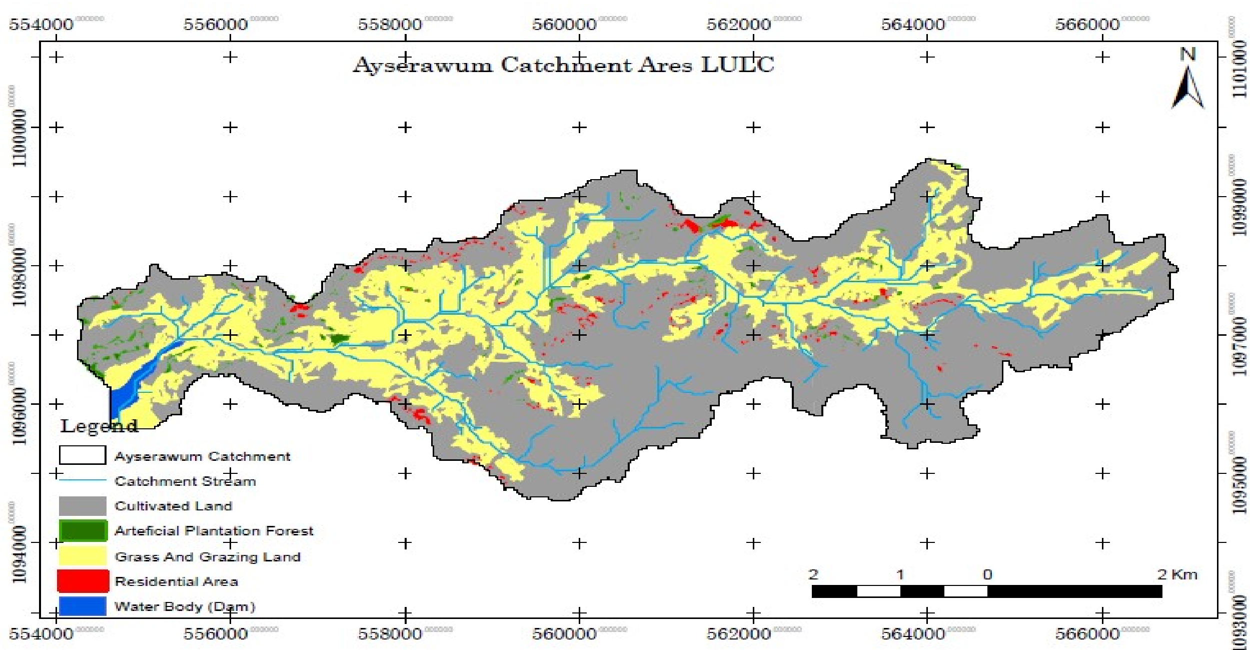

Figure 4.1. Land use Land Cover of Ayserawum dam Watershed area

The soil groups classified in the study area were as shown in table 4.2 and figure 4.2: Eutric Leptosols and Eutric Vertisols. Eutric Leptosols cover an area of 2495.71 ha which account for 77.65% of the total area of the study watershed.

Table 4.2.Major soil types and area coverage (ha, %), of the study area

Type of soil	Symbol	Area in ha	Percent (%)
Eutric Leptosols	Lpeu	2495.72	77.65
Eutric Vertisols	VReu	718.39	22.35
Total		3214.11	100.00

Source: (FAO/UNSCO Soil Classification System)

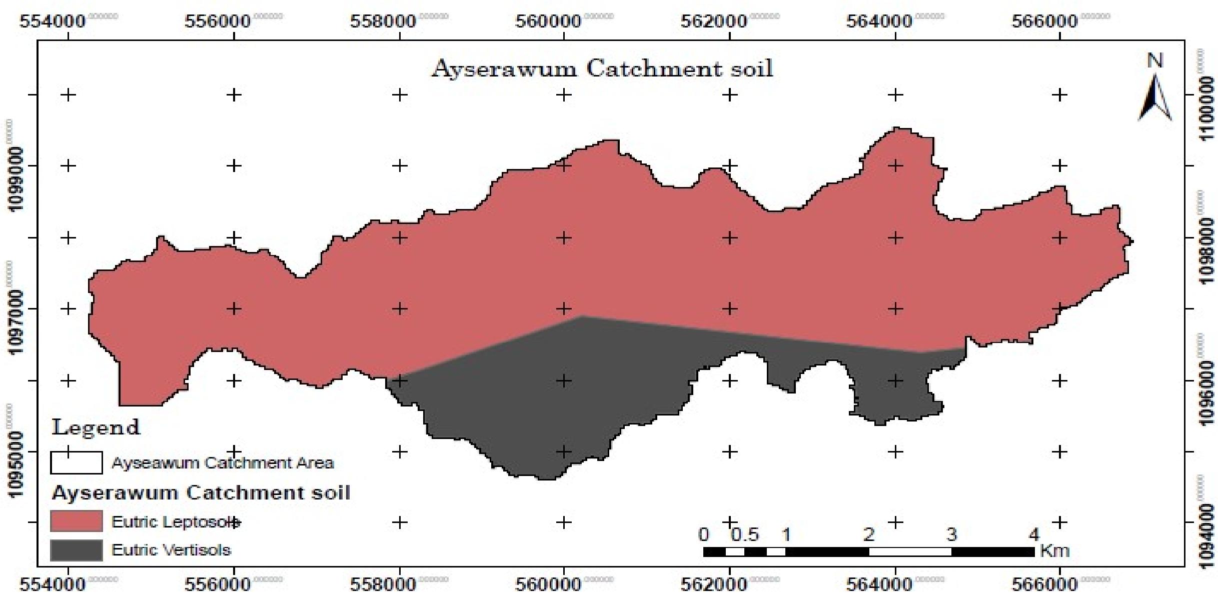

Figure 4.2. The spatial distribution of major soil groups of the study area

The results as shown table 4.3 and figure 4.3 indicate that 924.95ha of lands account for 28.76% of the total area lies in between the slope range of 0% to 8%., i.e. flat to moderate slopes, while rest 13.67% of the watershed 2289 ha of land steep slope.

Table 4.3. Slope classes and area occupied in ha of the study area

Slope (%)	Area in ha	Percent (%)
0 - 3	305.44	9.50
3 - 8	619.15	19.26
8 - 15	936.13	29.13
15 -30	1007.39	31.34
>30	346.00	10.77
Total	3214.11	100.00

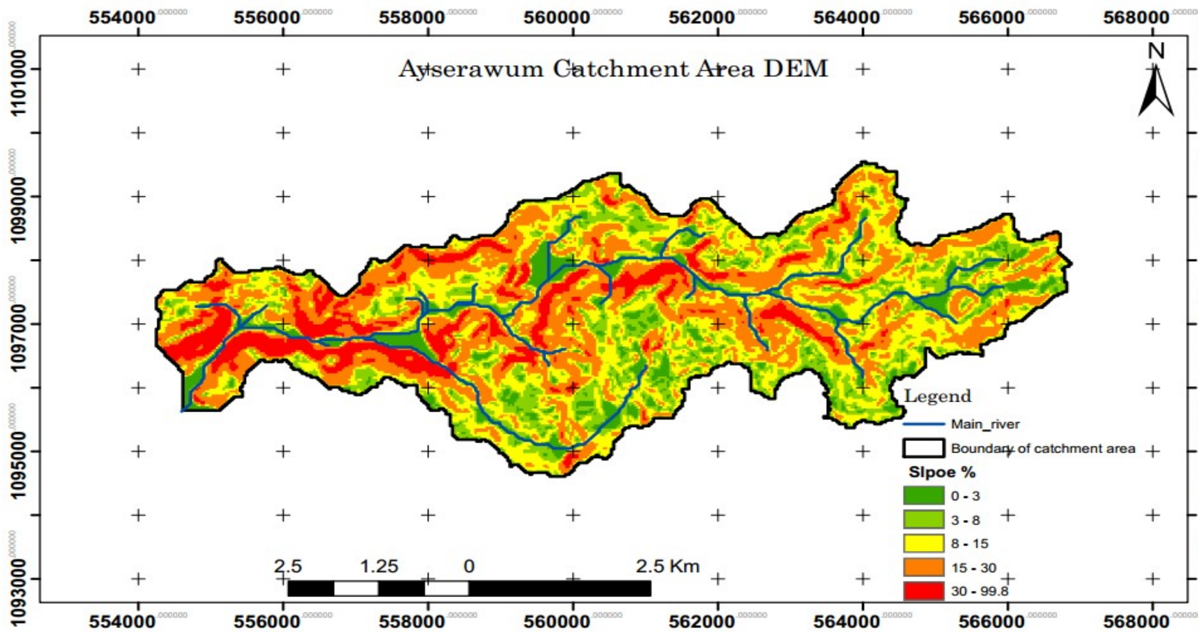

Figure 4.3. Slope class of Ayserawum Watershed

4.2 Consistency Analysis and Homogeneity Test

4.2.1 Consistency analysis of rainfall data

The graph of the double mass curve plot was found almost linear for all meteorological station with a coefficient of determination (R^2) of 0.9992 to 0.9994 as shown in figure 4.4. This implies that the rainfall data were consistent over the considered period. The slight change in slope might occur due to micro-meteorological and climatic properties of the stations, and the changes were not significant for the existence of inconsistency of records.

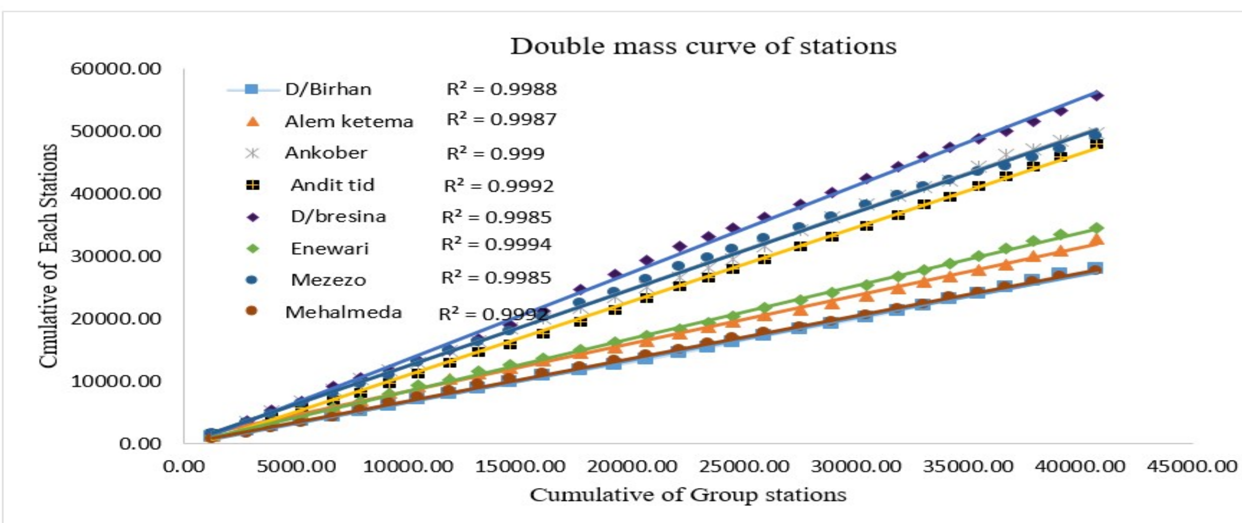

Figure 4.4. Double mass curve of meteorological station

4.2.2 Homogeneity test of meteorological and hydrological data

Thirty years (1985–2014) rainfall and twenty years (1989-2008) hydrological data were collected from NMSA and WLRC respectively.These data were used for simulation. The homogeneity of the annual rainfall and hydrological data were tested by using RAINBOW software. The result of homogeneity test for climate data shows (appendix table 7.9-7.24 and appendix figure 7.8-7.23) that the collected data were homogeneous. This was due to the maximum cumulative deviation crossed the 90% and 95% probability line (Raes *et al.,* 2006).Even though, deviations of one station cross one of the horizontal lines, the data were accepted. Hence, the restriction of homogeneity assured that the observation had been come from the same population which was assured by the value of closeness of linear relationship (R^2) ranging from 0.90 – 0.98.

4.3 Sensitivity Analysis

The results of sensitivity analysis with observed data (table 4.4) showed that most sensitive parameters for flow in the watershed, in their priority order, are soil evaporation compensation factor (ESCO), curve number (CNII), threshold water depth in shallow (GWQMN), available water capacity (mm water/mm soil) (SOL_AWC), Base flow Alpha factor (ALPHA_BF) and soil depth (mm) (SOL_Z). The top five sensitive parameters which had effect on the runoff along with their ranking are presented in table 4.4.

The result of sensitivity analysis indicated that out of twenty-six hydrological parameters tested for the simulation of the stream flow in the study area, the six most sensitive parameters values found in the parameter were considered for calibration and validation of the model for stream flow.

Table 4.4.Results of sensitivity analysis for stream flow

Parameter	Boundary		Rank	Relative sensitivity	Category
	Lower	Upper			
Soil evaporation compensation factor; ESCO	0	1	1	0.12	Medium
Initial SCS CN II value; CNII	-25	25	2	0.12	Medium
Threshold water depth in shallow; GWQMN	-1000	1000	3	0.08	Medium
Available water capacity; SOL_AWC	-25	25	4	0.06	Medium
Base flow Alpha factor (ALPHA_BF)	0	1	5	0.06	Medium
Soil depth(mm); SOL_Z	-25	25	4	0.05	Medium

4.4 Model Performance Evaluation

4.4.1 Calibration of SWAT model for Stream flow simulation

Before calibration proceeds, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this, the monthly Nash Sutcliffe model efficiency (E_{NS}) of 0.32, coefficient of determination (R^2) of 0.46and mean deviation of +19% were obtained from the initial model run. The calibration was, therefore performed for a period of nine years (January 1, 1991 to December 31, 1999) stream flow data. However, the first two years (1989 – 1990) stream flow data were used for stabilization of model runs (warm up period). Calibrated and fitted values of sensitive parameters are shown in table 4.5.

Table 4.5. Final calibrated parameters and fitted values for stream flow

Parameter	Parameter code	Range	Initial value	Calibrated value	Imet
Soil evaporation compensation factor	ESCO	0-1	0	-0.4	1
Initial SCS CN II value	CNII	±25%	10	+4.7	3
Threshold water depth in shallow	GWQMN	0-1000	0	+50	2
Available water capacity	SOL_AWC	±25%	0.01	+0.1	3
Base flow Alpha factor	ALPHA_BF	0-1	0.05	+0.25	1
Soil depth(mm)	SOL_Z	±25%	6	+10	3

Where: Imet stands for variation methods, 1 stands for replacement of initial parameter by value, 2 for adding value to initial parameter and 3 for multiplying initial parameter by value.

Statistical criteria were used during the calibration process to check the estimates had been in acceptable ranges. According to SWAT developers (Santhi, *et al.*, 2001) they assumed an acceptable calibration for hydrology at a $D < \pm 25\%$, $R^2 > 0.6$ and $E_{NS} > 0.5$. These values were also considered in this study as adequate statistical values for acceptable calibration. The model performance statistics had been found as $D = +8.58\%$, $R^2 = 0.89$ and $E_{NS} = 0.85$ for monthly calibration period as shown in figure 4.5.

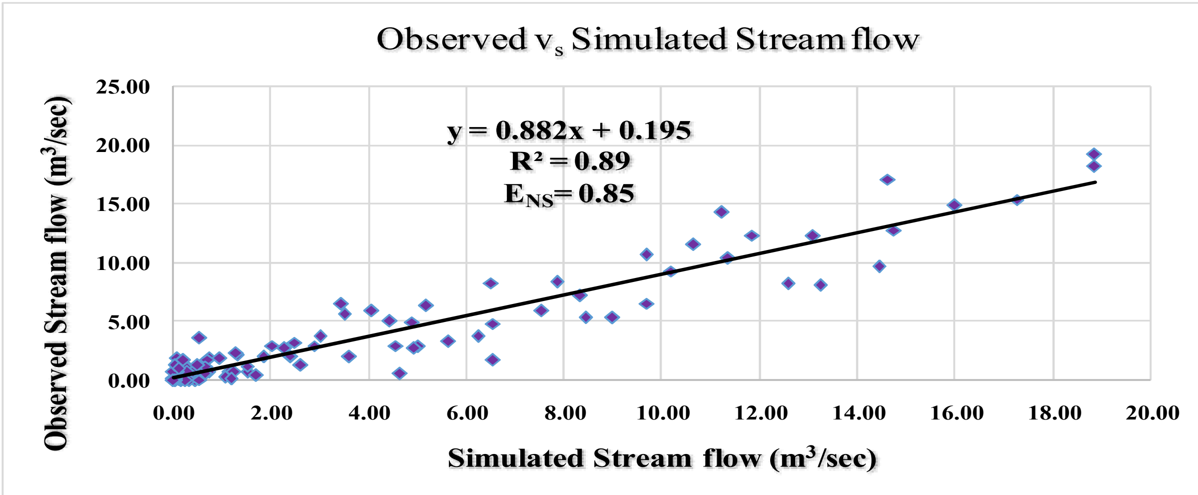

Figure 4.5. Scattered diagram of observed and simulated stream flow for calibration period

Calibration resulted in Nash–Sutcliffe simulation efficiency (E_{NS}) of 0.85, coefficient of determination (R^2) of 0.89, and mean deviation of +8.58% showed a good agreement between measured and simulated monthly flows (table 4.6). The result also indicated that model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates the SWAT's ability to predict realistic flow.

Table 4.6. Calibration results of monthly observed and simulated flow

Parameter	Default	Calibrated(1991 - 1999)
R^2	0.46	0.89
ENS (Nash-Sutcliffe model efficiencies)	0.32	0.85
D% (deviation of mean discharge)	-19%	+8.58%

The Average yearly runoff computed by the model was, against the observed runoff during calibration period.

Table 4.7. Yearly average observed and simulated flow (m^3/sec)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
Observed	4.91	2.94	3.43	3.80	4.63	5.52	4.33	2.02	2.38
Simulated	3.14	2.57	3.03	3.51	4.24	4.36	5.01	2.73	2.78

From figure 4.6, it can be observed in general that the model estimated runoff in the period of calibration.

