2018-10-01

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MEKONNEN, YESHIWAS

http://hdl.handle.net/123456789/9006

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND GRADUATE STUDIES
FACULTY OF CIVIL AND WATER RESOURCE ENGINEERING

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BY

YESHIWAS MEKONNEN MENGISTU

May 29, 2018

Bahir Dar, Ethiopia

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YESHIWAS MEKONNEN MENGISTU

A thesis submitted to the school of Research and Graduate Studies of Bahir Dar
Institute of Technology, BDU in partial fulfillment of the requirements for the degree
of
Master of Science in the Hydraulic Engineering in the Faculty of Civil & Water Resource
Engineering

Advisor Name: Mamaru A.(Ph.D.)
Co-Advisor Name: Getnet N.(MSc.)

BahirDar, Ethiopia
May 29, 2018

DECLARATION

I, Yeshiwas Mekonnen Mengistu, the undersigned, declare that the thesis comprises my own work. In the compliance with the internationally accepted practices, I have acknowledged and refereed all the materials used in this work. I understand that non-adherence to the principles of the academic honesty and integrity, misrepresentation/ fabrication of any idea/fact or source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

Name of the student________________________________ Signature _____________

Date of submission: ________________

Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

Advisor Name: ___________________________________

Advisor's Signature: _______________________________

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School of Research and Graduate Studies

Faculty of Civil and Water Resource Engineering

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Student:

Name Signature Date

The following graduate faculty member certify that this student has successfully presented the necessary written final thesis and oral presentation for partial fulfillment of the thesis requirements for the Degree of Master of Science in Hydraulic Engineering

Approved By:

Advisor:

Name Signature Date

External Examiner:

Name Signature Date

Internal Examiner:

Name Signature Date

Chair Holder:

Name Signature Date

Faculty Dean:

Name Signature Date

I dedicate this thesis to my parent

ACKNOWLEDGEMENTS

Above all I thank the LORD GOD for his mercy and grace upon me during all my works and in all my life.

I would like to express my sincere gratitude to Ministry of Water, Irrigation and Electricity (MoWIE) for allowing me study time, tuition fee and necessary materials during the study period.

I would like thanks to my Advisor Dr.Mamaru A. Moges who introduces me the guidance, encouragement and critical comments throughout my thesis work. Without him, this work wouldn’t have been realized.

I would like also to thank the Ministry of Water, Irrigation and Electricity (MoWIE), Water and Land Resource Center (WALRC),Ethiopian National Meteorological Agency (ENMA) and Abbay Basin Authority (ABA) for their cooperation in availing the necessary data.

I would like to express my appreciation to all my friends and class mates for their support and wonderful social atmosphere.

Last but the best, I would like to thank my wonderful parents, for their unlimited support throughout my life.

ABSTRACT

The study presents on the application of hydrological watershed models in the Blue Nile basin to evaluate the sediment prediction capability of SWAT and PED-WM in the range of scale of watershed. Watersheds were AnditTid (4.84km^2),Temcha (410.09km^2) and Gumara(1270.75km^2). Calibration and validation was carried out for both stream flow and sediment load at the outlet, for sixteen years measured data 2000 to 2015considering the warm-up, calibration and validation(2000, 2001-2010&2011-2015) respectively. Good agreement between measured and simulated flow and sediment load were observed, which was verified using both graphical technique and quantitative statistics. Model efficiency criteria for SWAT model stream flow; the calibration of AnditTid, Temcha and Gumara SWAT(NSE=0.70,0.62,0.64)and(NSE=0.91,0.75,0.89)andvalidation(NSE=0.84,0.65,0.68) and(NSE=0.89,0.93,0.71) the daily and monthly time. Similarly; PED-WM for Gumara (NSE=0.74,0.58,0.80)and(NSE=0.90,0.80,0.91)andvalidation(NSE=0.85,0.51,0.83)and(NSE=0.94,0.57&0.94) in the daily and monthly time respectively. Similarly; SWAT model sediment load calibration in AnditTid, Temcha and Gumara (NSE=0.68, 0.56, 0.63) and (NSE=0.88, 0.65,0.78) and validation of the SWAT model (NSE=0.77,0.72,0.73) and (NSE=0.92,0.86,0.85) in daily and monthly respectively. PED-WM sediment calibration in AnditTid, Temcha and Gumara (NSE=0.73,0.75,0.81) and (NSE=0.90,0.82,0.83) and validation (NSE=0.75,0.65,0.91)and(NSE=0.92,0.80,0.90) in the daily and monthly time respectively. Difference in model behavior depends on runoff mechanism. SWAT model the main direct runoff generation process is infiltration excess and could predict better monthly discharge and sediment load than daily time step. In case of PED-WM saturation excess is the main direct runoff process and could predict the maximum extent of runoff generation area 6% (5% saturated and1% degraded). Generally, the output of this study it will support planners and decision makers to take relevant soil and water conservation measures and diminish the frightening soil loss and land degradation troubles in the Blue Nile Basin, Ethiopia.

KEYWORDS: Hydrological Model, Blue Nile basin, Sediment Yield, SWAT & PED-W

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LIST OF ABBREVATIONS

ABA	Abbay Basin Authority
	ASTER Advanced Space borne Thermal Emission and Reflection
ASTER	Radiometer
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
DEM	Digital Elevation Model
EPIC	Erosion Productivity Impact Calculator
ENMA	Ethiopian National Metrological Agency
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
HBV	Hydrological Byråns Vatten balansavdelning
HEC HMS	Hydrologic Engineering Center‘s Hydrologic Modeling System
HUMS	Hydrologic Unit Model of the United States
HRUs	Hydrologic Response Units
HSPF	Hydrologic Simulation Program Fortran
HWSD	Harmonized World Soil Database
MoWIE	Ministry of Water, Irrigation and Electricity
MRS	Mean Relative Sensitivity
NSE	Nash Sutcliff Efficiency
PED-WM	parameter efficient semi distributed watershed model
95PPU	95% Prediction Uncertainty
R^2	Coefficient of Determination
RCA	Resource Conservation Act
RSR	Ratio of root mean square error
SRTM	Shuttle Radar Topography Mission
SSC	Suspended sediment concentration
SUFI-2	Sequential Uncertainty Fittings 2
SWAT	Soil and Water Assessment Tool
SWAT –CUP	Soil and Water Assessment Tool Calibration Uncertainty Program
UTM	Universal Transverse Mercator
WALRC	Water & Land Resource Center
WEPP	Water Erosion Prediction Project
WGEN	Weather Generator

LIST OF SYMBOLS

α	Recession Coefficient
NSE	Nash-Sutcliffe Efficiency(%)
O_i	Observed runoff at the i^{th} day (mm)
P	Daily Rainfall amount (mm)
Q_{or}	Surface Runoff from out rocked areas
Q_{st}	Surface runoff from saturated areas
R	Saturation Excess Runoff
R^2	Coefficient of determination
S	Water stored in the soil (mm)
S_l	Stream sediment load
S_i	Simulated runoff at the i^{th} day (mm)
Smax	Maximum soil storage capacity
$St\text{-}_{\Delta}t$	Previous time step soil water storage (mm)
τ^*	Duration of the period after the rainstorm until the interflow ceases

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1. INTRODUCTION

1.1 Background

Blue Nile River in Ethiopia contributes the significant flow and sediment to the Nile River and it is better to understand the hydrological processes, erosive losses and sedimentation mechanisms in the various watersheds in the headwaters of the Nile River. There is a need to improve and increase current resource management and development activities in areas with heavy degradation and low productivity, particularly in the Ethiopia (Steenhuis et al., 2009).

Especially, Blue Nile basin is experiencing increasing the human pressure due to rapidly growing population both in the Sudan and Ethiopia. This has already resulted in a number of environmental problems caused by the extensive exploitation of the resources (Garzanti et al., 2006).

Fast land-use changes from natural forest to farmland speeded up the soil erosion process. Erosion reduces soil fertility and agricultural productivity in the highlands and increases the sedimentation downstream. Eroded sediment particles are transported away by the flowing water and settle in reservoirs, the river channel and irrigation canals.

Estimating the sediment loads along the Blue Nile River is important for the proposed and existing dams along the Blue Nile, since this is necessary to obtain realistic quantifications of the sedimentation rates inside their reservoirs.

Whittington et al.(2014) identified that the major hydropower development sites of Blue Nile basin. One of them was the Grand Renaissance Dam at present under construction in Ethiopia 30km upstream of border with Sudan, will be largest hydroelectric power plant of Africa with the storage capacity of 74 billion m^3.

Once completed, the reservoir will receive all the sediment generated in the Ethiopian part of the Blue Nile catchment and physically-based (conceptual) water balance models are perhaps the most appropriate method for simulating Blue Nile stream flow and sediment concentration. The problems involved with developing even simplest models lie primarily in data availability.

Most established hydrological models are data intensive, yet the Blue Nile has limited rain gauge coverage, few long term temperature records, few gauged sub catchments and very scarce data (Conway, 1997).

At present, the first dam encountered by the Blue Nile sediment is Roseires, built in 1966 for irrigation and hydropower generation. It is located in Sudan110 km downstream of the border with Ethiopia. The design capacity of the reservoir was three billion m3 at its initial maximum impoundment level, but one third of this volume has already been lost due to sedimentation (Yasir et al., 2014).

The objective this study is to estimate the sediment evaluating capability of SWAT and PED-W models along the entire Blue Nile River network in the range of watershed size.
This is achieved by integrating the results of the physical based hydrological model; Soil and Water Assessment Tool (Arnold et al., 1998) with estimations based on data. It has already been applied on the number of Blue Nile sub basins. For instance, it was used to study soil erosion vulnerability in Lake Tana region and to predict the impact of climate change on hydro-climatology of the Lake Tana Basin (Setegn et al., 2011b).
White et al.(2011) was used the new water balance version of the model (SWAT-WB) to predict flow and soil erosion in the upper Blue Nile and previous studies focused on the hydrology of the Blue Nile basin and only a few of them addressed the sediment transport issue (Steenhuis et al., 2009).
However, recent studies indicated that both the infiltration and saturation excess runoff mechanisms. For the sediment transport runoff mechanisms are vital, thus evaluating both runoff mechanism models is critical.
Therefore, this study is undertaken to estimate the predicting capability of stream flow and sediment yield in the selected watersheds using spatially distributed SWAT and PED-W model. Performance model in simulating discharge and sediment outflow is evaluated using SWAT Calibration and Uncertainty Program (SWAT-CUP) and manually based on default value respectively.

1.2 Statement of the Problem

The poor land use practices, improper management system and lack of appropriate soil conservation measures have played a major role for causing land degradation problems in the country. High rate of surface erosion in Blue Nile basin and rate of sediment transport in the river system contribute to increase sedimentation problems in the Blue Nile basin and reservoirs as well as the downstream areas (Setegn et al., 2008). Blue Nile River, which originates from the steep mountains of an Ethiopian Plateau and the major source of sediment loads in the Nile basin. Soil erosion from the upstream of the basin and the subsequent sedimentation in the downstream area is immense problem threatening the existing and future water resources development in the Nile basin (Betrie et al., 2011).

Despite long term efforts to diminish the erosion in the Blue Nile basin, river sediment concentrations have not declined. Lack of progress on sediment reduction indicates that runoff and erosion processes are not fully understood and Soil erosion has been common for an extended period of time in the Blue Nile basin in the Ethiopian highlands. Blue Nile basin has an experienced severe degradation due to an intensive cultivation, deforestation, unwise utilization of land and water resources. Which, lead to the beginning of the soil erosion (Tilahun, 2012), as the soil storage is fundamentally important for the agricultural practice and has an influence on the rate of actual evaporation, ground water recharge and generation of sediment.

Therefore, this study evaluates the responses of soil, water availability and agricultural production to a range of the arid region variability of physical based watershed models capability of SWAT and PED-W on sediment evaluation, considering in the range of watershed sizes in Andit Tid, Temcha and Gumara watersheds, Blue Nile basin. So a due attention should be given to understand the current rate of Blue Nile basin sedimentation problem.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study is to evaluate predicting capability of SWAT and PED-W models for estimating sediment load in the AnditTid, Temcha and Gumara watersheds, in Blue Nile basin.

1.3.2 Specific objectives

- To calibrate and validate SWAT and PED-W models in the AnditTid, Temcha and Gumara watersheds.

- ➢ To evaluate the sediment prediction capability of SWAT and PED-W models in the AnditTid, Temcha and Gumara watersheds.

1.4 Research Questions

This study designed to answer the following research questions:

- ✓ Is it possible to verify the appropriate hydrological model that is suitable for discharge and sediment load prediction in Blue Nile basin?
- ✓Which hydrological model is capable for predicting stream flow and sediment load with watersheds scale?
- ✓ What is the highest predicating capability, among the selected hydrological watershed models?

1.5 Scope of the study

The scope of the study limited to evaluate the predicting capability of the physical based watershed models, specifically SWAT and PED-W for estimating sediment load and also understanding the current capacity of the sediment load and accumulation in the selected watersheds.

1.6 Significance of the study

Blue Nile basin is significant importance to Ethiopia concerning water resources aspects and the ecological balance of the area.

This study presents to the important preservation of the catchment against the undesirable effects of future accumulation of sediment that helps decision makers to take measures up on problems and prediction mechanisms to take action on upstream catchments safeguard and to get overall prosperity of the country**.** Hence, it is important for all water institutions and individuals understanding the rate of sediment deposition for further development of the water resources.

1.7 General Thesis Organization

The entire thesis is divided into five chapters and contents of each chapter are described as follows: The first chapter deals the background, problem statement, objectives, research question, scope and significances of the study. Chapter two describes reviewed literature related to this study and previous work in Andit Tid, Temcha and Gumara watersheds. Chapter three deals with the materials and methodology including description of the study, data collection and software used, data quality analysis, input data for SWAT and PED-W model, estimating the missing precipitation data, consistency and homogeneity of hydro meteorological data, determination of areal rain fall, PET and stream flow data analysis and the determination of sediment load vs discharge rating curve, sensitivity analysis of SWAT and PED-WM, calibration & validation and also model performance evaluation. The forth chapter focus on the result obtained in this study and discussion of the results. The brief presentation of various results from the whole study and discussion was given in this heading and also last fifth chapter presents general conclusions and recommendations of the study.

2. LITERATURE REVIEW

2.1 Hydrological Model

Model is defined as mathematical(physical)system obeying certain specified conditions, whose behavior is used to understand a physical, biological and social system to which it is analogous in some way(Bennett, 1974).

Hydrological models are indispensible tools to understand the natural processes occurring at the watershed and sub basin scales. The abundance of the computer-based models have been developed for applications in hydrologic modeling and water resources studies.

Hydrological models are used to simulate the stream flow and sediment concentration and also calculate water quality. Models generally came in to use in the 1960s and 1970s when demand for numerical forecasting water quality was driven by environmental legislations in USA. At this time, computers became more widely accessible and powerful enough to significantly assist in modeling processes.

There are numerous hydrological models and they can be grouped by pollutant addressed, complexity of pollutant sources, whether the model is steady state or dynamic and the time period modeled. Also important in determining the selection of model is whether it is distributed (capable of predicting multiple points within a river) or lumped. Simple models may only address a single pollutant; whereas complex model could have multiple runoff and point sources for pollution for more than one chemical as well as sediment data. It could further divide the channel flow in to strata in which various biotas are modeled in relation to chemical and sediment transport. The ground water component may also be presented in a model (Engel et al., 2007).

Moges et al.(2017) carried out on the watershed hydrological models can be categorized in several groups depending on its model structure, conceptualization and spatial-temporal resolution: i) empirical models: Genetic programming and Unit hydrograph, ii) conceptual models: HBV-IHMS, TOP Model, SWM, ARNO, iii) physically based; SWAT, MIKE-SHE, AGNPS, CREAMS, PED-W and iv) a hybrid combining two or more types i to iii.

Models often address the individual steps modularly in the simulation process. Typically subroutines for surface runoff include components for a land use and soil type, vegetation cover, topography and land management practice. There are many models that have been developed to simulate the sediments transport and discharge from the watershed as well as to predict impacts of the watershed management practices or land use changes on sediment transport. One of these models that includes Chemical, Runoff &Erosion from the management systems (Knisel, 1980) model to simulate the long-term impact of land management on water leaving the edge of a field developed by the USDA-Agricultural Research Service.

The predictions of the model are directly compared with measurements for two purposes. First most water Resource models include "free parameters," i.e. variables used in the mathematical formulation for which direct measurements do not exist. These can be estimated by adjusting their values until the resulting model prediction agrees with the measurements process referred to as model "calibration." On the other hand, the model is operated under the same external conditions as encountered during collection of a set of field data and model predictions compared to field measurements, without any adjustment of the model, to evaluate the performance of the model and process referred to as model "validation" (Ward and Benaman, 1999).

2.1.1 Hydrological and Soil Erosion Models

Many hydrological and soil erosion models are developed to describe hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling transformation of precipitation to the stream flow and transport of sediments. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. These models are focus on establishment of the relationship between various hydrological components such as precipitation, evapotranspiration, surface runoff, ground water flow and soil water movement (infiltration).

Many of hydrological models describe the canopy interception, evaporation, transpiration, snow melt, interflow, overland flow, channel flow, unsaturated subsurface and saturated subsurface flow. These models range from simple unit hydrograph based models to more complex models that are based on the dynamic flow equations.

Erosion modeling is based on understanding the physical laws of landscape processes that occurs in the natural environment. Erosion models can provide better understanding of natural phenomena such as the transport and deposition of sediment by overland flow and allowed for reasonable prediction and forecasting.

Many different models have been proposed to describe and predict soil erosion by water and associated sediment yield. They vary considerably in their objectives, time and spatial scales involved. On the basis of process description, hydrological models can be classified in to three main categories (Cunderlik, 2003).

I. Lumped Models: Parameters of lumped hydrologic models do not vary spatially within the basin and basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism.

II. Distributed Models: Parameters of distributed models are fully allowed to vary in space a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate influence of distribution on simulated precipitation runoff behavior. Distributed models generally require large amount of (often unavailable) data. However, governing physical processes are modeled in detail and if properly applied, they can provide the highest degree of accuracy.

III. Semi-Distributed Models: Parameters of the semi-distributed also called simplified distributed models are partially allowed to vary in space by dividing basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically based than the structure of lumped models and they are less demanding on input data than fully distributed models. Recent years distributed watershed models are increasingly used to implement alternative management strategies in the areas of water resources allocation, flood control, impact of land use change, climate change and finally environmental pollution control.

Most of the hydrological and soil erosion models share common base in their attempt to incorporate heterogeneity of the watershed spatial distribution of topography, vegetation, land use, soil characteristics, rainfall and evaporation.

2.2 Types of Rainfall-Runoff Models

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as function of space and time and deterministic and stochastic models based on the other criteria. Deterministic model will give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs. Devia et al.(2015) found out, the lumped models considered as the entire river basin is taken as a single unit. Whereas spatial variability is disregarded and outputs are generated without considering the spatial processes where as distributed model can make predictions that are distributed in space by dividing the entire catchment in to small units, usually square cells or triangulated irregular network, so that parameters, inputs and outputs can vary spatially. Another classification is static and dynamic models based on time factor. Static model exclude time. The study has been classified models as event based and continuous model and also the former one produce output only for specific time periods. One of the most important classifications is the empirical model, conceptual models and physically based models.

I. Empirical Models

These are also called metric models which are observation oriented models which take only the information from the existing data without considering the features and processes of hydrological system and hence these models are also called data driven models. It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment. These models are valid only within the boundaries. Unit hydrograph is an example of this method. Statistically based methods use regression and correlation models and are used to find the functional relationship between inputs and outputs. Artificial neural network and fuzzy regression are some of the machine learning techniques used in hydro informatics methods (Ansari, 2017).

II. Conceptual Methods

Conceptual model describes all of the component hydrological processes and they are also called parametric models. It consist number of interconnected reservoirs and represented by physical elements in a catchment and recharged by rainfall, infiltration and percolation and also emptied by evaporation, runoff and drainage. Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. Large number of meteorological and hydrological records is required for calibration. Calibration involves curve fitting which makes interpretation of difficulty and hence, effect of land use change cannot be predicted with much confidence. Many conceptual models have been developed with varying degree of the complexity. Stanford Watershed Model IV (SWM) is the first major conceptual model developed by (Crawford and Linsley, 1966) with 16 to 20 parameters.

III. Physically Based Models

This is the mathematically idealized representation of the real phenomenon. These are also called mechanistic models that include principles of physical processes. The hydrological processes of water movement are represented by finite difference equations. It does not require extensive hydrological and meteorological data for calibration but evaluation of large number of parameters describing the physical characteristics of the catchment are required (Abbott et al., 1986).

Physical model can overcome many defects of the other two models because of the use of parameters having physical interpretation. It can provide large amount of information even outside the boundary and can applied for a wide range of situations (Abbott et al., 1986).

Table 2. 1 Summary of rain fall runoff model characteristics (Nruthya and Srinivas, 2015)

Empirical model	Conceptual model	Physically Based model
Data based or metric or black box model	Parametric or grey box model	Mechanistic or white box model
Involve mathematical equations , derive value from available time series	Based on modeling of reservoirs and Include semi empirical equations with a physical basis	Based on spatial distribution, Evaluation of parameters describing physical characteristics
Little consideration of features and processes of system	Parameters are derived from field data and calibration	Require data about initial state of model and morphology of catchment
High predictive power, low explanatory depth	Simple and can be easily implemented in computer code.	Complex model. Require human computation capability
Cannot be generated to other catchments	Require large hydrological and meteorological data	Suffer from scale related problems
ANN, unit hydrograph	HBV model, TOPMODEL	SHE model, SWAT and PED-W
Valid within the boundary of given domain	Calibration involves curve fitting make difficult physical interpretation	Valid for wide range of situations.

Among the above mentioned table 2.1 models, physically based distributed model SWAT and PED-W are selected models for analyzing impacts of land management practices on water, sediment and agricultural chemical yields in the large complex watersheds.

2.2.1 Description of SWAT model

SWAT is the acronym for Soil and Water Assessment Tool; river, basin and watershed scale model developed by USDA-Agricultural Research Service (Arnold et al., 1998). It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large basins with varying soils, land use and management over long periods of time.

Mango et al.(2011) studied that water balance is driving force behind all the processes in model because it impacts plant growth and movement of sediments, nutrients, pesticides and pathogens. Simulation of the watershed hydrology is separated into the land phase, which controls amounts of water, sediment and pesticide loadings to the main channel in each sub basin and stream or routing phase, which is movement of water and sediments through the channel network of the watershed to the outlet.

Hydrologic cycle is climate driven and provides moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity controls water balance. SWAT can read these observed data directly from files or simulated data at runtime from observed statistics. Hydrologic processes simulation of SWAT model includes the canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow and redistribution of water in soil profile, consumptive use through pumping, return flow and recharge by seepage from surface water bodies. SWAT uses the Modified Universal Soil Loss Equation (Abbaspour et al., 2007) to predict sediment yield from the landscape. It allows the user to define management practices taking place in every HRU. Once the loadings of water, sediment, nutrients and pesticides from the land phase to the main channel have been determined, the loadings are routed through the streams and reservoirs within the watersheds.

Model equations are given in theoretical documentation (http://swatmodel.tamu.edu) and (Arnold et al., 1998; Gassman et al., 2007) presented an overview of: (1) climatic inputs and HRU hydrologic balance,(2)cropping, management inputs and HRU-level pollutant losses,(3) flow and pollutant routing. Arnold et al.(2010) described the current research on enhancements to SWAT to route water across discretized landscape units that simulate the impacts of spatial land use and land management on the hill slope-valley continuum.

Arnold and Fohrer (2005) SWAT model was developed for investigation of watersheds with surfaces going from few hundreds of Km² to several thousands of Km². Many parameters have been predefined according to United States data. Therefore it is necessary to adapt some values to local conditions to get realistic results. The basic spatial unit to the calculation is the HRU that is the result of the combination of soil type, class of land cover and sub-basin.

SWAT is the river basin or watershed-scale model developed to predict, the impact of land management practices on water, sediment & agricultural chemical yields on large complex watersheds with varying soils, land use and management conditions over long periods of time (Srinivasan and Arnold, 1994).

The model combines the empirical and physically-based equations, uses readily available inputs and enables users to study the long-term impacts. SWAT model is defined by eight major components; hydrology, weather, sedimentation, plant growth, nutrients, pesticides and land management.

Arnold et al.(1998) performed studies in large area hydrologic modeling and assessment of model development to predict impact of land management practices on water, sediment and agricultural chemical yields in large and complex watersheds with varying soils, land uses and management conditions over a long period of time.

Compared to the other physical based watershed modeling environment SWAT model has some unique features (Neitsch et al., 2005a).

- SWAT model is the process based rather than incorporating regression equations to describe the relationship between the input and output variables; it requires specific information about weather, soil data and land management practices occurring in the watershed.
- SWAT uses readily available input data and it can be used to study more specialized processes such as bacteria transport, the minimum data required to make a run such as weather and spatial data.
- SWAT is computationally efficient and could simulate very large basin or a variety of management strategies can be performed without excessive investment of time.
- SWAT enables users to study long-term impacts and many of the problems currently addressed by users involved the gradually build-up of the pollutants and impacts on downstream water bodies.

2.2.1.1 Previous Applications of SWAT model

Applications of SWAT model have expanded worldwide over the past decade (Gassman et al., 2007). Many applications have been driven by the needs of the various government agencies, particularly United States & European Union. These applications were done for

assessments of anthropogenic, climate and other influences on a wide range of the water resources assessments of model capabilities for potential future applications.
The performance of SWAT model to some extent can be affected by the resolution of the time series dataset used in calibration and validation of model. In general, SWAT model is known to perform well with monthly data compared to daily data (Jeong et al., 2010).

At present time over 250 peer-reviewed, published articles have been identified that report SWAT applications, reviews of the components and articles are summarized in to relevant application categories such as flow calibration and related hydrologic analysis, the climate change impacts on hydrology, pollutant load assessment, comparisons with other models and sensitivity analysis and calibration techniques(Gassman et al., 2007).

Ayana et al.(2012) performed the studies on simulation of sediment yield using SWAT model in Fincha Watershed, Ethiopia. The model was calibrated using a time series data set of 22 and estimated monthly sediment yield with R^2value of 0.82 and NSE value of 0.80 during calibration and R^2value of 0.80 and NSE value of 0.78 during the validation period. The result of the study showed that the model adequately predicted the sediment yield from the study watershed with high performance.

Soil and water assessment tool historical development, applications and future research directions were given by Douglas-Mankin et al.(2010) model was developed primarily for long time (two years and above) simulations. But, this didn’t prevent the researchers from applying model to short simulation periods less than one year and also having much longer period of daily flow record for both calibration and validation likely would have resulted in better comparisons between recorded and simulated daily flows, because longer record would not be affected by a few high values of discharge.

Application of SWAT model to at data scarce tropical complex catchment was carried out in the Tanzania (Ndomba et al., 2008). The result showed that the model can be used in ungauged catchments for identifying hydrological controlling parameters. The study also showed that length of the period of simulation affects the result i.e. the longer the period, the more reliable the result.

Setegn et al.(2008) carried out the hydrological modelling in Lake Tana Basin, Ethiopia using SWAT model was well performed in simulating the daily runoff from the watershed with the value of Nash-Sutcliffe efficiency coefficient of 0.55 and 0.68 for calibration and validation period respectively. Therefore, the study further suggested that using processed, adequate and reliable spatial rainfall data and relatively long flow records for SWAT model calibration can improve the performance, fully distributed SWAT model.

Easton et al.(2010) performed studies on the analysis of runoff and sedimentation in Blue Nile basin using a multi basin SWAT model and found out result was an incapable of realistically model the gully erosion and also the study showed that the model was under predicted sediment from a basin in gully erosion is high.

2.2.1.2 SWAT-CUP

The objectives of SWAT Calibration and Uncertainty Procedures are:

- ✓ Integrate various calibration or uncertainty analysis procedures for SWAT in one user interface
- ✓ Make the calibrating procedure easy to use for students and professional users
- ✓ Make the learning of the programs easier for the beginners
- ✓ Provides time consuming calibration operations and standardized calibration steps and
- ✓ Add extra functionalities to calibrate operations like creating graphs of calibrated results of data comparison (Yang and Abbaspour, 2007).

SWAT-CUP was designed for integration of various calibration and uncertainty analysis programs for SWAT using different interface. Study was conducted considering different SWAT parameters related to the discharge and sediment through SUFI-2 technique. This optimization technique uses the range of parameters as constraints and model evaluation coefficients as Objective Functions (OF) during calibration.

The multiplicative form of the square error (mult), summation form of the square error (sum), Coefficient of determination (R^2),Nash and Sutcliffe (1970),Chi-squared $\chi 2$ (Chi2), Coefficient of determination R^2multiplied by the j of the regression line (br2) and sum of square of residual (SSQR).

Each SWAT-CUP project contaminated one calibration method and allows running the procedure many times until convergence is reached. It allows saving calibration iterations in the iteration history for later use. Sequential uncertainty fittings (SUFI-2) is automated model calibration requires that the uncertain model parameters are systematically changed the model is run and required outputs are extracted from model output files.