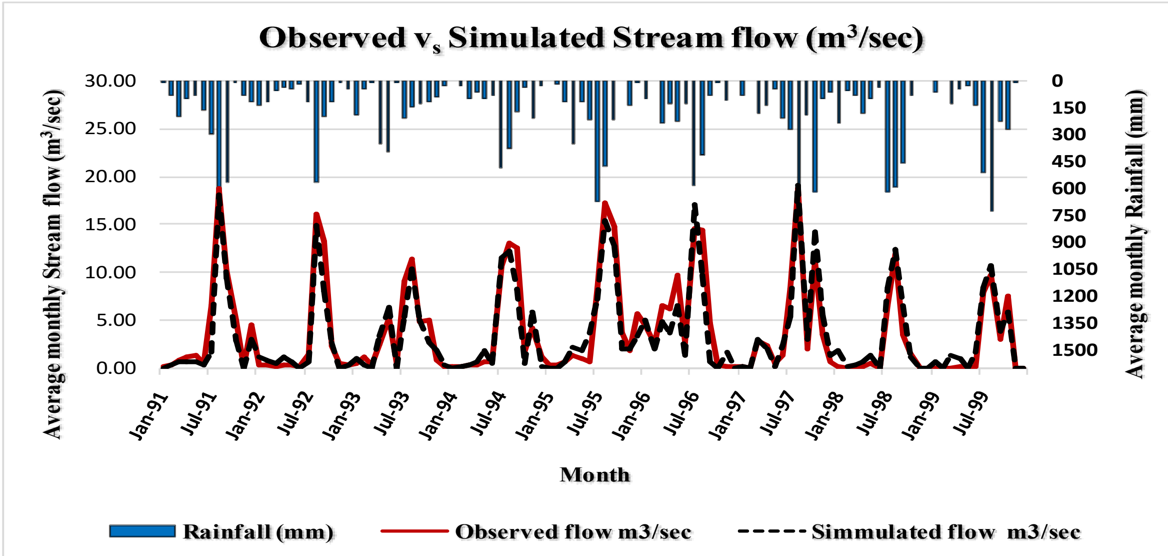

Figure 4.6. Calibration results of monthly observed and simulated discharge

In the above figure 4.6 there is higher rainfall, but lower surface runoff in 1991and vice versa in 1998 and 1999. Rainfall system, agricultural practice and soil and water conservation structure construction may be the reason. The rainfall in the area is bimodal system if there is rain in the belg season the ground cover of the catchment is high with annual crop, grass and bushes and the soil moisture is high and lower infiltration may cause to higher runoff with lower amount of rain for the next summer season, while there is no rain in the belg season the soil is dry, disturbed by land preparation for summer (increase infiltration) and the ground cover is lower due to this generate lower surface runoff with higher amount of rainfall. On the other hand, in the watershed construct different type of soil and water conservation structure by mobilizing community. Once conservation structures construct and stabilize reduce runoff and increase infiltration for the next successive years like in 1998 and 1999 with highest rainfall amount.

4.4.2 Validation of SWAT model for Stream flow simulation

SWAT with calibrated parameters was validated by using independent set of stream flow data of Andit tid that was not used for model calibration. The three statistical goodness of fit were used for model validation. Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the coefficient of determination (R^2) of 0.79, Nash-Sutcliffe simulation efficiency (E_{NS}) of 0.73 and mean deviation (D) +5.32% showed in table 4.8 and figure 4.7.

Table 4.8. Validation results of average monthly observed and simulated flow

Parameter	Validated (2000 - 2008)
R^2	0.79
E_{NS} (Nash-Sutcliffe model efficiencies)	0.73
D% (deviation of mean discharge)	+5.32%

The total yearly runoff computed by the model is show in table 4.9 against the observed runoff during validation period. In 2001 at the downstream outside of the catchment irrigation command is develop and divert the required water for irrigation in dry season above the gauge station. The amount of water diverted to the irrigation cannel record and added to the daily flow data to get daily stream flow data.

Table 4.9.Yearly average observed and simulated flow (m^3/sec)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Observed	2.16	1.75	1.13	1.34	1.52	1.46	1.86	1.96	1.61
Simulated	2.71	2.09	1.24	1.97	1.88	1.88	2.20	2.43	2.02

From figure 4.7, it can be observed in general that the model estimated runoff in the years of validation.

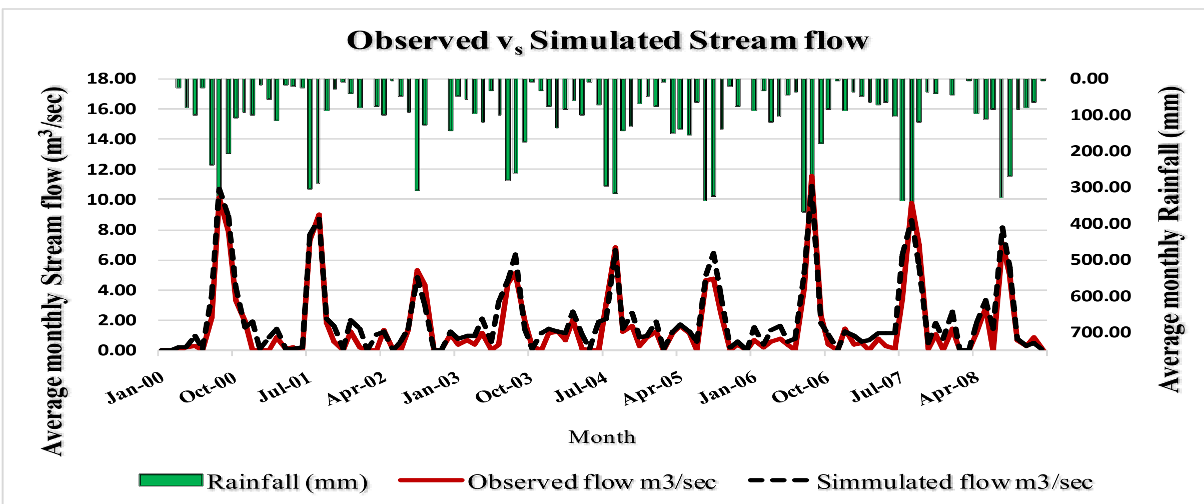

Figure 4.7. Validation results of monthly observed and simulated discharge

The calibration and validation results for monthly stream flow using monthly rainfall showed that Nash-Sutcliffe simulation efficiency (E_{NS}) values ranges from 0.85 to 0.73 respectively. Based on the model performance criteria, the model simulated stream flow trend as good to satisfactory respectively for calibration and validation. The volumetric or mean deviation (D) fit which ranges from 5.32% to 8.58% indicates in both cases it showed over estimation and the model simulated volumetric values fit very good to good performance in calibration and validation periods respectively. As observed from figure 4.5 and 4.8 coefficients of determination (R^2) for calibration and validation were 0.89 and 0.79 respectively, in both case it was greater than 0.60. However, calibration and validation results for monthly stream flow were very good fit with observed stream flow.

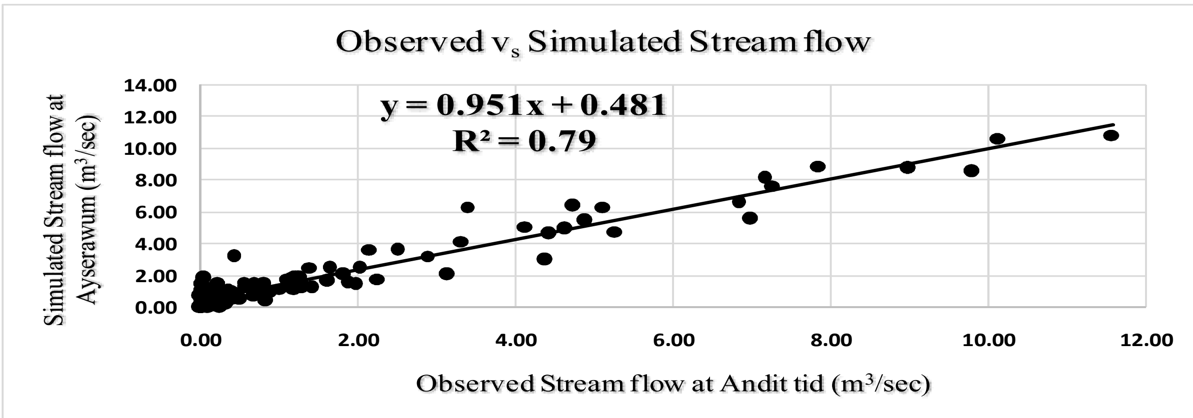

Figure 4.8. Scattered diagram of observed and simulated stream flow for validation period

4.4.3 Regionalization of SWAT model parameters

Similarity indices, computed from watershed attributes based on physical and hydrological similarity measured between Andit tid and Ayserawum watershed by calculating the measure of pattern similarity (SI_{td}) between the Ayserawum and Andit tid watershed. The measure of pattern similarity had been found as +0.94. Hence, value of near to +1.00 and it indicated Andit tid watershed is the most similar attributes to the Ayserawum watershed. Transpose the parameters of the Andit tid watershed upon the Ayserawum watershed. Model parameter value of Andit tid watershed used to get value of Ayserawum watersheds.

Many researchers have suggested that the accuracy of models in making watershed response predictions in ungauged watersheds can be improved by developing regionalized parameter values (Jarboe and Hann, 1974; Vogel, R.M, 2006). In this study, parameter values are extended using calibrated Andit tid watershed located in the similar region. The characteristics of the two watersheds are similar; therefore, used physical similarity method parameter regionalization to predict the observed data at the outlet of Ayserawum watershed area.

4.4.4 Annual water balance

The SWAT model estimated other relevant water balance components in addition to the daily and monthly discharge of the watershed. Thus, the main water balance components of the watershed include: the total amount of precipitation during the time step, actual evapotranspiration and the net amount of water that leaves watershed and contributes to stream flow in the reach (water yield). The water yield includes surface runoff contribution to stream flow, lateral flow contribution to stream flow; groundwater contributes to stream flow minus the transmission losses.

The average annual water balance in the watershed is given in table 4.10. The standard land phase hydrologic parameters used in SWAT were considered for annual water balance. The simulated annual water balance components for watershed (table 4.10) indicate that 54.67% of the annual precipitation is recharging the ground water and shallow aquifers. Surface runoff contributes 15.23% of the water yield. Whereas the ground water contributes 13.88% of the water yield.

Table 4.10. Mean annual simulated water balance values (mm)

Water balance parameters	Validation Period(2000 - 2008)
Precipitation	1428.60
Surface runoff	216.63
Lateral soil flow	198.25
Total aquifer recharge	780.96
Actual evapotranspiration	225.81
Potential evapotranspiration	228.56
Transmission losses	0.26
Change in soil storage	3.94

4.5 Simulated Stream flow and Water Yield of Ayserawum Watershed

The model simulation output was given stream flow of each sub watershed of Ayserawum watershed. As shown in appendix table 7.24 the 18 years average annual simulated average annual stream flow by SWAT model was 2.33m^3/sec. The results of simulation after validation with the seasonal and time steps for stream flow for the annual, intermediate (October to January), wet (June to September) and Belg (February to May) seasons were 2.33, 1.09, 4.56, and 1.37 m^3/sec, respectively. The stream flow of Ayserawum sub watershed as simulated by model is presented in appendix table 7.24 and figure 4.9. These simulation values allow us to identify sub watershed which generates high stream flow. From appendix table 7.24 and figure

4.9, it can be observed that from the 36 sub watersheds, 3 sub watersheds (36, 1 and 7) generate relatively high average annual stream flowsof0.38,0.32and 0.17m^3/sec respectively.The rest 33 sub watersheds generate average annual stream flow of below 0.1 m^3/sec. The three highest sediment loading sub watershed are found top and middle right part of the watershed with moderate slope and covered by cultivated land. The lower stream flow was found in the midstream part of the watershed, this is due to moderate slope and grass cover

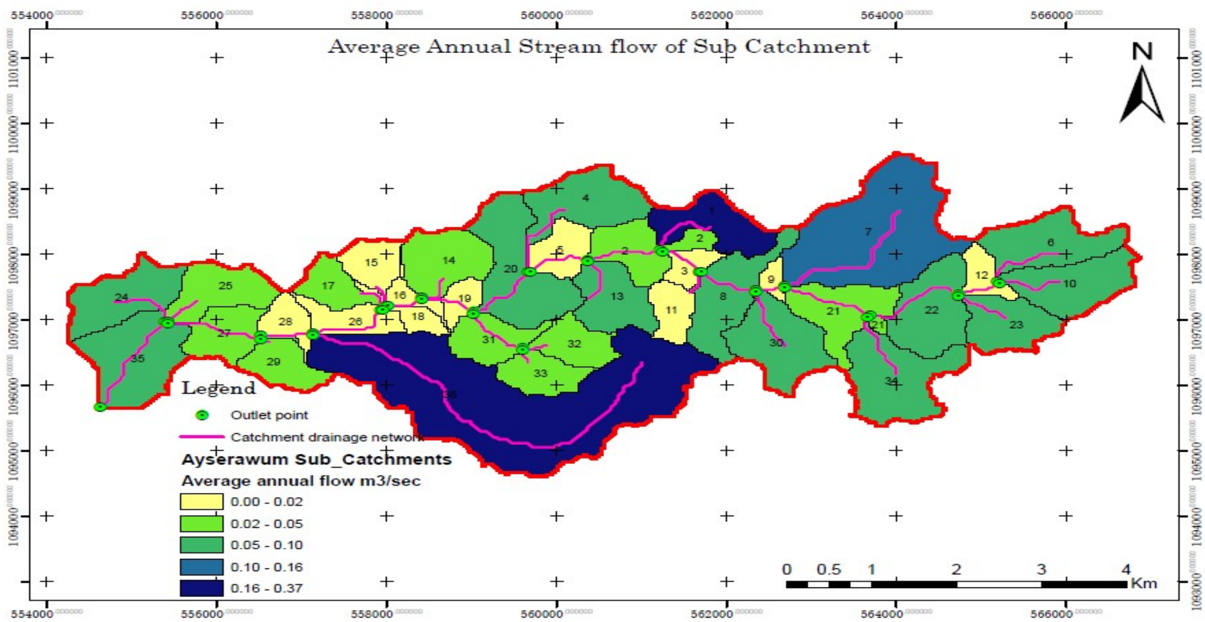

Figure 4.9.Simulated average annual stream flow of sub watershed of Ayserawum

4.6 Sediment Load Simulation

Sediment load was the amount of sediment transported out of a watershed or sub watershed. This value was used to calibrate and validate the model by comparing simulated and observed data sets until becomes nearly equal for the set of time.

4.6.1 Sensitivity analysis

Sensitivity analysis was carried out for sediment load to identify parameters that affect sediment load in the watershed. Ten parameters were identified as the most sensitive parameters that significantly affect sediment load (table 4.11).

Table 4.11. Sensitivity analysis of input parameter

Parameter	Parameter code	Boundary		Rank	Relative sensitivity	Category
		Lower	Upper			
Conservation Practice factor	USLE_P	0	1	1	2.27	Very high
Average slope of the sub-basin	SLOPE	-25	25	2	1.05	Very high
Surface runoff lag coefficient	SURLAG	0	10	3	0.944	High
Initial SCS CN II value;	CNII	-25	25	4	0.748	High
Leaf area index for the plant	BLAI	0	1	5	0.658	High
Manning's n for main channel	CH_N2	0	1	6	0.2	High
Average slope length	SLSUBBSN	-25	25	7	0.17	Medium
Saturated hydraulic conductivity	SOL_K	-25	25	8	0.108	Medium
Soil evaporation factor	ESCO	0	1	9	0.0864	Medium
Available water capacity	SOL_AWC	-25	25	10	0.0826	Medium

4.6.2 Calibration of SWAT model for sediment load simulation

Before calibration proceeds, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this the monthly Nash Sutcliffe model efficiency (E_{NS}) of 0.15, coefficient of determination (R^2) of 0.42 and mean deviation of +17.5% were obtained from the initial model run. All these values were found below the acceptable limit which required some adjustment of the most sensitive parameters through calibration. In this study, both the manual and auto-calibration techniques were employed to get the best model parameters. It had been started by manual calibration and the automatic calibration was then followed. Finally based on the result of automatic calibration, adjustment was done manually as much as possible to get the simulated values at par with the observed values as shown in table 4.12. The model was, then, run for a period of seven years from January 1, 1989 to December 31, 1999 for simulation of sediment load data of Andit tid watershed. However, the first two years (1989 - 1990) sediment data was used for stabilization of model runs (warm up period). The calibration was, therefore performed for a period of nine years (January 1, 1991 to December 31, 1999) of sediment load data. Parameters that were adjusted for sediment load calibration are shown in table 4.12.

Table 4.12. Final calibrated parameters and fitted values for sediment load

Parameter	Parameter code	Range	Initial Value	Final Calibrated Value
Conservation Practice factor;	USLE_P	0-1	1	0.64
Average slope of the sub-basin	SLOPE	±25	15.9	+3
Surface runoff lag coefficient	SURLAG	0-10	4	3
Initial SCS CN II value;	CNII	±25	78.32	-3.33
Manning's "n" for main channel	CH_N2	0-1	0.014	+0.001
Average slope length	SLSUBBSN	±25	15.24	-1.341
Saturated hydraulic conductivity	SOL_K	±25	200	150
Soil evaporation factor	ESCO	0-1	0.009	0.008
available water capacity	SOL_AWC	±25	0.11	0.132

The SWAT model was found to simulate well on monthly basis of sediment load. Coefficient of determination (R^2) value and Nash-Sutcliffe model efficiency (E_{NS}) statistic computed between the simulated and observed monthly sediment loads for the calibration periods were found as 0.77 and 0.73 respectively (table 4.13). Calibration results show that model performance was good enough with simulation of monthly sediment load.

Table 4.13. Calibration results of monthly observed and simulated sediment load

Parameter	Default	Calibrated(1991-1999)
R^2	0.42	0.77
E_{NS} (Nash-Sutcliffe model efficiencies)	0.15	0.73
D% (deviation of mean discharge)	+17.5%	+12%

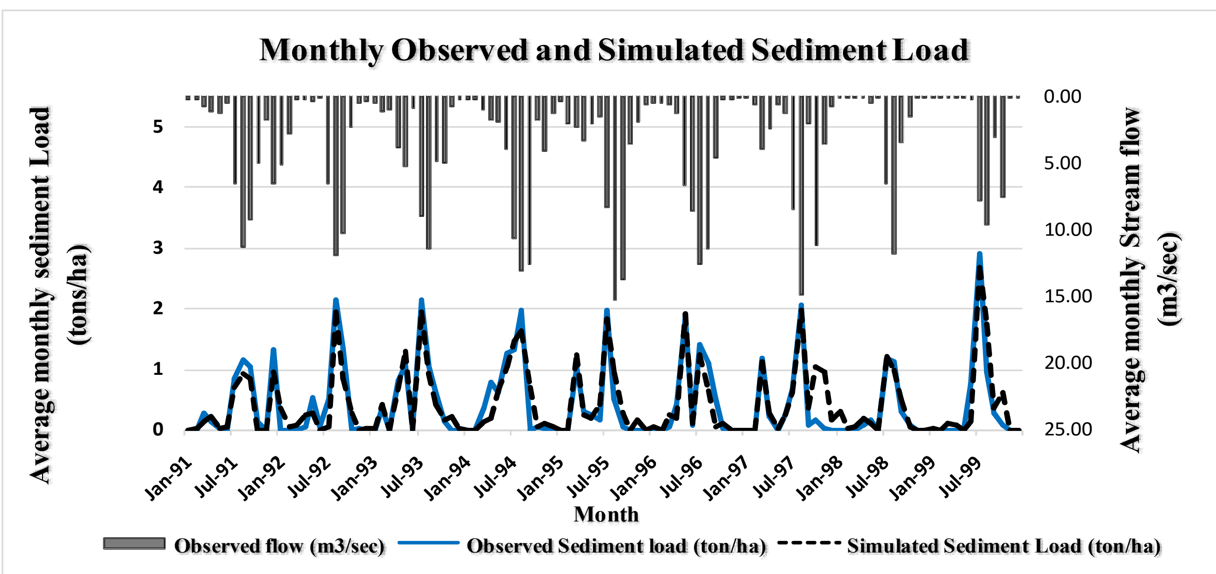

Figure 4.10. Calibration results of monthly measured and simulated sediment load

From figure 4.10, it can be observed that the sediment load computed by the model during calibration in the respective years were obtained sediment load as show in table 4.14. In 1991and 1995 observes high discharge, while the sediment load is low and vice versa in 1999. This might be the seasonal rain distribution in 1991 and 1995, the rain was continuing to September and October, here the ground cover is higher during this season and the soil is stable and covers by annual crop to reduce the sediment load. On the other hand, in 1999 the rain was single mode and the cultivated land is disturbed by land preparation for summer cultivation, so the first rain of summer rain higher may cause for severe erosion with less rainfall. Farmers also practice fallow system use the farm land as grazing land in summer season and plow at end of august and begging of September, this increase soil loss at the month September.