2.2.2 Description of PED-W model

PED-W model is the physically based runoff and sediment loss model having a minimum calibration parameters based on saturation excess (i.e. runoff is generated when the soil becomes saturated) runoff process.

PED-W is a simple hydrology and erosion model, which was developed by (Steenhuis et al., 2009; Collick et al., 2009) using saturation excess runoff principles and interflow processes appropriate for a monsoonal climate and a mountainous landscape. The model was validated in Abay(Blue Nile basin),Ethiopia for predicting discharge and sediment.

PED-W model has been applied to catchments ranging from small catchment such as in Anjeni (1.1km^2) by (Tilahun et al., 2013a),Andit Tid(4.8km^2) by (Engda et al., 2011) and Debere Mawi (0.95km^2) by (Tilahun et al., 2013b;Tilahun et al., 2015) to large catchment area like in Blue Nile,180,000km^2). The model is classifies the watershed into two runoff producing areas (saturated areas and degraded hill slopes) and remaining is recharge area (permeable hill slopes) that releases excess precipitation, the base flow and inter flow and the two runoff producing areas are assumed to be sources of sediment, while the base flow may pick up the sediment at low concentrations from banks and the schematic of model is as shown in figure 2.1.

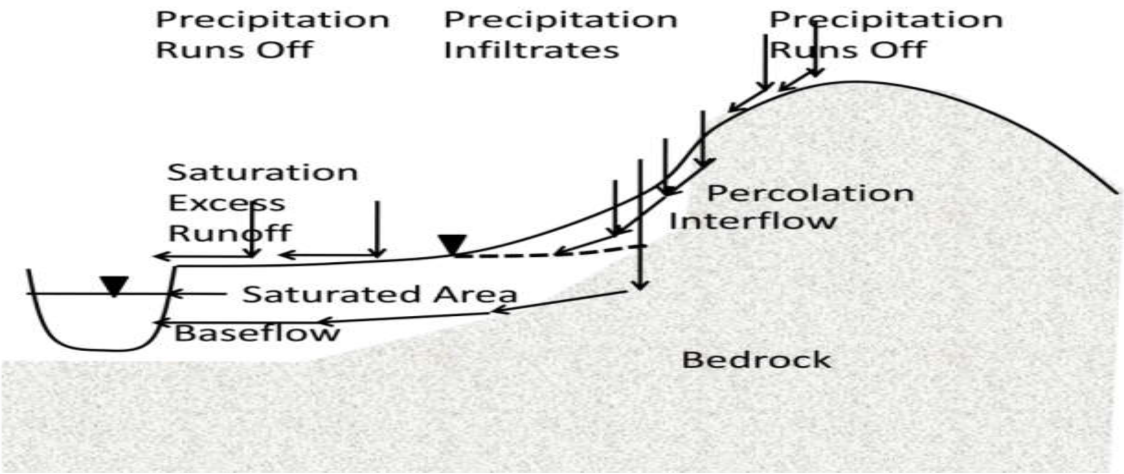


Figure 2. 1 Schematic representation of the hydrology model (Steenhuis et al., 2009)

2.2.2.1 Previous Studies using PED-W model

The saturation excess erosion model (Steenhuis et al., 2009; Collick et al., 2009),were performed for predicting discharge and erosion for the Blue Nile basin to develop a simple hydrology and erosion models using saturation excess runoff principles and interflow processes appropriate for monsoonal climate and mountainous landscape. They develop model using a water balance approach by dividing the landscape into variable saturated areas, exposed rock and hill slopes.

A simple distributed saturated excess hydrology model were applied to improve sediment concentration prediction in the Anjeni watershed the subhumid Ethiopian Highlands and it predicts surface runoff from bottom lands that become saturated during the rainy season and from degraded lands and interflow and base flow from the remaining portions of the landscape (Tilahun et al., 2013a) and the study found that NSE ranging from 0.64–0.77.

Tilahun et al.(2015) studied that the applicability of PED-W modeling on the distributed discharge and sediment concentration predictions in sub-humid Ethiopian highlands, in Debre Mawi watershed. The study suggested that distributed storm runoff and sediment concentration of the model were well simulated and also found out NSE values for daily storm runoff for outlet and sub-watersheds ranged from 0.66 to 0.82 and NSE for daily sediment concentrations were greater than 0.78.

Zimale et al.(2018) was carried out for investigation of budgeting suspended sediment fluxes in tropical monsoonal watersheds in the Lake Tana basin using PED-W model for developing a prototype quantitative method with limited observational data. The model has shown to perform well in the Ethiopian highlands is used to overcome the limitations of data scarcity and the result showed that 34t $ha^{-1}yr^{-1}$ sediment load was removed from the gauged part of the Lake Tana basin watersheds.

2.3 Hydrological Model Selection Criteria

Hydrological models are mathematical formulations which determine the runoff signal which leaves watershed basin from the rainfall signal received by this basin. They provide a means of quantitative prediction of catchment runoff that may be required for efficient management of the water resources. Such hydrological models are also used as means of extrapolating from those available measurements in both space and time into the future to assess the likely impact of future hydrological change.

Changes in global climate are believed to have significant impacts on local hydrological regimes like; stream flow and sediment concentration, which supports aquatic ecosystem, navigation and irrigation system.

Many comprehensive spatially distributed hydrologic models have been developed in the past decade due to advances in hydrologic sciences, Geographical Information System and Remote Sensing. Among many hydrological models developed past decade; SWAT model was developed by (Arnold et al., 1998) and has been used extensively by researchers due to:

- ✓ Uses readily available inputs for weather, soil, land and topography
- ✓ Allows considerable spatial detail for basin scale modeling and
- ✓ It is capable of simulating changes in catchment scale using different scenarios.

SWAT was recognized by the United States Environmental Protection Agency and has been incorporated into the EPA's BASINS, Better Assessment Science Integrating Point and Nonpoint Sources (Cunningham et al., 2009).

In order to optimally calibrate model parameters, especially for the large-scale modeling, an auto-calibration routine has been added to SWAT (Mukundan et al., 2010). Hence, it was used in this study to simulate evaluation of sediment capability in watershed size in different arid region of the Blue Nile.

Hydrological practice would improve if models were objectively, chosen on the basis of making the best use of information available and following some systematic procedure of selection and verification (Reid and Nygren, 1988). The choice of the best model depends on the large extent of the problem. Generally, speaking and item that should be considered in the selection process (Tripathi et al., 2004) are:

- ✓ The nature of the physical processes involved
- ✓ The use to be made of the model
- ✓ The quality of the data available and
- ✓ The decisions that rest on the outcome of the model's use.

Several models may be capable of describing the same process and great extent; selection of the one to be used depends on comparison of sampled data and model output. In model selection, decisions that may depends on outcome of the model‘s use must be considered. To a great extent, these decisions will dictate the criteria that should be used to judge the quality of the models performance.

SWAT is physically based and can model ungauged watersheds that have no monitoring data and can quantify impact of changes in management practices (White et al., 2011). In addition to abovementioned models predicting capability of sediment load in the selected watersheds the following criteria were considered by (Gassman et al., 2007) for selecting a type of model to be used:

- ✓ Applicability over large catchment sizes
- ✓ Ability to simulate stream flow and sediment
- ✓ Continuity and spatial distribution
- ✓ The output is in daily, monthly and yearly values
- ✓ The model able to use data from various global databases, measured data and
- ✓ The model is readily and freely available

Based on the above selection criteria models were selected for detail analysis of evaluating stream flow and sediment prediction capability of the study. Even though the above listed criteria of model selection all may not satisfy for PED-W model.

Moreover, with the development of Geographic Information Systems and Remote Sensing techniques, the hydrological models have been more physically based and distributed to enumerate various interactive hydrological processes considering spatial heterogeneity. Hence, ability of the hydrological model to integrate GIS for hydrologic data development spatial model layers and interface may be considered as model selection criteria.

2.4 Performance Evaluation of Hydrological Models

Hydrological models have different behavior and performance, which depends on runoff generation mechanism. In the SWAT, model the main direct runoff generation is based on infiltration excess referred to as hortonian runoff (Horton, 1933) and could predict better monthly discharge and sediment load as compared to the daily time step and was not capable of locating the runoff source areas in the valley bottom. But, in case of PED-WM (semi distributed saturation excess runoff model) was relatively accurate in predicting the discharge and sediment at the outlets of the watersheds.

Tilahun et al.(2015) demonstrated that applicability of PED-W model was not only at the out let of the watersheds. But, also for predicting both distributed discharge and sediment concentration predictions in the sub humid Ethiopian highlands in Debre Mawi watershed. The difference in the magnitude of the total contributing rainy monsoon phase and then increased when the watershed became more and more saturated.

The uniqueness of the present study was evaluating the capability of hydrological models for predicting sediment concentration in the range of watersheds size and considering the driving factor such as rain fall distributions over the selected watersheds as well as the Blue Nile basin. However, other similar studies were investigated as the evaluation of both models performance’s for prediction of discharge and sediment concentration on single and micro watersheds.

2.5 Previous Study in the Blue Nile Basin

Hurni(1993) investigated that the World Soil Erosion and Conservation effects on Land degradation, famine and land resource scenario in Ethiopian highlands may reach as high as 200-300 t $ha^{-1}yr^{-1}$. The study presented by the United States department of the interior, bureau of reclamation in1964 is named as study of land and water resource of the Blue Nile basin and at this time there was no enough the available data recorded. This study was conducted at reconnaissance level mainly done to identify the considerable potentials for irrigation and hydropower in both Tana and Beles basins.
Surface and subsurface flow effect on permanent gully formation and upland erosion near Lake Tana in the northern highlands of Ethiopia, reported soil losses vary from 1to over 400 t $ha^{-1}yr^{-1}$ (Tebebu et al., 2010).

Wudneh(2012) studied that the SWAT model on the characteristics and onsite costs of the sediment lost by runoff from Dapo and Chekorsa watersheds, amount of sediment yield delivered at Ethio-Sudanese boarder from upper Blue Nile was estimated to be 62 Million ton per year. Another study conducted by Ashagre (2009) was applied to identify the watershed management Options in Anjeni Watershed, Blue Nile Basin. The study found out the estimated sediment loss of 16-50 t $ha^{-1}yr^{-1}$ from the Ethiopian highlands.

Setegn et al.(2008) performed that modeling on the hydrological water balance to test the performance and feasibility of the SWAT model for prediction of stream flow in the Lake Tana Basin. The study made modeling of four tributaries of Lake Tana and found out the model gives good agreement with observed and simulated discharge.

Awulachew et al.(2009) conducted the review of hydrology, sediment and water resource use in the Blue Nile basin using SWAT model. The study used regionalization techniques to transfer parameters from gauged catchment to ungauged catchments and evaporation from the Lake surface was estimated using Penman combination equation.

Tenaw and Awulachew(2009) were investigated on the runoff and sediment yield using SWAT model in case of the Gumera watershed in the Lake Tana subbasin to imprve water and land management in the Ethiopian highlands. And also its impact on the downstream stakeholder dependent on the Blue Nile basin. The study that showed that about72% of the erosion potential area with annual sediment load ranging from 11 to 22 t ha^{-1}yr^{-1}exceeding tolerable soil loss rates of Ethiopia.

Betrie et al.(2011) studied on the sediment management modeling in the upper Blue Nile basin using SWAT model under different Best Management Practice scenarios. The study found out that sedimentation was immense problem that has threatened water resources development in the Blue Nile basin, in the Eastern Nile (Ethiopia, Sudan and Egypt).

Wosenie et al.(2014) investigated on the analyzing runoff processes through conceptual hydrological modeling that runoff presumed impermeable areas were modeled in the upper Blue Nile basin by conceptual hydrological models (SWAT and FlexB model were the benchmarks as compared to Wase-Tana) for infiltration excess (Hortonian flow) runoff and soil surface.

3. MATERIALS AND METHODOLOGY

3.1 Description of the Study Area

Blue Nile basin at the border with Sudan covers an area of approximately 180,000 km^2 and tributaries drain a large proportion of central, western and south western highlands of Ethiopia. The Blue Nile basin is characterized by the rugged topography and considerable variation of altitude ranging from about 500m to4250m above mean sea level in Ethiopian highlands (Steenhuis et al., 2009;Yasir et al., 2014) during the evaluation of the Sediment Blue Nile basin, found out that mean annual temperature varies with the altitude in upper Nile basin from 6°C to28°C and daily temperatures ranges from 14 to 44°C in Sudan.

The most dominant soils in Blue Nile basin were Vertisols, Luvisols and Leptosols (FAO, 1995) and basin was dominated by wooded grassland and natural forests in and also it was dominated by rain fed cropland (Gebremicael et al., 2013). The study is conducted in the Blue Nile basin specifically in the Andit Tid, Temcha and Gumara watersheds as shown in figure 3.1.

Andit Tid Watershed is located in 9°48’00" & 9°48’00"N latitude and 39°43’00" and 39°43’00" E longitude. Elevation ranges from 2996m to 3439m above mean sea level and the mean annual rain fall is 1489.87mm. It covers a total area of 4.84km^2(484ha).

It is situated 180 km northeast of Addis Ababa. Hill slopes are very steep and degraded, resulting in 54% of the long-term precipitation becoming runoff (Engda et al., 2011).

Temcha Watershed is located in 10°29'00" & 10°45' 00" N latitude and 37°31'00" and 37°51' 00" E longitude. The elevation ranges from 2022m to 4084m above mean sea level and mean annual rain fall is 1410.33mm. It area coverage is 410.09km^2(41009ha).

Temcha is about 345km far from Addis Ababa to the North West and 285 km from the regional city, Bahir-Dar. Study area is found in side of West and Eastern part of Gojjam (Assefa et al., 2010).

Gumara Watershed is located in 11˚34'00"N & 11˚55'00"N latitude and 37˚40'00"E & 38˚12'00" E longitude. The elevation ranges from 1769m to 3683m above mean sea level and mean annual rain fall is 1466.97mm. The mean annual temperature is about 18.92^0C, where as monthly min temperature is 9.39^0C in December and max temperature is 29.03^0C in April. It covers a total area of $1270.75km^2$(127075.4ha). Gumara watershed is located in the eastern part of Lake Tana sub basin.

The selected watersheds are located in the Blue Nile basin map in the range of the scale of watershed size Andit Tid ($4.84km^2$), Temcha ($410.09km^2$) and Gumara ($1270.8km^2$) as described in the figure 3.1.

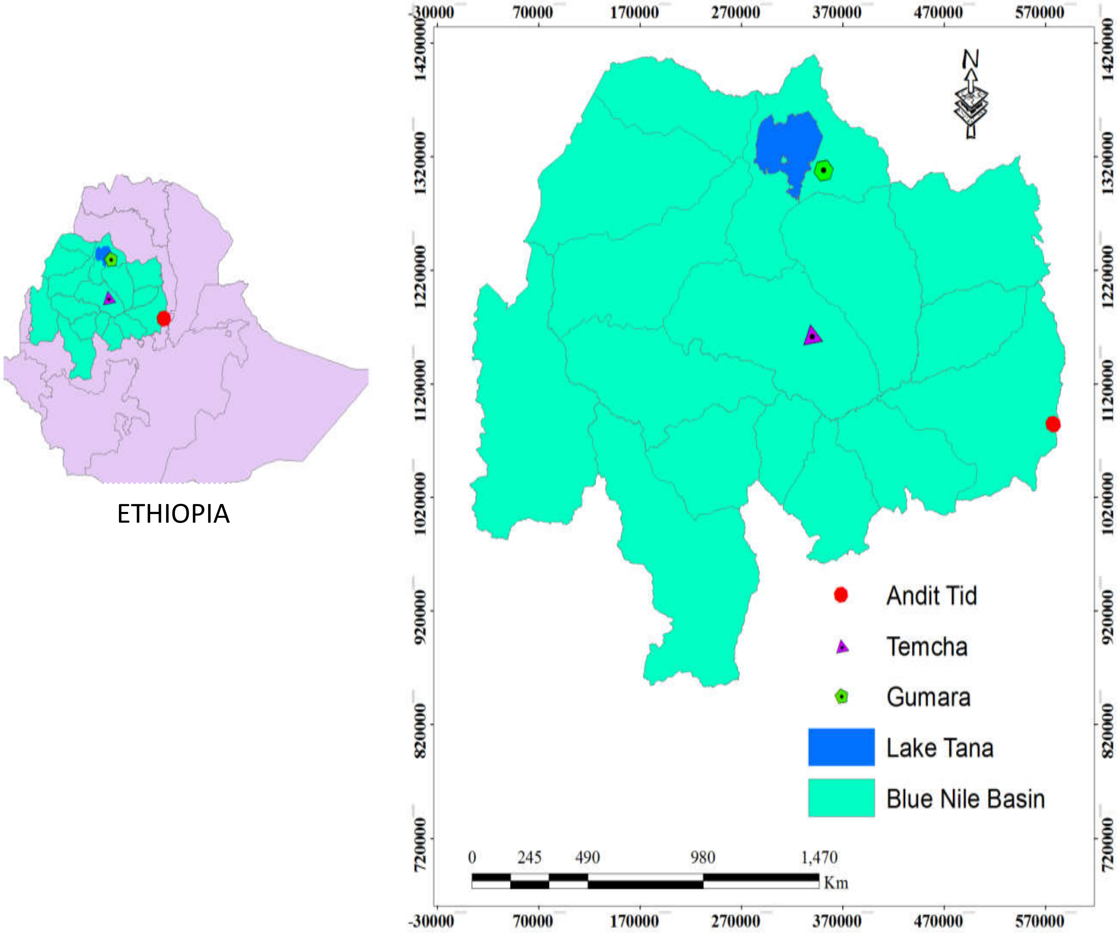


Figure 3. 1 Location Map of the study Area

Table 3. 1 Summery of the Study Area description

No.	Catchment Characteristics	Andit Tid	Temcha	Gumara
1	Area(km^2)	4.84	410.09	1270.75
2	Latitude(°)	9°48’00"-9°48’00"N	10°29'00"-10°45'00"N	11˚34'00"-11˚55'00"N
3	Longitude(°)	39°43’00"39°43’00"E	37°31'00"- 37°51'00"E	37˚40'00"-38˚12'00" E
4	Elevation(m)	2996 -3439	2022-4084	1769- 3683

3.2 Materials and Data Used

3.2.1 Data Collection and soft ware used

Arc Map 10.1 interfaces with Arc SWAT 10.1 was used for different map preparation and simulation of outputs. PED-W is simple hydrologic model used for simulation of flow and sediment results, digital elevation model (DEM) is required for watershed delineation, soil and land use data are important to define hydrologic response unit (HRU), discharge was used to generate the sediment data by discharge vs sediment load rating curve, calibration and validation, Swat-Cup was used for automatic calibration purpose and Microsoft office 2007 is used to build up every documentation process and they were provided in table 3.2.

Table 3. 2 Summary of different data and soft ware source

No	Types of data	Source of data	Uses
1	Meteorological Data	Ethiopian meteorological Agency(ENMA)	Input for SWAT and PED-W models
		Water and Land Resources Center(WALRC)	Input for SWAT and PED-W Models
2	Discharge and Sediment	MoWIE, Abbay Basin Authority(ABA)	For SWAT and PED-W Model Calibration and Validation
3	ASTER DEM(30m*30m)	http://www.earthexplorer.usgs.gov/	For SWAT Model, automatic Watershed Delineation
4	Soil &Land use/cover	MoWIE	For SWAT HRU Definition
5	WXGEN	http://www.swat.tamu.edu/	To generate weather data and fill the missed data
6	SWAT-CUP	http://www.swat.tamu.edu/	For calibration and validation

3.2.2 Data Quality Analysis

Rough rainfall data screening of the metrological stations in the study area was first done by visual inspection of daily rainfall data. Because of long breaking the rainfall records of some stations, it was necessary to fill all the missed values in the recording stations for the years of 2000 to 2015. After initial screening was completed all meteorological data and is subjected to detail hydrologic screening to check the data quality against different indexes.

Estimating the missing data

The data were missed from the particular gauging station or representative precipitation is necessary at the points of the interest. There are different methods for filling the missing data, from the methods arithmetic mean, normal ratio and distance power methods.

$$\%\text{Difference} = [\frac{Nx-Ni}{Nx}] \quad 100 \tag{3.1}$$

Nx–Ni must be positive. If Ni > Nx the numerator will become Ni – Nx. Then, the mean of the nearby stations differences is determined.

I. Arithmetic Mean Method

Arithmetic mean can be used when the annual normal rainfall of the neighboring stations varies within 10% of the rainfall of station to be modeled (Kim and Ryu, 2016).

If the normal annual precipitations at the adjacent stations are within 10% of the normal rainfall of the station under consideration, then the missing rainfall data may be estimated as simple arithmetic average of the rainfalls at the adjacent gauges. Thus, if the missing precipitation at station X is Px and P_1, P_2..., Pn are the rainfalls at the n surrounding stations (Radi et al., 2015).

$$P_x = \frac{1}{n}(P_1 + P_2 + \quad + P_n) \tag{3.2}$$

II. Normal Ratio Method

Normal ratio method is used when variation of normal annual rainfall of the surrounding stations exceeds 10% of the values of the station under consideration (Derib, 2015). In this method, the rainfall values at surrounding stations are weighted by the ratio of the normal annual rainfalls. The general formula for computing P_X is as follows:

$$P_x = \frac{1}{m} \quad \left[\left(\frac{N_x}{N_1}\right) \quad P_1 + \left(\frac{N_x}{N_2}\right) \quad P_2 + \quad + \left(\frac{N_x}{N_m}\right) \quad P_m\right] \tag{3.3}$$

Where, N_x is the normal annual rainfall at station X and N_1, N_2….. N_m, are the normal annual rainfalls at the m surrounding stations respectively.

In the present study mean daily rainfall values have been determined and the missing daily rainfall data have been filled using Simple Arithmetic mean and Normal Ratio methods. Graphical comparison of the rainfall data done by creating time series plotting of monthly rainfall data for the selected watersheds to know periodic patterns are described in the following (Figure 3.2 to 3.4). Rainfall detail data used in the model was given in (annex IA and IIB) for Temcha and Gumara watersheds respectively.

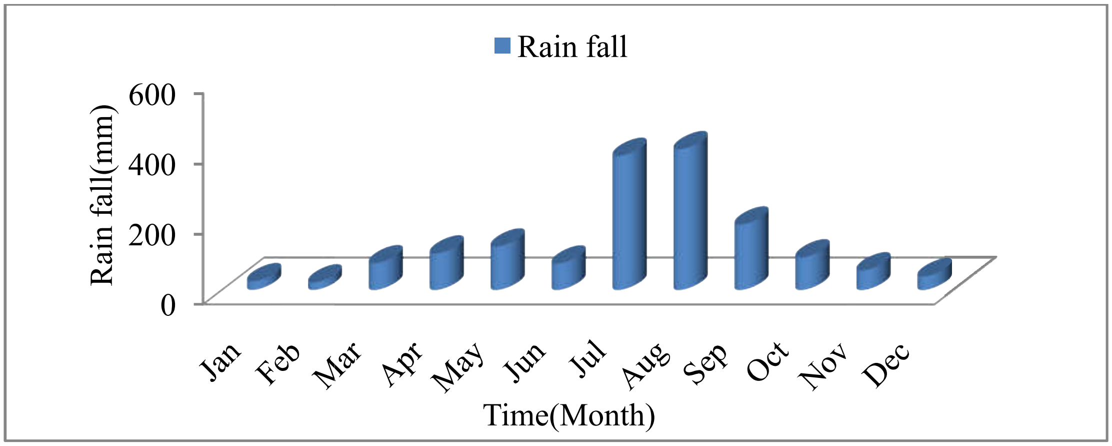


Figure 3. 2 Average Rainfall (mm/month) of Andit Tid Watershed (2000-2015)

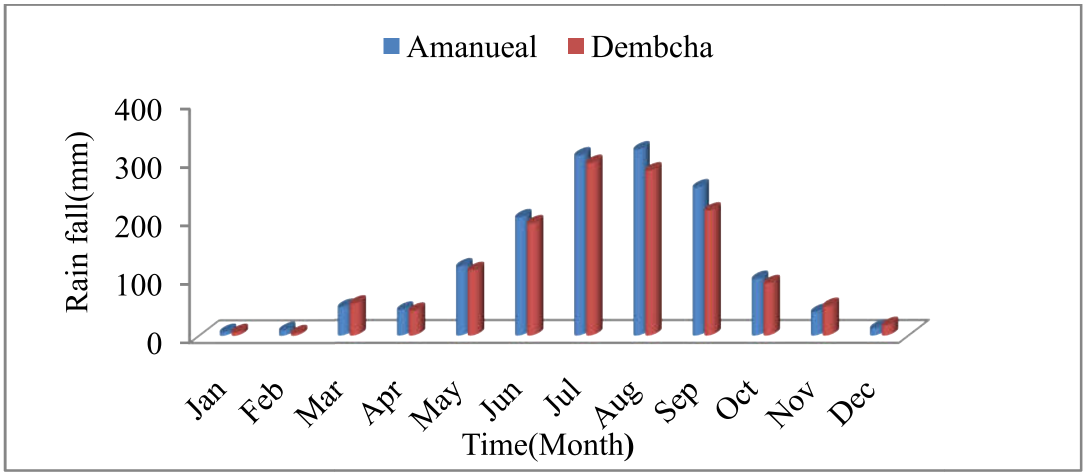


Figure 3. 3 Average Rainfall (mm/month) of Temcha Watershed (2000-2015)

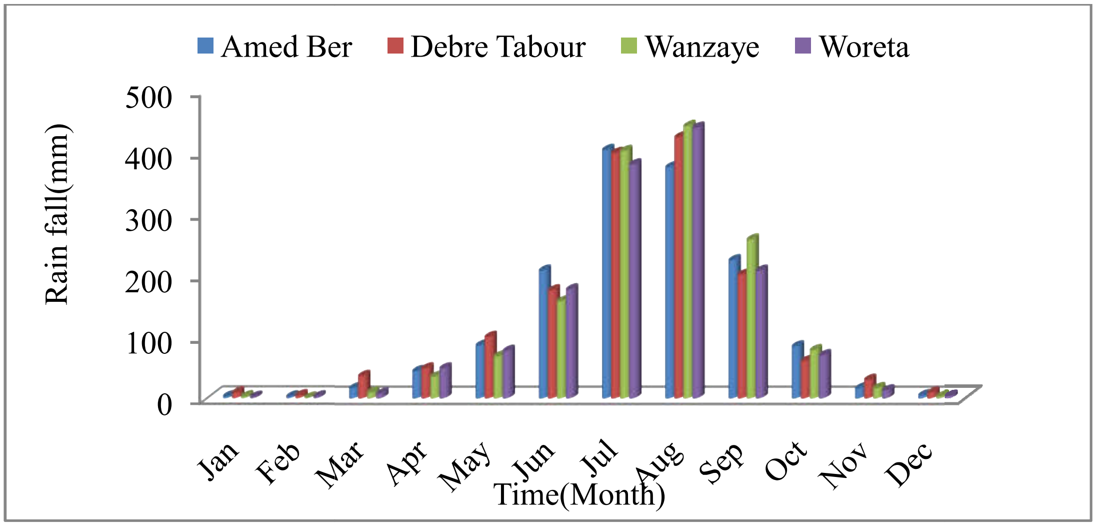


Figure 3. 4 Average Rainfall (mm/month) of Gumara watershed (2000-2015)

Consistency and Homogeneity of Hydro meteorological Data

Double mass curve was used to check consistency for rainfall adjustment of inconsistent data. It is based on the principle that each recorded data comes from the same parent sample, if so they are consistent. Group of base stations in the neighborhood of station was selected. It was a graph of cumulative each at rain gage of interest versus the cumulative each of one or more rain gauges in the region that has been subjected to similar hydro meteorological occurrences and is known to be consistent. Double mass curve is a simple, visual, practical method and it is widely used in the study for consistency and long-term trend test of hydro meteorological data (Gao et al., 2011).

If a rainfall record was consistent estimator of the hydro meteorological occurrences over period of record. The curve is determined by plotting the cumulative values of observed time series of station, for which consistency and homogeneity need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x-axis and station affected by trend a break in slop of curve would indicate that conditions have changed that location.

If the data series is inconsistent and non-homogenous, it should be adjusted to consistent and homogenous. The proportionality for the stations to be adjusted for consistency and homogeneity was done using equation developed by (Searcy and Hardison, 1960).

$$P_a = \frac{b_a}{b_o} \quad P_o \qquad 3.4$$

Where, P_a is the adjusted Precipitation, Po is Observed Precipitation, Ba is Slope of graph to which records are adjusted and bo is Slope of graph at time Po was observed

After the precipitation data was checked for quality and the appropriate station selected the statistical parameters of precipitation data for synoptic stations must be calculated before model set up and the detail computation for one of the selected Gumara watershed were given in annex IIIC.

Weather Generator

Neitsch et al.(2005b) and Arnold et al.(2005) SWAT includes WXGEN weather generator model to generate the weather data or fill missed measured records. Weather generator was developed for the continuous U.S. If the user prefers a different weather generator daily input values for different weather parameters may be generated with an alternative model and formatted for input to SWAT**.**

Daily values for weather are generated from average monthly values. Model generates a set of weather data for each sub basin will be generated independently and there will be no spatial correlation of generated values between different sub basins (Allen et al., 1998).