Table 4.14. Observed and simulated sediment load during calibration

Sediment loads	1991	1992	1993	1994	1995	1996	1997	1998	1999
Observed (ton/ha/yr)	4.88	4.59	6.16	6.33	4.25	5.37	4.62	2.89	4.91
Simulated (ton/ha/yr)	3.77	4.07	6.11	5.94	4.7	4.49	6.72	3.38	5.67

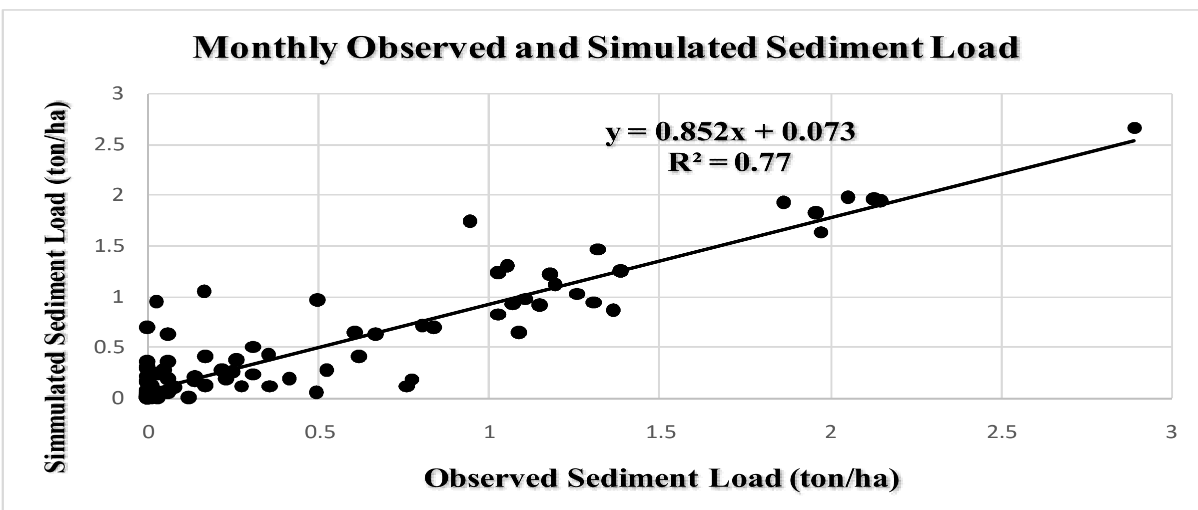

Figure 4.11.Scattered diagram of observed and simulated sediment load for calibration period

4.6.3 Validation of SWAT model for sediment load simulation

The period from January 1, 2000 to December 31, 2008 was used for validation. Validation was done in Ayserawum watershed through parameter regionalization as explained in part 4.4.2. In the validation period, good agreement between simulated and measured sediment load was demonstrated by coefficient of determination (R^2) of 0.76and Nash-Sutcliffe model efficiency (E_{NS}) of 0.73(table 4.15). The validation statistics indicate that calibrated SWAT model can simulate sediment load satisfactorily outside of the calibration period. The mean deviation between simulated and measured sediment load was found as +17.5% (table 4.15) for validation period, which is within the acceptable range of ±20%.

Table 4.15. Validation result of monthly observed and simulated sediment load

Parameter	Validated (2000-2008)
R^2	0.76
E_{NS} (Nash-Sutcliffe model efficiencies)	0.73
D% (deviation of mean discharge)	+17.5%

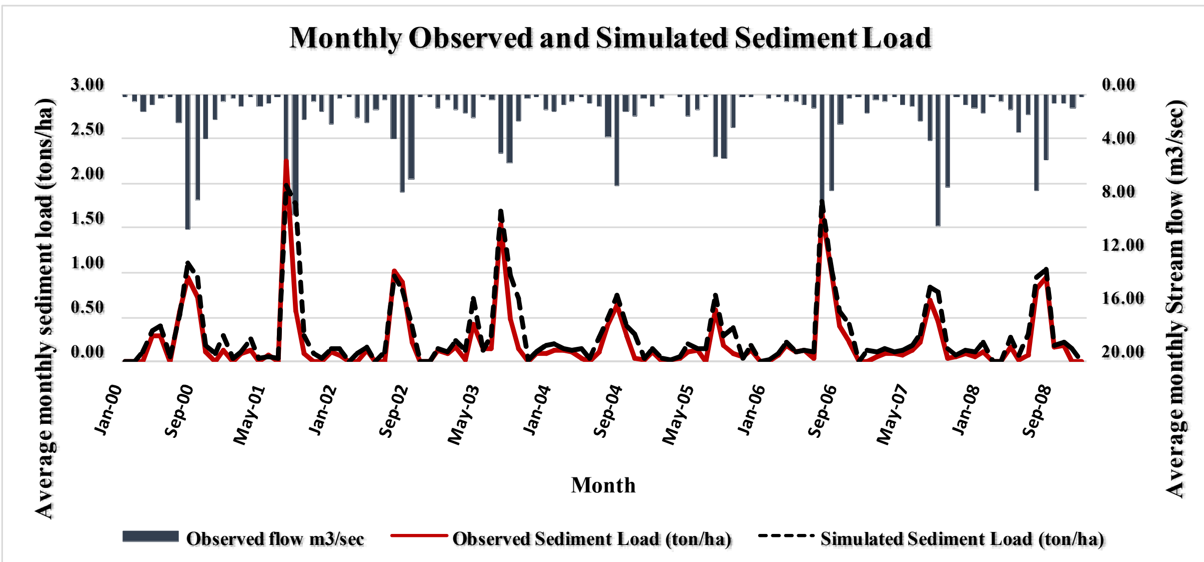

Figure 4.12. Validation results of monthly measured and simulated sediment load

From figure 4.12, it can be observed that the sediment load computed by the model during validation period against the observed sediment load as show table 4.16.

Table 4.16. Observed and simulated sediment load during validation

Sediment loads	2000	2001	2002	2003	2004	2005	2006	2007	2008
Observed (ton/ha/yr)	3.01	3.28	2.43	3.29	1.96	1.31	3.81	2.01	2.46
Simulated (ton/ha/yr)	4.05	4.79	2.76	5.24	3.00	2.21	4.59	3.02	3.38

The calibration and validation results for monthly sediment load simulation showed that Nash-Sutcliffe simulation efficiency (E_{NS}) value 0.72 in both periods. Based on the model performance criteria ($0.65 < E_{NS} < 0.75$), the model simulated sediment load trend as good for both calibration and validation periods. The volumetric or mean deviation (D) fit which ranges from +12% to +17.5% indicate in calibration and validation period, it showed as satisfactory for both cases. The coefficients of determination (R^2) for calibration and validation were 0.77 and 0.76 respectively, in both case it was greater than 0.60. However, calibration and validation results for monthly sediment load were good.

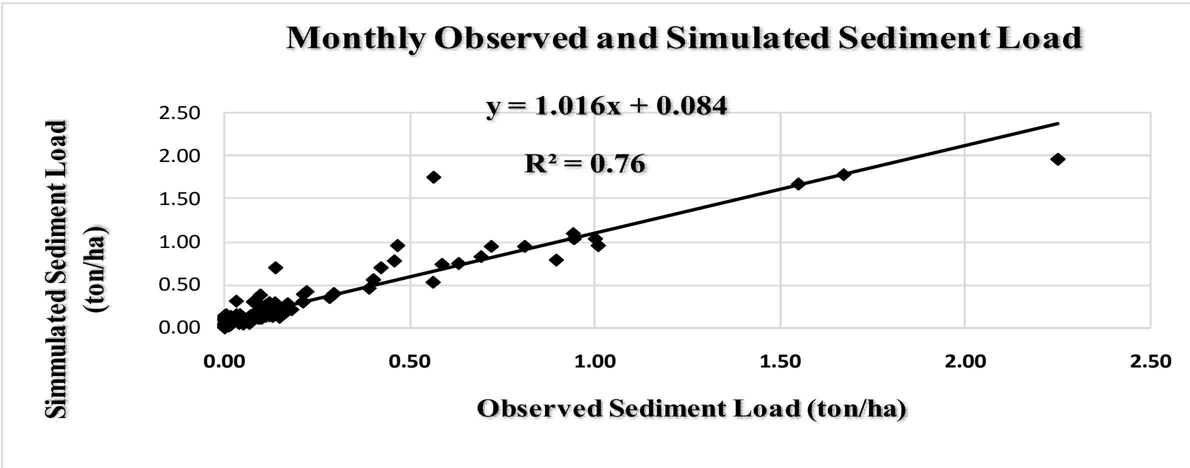

Figure 4.13. Scattered diagram of observed and simulated sediment load for validation

4.7 Simulation of Sub Watershed Sediment Load

After calibration and validation, the model was run for a period of 18 years from 1991 to 2008. From this model simulation output, sediment load of each sub watershed areas were identified in Ayserawum watershed. Sediment load for each sub watershed of Ayserawum watersheds simulated by model as shown in Appendix table 7.24 and figure 4.14. Finally, the 18 years average annual simulated average sediment load by SWAT model was 15.13ton/ha/yr.

4.7.1 Identifying hotspot area

The spatial variability of erosion rate were identified and represented in figure 4.14, based on this result that potential areas of intervention were identified. SWAT simulated annual sediment loads for the Ayserawum sub-watershed for the years 1991- 2008 were in the range of 297.64 to 1.85 tons/ha/yr with an annual average of 15.13 tons/ha/yr. Average annual sediment load predicted by the model were used to generate sediment source maps (figure 4.14)

The degree of erosion hazard in the sub-watershed (appendix table 7.24and figure 4.14) was reclassified in to different erosion hazard classes based on FAO/ United Nations Development Programme's (1984) soil removal and erosion risk prioritization mapping scale applied to the Ethiopian highlands and used five soil erosion severity classes, namely very high, >50 ton/ha/ yr., high, 30-50 ton/ha/ yr., medium 15-30 ton/ha/ yr., low 5-15 ton/ha/ yr. and very low 0-5 ton/ha/ yr. In the present study, using four erosion severity classes (Very high, moderate, low and very low erosion-vulnerable sites). Hence, the extent of sediment load in the watershed was classified in to four erosion hazard classes (table 4.17). Appendix table 7.24 and figure 4.14 allow us to identify sub watershed which are producing high sediment load.

Hurni (1983) has conducted a research to estimate the rates of soil formation for Ethiopia. The range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to 15 ton/ha/yr (Hurni, 1985). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 15 ton/ha/yr. This fact shows how far soil erosion is a serious threat to the study area.

Table 4.17. Sediment load and severity classes of Ayserawum watershed

Soil loss (ton/ha/yr)	Number of Sub watershed	Severity classes	Area (ha)	Percentage
0 -5	13	Very low	1719	54.50
5 - 15	20	Low	1142.95	34.34
15 - 30	2	Moderate	271.8	8.61
30-50	0	High	-	-
>50	1	Very high	80.3	2.54
Total	36		3214.11	100

Source: (FAO, 1984)

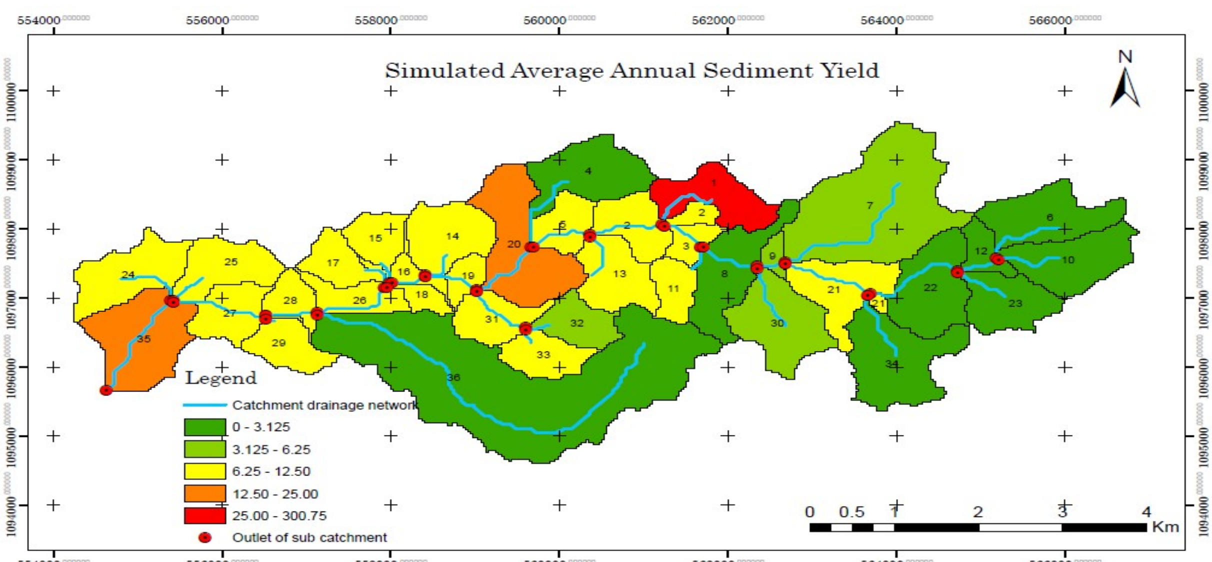

Figure 4.14. Spatial distribution simulated annual sediment load of Sub watershed ton/ha/yr

Based on the estimated sediment load (appendix table 7.24and figure 4.14), 3 sub watershed is generated beyond the maximum tolerable soil loss limit (>15 ton/ha/yr). Accordingly, the estimated sediment load which was classified as very high severity class of 1 sub watersheds (1) accounts about 2.54% of the watershed area, in moderate severity class also 2 sub watershed (20 and 35) account about 8.61%of the watershed area and about 34.34% of the watershed area of 20 sub watersheds expected sediment load was low soil loss rate as shown in table 4.17. The rest very low severity class includes 13 sub watersheds accounts 54.50% of the watershed area. Sub watershed 36 has generated high flow and lower sediment load, this may due to soil, slope and land cover. So, sub watershed 36 covered by vertisols, cultivated land and gentle to moderate slope. Farmers practice Broad Bed Furrow to drain the heavy vertisols in low to moderate slope cultivated land. This practice drains water with lower soil loss rate.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Runoff and soil erosion are the major challenges for sustainable agricultural development in the upper basin. These problems are more serious in the Ethiopian highlands. Sediment particles originating from soil erosion processes in the watershed are propagated along with the river flow. When the flow of river is obstructed and stored in reservoirs, the sediment settles and reduces its capacity. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was designed. This sediment deposition becomes crucial for the operation of reservoirs and thus necessitates the management of watershed to control its generation.

The process is dominated by natural variability, predicting runoff and sediment load is a challenging task especially in the absence of hydrological data, resources and widely accepted model. Distributed hydrological model (SWAT) to a watershed for predicting runoff and sediment load for ungauged watershed has got wise acceptance.

The model shows that the erosion/sedimentation prone area at Hydrological Response Units (HRUs) level and also capable of identifying areas within the basin with high water and sediment load. This provides a useful guide designer, for formulating policies and developing plans to counteract erosion effects, to optimize land use, and to achieve sustainable land development.

Estimating of runoff and sediment load at watershed level is important for better understanding the processes, estimating design parameter and identifying appropriate measures sites specific soil and water conservation measure. In this research work, attempts were made to estimate runoff and sediment load using SWAT model for Ayserawum micro earth dam watershed by transferring daily hydrological data (stream flow and sediment) from Andit tid gauged watershed using model parameter regionalization.

During the study, six parameters were identified as sensitive impacting for flow and all of them, were found medium sensitive parameters and ten parameters were also identified as sensitive for sediment load and out of them the USLE conservation practice factor (USLE-P) initial SCS CN II, Surface runoff lag coefficient (SURLAG) Potential maximum leaf area index for the plant (BLAI) and Manning's "n" for main channel (CH-N2) value were found as most sensitive (very high and high) parameters impacting generation of sediment load in Andit tid watershed. After identification of sensitive parameters, calibration of the model was conducted from January 1, 1991 to December 31, 1999 and validation of the model were conducted from January 1, 2000 to December 31, 2008at Ayserawum micro earth dam watershed area. The model performance indicators for calibration and validation, coefficient of determination (R^2), Nash-Sutcliffe efficiency (E_{NS}) and percent difference(D) were found greater than 0.6, 0.5 and ±25 respectively, and it is possible to say that SWAT model works successfully in the Ayserawum micro earth dam, and it is appropriate model to estimate runoff and sediment load for the study area.

The 18 years' simulation of stream flow result indicates that the simulated average annual stream flow by SWAT model was 2.33m^3/sec. The simulation result of stream flow of Ayserawum micro earth dam watershed area with the seasonal and annual time steps for the annual, intermediate (October to January), wet (June to September) and Belg (February to May) season were 2.33, 1.09, 4.56, and 1.37 m^3/sec respectively. Therefore, simulation output of the 36 sub watershed was contributed varying degree of average annual stream flow from the highest 0.38 m^3/sec (sub watershed36) to the lowest 0.01 m^3/sec (sub watershed9).

The 18 years' simulation of sediment load result indicates that the simulated average annual suspended sediment load by SWAT model was 15.13 tons/ha/yr. Hence, the simulation output of the 36 sub watersheds was contributed varying degree of average annual sediment load from the highest 297.64 tons/ha/yr (sub watershed1) to the lowest 1.85 tons/ha/yr (sub watershed 12). Even though 45.5% of the watershed area was generating high annual sediment load (>15 tons/ha/yr), sub watersheds of 1, 20 and 35 were contributed high amount of sediment load which was 297.64 tons/ha/yr, 18.52 tons/ha/yr and 15.46 tons/ha/yr respectively. Hence, three of them were identified the hot spots that needs urgent intervention.

5.2 Recommendations

The following recommendation suggested from this particular research includes:

- From the watershed, 42.11% of the areas have a slope more than 30%, which is a danger for the area if the LULC of natural cover is disturbed. In this slope range no need of conducting any agricultural and related works unless necessary physical and biological conservation measures are taken. This area shall be protected from any human interference.

- The sub watersheds that produce the highest sediment 1, 20 and 35 are hot spots in their order of importance contributing sediment load, this can be reduced by using sediment load intervention strategies such as land slope stabilization, construction of terraces, changing the land use of steep area and afforestation.
- The calibrated parameter values can be considered for further hydrologic simulation of the watershed. The model can also be taken as a potential tool for simulation of the hydrology of ungauged watershed in mountainous areas, which behave hydro-meteorologically similar with Ayserawum micro earth dam area.
- Future studies on Ayserawum micro earth dam area modeling should address the issues related to soil and water conservation and evaluate best conservation practices to increase the useful life of the dam.

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7. APPENDICES

7.1 Appendix Tables

7.1.1 Soil in SWAT database for each soil layers in the watershed

Appendix Table 7.1. Soil Parameters in SWAT Database for Each Soil Layers in the Watershed

Soil Name:	EutricLeptosols	
Soil Hydrologic Group:	B	
Maximum rooting depth(mm) :	900	
Texture	L	
Layers	1	2
Depth (mm)	600	900
Bulk Density Moist (g/cm^3)	1.5	1.46
SOL_AWC (mm/mm)	0.2	0.18
SOL_CBN (weight %)	1.63	0.1
SOL_K (mm/hr)	38.63	39.8
Clay (weight %)	21	13
Silt (weight %)	33	46
Sand (weight %)	46	41
Rock Fragments (weight %) (Optional)	0	0
Soil Albedo (fraction)	0	0
USLE_K	0.31	0.34
SOL_EC (ds/m)	0	0

Soil Name:	Eutric Vertisols				
Soil Hydrologic Group:	C				
Maximum rooting depth(mm) :	1635				
Texture	SIL-UMB				
Layers	1	2	3	4	5
Depth (mm)	181	363	1029	1392	1635
Bulk Density Moist (g/cm^3)	1.1	1.27	1.28	1.22	1.13
SOL_AWC (mm/mm)	0.11	0.11	0.1	0.1	0.1
SOL_CBN (weight %)	1.47	1.37	1.41	0.88	1.17
SOL_K (mm/hr)	4.34	4.54	5.16	4.24	4.34
Clay (weight %)	60.6	60.6	62.6	62.8	62.6
Silt (weight %)	23.3	18.6	17	8.4	9.4
Sand (weight %)	16.1	20.8	20.4	28.8	28
Rock Fragments (weight %)	0	0	0	0	0
Soil Albedo (fraction)	0.09	0.09	0.09	0.09	0.09
USLE_K	0.2	0.2	0.2	0.2	0.2
SOL_EC (ds/m)	0	0	0	0	0

Source,(Lauren *et al.,* 2002)

Appendix Table 7.2. Available water capacity of the soil layer (SOL_AWC (mm/m))

Soil texture classes	Available water in mm/m of depth
Coarse sands	20-65
Fine sands	60-85
Loamy sands	65-110
Sandy loams	90-130
Fine sandy loams	100-170
Silt loams	150-230
Silty clay loams	130-160
Silty clay	125-170
Clay	110-150

Source,(Hargreaves. *et al.*, 2004)

Appendix Table 7.3. Soil erodibility (USLE_K)

Soil Colour	Soil Erodibility (K)
Black	0.15
Brown	0.20
Red	0.25
Yellow	0.30

Source: (Hurni, 1985)

Appendix Table 7.4. Soil organic carbon content (SOL_CBN (%soil weight))

Textural Classes	Symbol	Average Organic carbon content
Sand	S	0.9
Loamy sand	lS	1.0
Loamy silt	lU	1.6
Sandy loam	sL	1.3
Loam	L	1.7
Silty loam	UL	1.7
Clay	T	1.9

Sources, (Lieberoth, 1982)

Appendix Table 7.5. Saturated hydraulic conductivity of each texture class

Texture class	Saturated hydraulic conductivity (mm/hr)	Texture class	Saturated hydraulic conductivity (mm/hr)
Sand	210.0	Clay loam	2.3
Loamy sand	61.1	Silty clay loam	1.5
Sandy loam	25.9	Sandy clay	1.2
Loam	13.2	Silty clay	0.9
Silt loam	6.8	Clay	0.6
Sandy clay loam	4.3		

Sources, (Rawls *et al*., 1982)

7.1.2 Meteorological data tables

Appendix Table 7.6. Debre Birhan total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	17.4	0.0	27.3	58.6	83.2	15.8	314.6	376.6	88.4	6.5	5.7	0.0	994.1
1986	0.0	74.7	99.2	52.5	27.0	141.9	271.3	274.7	115.7	11.3	0.0	0.0	1068.3
1987	5.0	19.2	108.1	51.7	100.2	0.0	32.3	309.5	47.5	18.7	0.0	6.3	698.5
1988	10.6	37.5	16.9	83.1	16.2	16.0	286.2	290.0	153.1	12.1	0.0	0.0	921.7
1989	2.3	40.5	97.6	42.7	1.4	41.1	211.4	177.4	67.7	18.6	0.0	30.7	731.4
1990	0.0	62.2	20.7	59.5	0.9	1.6	321.0	217.2	168.7	0.6	0.0	0.0	852.4
1991	4.8	8.3	64.6	21.0	0.0	63.7	215.6	387.5	86.6	6.4	0.0	6.4	864.9
1992	30.3	26.7	19.4	80.2	19.3	13.3	307.6	267.6	92.9	41.9	0.5	1.8	901.5
1993	4.3	43.2	0.0	116.9	60.5	9.1	395.5	168.4	114.9	43.2	0.0	1.1	957.1
1994	0.0	0.0	95.6	0.0	23.2	92.7	281.7	222.9	101.7	48.9	36.5	0.0	903.2
1995	0.0	28.5	19.1	68.4	26.3	23.3	489.2	233.8	60.4	5.1	0.0	1.7	955.8
1996	20.7	2.8	75.4	9.7	129.2	138.0	328.4	252.5	24.3	0.0	3.0	0.0	984.0
1997	29.5	4.0	41.2	82.4	25.9	96.9	272.1	200.6	34.8	89.7	0.0	0.0	877.1
1998	23.1	13.2	14.9	49.3	43.0	13.5	337.3	289.0	70.6	5.2	2.1	0.0	861.2
1999	6.9	0.0	26.5	2.8	11.0	48.9	362.4	365.1	52.4	59.6	1.4	0.0	937.0
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8	985.3
2001	0.0	33.8	71.2	18.8	64.6	34.9	406.7	260.4	32.2	4.1	0.0	3.4	930.1
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	0.0	8.4	830.1
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	0.0	0.0	7.4	1005.5
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0	1023.2
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0	932.4
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	0.2	26.3	947.7
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0	1083.5
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2	946.7
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3	906.3
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9	942.4
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0	1060.3
2012	0.0	0.0	5.2	93.3	57.9	332.6	75.0	394.5	92.4	0.0	0.0	0.0	1050.9
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0	884.9
2014	0.0	16.0	67.7	44.1	46.9	16.8	260.3	291.0	110.0	55.9	0.0	0.0	908.7
Mean	12.1	19.1	44.5	55.5	39.1	60.8	307.9	279.5	83.2	19.9	5.6	4.4	931.5

Appendix Table 7.7. Debre Birhan mean monthly Tmax, Tmin and Relative Humidity

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	19.82	20.66	20.94	20.80	21.56	21.89	18.68	18.16	18.83	18.73	18.94	19.09
Tmin (°C)	4.71	6.28	7.69	7.86	7.44	7.53	8.77	8.81	7.14	3.75	2.50	3.24
RH (%)	60.72	60.02	63.04	64.70	57.10	58.98	79.21	81.39	73.01	63.44	61.47	59.85

Appendix Table 7.8. Enewari total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1989	17.8	0.5	15.2	114.4	76.2	13.8	336.4	372.2	92.4	2.0	2.3	0.3	1043.4
1990	0.0	55.4	67.8	67.5	60.7	146.1	293.5	377.0	141.5	5.9	0.0	0.0	1215.2
1991	2.1	28.7	157.6	142.7	186.9	4.7	118.0	321.6	46.4	13.1	0.0	20.0	1041.8
1992	13.1	38.2	7.5	71.3	5.1	39.2	450.8	335.7	163.0	18.8	0.0	0.0	1142.8
1993	9.7	75.0	124.5	82.2	4.9	52.0	254.4	524.2	107.8	39.6	0.0	64.8	1339.1
1994	0.1	73.5	39.7	78.9	0.6	3.0	346.2	240.6	221.6	33.5	0.0	0.0	1037.5
1995	5.9	32.9	110.9	75.8	52.5	65.7	278.7	359.6	142.8	31.7	0.0	7.3	1163.8
1996	32.8	50.9	34.5	92.7	23.0	26.3	331.3	401.5	146.2	63.2	80.7	2.1	1285.1
1997	1.9	30.9	7.3	120.9	89.3	28.3	341.3	214.2	145.8	32.7	0.0	0.3	1012.8
1998	0.0	0.0	89.1	26.0	17.7	113.7	394.4	390.1	180.8	1.0	18.8	0.0	1231.7
1999	0.0	17.6	52.3	76.9	52.1	35.1	350.5	391.2	98.2	4.2	0.0	15.3	1093.2
2000	29.2	4.3	98.1	9.7	93.9	157.2	318.1	306.3	67.6	0.4	12.9	0.0	1097.5
2001	36.3	1.7	53.7	69.2	42.2	196.4	416.8	296.7	80.9	103.5	37.8	1.7	1336.8
2002	28.1	23.2	37.5	55.4	81.2	55.1	419.2	438.2	103.0	11.6	0.0	0.0	1252.5
2003	9.1	0.0	12.0	4.3	12.5	40.7	343.6	426.8	58.9	109.2	0.4	0.9	1018.5
2004	0.0	0.0	28.5	84.9	60.1	55.0	381.3	286.4	101.7	29.6	3.4	12.3	1043.2
2005	0.0	1.9	87.5	31.5	108.4	62.8	397.1	268.2	62.8	2.2	0.0	4.8	1027.2
2006	45.3	44.7	79.9	54.1	16.9	41.2	350.1	291.7	111.1	0.0	0.0	22.3	1057.4
2007	20.7	48.2	21.9	65.3	15.5	110.8	464.0	426.6	112.3	0.0	1.2	10.9	1297.5
2008	21.2	15.2	76.2	145.8	20.2	158.1	265.8	338.1	98.4	14.7	2.7	1.5	1157.9
2009	13.9	3.6	59.0	159.3	95.4	123.8	345.1	389.6	153.0	0.0	0.5	0.0	1343.3
2010	2.8	59.8	75.5	106.4	153.0	65.9	333.2	153.0	95.2	0.0	10.7	5.6	1061.1
2011	4.3	0.0	68.3	27.5	83.6	116.6	360.7	434.1	149.9	0.0	9.7	0.0	1254.8
2012	0.0	0.0	84.7	152.1	16.1	55.3	471.0	371.6	71.8	0.0	1.5	0.0	1224.1
2013	0.0	0.0	65.5	25.5	19.1	78.3	308.4	387.4	80.6	38.3	6.1	0.0	1009.2
2014	4.5	28.4	57.6	30.4	124.9	62.5	359.6	338.5	127.2	1.5	0.0	0.0	1135.1
Mean	11.5	24.4	62.0	75.8	58.2	73.4	347.3	349.3	113.9	21.4	7.3	6.5	1150.9

Appendix Table 7.9. Enewari mean monthly Tmax, Tmin and Relative Humidity

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	21.33	22.49	22.75	22.68	23.18	23.27	19.05	18.43	19.47	19.72	20.37	20.68
Tmin (°C)	8.27	9.27	10.12	10.48	10.79	10.57	10.27	10.23	9.83	8.12	7.00	7.13
RH	53.84	53.66	58.23	57.74	49.75	51.75	75.03	78.87	69.49	60.53	55.86	53.16

Appendix Table 7.10. Alem Ketema total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	20.3	0.0	13.2	171.2	68.6	17.4	406.7	376.1	108.6	0.0	1.0	0.0	1183.1
1986	0.0	42.7	48.1	95.5	95.8	138.7	345.0	471.2	172.6	2.7	0.0	0.0	1412.3
1987	0.0	4.1	125.3	146.4	173.4	6.8	138.9	191.7	27.3	0.0	0.0	24.1	838.0
1988	13.3	30.4	0.0	54.0	0.0	57.0	574.1	396.0	193.9	23.4	0.0	0.0	1342.1
1989	11.4	57.8	82.7	70.9	4.3	43.3	173.2	561.2	98.6	38.2	0.0	65.5	1207.1
1990	0.1	63.0	41.7	83.2	0.5	6.1	338.8	242.6	216.4	34.4	0.0	0.0	1026.7
1991	6.8	34.9	115.4	68.5	46.4	63.9	308.9	342.9	125.9	21.1	0.0	7.9	1142.7
1992	14.1	48.6	33.2	56.1	15.9	24.8	204.4	326.7	133.9	50.1	112.9	0.0	1020.7
1993	0.0	23.5	11.7	123.3	111.4	48.3	345.5	256.6	194.6	23.6	0.0	0.0	1138.5
1994	0.0	0.0	44.0	26.2	8.3	98.6	290.7	320.5	170.5	0.0	2.2	0.0	961.0
1995	0.0	3.4	53.9	43.9	50.1	26.0	229.2	342.0	83.3	0.0	0.0	12.8	844.6
1996	25.9	6.7	101.6	11.5	79.0	191.1	319.9	338.5	104.0	0.0	16.0	0.0	1194.2
1997	20.3	0.0	49.3	37.1	40.3	190.0	344.2	252.5	85.0	76.0	46.3	2.1	1143.1
1998	17.4	17.6	28.3	25.0	73.4	66.8	247.2	355.5	87.1	9.0	0.5	0.0	927.8
1999	7.2	0.0	0.0	1.5	10.0	39.3	297.4	514.6	66.3	151.8	0.0	1.3	1089.4
2000	0.0	0.0	36.1	103.7	88.1	58.6	449.1	311.5	122.1	7.2	32.2	0.4	1209.0
2001	0.0	5.0	45.7	20.5	29.9	96.0	373.5	266.5	90.9	0.3	0.0	6.1	934.4
2002	41.6	38.2	44.8	40.8	9.3	39.3	283.9	282.2	121.1	0.0	0.0	13.4	914.6
2003	9.0	54.0	53.4	61.3	1.5	90.5	308.8	254.0	139.0	2.5	0.5	31.2	1005.7
2004	9.2	6.1	21.9	71.5	23.2	96.4	206.8	258.9	142.8	32.6	1.1	0.0	870.5
2005	18.9	0.0	53.6	47.0	97.9	91.1	273.8	328.7	142.0	15.4	7.4	0.0	1075.8
2006	12.6	13.0	96.4	27.8	31.2	103.7	388.9	355.6	166.1	5.4	6.2	0.0	1206.9
2007	2.4	37.0	34.5	57.4	24.3	138.7	373.4	299.4	201.7	8.0	0.0	0.0	1176.8
2008	0.0	0.0	0.0	37.8	46.3	96.5	301.0	313.0	106.2	13.0	47.2	0.0	961.0
2009	17.7	2.6	25.2	18.1	13.6	24.6	371.8	285.3	71.6	23.1	1.0	55.7	910.3
2010	0.0	37.6	22.1	38.3	57.7	13.5	252.5	369.8	156.0	1.1	13.2	18.4	980.2
2011	2.6	0.0	59.9	24.1	32.3	64.6	231.7	362.0	153.7	0.0	19.6	0.0	950.4
2012	0.0	0.0	60.8	122.7	30.0	114.3	385.1	399.0	170.8	0.0	0.0	5.3	1287.9
2013	1.0	0.6	21.7	43.8	30.8	91.1	314.7	325.1	114.0	82.1	0.0	0.0	1024.9
2014	4.6	71.1	166.3	119.3	209.9	97.7	467.1	475.0	223.4	55.0	1.6	0.4	1891.4
Mean	8.5	19.9	49.7	61.6	50.1	74.5	318.2	339.2	133.0	22.5	10.3	8.2	1095.7

Appendix Table 7.11. Alem Ketema mean monthly Tmax, Tmin and Relative Humidity

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	25.63	26.97	27.26	27.13	27.58	27.49	22.86	21.90	23.25	24.02	24.63	24.91
Tmin (°C)	13.46	14.25	14.82	15.24	16.27	15.49	12.85	12.52	13.18	13.26	12.46	12.40
RH (%)	49.76	48.06	52.89	54.53	49.60	56.40	79.05	83.70	75.38	57.54	52.15	49.97

Appendix Table 7.12. Mehal meda total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	11.2	2.8	0	46.5	85.9	0	169.5	353	52	0	0	1.6	722.5
1986	0	58.5	70.3	12	24.88	175	182	281	95.7	50.17	0	0	949.6
1987	0	74.8	106.9	81.4	103.5	0	33.8	249.2	31.9	22.2	0	2.8	706.5
1988	17.1	62.7	13.2	101.3	0.6	27.8	378.9	239.9	90.2	17.3	0	0	949
1989	3.5	75.3	110.7	63.6	5.5	19.9	192.7	252.8	46.6	22.3	0	29.71	822.6
1990	76.69	106.5	39	121.8	0	19.68	337.5	276.2	254.2	74.05	0	0	1306
1991	11.82	70.09	184.6	100.3	80.59	59.01	193.5	277.3	155.3	7.261	0	7.2	1147
1992	43.5	68.97	14	89.2	16.47	13.86	264.5	264	58.59	49.1	8.5	44.72	935.4
1993	59.47	39.82	3.617	292.6	77.05	3.3	231.8	170.5	67.6	40.6	0	0	986.4
1994	0	0	78.6	32.7	9.3	27.6	377.4	312.3	83.7	3	8.7	0	933.3
1995	0	13.9	29	75.2	26.5	30.6	348.2	235.3	63.4	8.6	0	23.8	854.5
1996	53.4	0	127.4	4.3	75.6	91.9	294.6	306.4	37	2.3	21.3	0	1014
1997	41.5	0	9.6	38.2	14.2	100.7	269.4	297.1	30.7	55.9	23.4	1	881.7
1998	26.9	23	48.7	73.4	51.3	12.9	448.2	296.6	54.7	14.5	0	0	1050
1999	18.5	0	21.7	15.3	22.3	30.5	445.3	279	48.6	72	0	1.2	954.4
2000	0	0	11	96	18.5	32.9	337.6	289.5	77	10.8	13.4	9.3	896
2001	0	19.1	146.2	32.3	54.4	14.7	449.1	286.8	34.6	4.4	0	3.4	1045
2002	37.3	27.1	98.6	27.3	11.8	7.6	266.4	229.6	33.3	5.8	0	22.2	767
2003	23.9	32.3	43.6	60.9	6.6	73.8	322.4	247.5	84.1	0.1	5.4	8.9	909.5
2004	37.1	22.5	75.5	94.1	6	59.7	240.2	244.9	62.8	9.3	7.3	7.4	866.8
2005	54.4	1	63.9	97.1	108.6	54.5	243.2	198.3	67.4	3.7	1.4	0	893.5
2006	24.5	9	157.1	32.3	18.6	24.3	319.6	358.2	58.5	10.9	0	14	1027
2007	25.9	55.2	29.1	49.1	11.5	82.8	286.7	272.6	112.8	5.6	5.9	0	937.2
2008	1.9	5.1	0	33.4	27	40.8	302.8	187.5	101.7	32	61.8	0	794
2009	17.1	12.4	72.8	8.7	18.4	58.7	341.5	245.9	52.4	39.2	110.8	88.35	1066
2010	12.2	50.2	38.9	105.8	64.5	30.7	325.5	64.5	47.4	6.8	3.2	21.7	771.4
2011	5.601	0	92.6	45.3	159.9	12.9	181.4	292.5	70.6	1.6	4.6	0	867
2012	0	0	54.3	71.7	38.6	78.2	362	229.1	18.9	16.89	0	0	869.7
2013	0	0	43.6	26.3	15.8	69.2	364.4	264.4	72.9	60.9	2	0	919.5
2014	0	49	39.2	21	29	10.1	229.2	304.3	87.1	19.6	11.6	1.4	801.5
Mean	20.12	29.31	60.79	64.97	39.43	42.12	291.3	260.2	71.73	22.23	9.642	9.623	921.5

Appendix Table 7.13. Mehal meda mean monthly Tmax, Tmin and Relative Humidity

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	18.70	19.14	18.95	18.79	19.18	19.92	17.39	16.97	17.09	16.63	17.19	17.89
Tmin (°C)	5.98	7.08	7.78	8.12	8.41	8.11	8.10	8.15	7.80	6.20	5.29	5.33
RH	59.64	57.41	61.02	61.73	54.45	59.08	80.09	83.17	73.65	60.04	57.07	57.81