Average daily dew point temperature was calculated using dew point 02 calculator (Sime, 2009) from daily max. & min. temperature and average relative humidity and also solar radiation were calculated from the daily available sunshine hours. Location and weather generator data formatting of one of the selected watershed is provided in table 3.3.

Table 3. 3 Gumera watershed meteorological station locations and weather data

Stations Name	Latitude	Longitude	Elevation	Rain Fall	Max Tmp	Min Tmp	Solar Radiation	Wind Speed	Relative Humidity	Sun Shine Hour
Debre Tabour	38.00	11.87	2612	√	√	√	√	√	√	√
Amed Ber	37.89	11.91	2051	√	√	√				
Wanzaye	37.68	11.78	1850	√	√	√				
Woreta	37.70	11.92	1819	√	√	√				

3.3 SWAT Input Data

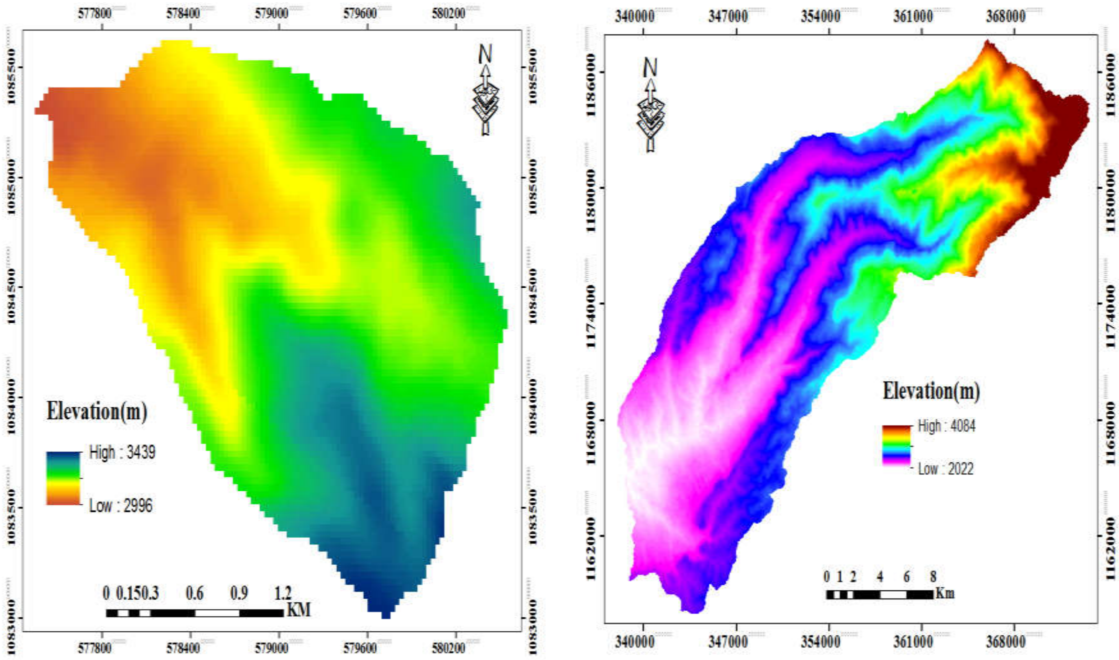
Spatial data needed for SWAT model interface includes; Digital Elevation Model (DEM), Soil data and land use. Data on the weather, stream flow and Sediment concentration were also used for calibration and validation purposes.

3.3.1 DEM Data

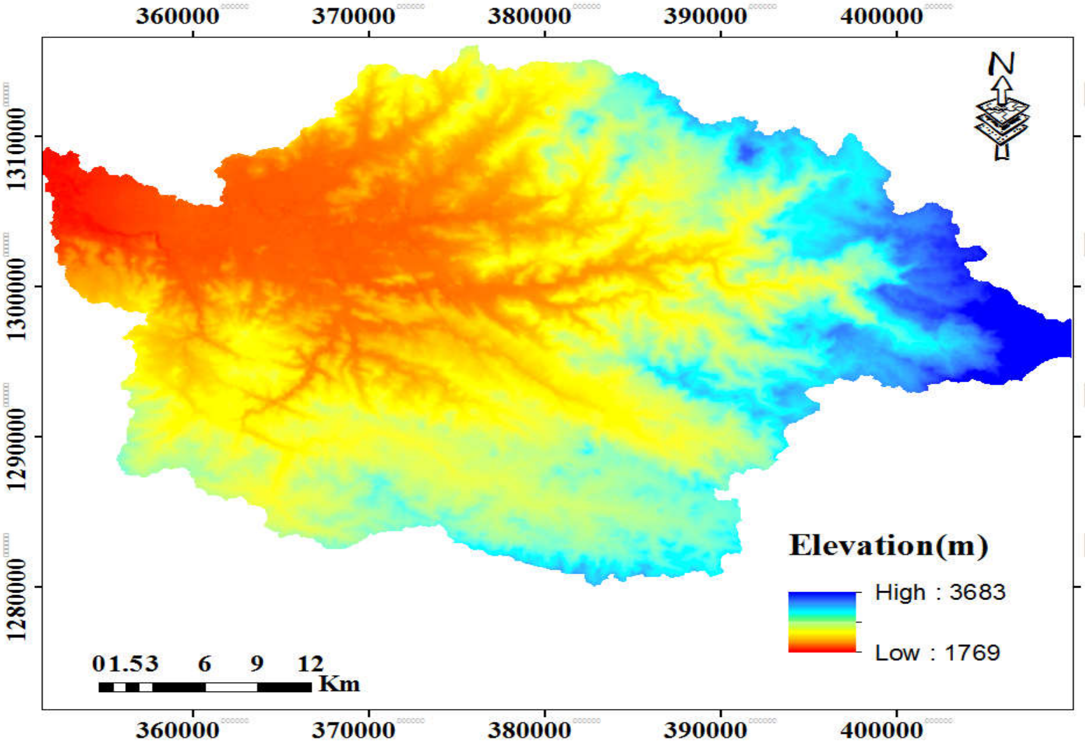
There are two publicly available DEM dataset; SRTM (Shuttle Radar Topography Mission and ASTER GDEM (Advanced Space borne thermal Emission and Reflection Radiometer Global-DEM). ASTER GDEM has30m resolution compared to 90 m resolution in SRTM DEM (Tachikawa et al., 2011) and is better for mountainous terrain than SRTM.

ASTER-GDEM was downloaded from (http://www.earthexplorer.usgs.gov/) and used for analysis of the selected watershed delineation.

DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain and generate topographic wetness index. Sub-basin parameters such as slope and the stream network characteristics such as slope, length and width were derived from the DEM. The created elevation maps of the selected watersheds are described in the figure 3.5.



a) Andit Tid b) Temcha



c) Gumara

Figure 3. 5 Elevation Maps of the study

3.3.2 Soil Data

The soil data was provided form MoWIE. Even though, data is obtained there, I was try to investigate soil type using the harmonized world soil database (HWSD)-Viewer tool to visualize the soils on the selected watersheds and the way visualization of HWSD was given in annex VIE.

3.3.3 Land Use and Land Cover Map

It is the most important factors that affect surface erosion, runoff and evapotranspiration in the watershed. Land use map of study was obtained from Ministry of Water, Irrigation and Electricity (MoWIE).

Major land cover types of Gumara were dominantly cultivated lands (63.2%), Moderately Cultivated land (31%),Grass land (3.2%),Forest(0.36%),Urban and Built-Up (0.063%) and Water Body (0.059%)(Mamo and Jain, 2013).

3.3.4 Hydrological Response Units (HRU) Analysis

Model requires the land use, soil and slope data in order to determine the study area and hydrologic parameters of each land use and soil category simulated in each sub watershed.

Model allowed a maximum of five different ranges of slope to define HRUs discretization. Ranges were designated such as similar basin area fits within each slope interval, looking for the change in the input. This analysis was applied to limit the number of parameters required to obtain a good fit between simulated and measured data. Hence, number of free parameters to be adjusted could be considerably reduced (Eckhardt and Arnold, 2001).

Setegn et al.(2008) carried out hydrological modelling in Lake Tana Basin, Ethiopia using SWAT model and study justified that HRU definition with multiple option accounts 10% land use,20%soil and10% slope threshold combination gives a better estimation of runoff and sediment components. Therefore, HRU definition with multiple options that accounts for10% land use, 20% soil and10% slope threshold combinations were used for this study. Hence, 20, 29 and 184 HRUs threshold combinations were created for Andit Tid, Temcha and Gumara watersheds respectively.

Reclassified land use, major soil and slope distribution SWAT model HRU distribution and map of the selected watersheds were described in table 3.4 to 3.12 and figure 3.6 to 3.8 as follows:

Table 3. 4 Reclassified land use and land cover for Andit Tid watershed

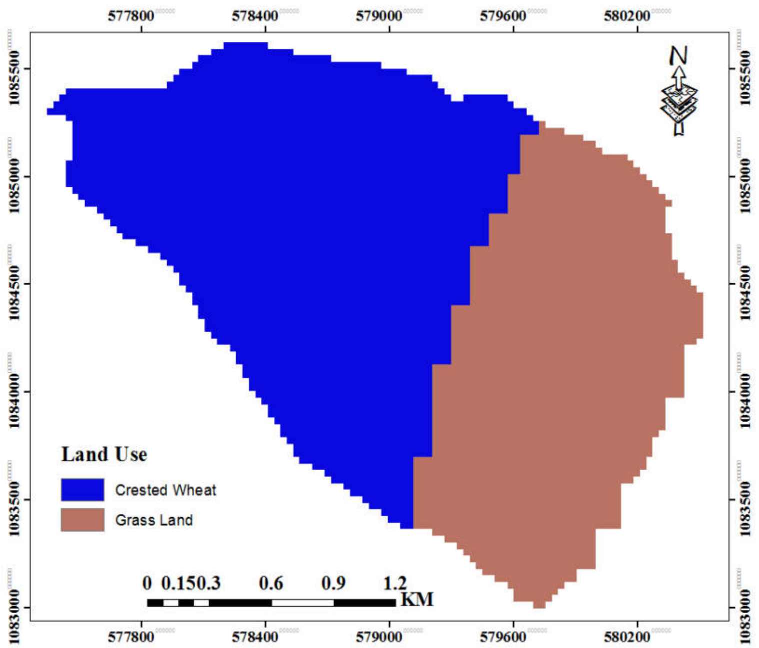
No.	Land use and land Cover	SWAT Code	Area (km^2)	Percentage of the Catchment area (%)
1	Crested Wheat	CWGR	2.85	58.934
2	Grass Land	PAST	1.99	41.066
	Total		4.84	100

Table 3. 5 Reclassified major soil types for Andit Tid watershed

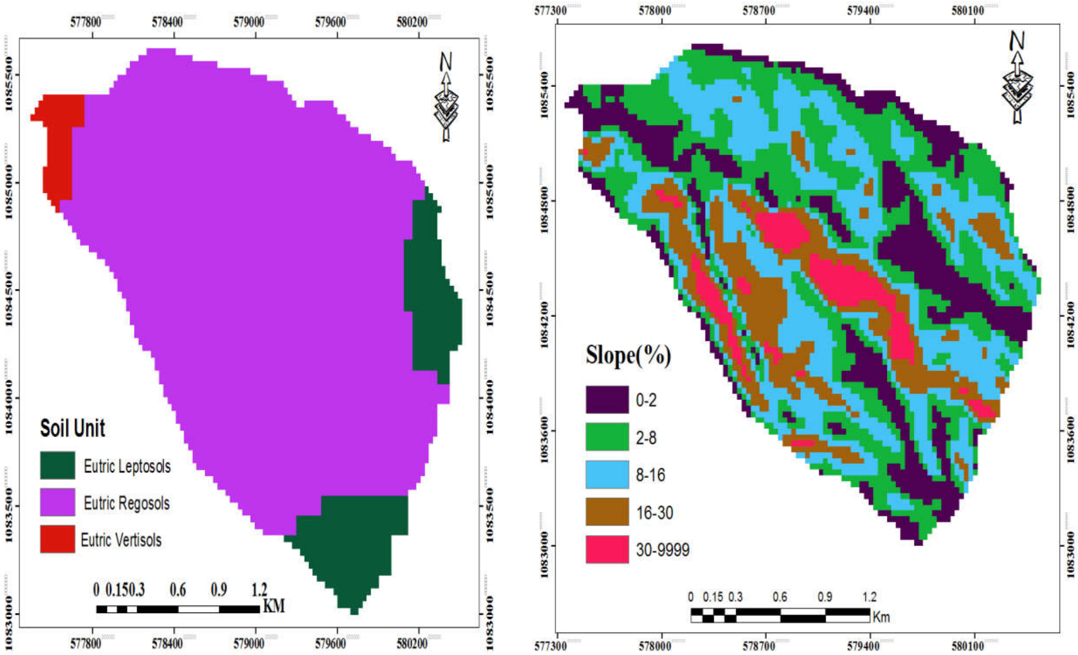
No	Soil Unit Name	Soil Unit Code	Area (km^2)	Percentage of the Catchment (%)
1	Eutric Regosols	RGe	4.17	86.07
2	Eutric Leptosols	LPe	0.55	11.44
3	Eutric Vertisols	VRe	0.12	2.49
	Total		4.84	100.00

Table 3. 6 Reclassified Slope classes for Andit Tid watershed

No.	Range of Slope	Area	Weight of Slope (%)
1	0-2	0.005	0.099
2	0-8	0.010	0.198
3	8-16	0.014	0.297
4	16-30	0.019	0.396
5	≥30	4.792	99.009
	Total	4.84	100



a) Land use and land Cover



b) Major Soil types

c) Slope classes

Figure 3. 6 Land use, Major Soil type and slope classification distribution of Andit Tid