Appendix Table 7.14. Andit Tid total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	31.2	0.0	25.5	108.1	133.1	5.6	404.5	640.0	207.1	53.0	2.1	13.0	1623.2
1986	0.0	37.6	201.3	94.4	115.6	237.0	346.9	325.2	235.9	56.2	0.0	13.3	1663.4
1987	13.3	19.7	128.5	92.4	192.0	2.0	43.9	327.0	91.5	131.2	0.0	1.2	1042.7
1988	90.5	44.9	6.9	50.2	29.9	23.4	367.8	454.5	210.4	109.5	0.0	0.0	1388.0
1989	1.0	21.9	110.7	125.6	24.0	85.0	261.3	266.8	217.4	97.7	1.3	74.4	1287.1
1990	5.0	45.9	92.4	47.9	15.9	4.6	364.4	228.9	245.3	22.1	0.0	0.0	1072.4
1991	3.2	24.8	98.9	152.0	104.8	68.5	319.9	469.9	236.0	67.6	0.0	144.6	1690.2
1992	34.0	24.6	18.7	74.6	74.4	54.8	280.6	493.3	306.2	73.8	28.9	16.1	1480.0
1993	17.3	72.5	19.6	191.5	193.6	12.9	552.9	298.6	160.1	176.0	0.0	0.0	1695.0
1994	0.0	0.0	104.6	76.3	90.3	83.8	434.9	395.4	281.7	57.8	178.7	20.4	1723.9
1995	0.0	43.7	82.5	168.6	83.3	82.3	339.0	420.1	3.4	21.2	0.0	56.2	1300.3
1996	36.2	1.3	97.3	115.6	238.9	113.7	483.7	354.3	158.6	44.7	47.6	0.8	1692.7
1997	40.6	0.0	123.0	83.8	72.4	188.7	301.8	424.3	133.9	315.5	97.2	0.0	1781.2
1998	186.5	64.7	80.4	128.5	87.2	32.0	532.6	477.3	293.4	83.3	0.7	0.0	1966.9
1999	26.8	0.0	20.5	29.1	40.6	104.8	609.9	526.4	169.6	334.2	30.4	0.0	1892.3
2000	0.0	0.0	3.5	146.9	52.5	34.6	407.3	494.3	317.6	181.1	171.4	28.7	1837.9
2001	0.0	27.8	206.4	37.9	86.1	45.7	534.4	391.4	111.9	31.8	3.7	21.0	1498.1
2002	110.4	9.4	86.8	106.7	18.7	52.1	181.6	404.0	155.4	5.7	0.0	161.8	1292.7
2003	62.6	62.7	129.8	210.7	26.4	125.9	409.9	236.4	232.9	5.1	28.7	85.8	1617.0
2004	171.0	85.7	90.9	246.7	8.8	111.9	378.6	454.5	167.9	136.6	73.2	53.5	1979.2
2005	20.1	0.5	111.0	46.0	135.5	112.8	477.7	353.2	221.1	64.5	0.0	0.0	1542.4
2006	80.2	14.6	56.4	38.6	70.5	82.3	477.2	433.4	256.8	127.1	1.2	181.4	1819.7
2007	10.9	56.9	52.4	80.5	34.7	108.5	374.2	732.9	155.7	83.6	70.7	0.0	1760.9
2008	37.0	0.5	0.0	141.3	182.8	129.8	500.0	301.7	163.2	119.6	63.8	0.0	1639.7
2009	26.9	2.2	34.6	93.0	37.1	63.0	434.1	412.3	126.1	48.5	0.0	0.0	1277.8
2010	0.0	0.0	74.8	161.7	247.7	42.6	395.0	501.7	185.0	24.6	17.6	11.6	1662.3
2011	11.4	0.3	184.4	75.1	141.8	44.5	325.9	352.4	274.7	6.7	70.8	0.0	1488.0
2012	0.0	0.1	12.6	139.3	117.7	186.0	546.9	447.6	178.8	7.1	0.0	23.4	1659.5
2013	21.3	20.4	31.4	77.0	64.1	46.9	497.5	428.8	119.1	159.7	71.9	0.0	1538.1
2014	0.0	3.5	153.7	213.1	243.5	28.1	318.3	510.4	221.4	349.7	14.4	5.2	2061.3
Mean	34.6	22.9	81.3	111.8	98.8	77.1	396.8	418.6	194.6	99.8	32.5	30.4	1599.1

Appendix Table 7.15. Mehal meda mean monthly Tmax and Tmin

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	15.64	16.65	17.14	17.27	18.27	18.64	16.66	15.97	16.02	15.51	15.20	15.06
Tmin (°C)	7.07	8.06	8.96	9.61	10.16	9.89	9.11	8.90	8.65	7.45	6.40	6.26

Appendix Table 7.16. Ankober total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	40.7	0.0	69.2	179.9	156.6	59.2	246.9	538.4	161.4	7.3	0.0	0.0	1459.6
1986	0.0	192.5	226.7	344.9	92.4	322.3	336.0	306.0	194.6	31.0	1.9	31.4	2079.7
1987	0.0	85.1	325.3	204.2	533.6	0.0	68.6	301.4	86.7	15.2	0.0	85.0	1705.2
1988	156.0	119.0	63.2	199.4	12.9	12.3	247.5	391.6	222.7	107.5	0.0	0.0	1532.2
1989	12.4	140.8	268.9	350.6	21.4	58.5	192.5	392.1	110.7	93.8	4.9	318.1	1964.6
1990	92.9	422.3	104.0	167.1	1.8	0.6	307.4	247.2	209.2	30.7	0.0	0.0	1583.3
1991	1.8	219.9	215.0	79.3	30.3	33.3	196.0	299.8	186.7	0.0	14.4	78.6	1355.2
1992	176.9	43.3	22.8	160.9	28.2	17.4	374.5	270.6	55.8	20.3	1.7	50.3	1222.7
1993	127.6	161.8	6.5	402.4	313.5	31.3	353.6	181.9	153.5	127.7	15.5	5.6	1880.8
1994	0.0	4.0	185.3	93.4	47.2	52.9	470.7	315.4	308.9	21.9	124.7	32.3	1656.6
1995	0.0	97.6	297.9	278.5	85.8	53.1	354.3	533.6	153.6	0.0	23.1	85.2	1962.8
1996	72.9	0.8	179.4	94.6	158.4	121.8	544.4	360.1	65.6	7.8	78.0	0.2	1684.0
1997	143.2	0.0	86.0	137.6	21.4	127.4	154.2	261.2	73.2	436.7	167.1	1.3	1609.4
1998	210.9	126.7	104.5	70.8	107.3	45.6	297.7	394.6	178.4	185.5	3.5	0.0	1725.5
1999	104.4	0.0	88.3	38.2	33.9	22.2	337.0	557.2	156.3	245.3	4.9	0.0	1587.7
2000	0.0	0.0	56.4	88.3	28.8	11.9	161.5	438.6	347.3	124.9	197.2	79.3	1534.2
2001	54.4	74.4	466.5	101.3	57.8	267.9	406.5	111.6	35.8	13.1	21.3	30.4	1641.0
2002	149.5	0.0	118.1	62.6	55.5	52.5	237.8	370.1	168.6	0.0	0.0	126.1	1340.8
2003	49.5	24.5	147.0	340.9	32.0	146.2	476.9	468.0	232.2	0.0	23.2	56.0	1996.4
2004	232.5	72.0	108.0	530.0	5.0	134.8	524.5	685.1	195.6	159.0	20.6	56.9	2724.0
2005	57.0	0.0	166.0	163.0	272.5	71.0	413.0	614.0	264.0	0.0	16.0	0.0	2036.5
2006	96.0	54.0	365.0	214.0	12.5	78.0	297.0	392.0	171.0	118.0	0.0	148.0	1945.5
2007	27.3	50.1	53.9	88.6	51.5	115.8	401.7	525.5	147.7	30.5	35.4	0.0	1528.1
2008	72.0	0.0	0.0	149.0	107.0	109.0	301.0	264.0	143.0	72.0	25.5	0.1	1242.6
2009	89.7	4.1	40.4	61.7	59.0	5.0	326.0	367.0	60.0	69.0	36.0	56.0	1173.8
2010	28.0	145.0	283.0	91.0	205.0	28.0	336.0	951.0	140.0	11.7	28.9	2.0	2249.6
2011	10.0	0.0	100.0	104.0	265.5	57.0	136.0	947.4	118.5	0.0	99.0	0.0	1837.4
2012	0.0	0.0	5.3	45.2	35.1	76.6	147.4	326.0	155.0	30.0	0.0	5.6	826.2
2013	42.0	13.0	50.0	71.0	65.0	10.0	355.0	610.0	130.0	59.0	6.0	0.0	1411.0
2014	0.0	20.0	129.0	62.0	98.0	0.0	148.0	389.0	181.0	220.0	0.0	0.0	1247.0
Mean	68.3	69.0	144.4	165.8	99.8	70.7	305.0	427.0	160.2	74.6	31.6	41.6	1658.1

Appendix Table 7.17. Debre Sina total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	34.4	0.0	25.1	119.6	144.8	3.2	425.5	701.5	167.7	41.0	0.0	0.0	1662.8
1986	0.0	101.2	280.9	281.2	110.7	225.5	383.2	271.9	168.3	63.3	0.0	104.1	1990.3
1987	0.0	29.5	274.3	154.7	437.6	0.0	27.7	429.7	144.1	85.6	0.0	151.0	1734.2
1988	188.1	149.8	13.2	138.8	38.2	39.7	230.7	281.7	208.5	163.9	0.0	0.0	1452.6
1989	41.1	101.5	295.4	401.1	13.4	75.5	281.3	384.2	218.2	186.7	0.0	327.4	2325.8
1990	88.0	124.2	66.6	140.8	10.4	3.4	356.5	287.8	274.9	94.6	0.0	0.0	1447.2
1991	10.4	78.0	192.4	103.5	85.3	55.9	168.2	252.9	159.0	0.0	30.9	80.3	1216.8
1992	121.4	133.4	50.8	133.4	45.5	15.3	113.5	562.0	202.5	114.4	9.4	44.9	1546.5
1993	189.6	40.8	1.2	351.3	397.8	13.3	210.7	144.2	121.8	119.3	87.4	31.4	1708.8
1994	0.0	22.8	100.2	64.1	102.7	85.1	485.4	375.0	165.7	37.9	204.9	27.1	1670.9
1995	0.0	13.6	119.0	349.4	120.8	212.2	675.0	468.5	213.8	0.0	130.6	12.2	2315.1
1996	96.2	0.0	229.7	125.0	221.7	130.3	675.3	411.6	83.2	4.6	110.3	0.3	2088.2
1997	76.3	0.0	183.3	132.5	41.5	200.0	268.0	727.2	187.4	717.8	999.9	58.8	3592.7
1998	235.4	50.8	76.1	175.9	95.7	33.1	621.0	593.7	454.6	84.9	0.0	0.0	2421.2
1999	60.3	0.0	127.1	49.3	24.7	139.2	508.3	723.7	226.4	271.7	10.2	0.8	2141.7
2000	0.0	0.0	29.0	104.0	132.7	33.3	453.7	599.3	412.5	198.4	118.0	201.4	2282.3
2001	23.4	73.2	319.3	20.8	26.8	33.7	472.3	437.2	116.8	36.8	11.8	54.5	1626.6
2002	106.5	0.0	100.2	131.2	4.0	64.9	121.8	404.9	166.6	0.0	0.0	185.9	1286.0
2003	61.9	74.5	127.3	256.7	43.7	128.1	369.2	346.4	227.2	9.4	39.4	99.5	1783.3
2004	178.3	107.3	79.4	235.8	12.3	96.2	390.8	417.0	187.2	173.3	89.5	60.9	2028.0
2005	101.6	10.6	196.3	183.2	202.1	83.4	441.6	427.1	185.1	24.2	97.7	0.0	1952.9
2006	114.6	43.6	154.8	136.0	59.0	49.6	485.8	506.4	235.9	109.1	0.6	256.2	2151.6
2007	46.5	61.7	82.2	96.5	81.4	133.6	512.6	610.2	155.5	48.7	50.9	0.0	1879.8
2008	59.0	0.0	0.5	125.7	146.2	110.8	432.1	352.7	109.7	103.5	83.9	0.1	1524.2
2009	108.6	23.0	66.0	87.4	52.3	47.3	395.6	395.6	36.2	160.8	143.6	105.3	1621.7
2010	8.9	71.3	169.1	32.6	292.4	13.1	353.4	343.6	110.1	18.3	21.1	1.7	1435.6
2011	50.3	0.0	63.4	39.1	178.2	56.9	129.2	391.1	139.0	1.6	68.8	0.0	1117.6
2012	0.0	0.1	14.4	117.6	92.4	181.9	405.2	449.9	176.4	57.3	0.0	15.5	1510.6
2013	101.7	42.5	52.1	135.5	68.8	35.9	502.4	453.4	148.3	193.7	81.1	0.0	1815.4
2014	1.2	37.9	292.1	179.0	274.0	35.6	361.6	525.1	259.1	352.5	15.0	7.5	2340.6
Mean	70.1	46.4	126.0	153.4	118.6	77.9	375.3	442.5	188.7	115.8	80.2	60.9	1855.7

Appendix Table 7.18. Mezezo total monthly precipitation (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	30.8	0.2	26.9	118.1	134.8	6.6	381.9	634.1	167.4	38.2	0.6	3.6	1543.3
1986	0.0	83.8	231.2	208.3	101.5	226.7	347.8	290.0	183.4	56.6	0.1	29.8	1759.0
1987	4.4	25.6	148.4	165.9	356.4	2.3	53.5	358.7	85.7	72.2	0.0	57.6	1330.7
1988	101.2	175.7	12.5	78.1	14.8	33.1	333.8	523.3	302.1	131.1	0.0	0.0	1705.7
1989	20.4	93.2	166.6	173.9	22.1	79.4	304.5	306.5	150.5	96.4	0.0	207.7	1621.2
1990	138.8	231.4	171.7	87.8	43.1	135.1	241.4	270.6	194.6	27.7	0.0	0.0	1542.2
1991	29.1	87.1	254.6	103.9	82.0	55.0	214.5	311.5	178.2	20.1	9.3	113.0	1458.3
1992	181.4	135.1	102.2	96.3	88.7	60.1	372.1	409.3	271.8	99.1	44.6	88.1	1948.8
1993	190.8	48.9	10.8	250.6	274.4	8.1	549.9	266.3	132.1	165.3	0.0	6.8	1904.0
1994	0.0	23.9	109.3	27.8	65.9	116.3	370.4	319.9	221.2	24.7	58.6	22.6	1360.6
1995	0.0	47.1	80.7	180.1	105.6	62.4	369.1	609.4	161.8	14.5	0.0	115.5	1746.2
1996	154.7	0.0	283.2	249.3	271.7	158.0	519.7	480.0	91.8	16.8	111.7	0.0	2336.9
1997	33.9	0.6	154.8	98.3	51.9	156.5	372.6	443.8	117.6	521.5	210.3	0.1	2161.9
1998	157.1	82.2	107.2	108.2	82.0	31.7	594.6	395.4	153.6	61.0	0.0	0.0	1773.0
1999	143.3	0.0	144.8	29.7	17.2	83.3	663.4	502.9	180.6	224.2	21.9	0.0	2011.3
2000	0.0	0.0	14.5	169.8	63.7	50.0	499.3	507.5	202.5	174.6	214.2	147.4	2043.5
2001	35.4	39.3	230.3	14.6	74.4	33.2	454.6	350.5	101.8	12.6	12.5	30.9	1390.1
2002	137.3	24.1	55.9	111.0	26.5	38.0	249.7	469.0	147.6	20.8	0.0	203.4	1483.3
2003	83.3	73.2	156.5	105.8	0.0	122.1	330.9	299.9	316.2	1.8	24.2	111.4	1625.3
2004	188.9	85.9	131.3	170.5	5.4	134.9	291.6	404.1	155.3	108.6	98.5	61.4	1836.4
2005	70.7	6.2	151.8	132.4	169.2	86.3	411.5	370.2	180.4	31.5	58.5	0.0	1668.5
2006	92.0	30.7	112.5	102.9	50.8	127.9	489.0	470.3	167.2	59.8	8.1	153.0	1864.3
2007	37.6	89.1	84.8	158.0	21.5	86.5	379.0	627.2	99.0	0.0	9.3	0.0	1592.0
2008	160.8	0.7	0.0	134.7	85.7	27.9	458.9	318.3	60.0	42.3	118.6	0.0	1407.9
2009	50.4	0.6	77.4	37.7	6.3	24.6	265.0	155.8	22.7	80.6	81.8	202.5	1005.4
2010	39.1	39.5	67.5	151.6	60.4	18.0	431.1	381.7	178.3	4.5	33.0	0.0	1404.7
2011	0.0	8.5	34.3	33.1	52.9	21.4	252.4	256.1	88.5	3.7	63.1	0.0	814.0
2012	0.0	0.1	21.1	120.6	93.1	162.0	444.2	422.7	156.6	38.0	0.0	15.5	1473.8
2013	0.0	0.0	16.0	10.0	0.8	43.7	448.8	455.4	198.0	107.0	67.0	0.0	1346.7
2014	0.0	41.0	219.7	168.0	230.8	29.1	327.1	483.8	223.7	303.5	13.6	5.0	2045.4
Mean	69.4	49.1	112.6	119.9	88.5	74.0	380.7	403.1	163.0	85.3	42.0	52.5	1640.1

7.1.3 Weather Generator Statistic and Probability Values

Appendix Table 7.19. Weather GeneratorStatistical values for Debre Birhan station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	19.83	20.63	20.89	20.78	21.57	21.84	18.59	18.18	18.84	18.75	18.93	19.11
TMPMN	4.87	6.39	7.75	7.92	7.43	7.55	8.80	8.78	7.07	3.63	2.55	3.24
TMPSTDX	1.93	1.97	1.89	1.78	1.82	1.96	2.31	1.82	1.08	1.18	1.41	1.42
TMPSTDMN	3.60	3.57	2.74	2.16	2.17	1.99	1.29	1.27	1.98	2.86	3.19	3.82
PCP_MM	13.40	18.40	44.93	56.25	37.82	65.54	312.8	274.3	78.92	19.34	5.95	3.82
PCPSTD	2.16	2.81	4.26	4.81	3.82	5.34	11.12	9.90	5.36	2.51	1.76	1.00
PCPSKW	7.27	8.05	4.73	4.17	4.62	3.73	1.62	1.55	3.42	5.83	14.37	13.40
PR_W1	0.06	0.08	0.17	0.21	0.14	0.18	0.61	0.82	0.31	0.07	0.03	0.04
PR_W2	0.38	0.48	0.51	0.55	0.52	0.67	0.89	0.88	0.63	0.50	0.46	0.38
PCPD	2.57	3.70	7.57	9.93	6.80	9.80	25.93	27.07	14.60	4.33	1.37	1.71
RAINHHMX	24.6	46.5	44	46.6	38.4	47	84.3	60	43.1	25.43	32.2	19
SOLARAV	7.743	7.779	7.801	7.743	7.694	8.123	7.967	8.028	8.016	7.925	7.918	7.833
DEWPT	4.722	5.570	7.158	7.682	5.684	6.380	10.05	10.27	8.156	4.371	3.408	3.425
WINDAV	2.042	2.130	2.035	1.751	1.773	1.649	1.525	1.616	1.811	1.836	2.009	1.998

Where: TMPMX: Average or mean daily maximum air temperature for month (ºC)

TMPMN: Average or mean daily minimum air temperature for month (ºC)

TMPSTDMX: Standard deviation for daily maximum air temperature in month (ºC)