Table 3. 7 Reclassified land use and land cover for Temcha watershed

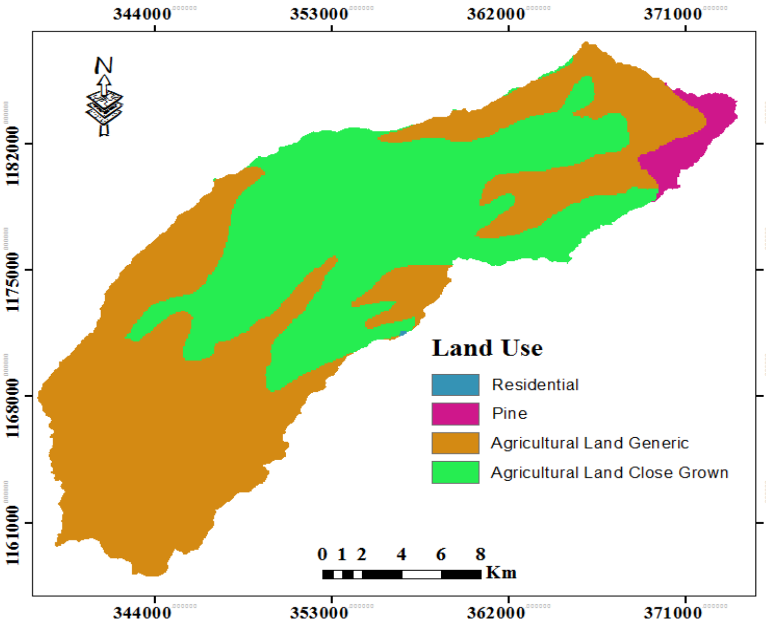
No	Land Use and land Cover	SWAT Code	Area (km^2)	Percentage of the Catchment area (%)
1	Agricultural Land Generic	AGRL	228.54	55.73
2	Agricultural Land Close Grown	AGRC	170.64	41.61
3	Pine	PINE	10.83	2.64
4	Residential	URBN	0.08	0.02
	Total		410.09	100

Table 3. 8 Reclassified major soil types for Temcha watershed

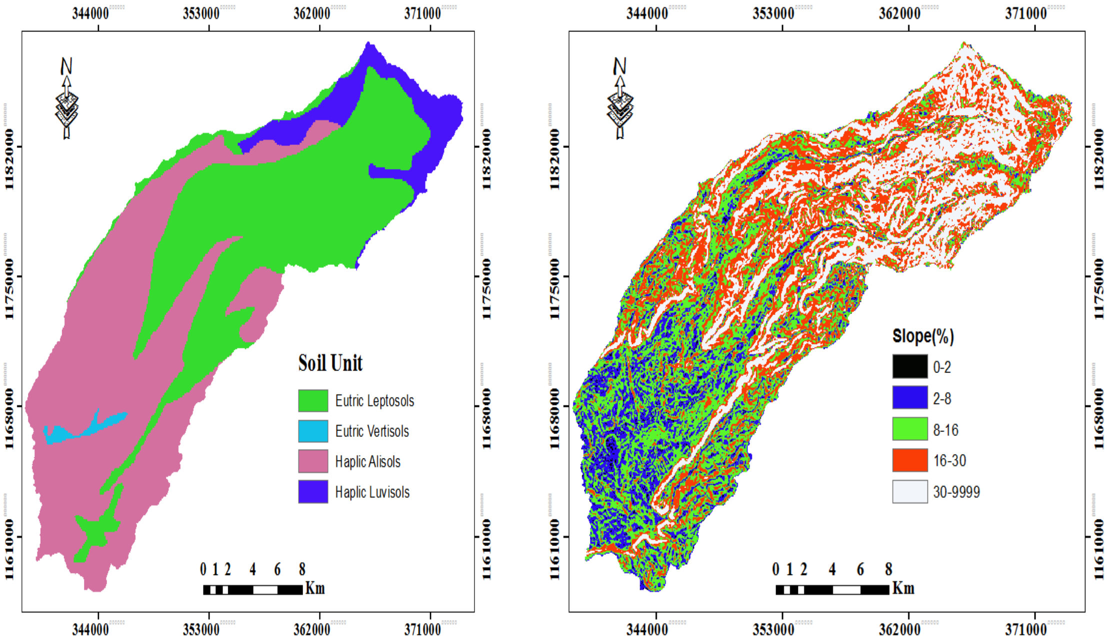
No.	Soil Unit Name	Soil Unit Code	Area (km^2)	Percentage of the Catchment area (%)
1	Haplic Alisols	ALh	198.11	48.31
2	Eutric Leptosols	LPe	174.98	42.67
3	Haplic Luvisols	LVh	33.72	8.22
4	Eutric Vertisols	VRe	3.28	0.80
		Total	410.09	100

Table 3. 9 Reclassified Slope classes for Temcha watershed

No.	Range of Slope	Area(km^2)	Weight of Slope (%)
1	0-2	0.406	0.099
2	0-8	0.813	0.198
3	8-16	1.219	0.297
4	16-30	1.626	0.396
5	≥30	406.026	99.009
	Total	410.09	100



a) Land use and land Cover



b) Major Soil type

c) Slope classes

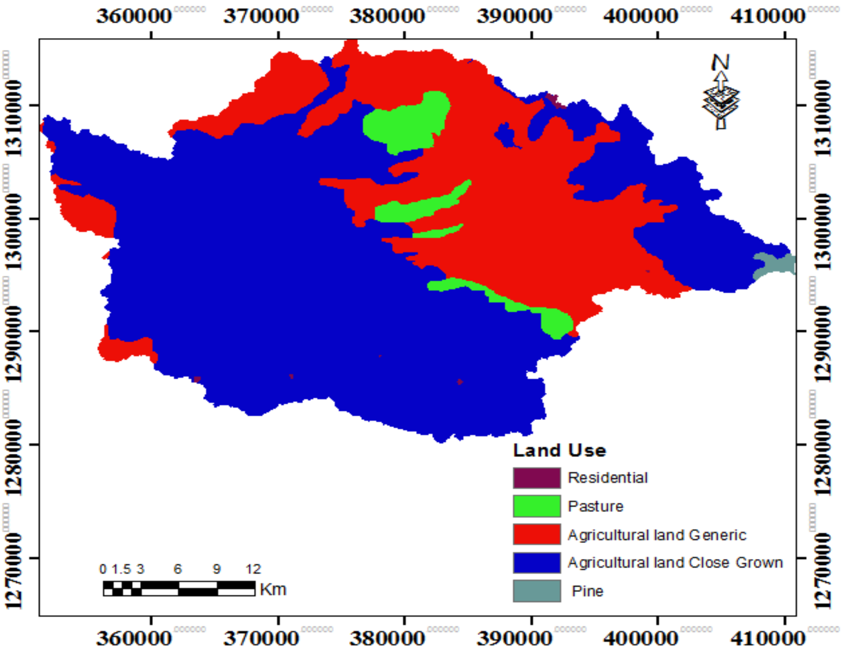
Figure 3. 7 Land use, Major Soil type and slope classification distribution of Temcha

Table 3. 10 Reclassified land use and land cover, major soil type and slope class respectively for Gumara watershed

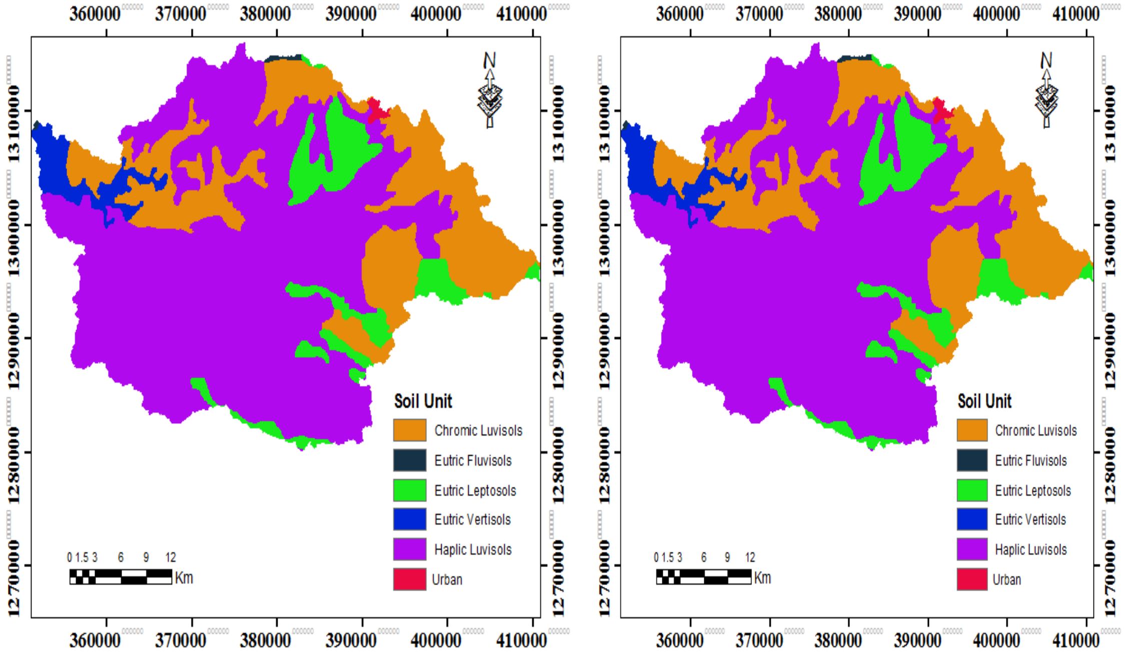
No.	Land use and land Cover	SWAT Code	Area (km^2)	Percentage of the Catchment area (%)
1.	Agricultural Land Close Grown	AGRC	819.62	64.50
2.	Agricultural Land Generic	AGRL	395.28	31.11
3.	Grass land/Pasture	PAST	49.42	3.89
4.	Pine	PINE	4.92	0.39
5.	Residential	URBN	1.52	0.12
	Total		1270.75	100

No.	Soil Unit Name	Soil Unit Code	Area (km^2)	Percentage of the Catchment Area (%)
1	Haplic Luvisols	LVh	807.51	63.55
2	Chromic Luvisols	LVx	309.62	24.37
3	Eutric Leptosols	LPe	107.24	8.44
4	Eutric Vertisols	VRe	41.24	3.25
5	Urban	UR	3.07	0.24
6	Eutric Fluvisols	FLe	2.07	0.16
		Total	1270.75	100

No.	Range of Slope	Area(km^2)	Weight of Slope (%)
1	0-2	44.50	3.50
2	2-8	44.02	3.46
3	8-16	45.34	3.57
4	16-30	52.73	4.15
5	≥30	1084.03	85.32
	Total	1270.75	100



a) Land use and land Cover



b) Major Soil type c) Slope Classes

Figure 3. 8 Land use, Major Soil type and slope classification distribution of Gumara

3.4 PED-W model Inputs

The model input requirements for semi distributed watershed models (PED-W) were daily the areal rainfall and potential evapotranspiration (PET). But, daily observed stream flow and sediment load were inputs for both SWAT and PED-W models.

3.4.1 Determination of Areal Rainfall

Rain gauges represent only point sampling of the areal distribution of a storm. However, hydrological analysis requires the understanding of the rainfall. Thiessen polygon methods have weights to the station data in proportion to space between stations (Bekele, 2009) and are computed by the following equation.

$$R_{areal} = \sum_{n=1}^{n} \left(\frac{\mathrm{R_i\,A_i}}{\mathrm{A_t}}\right) \qquad 3.5$$

Where, Ri is the rainfall at station i, Ai is the polygon area of station i, At is total catchment area, and n is the number of stations. The area functions Ai/At are known as the Thiessen coefficients and once they are determined for a given stable station network, the areal rainfall can be computed for the set of rainfall measurements.

Therefore, from the selected watersheds Temcha and Gumara have stations rain fall. The areal rain fall contributions of the metrological stations for Temcha (Figure 3.9 and Table 3.11) and for Gumara watershed (Figure 3.10 and Table 3.12) described as follows:

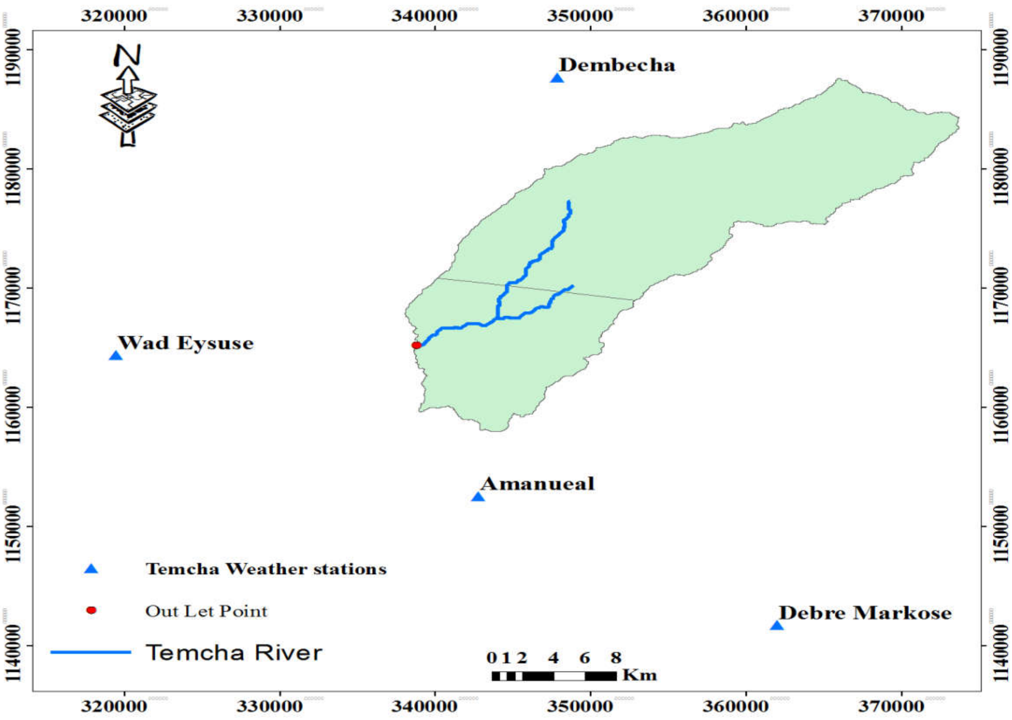


Figure 3. 9 Thiessen Polygon Map of Temcha watersheds

Table 3. 11 Thiessen Polygon Method Annual Rainfall & Temperature of Temcha Watersheds

Stations Name	Latitude	Longitude	Elevation	Areal Rain Fall(mm)	Areal Tmp (C^o)	Area (Km^2)	Weight (%)	Weighted Rain Fall	Weighted Tmp
Amanueal	10.42	37.56	2386	1459.29	19.91	118.23	28.83	420.72	5.74
Dembecha	10.74	37.61	2823	1361.37	26.09	291.86	71.17	968.89	18.56
Areal rain fall contribution of the watershed						410.09	100.00	1389.60	24.30