TMPSTDMN: Standard deviation for daily minimum air temperature in month (ºC)

PCPMM: Average or mean total monthly precipitation (mm H2O)

PCPSTD: Standard deviation for daily precipitation in month (mm H2O/day)

PCPSKW: Skew coefficient for daily precipitation in month

PR_W1: Probability of a wet day following a dry day in the month

PR_W2: Probability of a wet day following a wet day in the month

PCPD: Average number of days of precipitation in month

RAINHHMX: Maximum 0.5 hr rainfall in entire period of record for month (mm)

DEWPT: Average daily dew point temperature in month (ºC)

7.1.4 Hydrological Data Tables

Appendix Table 7.20. Observed stream flow data for Andit tid gauging station (m^3/hr)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1989	0.28	0.37	0.85	3.28	0.47	0.42	5.93	10.29	8.13	2.72	0.36	2.26	35.35
1990	0.55	0.64	1.47	1.72	0.26	0.11	6.51	12.22	13.52	4.54	0.60	0.18	42.31
1991	0.19	0.26	0.74	1.17	1.26	0.51	6.55	24.29	14.20	5.01	0.17	4.55	58.92
1992	0.31	0.28	0.16	0.27	0.32	0.11	1.53	15.99	13.23	2.28	0.47	0.30	35.25
1993	0.51	1.07	0.26	2.51	5.17	0.46	8.98	11.35	4.89	4.94	0.77	0.20	41.12
1994	0.20	0.18	0.34	0.32	0.72	0.57	10.66	13.09	12.57	1.71	4.08	1.20	45.65
1995	0.34	0.27	0.65	1.32	0.97	0.56	8.33	17.25	14.74	3.63	1.85	5.63	55.55
1996	4.45	2.42	6.56	6.23	9.70	2.61	14.61	14.43	4.64	0.27	0.18	0.07	66.19
1997	0.07	0.05	2.89	2.40	0.56	1.31	8.43	18.83	2.04	11.21	3.51	0.67	51.97
1998	0.09	0.02	0.04	0.10	0.52	0.02	6.51	11.84	3.45	1.53	0.05	0.03	24.20
1999	0.02	0.02	0.03	0.12	0.03	0.22	7.85	9.68	3.02	7.53	0.05	0.03	28.60
2000	0.02	0.02	0.02	0.16	0.30	0.02	2.15	10.13	7.85	3.32	1.86	0.05	25.90
2001	0.03	0.03	0.81	0.09	0.17	0.02	7.26	9.00	1.82	0.05	0.02	0.02	19.34
2002	0.02	0.02	0.02	0.29	0.02	0.02	1.29	5.26	4.38	0.02	0.02	0.02	11.37
2003	0.02	0.02	0.02	1.18	0.53	0.11	4.44	5.11	1.96	0.25	0.01	0.01	13.65
2004	0.00	0.02	0.02	0.12	0.01	0.04	3.14	6.82	1.28	1.63	0.28	0.02	13.38
2005	0.00	0.00	0.08	0.01	0.17	0.01	4.63	4.73	2.49	0.02	0.02	0.00	12.19
2006	0.02	0.00	0.00	0.00	0.04	0.00	4.13	11.58	2.26	0.34	0.03	1.41	19.80
2007	0.41	0.51	0.05	0.77	0.28	0.13	3.38	9.80	6.99	0.10	0.08	0.03	22.53
2008	0.00	0.00	0.00	0.17	0.87	0.02	7.15	4.89	0.68	0.33	0.83	0.00	14.94
Mean	**0.34**	**0.28**	**0.69**	**1.08**	**1.23**	**0.49**	**6.14**	**11.75**	**6.52**	**2.66**	**0.65**	**0.69**	**32.53**

Appendix Table 7.21. Observed sediment load data for Andit tid gauging station (ton/ha)

Year	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	4464.7	0.0	0.0	214.7	267.1	28.6	176.5	1683.8	920.6	1092.3	62.0	0.0	19.1
1990	725.0	0.0	4.8	109.7	95.4	0.0	0.0	338.7	0.0	171.7	4.8	0.0	0.0
1991	2327.8	0.0	0.0	128.8	66.8	9.5	0.0	400.7	548.6	491.3	57.2	0.0	624.8
1992	2194.2	0.0	0.0	0.0	14.3	248.0	14.3	233.7	1025.6	648.7	0.0	4.8	0.0
1993	2933.6	0.0	167.0	0.0	381.6	500.9	0.0	1016.0	510.4	295.7	66.8	0.0	0.0
1994	3062.3	0.0	0.0	314.8	224.2	386.4	601.0	581.9	939.7	0.0	14.3	4.8	0.0
1995	2027.3	0.0	0.0	491.3	147.9	109.7	81.1	934.9	238.5	23.9	0.0	0.0	0.0
1996	2561.5	0.0	0.0	19.1	195.6	887.2	38.2	663.0	519.9	233.7	4.8	0.0	0.0
1997	2389.8	0.0	0.0	567.6	104.9	0.0	119.3	319.6	1168.7	28.6	76.3	9.5	0.0
1998	1378.5	0.0	0.0	0.0	28.6	81.1	0.0	562.9	529.5	147.9	28.6	0.0	0.0
1999	2342.1	0.0	0.0	0.0	0.0	0.0	362.5	1378.5	448.4	124.0	28.6	0.0	0.0
2000	2480.4	0.0	0.0	0.0	238.5	248.0	0.0	481.8	806.1	620.1	85.9	0.0	0.0
2001	2642.6	0.0	0.0	95.4	0.0	62.0	0.0	1931.9	481.8	76.3	0.0	0.0	0.0
2002	1836.5	0.0	0.0	0.0	23.9	0.0	0.0	868.1	763.2	181.3	0.0	0.0	0.0
2003	2480.4	0.0	0.0	19.1	362.5	128.8	119.3	1330.8	405.5	119.3	0.0	0.0	0.0
2004	720.3	0.0	0.0	0.0	42.9	0.0	0.0	248.0	367.3	23.9	23.9	9.5	0.0
2005	868.1	0.0	0.0	66.8	0.0	128.8	0.0	505.6	152.6	9.5	0.0	0.0	0.0
2006	2876.3	0.0	0.0	0.0	0.0	52.5	0.0	1435.8	858.6	343.4	190.8	0.0	0.0
2007	877.7	42.9	0.0	23.9	42.9	0.0	19.1	319.6	395.9	33.4	0.0	0.0	0.0
2008	1030.3	0.0	0.0	0.0	147.9	0.0	0.0	267.1	462.7	152.6	0.0	0.0	0.0
Mean	**2518.6**	**0.0**	**4.8**	**104.9**	**195.6**	**195.6**	**152.6**	**849.1**	**667.8**	**257.6**	**66.8**	**0.0**	**23.9**
Total	**65492.1**	**42.9**	**176.5**	**2675.9**	**5084.8**	**5089.5**	**3954.3**	**22037.4**	**17358.0**	**6682.7**	**1702.8**	**28.6**	**643.9**

Appendix Table 7.22. Simulation results of stream flow and sediment load for sub watershed of Ayserawum watershed

Sub watersheds	Area coverage (ha)	Percent of Area cover	No of HRUs formed	Generated Flow in m^3/sec	Sediment load in tone/yr	Sediment load in tone/ha/yr
1	80.3	2.54	5	0.38	23900.49	297.64
2	75.45	2.39	6	0.32	713.76	9.46
3	25.67	0.81	8	0.17	215.37	8.39
4	103.5	3.28	4	0.12	258.75	2.5
5	47.68	1.51	9	0.1	379.53	7.96
6	100.03	3.17	4	0.09	285.09	2.85
7	267.29	8.47	5	0.08	919.48	3.44
8	101.49	3.22	5	0.07	298.38	2.94
9	13.79	0.44	4	0.07	58.06	4.21
10	99.02	3.14	4	0.07	291.12	2.94
11	99.02	1.29	8	0.06	1052.58	10.63
12	29.6	0.94	4	0.06	54.76	1.85
13	79.02	2.5	6	0.06	679.57	8.6
14	84.04	2.66	4	0.06	806.78	9.6
15	44.12	1.4	8	0.06	511.79	11.6
16	20.01	0.63	5	0.05	126.86	6.34
17	46.04	1.46	6	0.05	380.75	8.27
18	22.56	0.71	5	0.05	187.02	8.29
19	25.58	0.81	5	0.04	188.52	7.37
20	141.41	4.48	7	0.04	2618.91	18.52
21	91.35	2.89	6	0.04	795.66	8.71
22	107.7	3.41	4	0.03	294.02	2.73
23	76.37	2.42	2	0.03	226.06	2.96
24	96.56	3.06	8	0.03	777.31	8.05
25	76.46	2.42	5	0.03	635.38	8.31
26	47.41	1.5	8	0.02	352.26	7.43
27	63.3	2.01	8	0.02	622.24	9.83
28	35.17	1.11	6	0.02	390.39	11.1
29	53.35	1.69	6	0.02	440.14	8.25
30	111.9	3.55	4	0.02	358.08	3.2
31	57.82	1.83	5	0.02	611.16	10.57
32	52.89	1.68	2	0.01	174.01	3.29
33	52.34	1.66	7	0.01	359.05	6.86
34	129.99	4.12	2	0.01	306.78	2.36
35	130.36	4.13	10	0.01	2015.37	15.46
36	525.71	16.66	5	0.01	1424.67	2.71
Total	3214.3	100	200	2.33	43710.15	544.78

Appendix Table 7.23. Probability of rejecting homogeneity of annual rainfall of Debrebirhan station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.24. Probability of rejecting homogeneity of annual rainfall of Enewari station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.25. Probability of rejecting homogeneity of annual rainfall of Alem Ketema station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.26. Probability of rejecting homogeneity of annual rainfall of Mehal meda station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.27. Probability of rejecting homogeneity of annual rainfall of Andit Tid station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.28. Probability of rejecting homogeneity of annual rainfall of Ankober station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 7.29. Probability of rejecting homogeneity of annual rainfall of Debre Sina station

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

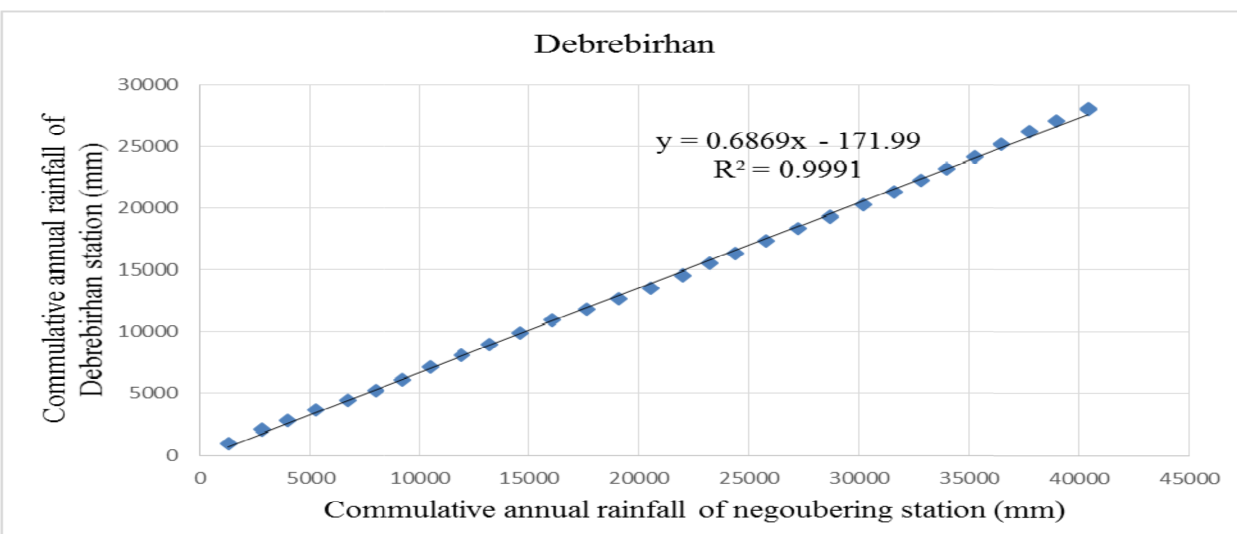
Appendix Table 7.30. Probability of rejecting homogeneity of annual rainfall of Mezezo station

Homogeneity test

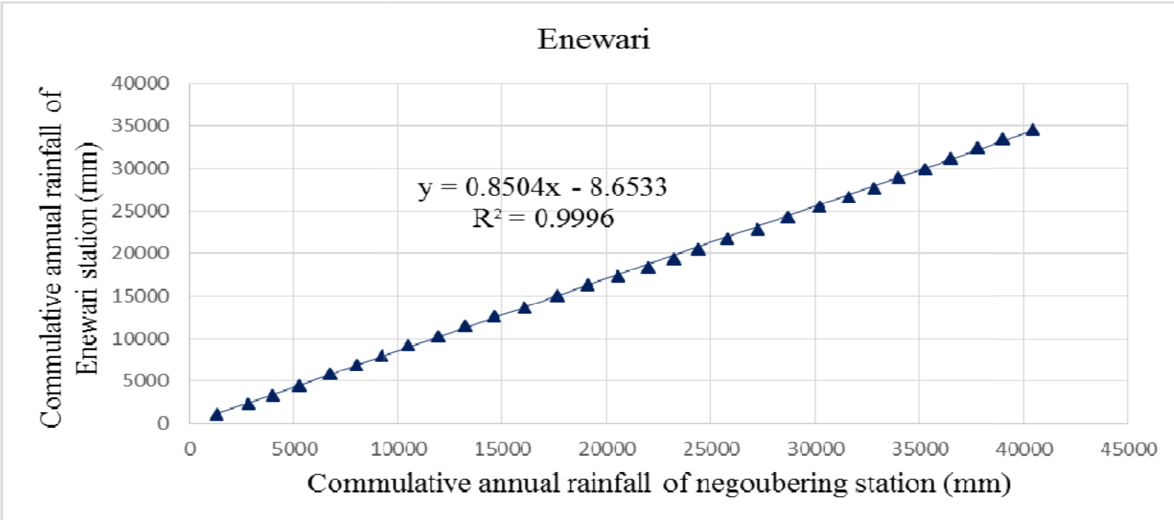
Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

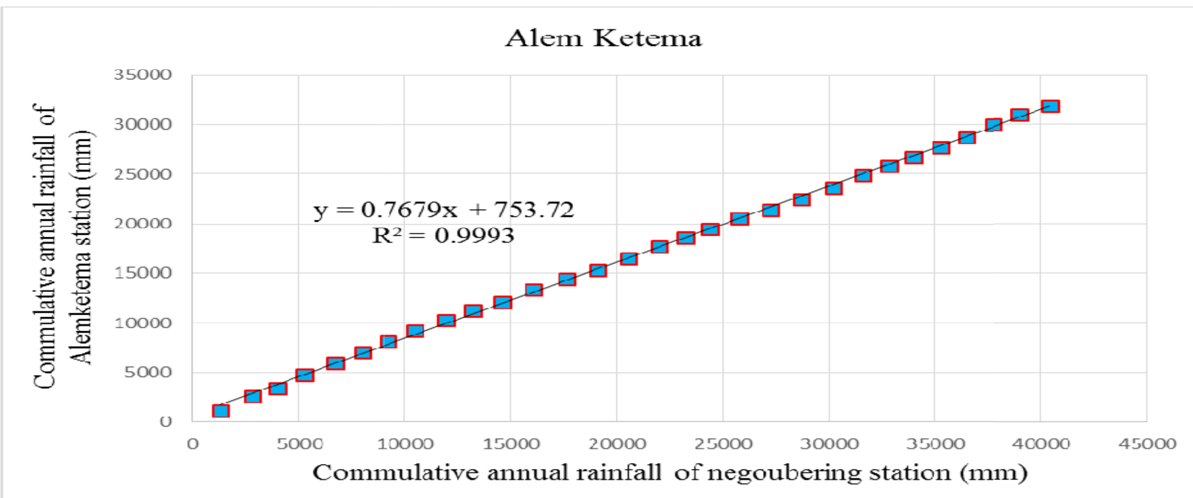
7.2 Appendix Figure



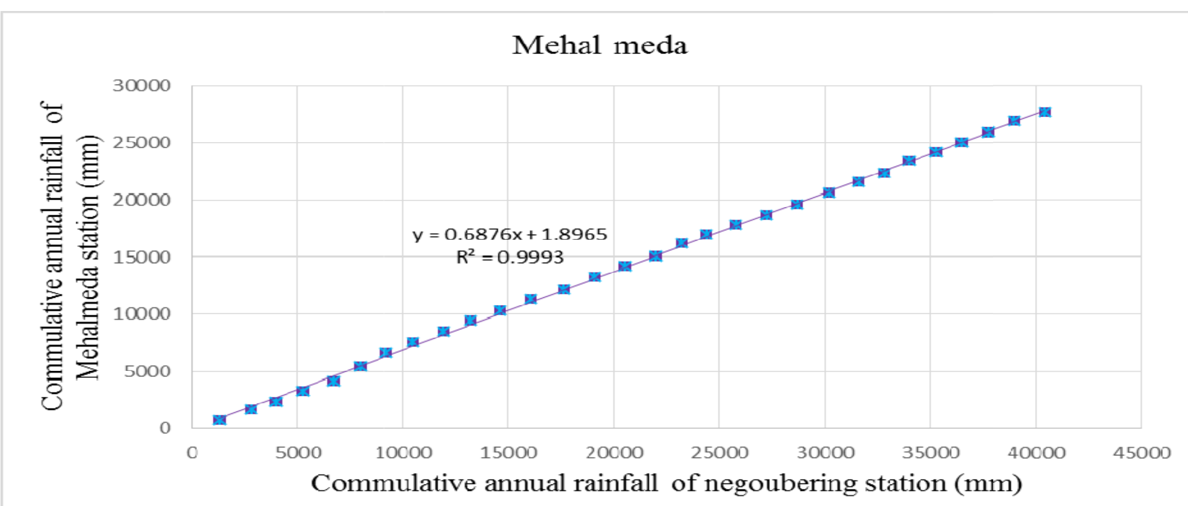
Appendix Figure 7.1. Double mass curve of Debrebirhan meteorological station



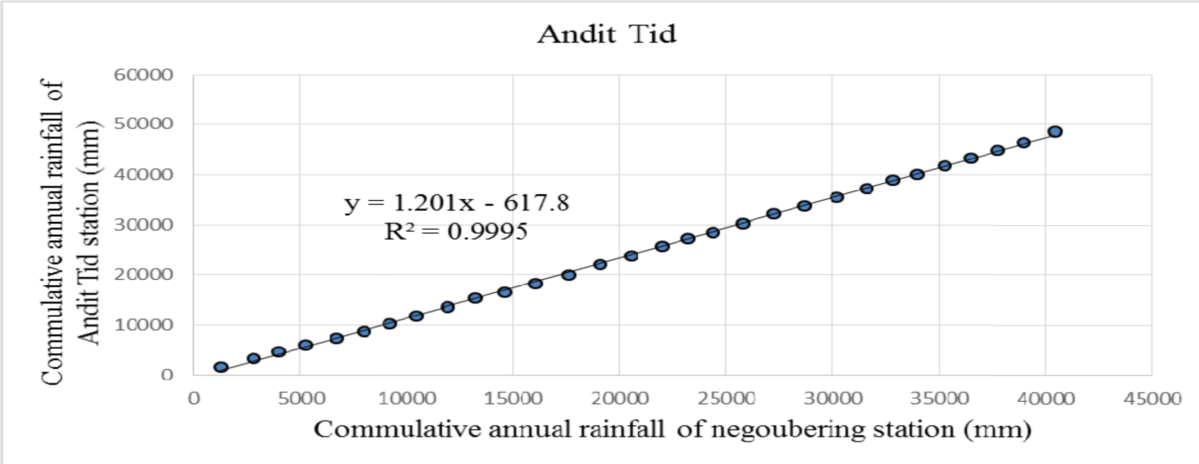
Appendix Figure 7.2. Double mass curve of Enewari meteorological station



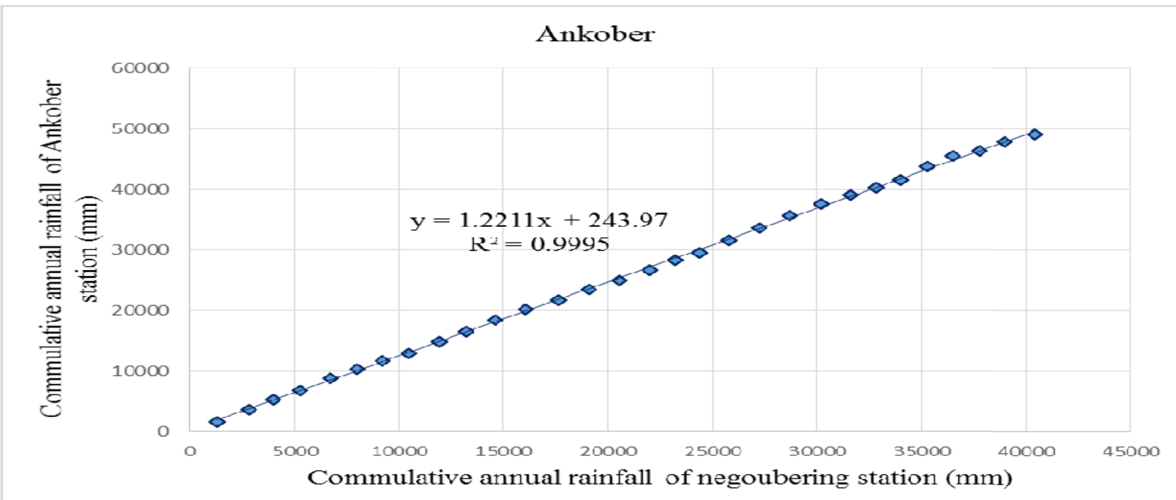
Appendix Figure 7.3. Double mass curve of Alem Ketema meteorological station



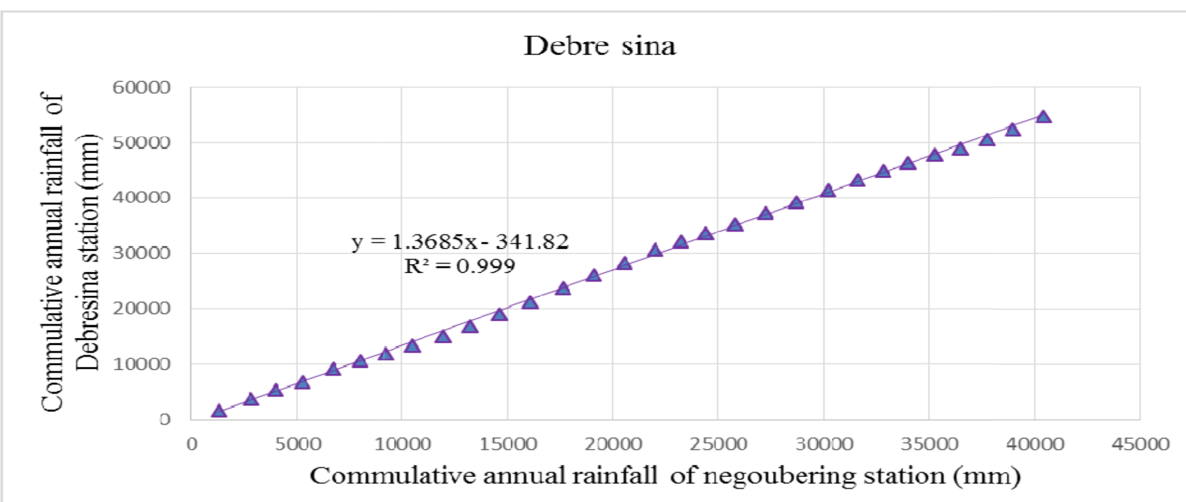
Appendix Figure 7.4. Double mass curve of Mehal meda meteorological station



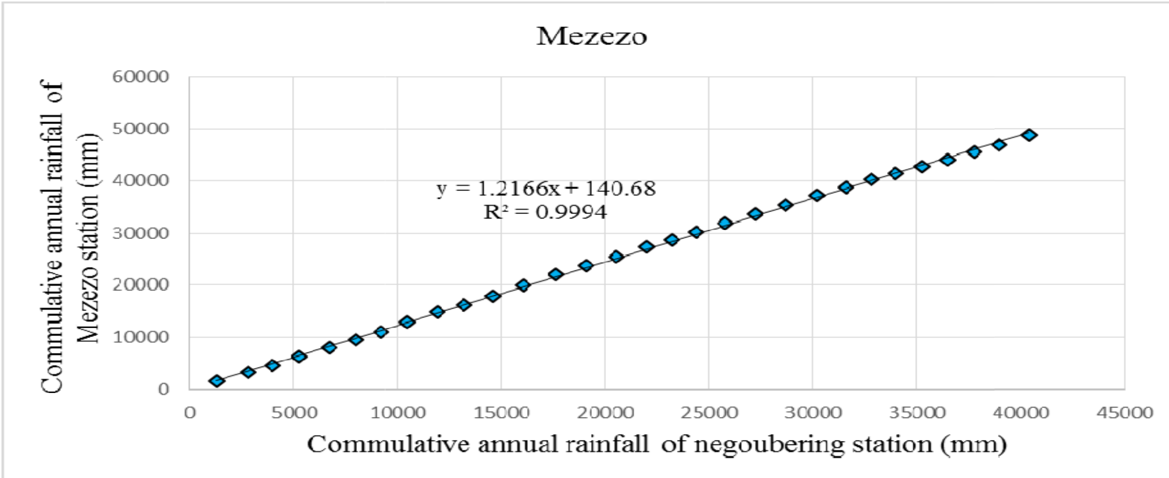
Appendix Figure 7.5. Double mass curve of Andit tid meteorological station



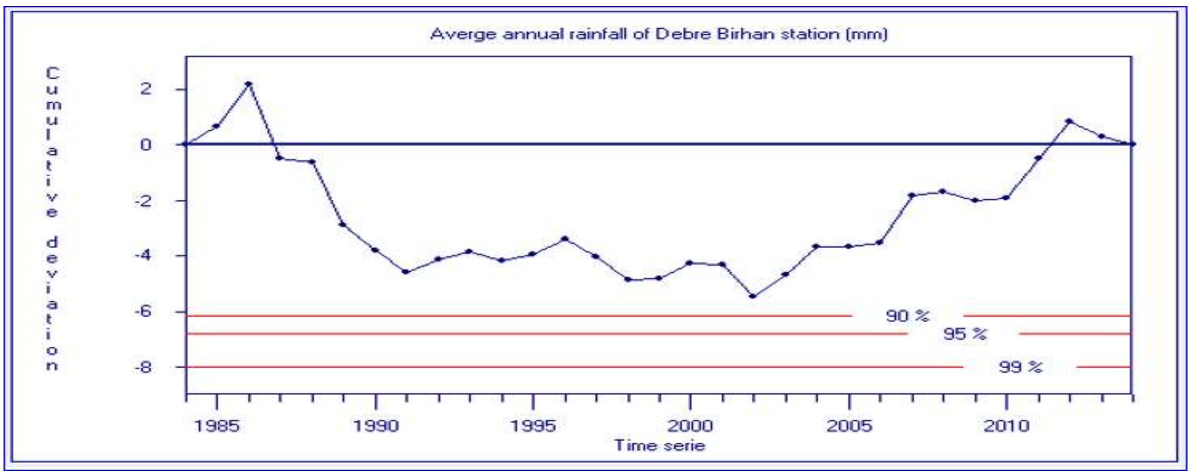
Appendix Figure 7.6. Double mass curve of Ankober meteorological station



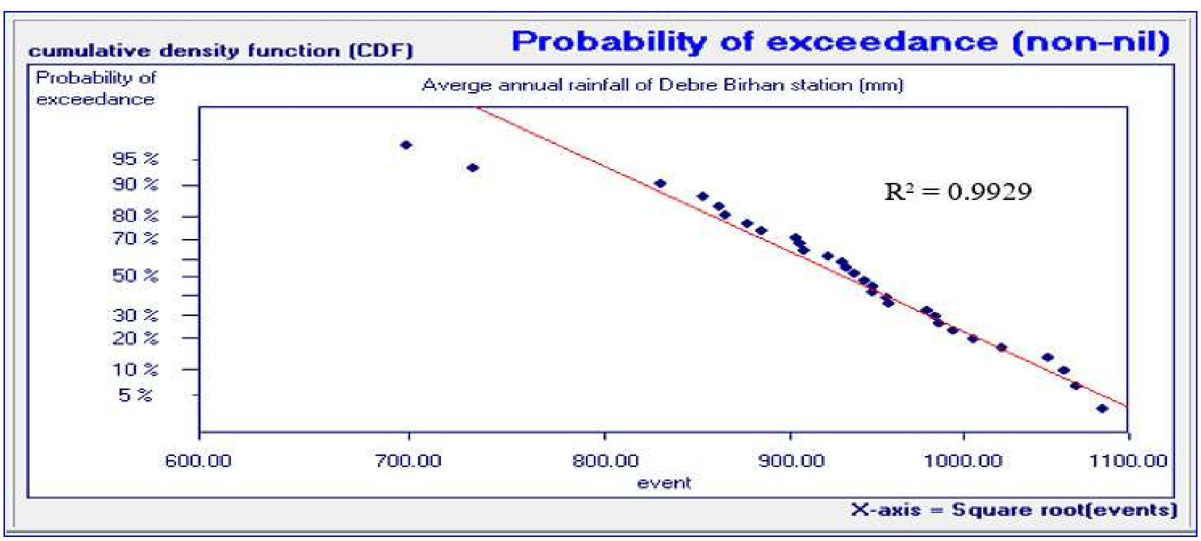
Appendix Figure 7.7. Double mass curve of Debre Sina meteorological station



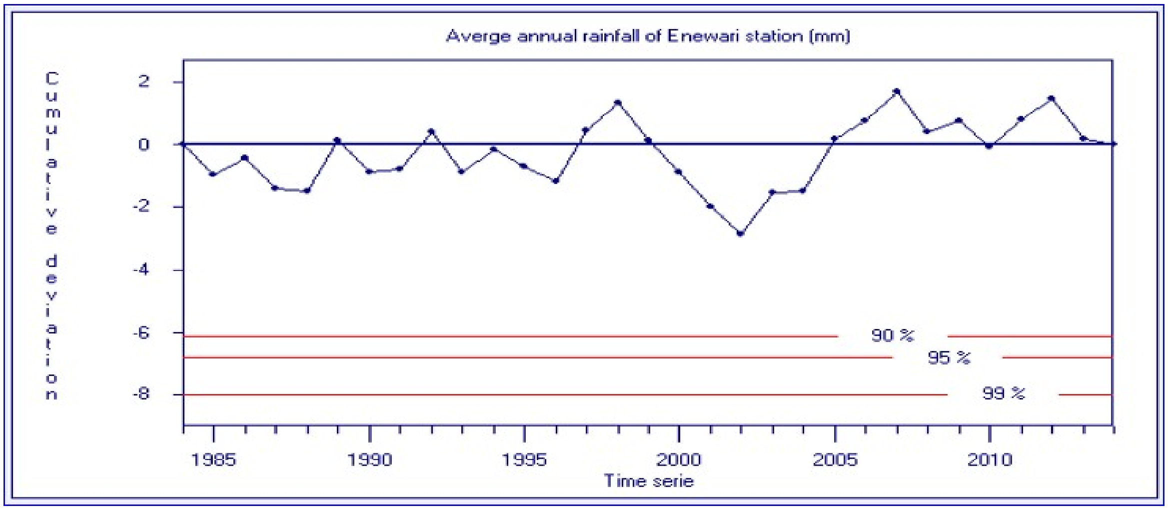
Appendix Figure 7.8. Double mass curve of Mezezo meteorological station



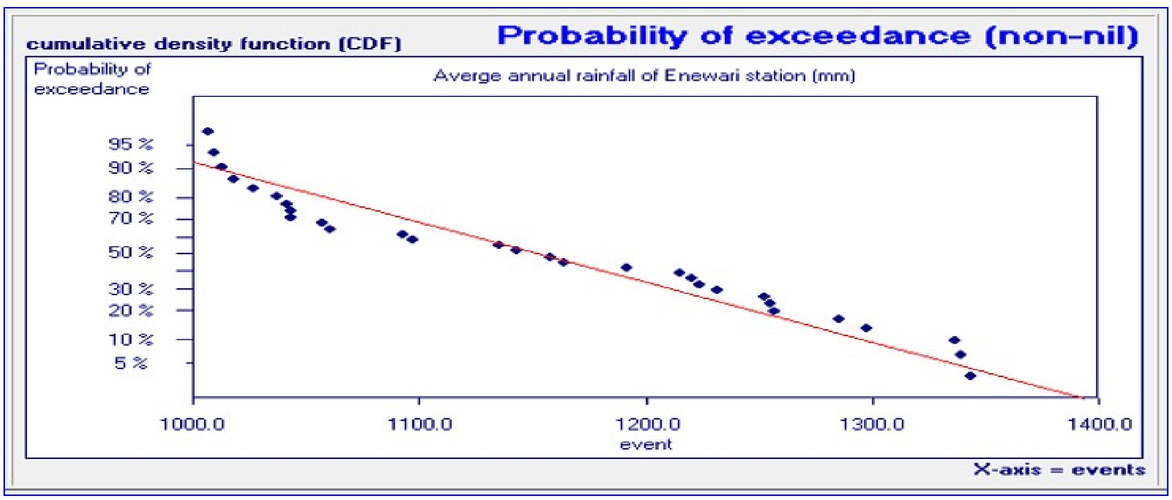
Appendix Figure 7.9. Cumulative deviation of annual rainfall of Debre Birhan station



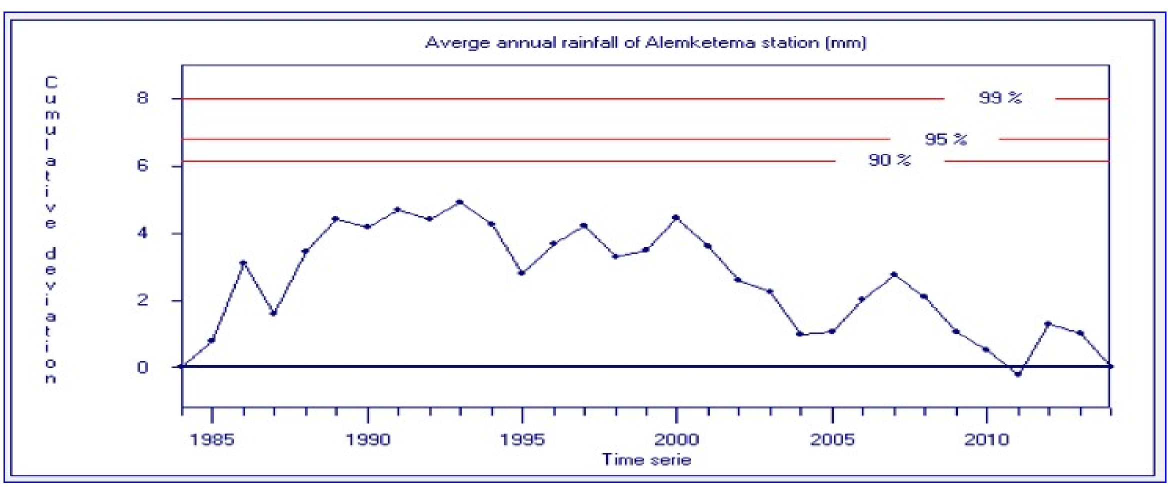
Appendix Figure 7.10. Probability plot of annual rain fall of Debre Birhan station



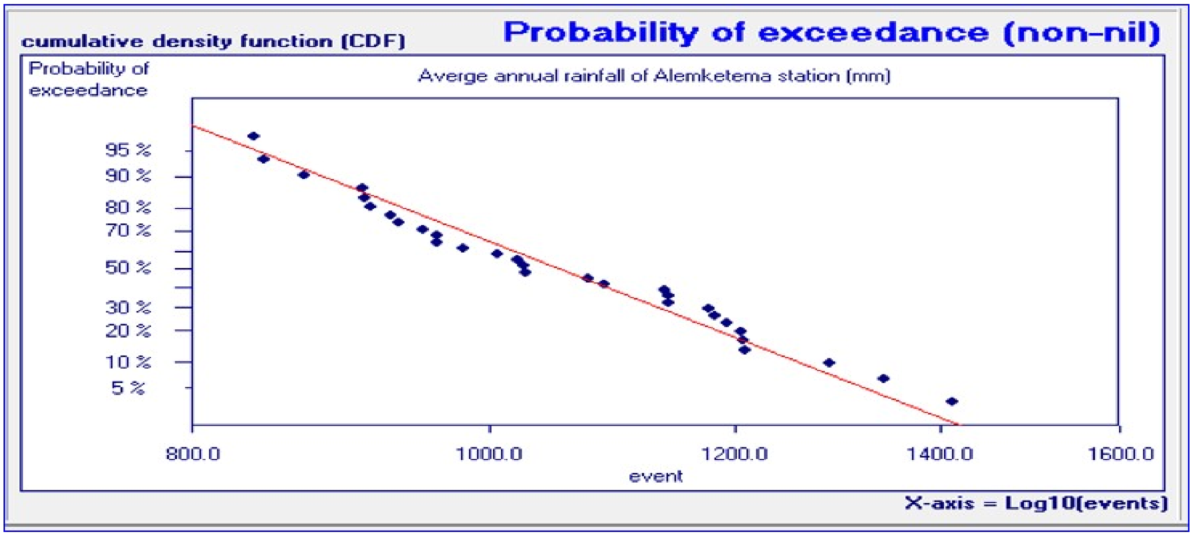
Appendix Figure 7.11. Cumulative deviation of annual rainfall of Enewari station



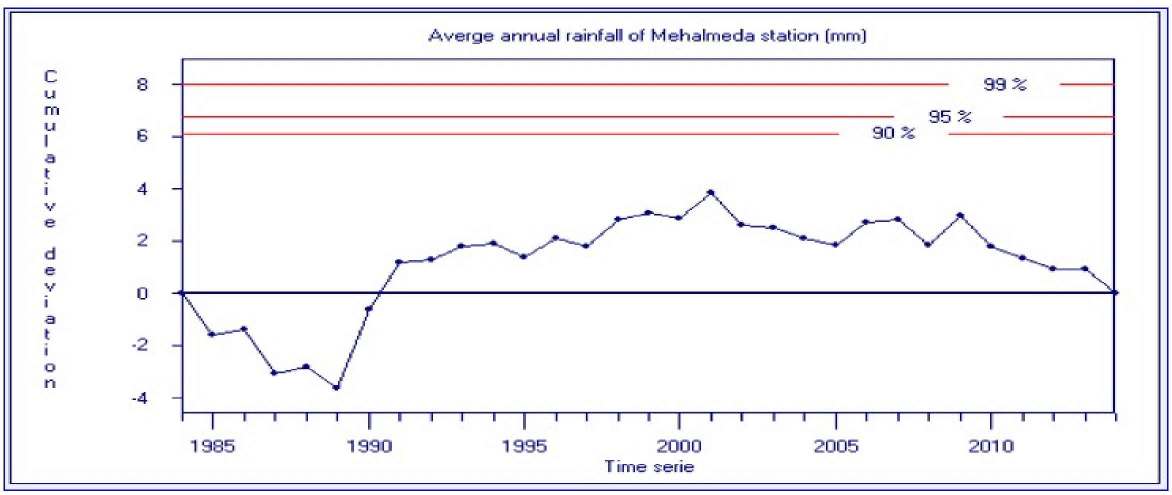
Appendix Figure 7.12. Probability plot of annual rain fall of Enewari station