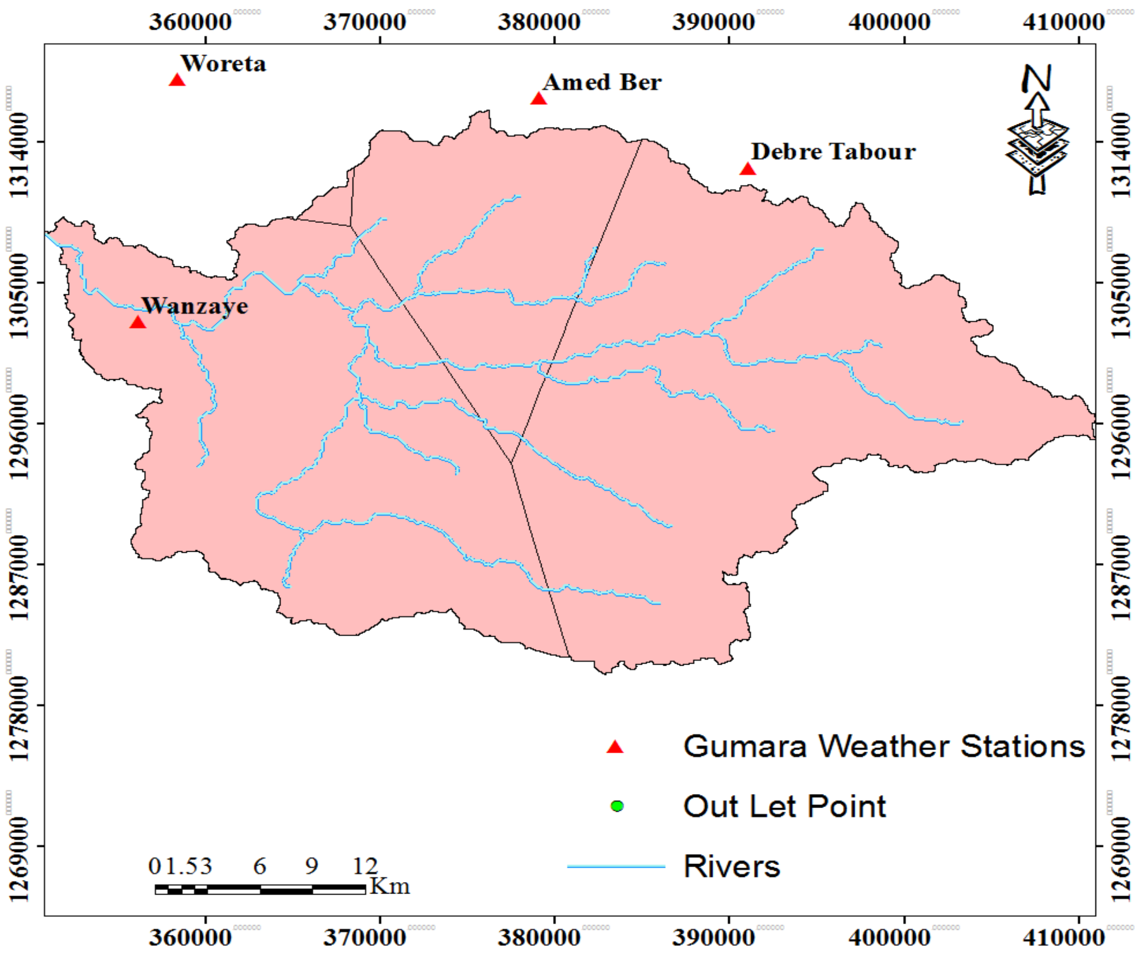


Figure 3. 10 Thiessen Polygon Map of Gumara watersheds

Table 3. 12 Thiessen Polygon Method Annual Rainfall & Temperature of Gumara Watershed

Stations Name	Latitude	Longitude	Elevation	Areal rain fall (mm)	Areal Tmp (C^o)	Area (Km^2)	Weight (%)	weighted rain fall	Weighted Tmp
Debre Tabour	38.00	11.87	2612	1745.77	22.423	577.07	45.412	792.78	10.1827
Amed Ber	37.89	11.91	2051	1903.75	26.509	203.51	16.015	304.8829	4.2454
Wanzaye	37.68	11.78	1850	1474.09	28.254	484.52	38.128	562.0464	10.7726
Woreta	37.70	11.92	1819	1490.07	27.625	5.66	0.445	6.636818	0.1231
Areal rain fall contribution of the watershed						1270.8	100	1666.346	25.3238

3.4.2 Potential Evapotranspiration (PET)

Potential evapotranspiration defined as the amount of water transpired by green 30 to 50 cm high alfalfa crop and completely shading the ground with unlimited soil water supply (Alblewi, 2012). It is the interaction of water from soil vegetation surface and atmosphere. Evapotranspiration exceeds the runoff generated at continental levels (Fekete et al., 2002).

Temperature data record was available from four weather stations: Debre Tabour, Amed Ber, Wanzaye and Woreta. But, daily maximum and minimum temperature was available with some missing data. Therefore, different methods are applied for estimating filing data as precipitation. This is very important to use as input to the SWAT model as it requires the same length of years as precipitation data.

The SWAT model calculates potential evapotranspiration by three methods; the Priestly-Taylor method, the Penman Monteith method and the Hargreaves method (Neitsch et al., 2005b).

Priestley-Taylor is "empirical approximation to eliminate penman Monteith combination equation to eliminate the need for input data other than radiation."

- ✓ The Hargreaves method requires only maximum and minimum air temperature and it can be used in the study. Where; solar radiation, relative humidity and wind speed data are not available.
- ✓ Among the three methods Penman-Monteith was used for this study because this method has the aerodynamic and energy balance components and which gives the reliable results for tropical Africa countries like Ethiopia (Setegn et al., 2011a) and the equation was provided in annex VID.

3.4.3 Stream flow data and analysis

River flow data was required for performing sensitivity analysis, calibration and validation of the model. Data was also collected from Ministry of Water, Irrigation and Electricity (MoWIE) of Ethiopia. Flow data at Andit Tid, Temcha and Gumara gauged station were collected and arranged as per requirement of SWAT model. Homogeneity and statistics test of stream flow data were also checked using RAINBOW (software package for hydro meteorological frequency analysis and testing homogeneity of the historical data sets). Homogeneity of the data of time series is tested by evaluating the maximum and the range of the cumulative deviations from the mean. The study of stream flow is homogeneous at 90%, 95% and 99% probability and frequency of histogram expression of the stream flow is found in annex VE.

3.4.4 Sediment rating curve method

It is used to estimating sediment discharge on a stream if there is only scattered water and sediment data, where we have the irregular or discontinuous sampling. The technique can be used to calculate suspended sediment for calibration and validation of sediment yield simulations. It is usually presented one of two basic forms, either as suspended sediment concentration/stream flow or a suspended sediment discharge/stream flow relationship.

In both cases a logarithmic plot is commonly used with least-squares regression employed to fit straight lines. However, various workers have suggested modifications of approach, including use of flow weighted regression (Fink et al., 2016). The sediment rating curve technique has the advantage that once the transport relationship has been developed. It can be applied to the stream flow data to reconstruct long term sediment records although necessary assumptions of stationary may sometimes need to be questioned.

A sediment rating curve relates the suspended sediment concentration in a river with water discharge. Commonly, the relation is of the following form:

$$Q_s = KQ^C \qquad 3.6$$

Where, Qs is the suspended sediment concentration (mg/l), Q is the discharge (m^3/s), and k *and* c are constants.

A sediment rating curve is applied for Temcha and Gumara watersheds to obtain the value of sediment concentration for the given discharge as described in the (Figure 3.11 & 3.12).

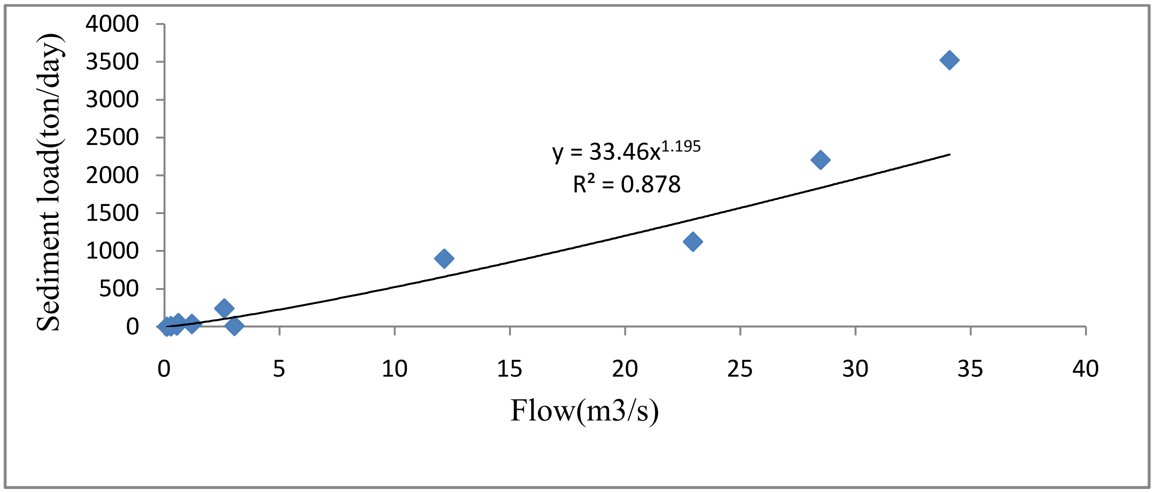


Figure 3. 10 Sediment load vs discharge rating curve for Temcha Watershed

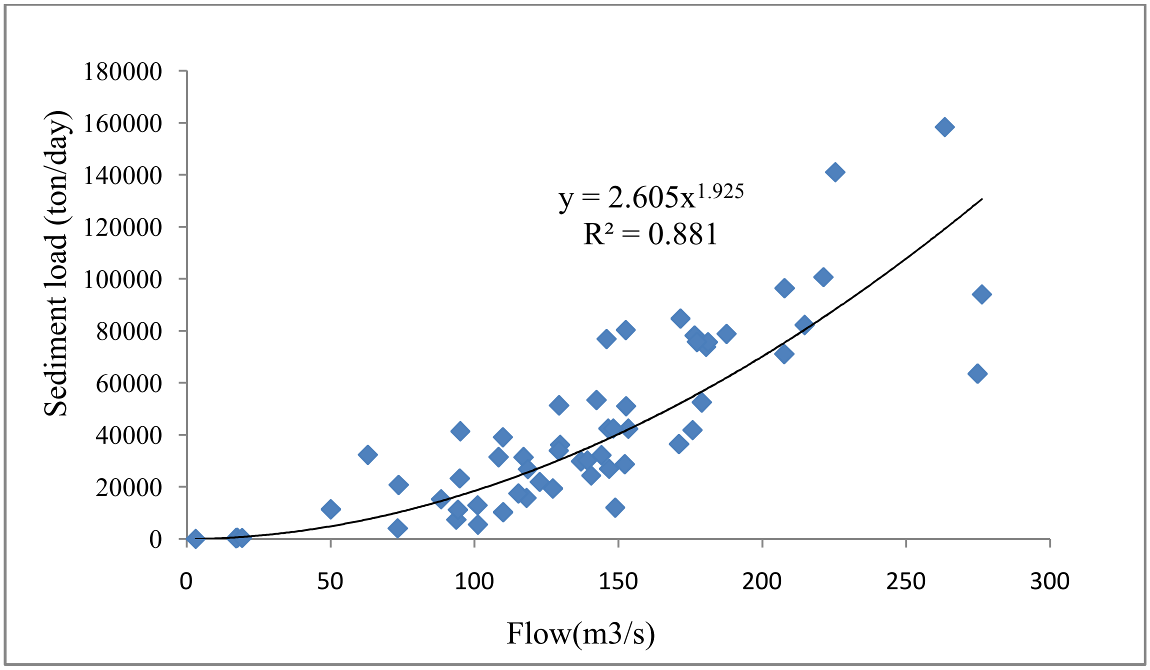


Figure 3. 11 Sediment load vs discharge rating curve for Gumara Watershed

3.5 Physical Based Watershed Models

Two physical based watershed models also called white box models; SWAT and PED-W model have been evaluated to simulating the steam flow and sediment yield in the Andit Tid, Temcha and Gumara watersheds. Each model is used in the different rainfall-runoff generation concept and thus requires distinct spatial-temporal and hydro-meteorological data sets.

3.5.1 Hydrologic Water Balance Component of SWAT model

No matter what type of problem studied with SWAT, Water balance is the driving force behind everything that happens in the watershed (Neitsch et al., 2011).

In simulation of SWAT the watershed can be separated in to two major divisions. The first division was the land phase of hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings in to main channel in each sub basin. The second division is the routing phase of hydrological cycle which can be defined as the movement of water, sediments through the channel network of the watershed to the outlet (Arnold and Fohrer, 2005).

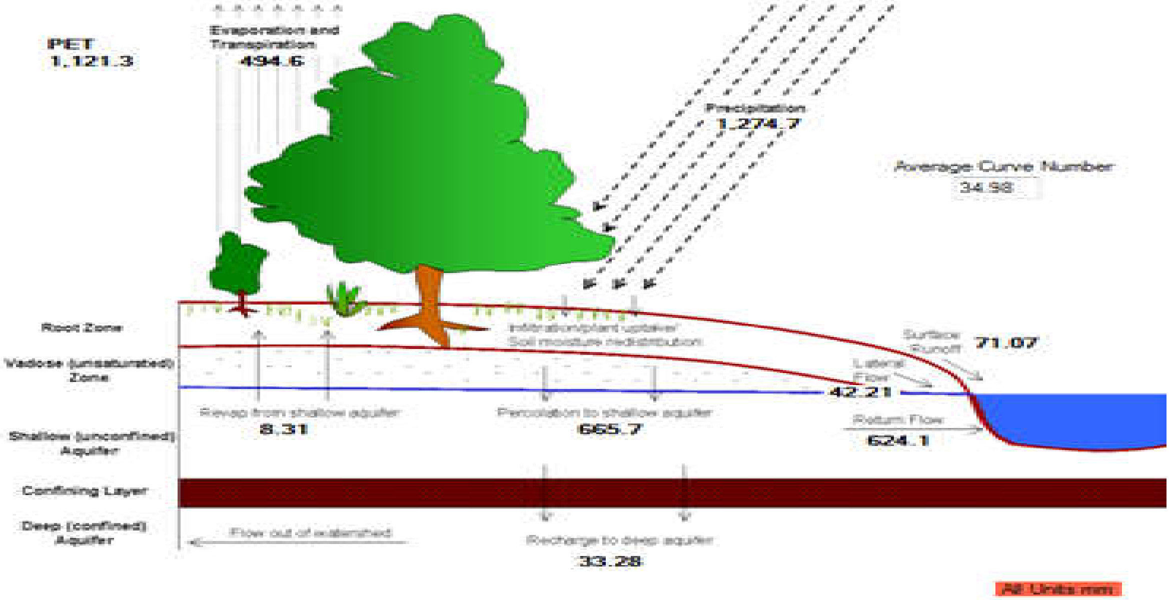


Figure 3. 12 Schematic Representation of the Hydrologic Cycle (Neitsch et al., 2011)

In the land phase of hydrologic cycles SWAT simulates the hydrological cycle based on the following water balance equation.

$$\mathrm{Swt} = \mathrm{Swo} + \sum_{i=1}^{t} \left(\mathrm{R_{day}} \quad \mathrm{Q_{surf}} \quad \mathrm{E_a} \quad \mathrm{W_{seep-}Q_{gw}}\right) \qquad 3.7$$

Where, S_{Wt} is the final water content(mm), $S_{W}o$ is the initial soil water content on day i(mm), t is time, days, R_{day} is the amounts of precipitation on day i(mm), Qsurf is the amount of the surface runoff day i(mm),Ea is the amount of evapotranspiration on day i(mm),Wseep is the amount of the water entering vadose zone from soil profile on day i(mm),Qgw is the amount of ground water flow on day i(mm).