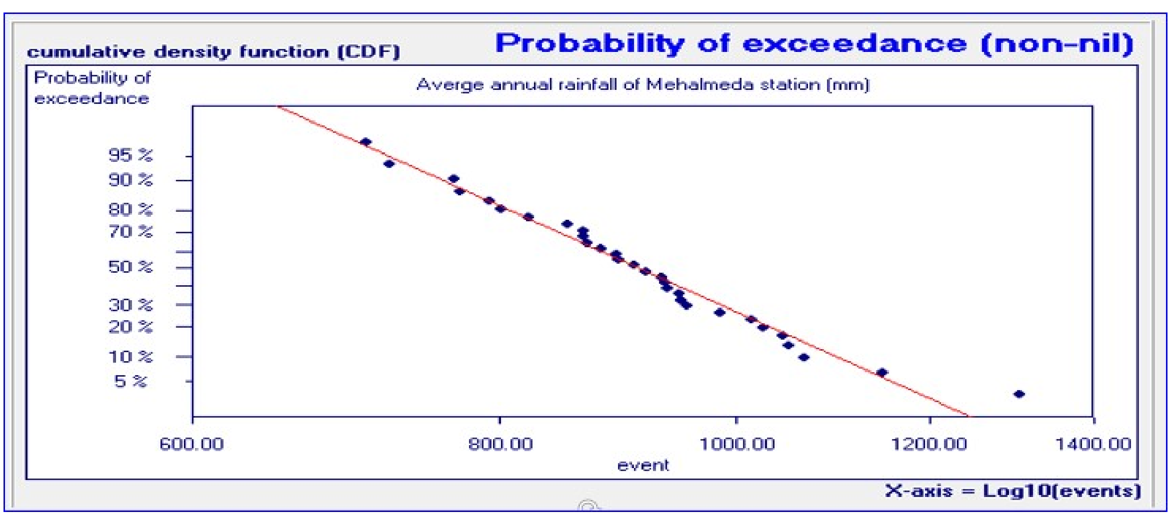
Appendix Figure 7.13. Cumulative deviation of annual rainfall of Alem Ketema station



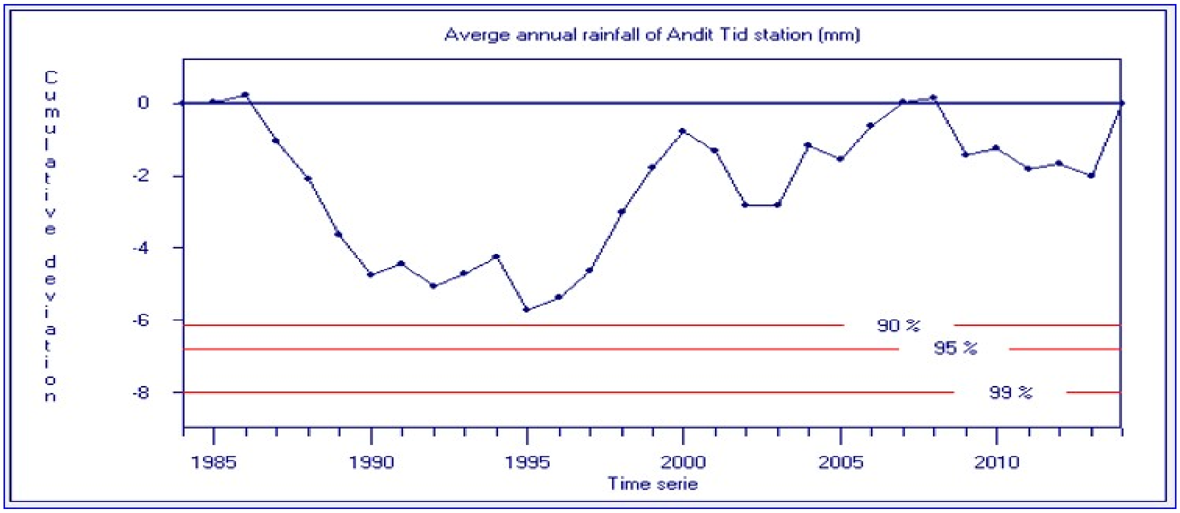
Appendix Figure 7.14. Probability plot of annual rain fall of Alem Ketema station



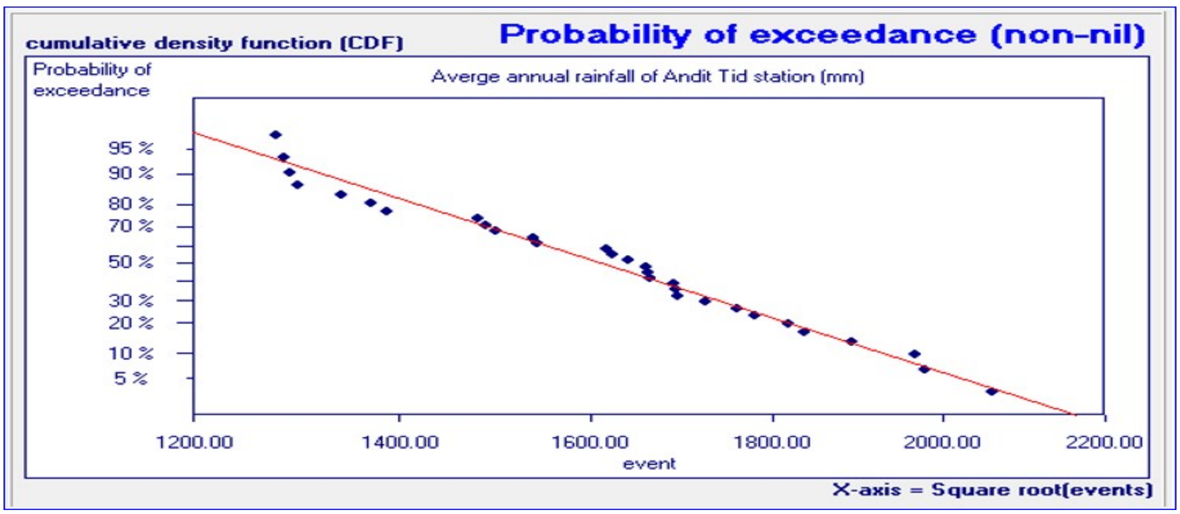
Appendix Figure 7.15. Cumulative deviation of annual rainfall of Mehal meda station



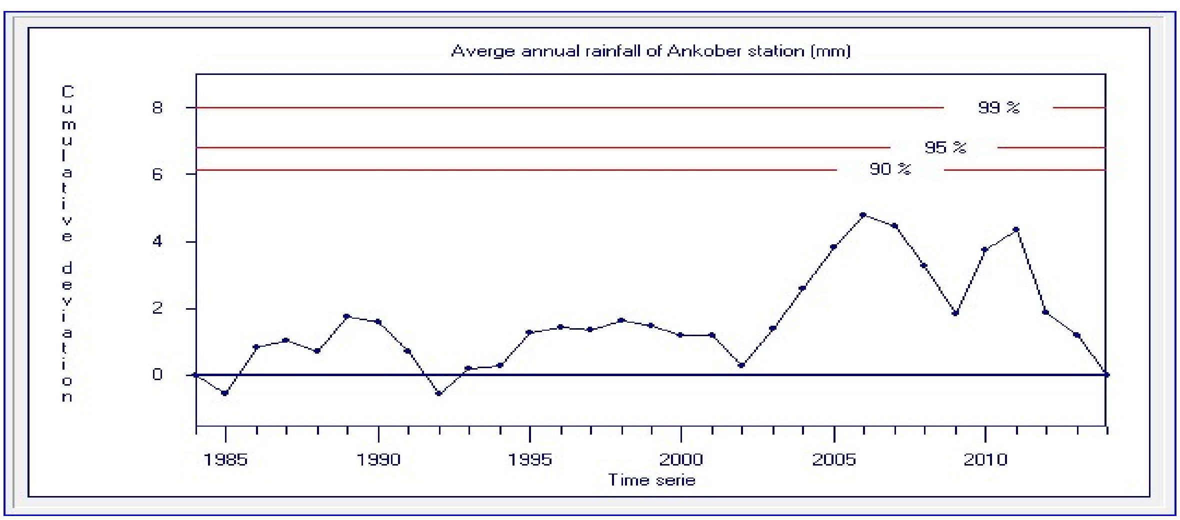
Appendix Figure 7.16. Probability plot of annual rain fall of Mehal meda station



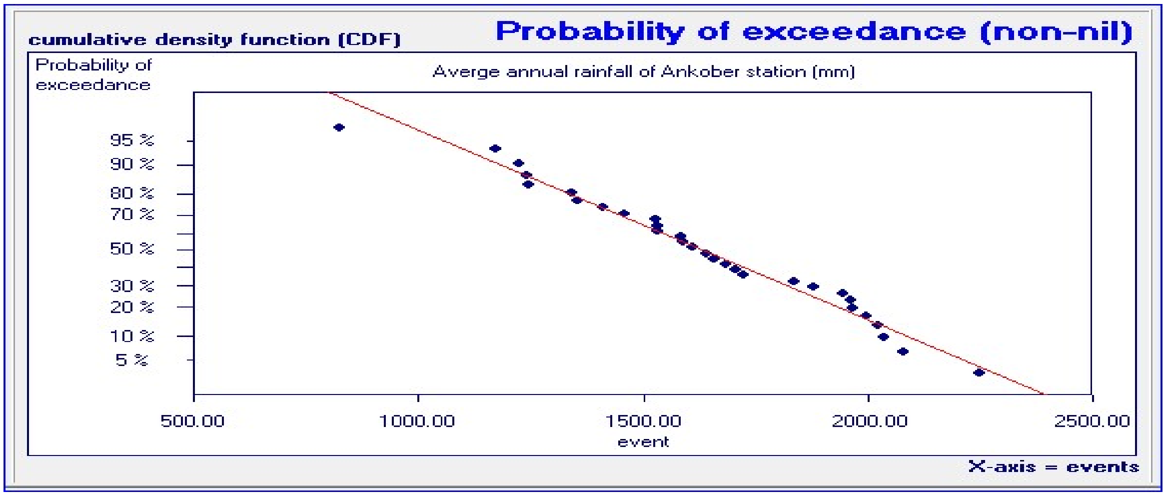
Appendix Figure 7.17. Cumulative deviation of annual rainfall of Andit Tid station



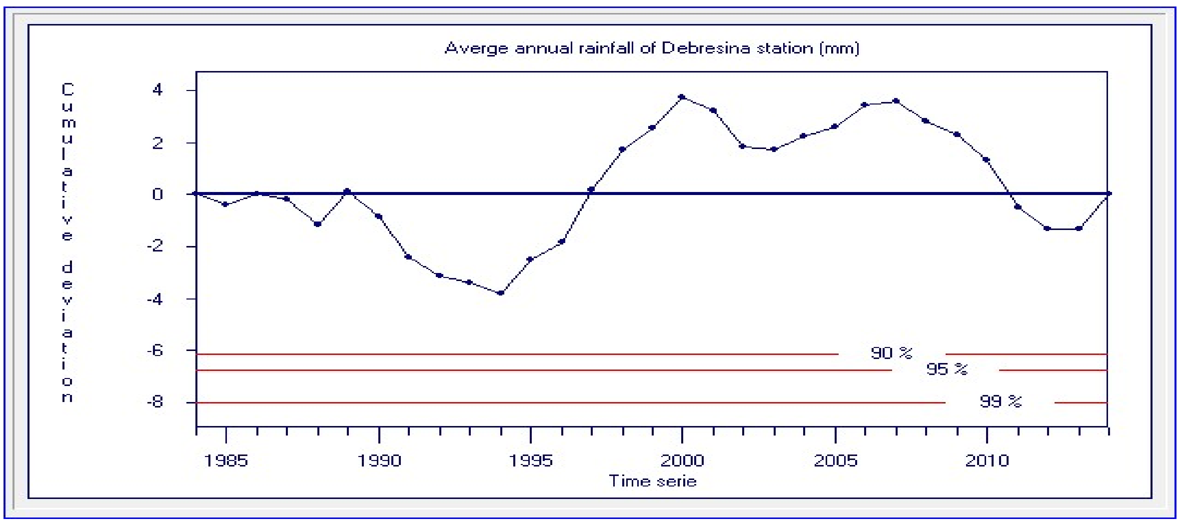
Appendix Figure 7.18. Probability plot of annual rain fall of Andit Tid station



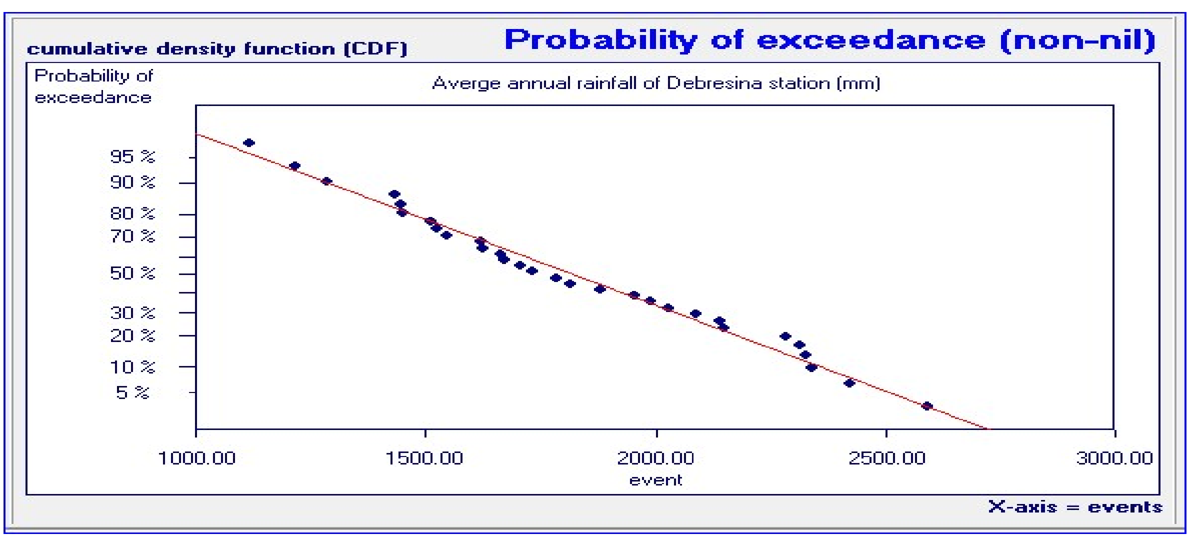
Appendix Figure 7.19. Cumulative deviation of annual rainfall of Ankober station



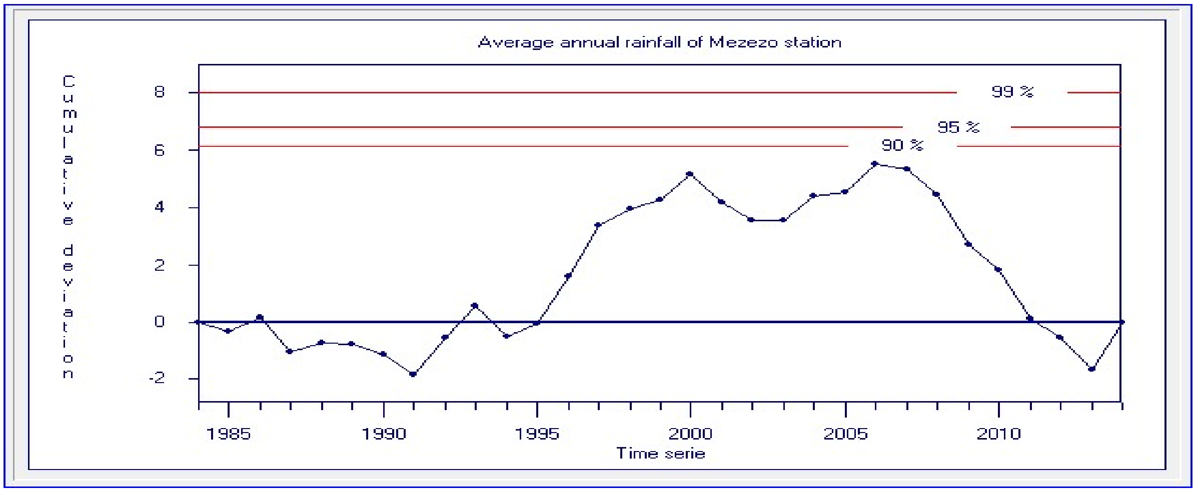
Appendix Figure 7.20. Probability plot of annual rain fall of Ankober station



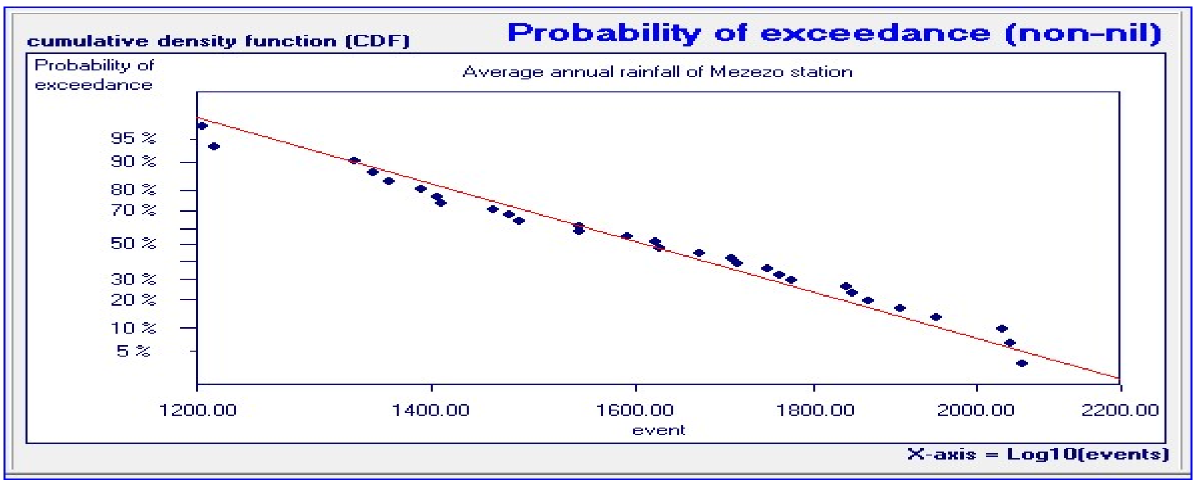
Appendix Figure 7.21. Cumulative deviation of annual rainfall of Debre Sina station



Appendix Figure 7.22. Probability plot of annual rain fall of Debre Sina station



Appendix Figure 7.23. Cumulative deviation of annual rainfall of Mezezo station



Appendix Figure 7.24. Probability plot of annual rain fall of Mezezo station