3.5.2 Sediment Component of SWAT model

Behavior of suspended sediment in water courses is often a function of energy conditions, i.e. sediment was stored at the low flow and transported under high discharge conditions. However, sediment transport rates are also function of sediment availability (Baca, 2002). Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach (Neitsch et al., 2011).

SWAT will compute deposition and degradation using the same channel dimensions for entire simulation. Alternatively, SWAT will simulate down cutting and widening of the stream channel and update channel dimensions throughout the simulation.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss equation (Williams, 1975). It is modified version of Universal Soil Loss Equation (USLE). It predicts average annual gross erosion as a function of rainfall energy. In MUSLE the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios and allows the equation to be applied to individual storm events.

Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. The delivery ratio (sediment yield at any point along the channel divided by source erosion above that point) is required by the USLE because the rainfall factor represents energy used in detachment only.

Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment (Neitsch et al., 2011).

SWAT computes erosion and sediment yield caused by rainfall and runoff with Modified Universal Soil Loss Equation (Williams, 1975) and the equation is given by:

$$\mathrm{Sed} = 11.8\left(\mathrm{q_{peak}} \quad \mathrm{Q_{surf}} \quad \mathrm{A_{hru}}\right)^{0.56} \quad \mathrm{K_{USLE}} \quad \mathrm{C_{USLE}} \quad \mathrm{P_{USLE}} \quad \mathrm{L_{USLE}} \quad \mathrm{C_{FRG}} \qquad 3.8$$

Where, Sed is the sediment yield on the given day (metric tons),Q_{surf} is the surface runoff volume(mm/ha, q_{peak} is the peak runoff rate (m^3/s),A_{hru} is the area of hru (ha),K_{USLE} is the erodibility factor((0.013metric-ton-m^2hr/(m^3-metric-ton-cm)),C_{USLE} is the cover and mgt factor, P_{USLE} is support practice factor and L_{SUSLE} is the topographic factor and C_{FRG} is the coarse fragment factor.

After sediment yield is evaluated using MUSLE equation SWAT model further corrects this value considering snow cover effect and sediment lag in surface runoff. SWAT model also calculates the contribution of sediment to channel flow from lateral and groundwater sources. Eroded sediment that enters channel flow is simulated in the SWAT model to move downstream by deposition and degradation.

Ability of SWAT model to illustrate processes in particular watershed partially dependent on the quality of input data (Neitsch et al., 2011). Inputs entered into the SWAT model are organized to have spatial characteristics and it provides three spatial levels, watershed, sub-basins and hydrologic response units (HRUs).

3.5.3 PED-W model Water Balance Module

Water balance module in the PED-W is a semi-distributed module capable of predicting discharge at a daily time step by considering saturation excess runoff (Moges et al., 2017). The model divides a watershed into saturated areas and hill slopes. Hill slopes are then further divided into high infiltration areas and low infiltration areas (also referred to as degraded). The Saturated areas are valley-like regions that become saturated more easily contribute most to runoff. While, high infiltration areas allow percolation routing flow to the subsurface. Low infiltration areas store some water before contributing to subsurface flow but can also contribute to runoff once saturation is reached.

Water balance model is based on Thornthwaite-Mather (1955) procedure and can be run for daily, weekly and monthly time steps using data from different areas of the upper Nile Basin in Ethiopia. Basic equation used to estimate the amount of water stored, S (mm), in the topmost soil layer of hill slope and runoff source areas for a time step Δt, is the Thornthwaite-Mather water balance equation as modified in Collick et al.(2009).

$$S = S_{t-\Delta t} + [P \quad AET \quad R \quad P_{erc}]\Delta_t \qquad 3.9$$

Where, P is precipitation (mm d^{-1}), AET is the actual evapotranspiration (mm d^{-1}), $St\text{-}\Delta t$, previous time step storage (mm), R is saturation excess runoff (mmd^{-1}), P_{erc} is percolation to the subsoil (mmd^{-1}) and Δt is the time step.

The model has nine main parameters including area fraction (A) and the maximum storage capacity (Smax) for the three zones and three subsurface parameters: the half-life ($t_{1/2}$) to describe the exponential decay in time and maximum storage capacity (BSmax) of the first order reservoir and the drainage time of the zero order reservoirs (τ^*) describing a linear decrease in time for interflow and detail description of model is found (Steenhuis et al., 2009).

3.5.4 PED-W model Sediment Module

In the sediment model, for simplicity the erosion process is a unique function of velocity and the concentration C(kg/m^3) is a function of flow rate and a coefficient(for each source area).

In the sediment model, there were two calibration parameters for each of the two surface runoff source areas A_1 & A_2 for transport limit at, in the beginning of the rainy phase and source limit as, at the end of the rainy phase and Sediment concentrations are obtained as a function of surface runoff per unit area and coefficient that decreases linearly from the transport limit at the start of the rainy monsoon phase to the source limit after about 500 mm rainfall (Steenhuis et al., 2014).

To calculate the suspended sediment concentration at the watershed outlet will considered the total discharge Q(mm/day) from the three areas at time t will be written in terms of the contributions of the watershed:

$$Q = A_1Q_1 + A_2Q_2 + A_3(Q_B + Q_1) \qquad 3.10$$

Where, Q_1 and Q_2 are the run off rates expressed in depth units for contributing area,A_1 is fractional saturated area and A_2 is fractional degraded area, A_3 is fractional Contributing area for base flow, Q_B and interflow, Q1.Sediment yield in the stream depends on the amount of suspended sediment delivered by each component of the stream flow. The daily sediment yield equation in its most general form is:

$$Y = A_1Q_1C_1+A_2Q_2C_2+A_3\ (Q_BC_B+Q_1C_1) \qquad 3.11$$

Where:C_1 and C_2 are sediment concentration in the runoff from of saturated area, degraded area respectively, C_B is sediment concentration in base flow and C_1 is the concentration in interflow (Tilahun et al., 2013).

Zimale et al.(2018) suggested that, the concentration of sediment (g/l) in the river will be obtained by dividing the sediment yield by the total watershed predicted discharge by the following mathematical equation:

$$\mathrm{C} = \frac{A_1{Q_1}^{1.4}[\mathrm{a}_{s,1}+\mathrm{H}(\mathrm{a}_{t,1}-\mathrm{a}_{s,1})]+A_2{Q_2}^{1.4}[(\mathrm{a}_{s,2}+\mathrm{H}(\mathrm{a}_{t,2}-\mathrm{a}_{s,2}))]+[(\mathrm{a}_{s,3}{Q_3}^{1.4})]}{A_1Q_1+A_2Q_2+A_3Q_3} \qquad 3.12$$

Where, H is the fraction of the runoff areas that occurs after plowing and measured field observations, a is constant relating the flux to the sediment concentration watersheds, t is transport limited and s is for source limited. A_1, A_2 and A_3 are area fractions of the saturated, degraded areas and the recharge hillside areas respectively. Q_1 and Q_2 are the saturation excess runoff from saturated and degraded areas (mmd^{-1}),Q_B and Q_1 are base flow and interflow (mmd^{-1}) respectively.

3.6 SWAT model Sensitivity Analysis

Results from the model simulation cannot be directly used for further analysis, instead of using for further analysis sufficiently predict constituents of the stream flow and sediment load evaluated by considering sensitivity analysis, calibration and validation of the model (White and Chaubey, 2005).

The study has five objective functions. These are; to maximize Nash-Sutcliffe Efficiency (NSE) and coefficient of determination (R^2), to minimize Ratio of root mean square error (RSR) and Percent Bias (PBIAS) and also p-factor. The Sequential Uncertainty Fitting (SUFI-2), global sensitivity analysis through multiple regression system, which is used to get statistics of t-stat and p-value against objective function, which is also better as camper to one-at-a-time sensitivity analysis.

Sequential Uncertainty Fitting version 2 (SUFI-2) was used for sensitivity analysis and to identify parameters for further optimization of the stream flow and sediment yield to determine the influence a set of parameters. Stream flow components are; the Moist Soil Bulk Density, Average slope length, manning roughness for main channel, deep aquifer percolation fraction, threshold depth of water in shallow aquifer, ground water delay time, base flow alpha, the total soil depth, soil available water capacity, hydraulic conductivity, runoff curve number, soil evaporation compensation factor, average slope depth, surface runoff lag time and maximum canopy storage and the sediment component are; average width of main channel, soil erodibility factor, peak rate adjustment factor for sediment routing, channel erodibility factor, exponent parameter used in the sediment routing, linear parameter for channel sediment routing, the channel cover factor, average depth of main channel and sediment concentration in lateral flow and ground water flow.

The sensitivity analyses were run for flow parameters for Andit Tid, Temcha and Gumara gauging station measured steam flow and sediment concentration was generated through rating curve method. In the analysis, sensitive parameters of stream flow and sediment yield of the watershed were identified. Parameters resulted from the analysis were ranked with their category of the classification according to the magnitudes of the mean relative sensitivity values based on (Lenhart et al., 2002) as presented in table 3.9.

Table 3. 13 SWAT Parameters Mean Sensitivity class

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

3.6.1 SWAT model Calibration and Validation

Calibration is the process of adjusting model parameters within reasonable limits to obtain the best fit of model simulation results to measured data. Model calibration is the means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted (Neitsch et al., 2002).

Sediment transporting modeling two steps of calibration procedure has been suggested by Neitsch et al.(2002) first check the water balance contribution and calibrate stream flow followed by sediment calibration.

In this study calibration and validation is carried out by using SWAT CUP until the model simulation result becomes acceptable as per the model performance measures. The main function of interface is to provide link between the input or output of calibration program and the model. SWAT-CUP is an interface that was developed for SWAT and using this generic interface, any calibration or uncertainty or sensitivity program can easily be linked to SWAT.

Schematic of linkage between SWAT and five optimization programs is illustrated in the figure 3.14.

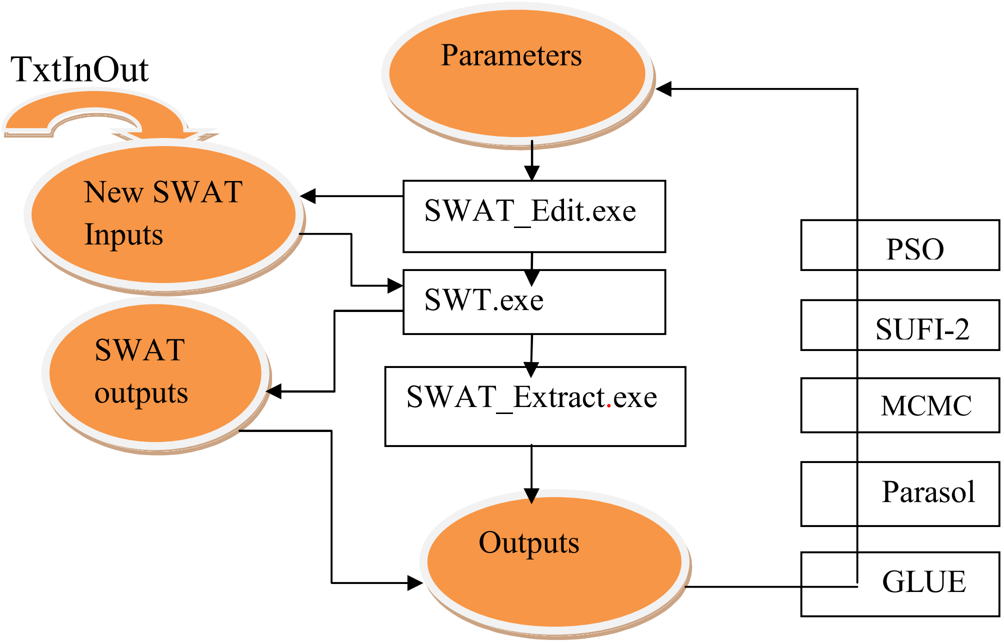


Figure 3. 13 Schematic linkage between SWAT and five optimization programs (Abbaspour et al., 2007)

Model validation is testing of calibrated model results with independent data set without any further adjustment at the different spatial and temporal scales (Neitsch et al., 2002). Flow and sediment validation was carried out at a station similar to the calibration for ten and five years respectively.

3.7 SWAT model Performance Evaluation

The evaluation of hydrologic model behavior and performance is commonly made and reported through comparisons of the simulated and observed variables. There are various methods to evaluate model performance during calibration and validation periods. Among thus, model performance criteria five objective functions were assigned and which is described as follows:

I. Nash-Sutcliffe Efficiency

Nash and Sutcliffe (1970) found out, it is normalized statistics that determines the relative magnitude of the residual variance ("noise") as compared to the measured data variance ("information"). It indicates how well the plot of observed versus simulated data fits the 1:1 line and it is computed using the following equation:

$$\mathrm{NSE} = 1 \quad \frac{\sum_i (Q_m - Q_s)_i^{\,2}}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \qquad 3.13$$

Where, Q_s is model simulated output, Q_m is measured hydrologic variable, $\bar{Q}_m$ is mean of the observations. NSE uses as a benchmark against which, performance of the hydrologic model is compared and N is total numbers of observations. The value of NSE ranges from negative infinity to 1 (best NSE value < 0) indicates the mean observed value is better predictor than the simulated value, which indicates unacceptable performance and while, NSE values greater than 0.5 is better predictor than mean measured value as compared to simulated viewed as acceptable performance (Santhi et al., 2001).

II. Coefficient of Determination

Coefficient of determination is an indicator of the extent to which the model explains total variance in observed data. Its value is indicator of strength of linear relationship between observed and simulated values. It ranges from 0(which indicates model is poor) to1 (model is good) with higher values indicating less error variance and the typical values greater than 0.5 are considered acceptable (Santhi et al., 2001). It is calculated using the following equation:

$$R^2 = \frac{[\sum_i (Q_{m,i-} \ \bar{Q}_m)(Q_{s,j-} \ \bar{Q}_S)]^2}{\sum_i (Q_{m,j-} \ \bar{Q}_m)^2 \sum_i (Q_{s,i-} \ \bar{Q}_S)^2} \qquad 3.14$$

Where, *Qm,* is the measured discharge, *Qs* is the simulated discharge, Q*m* is the average measured discharge and $\bar{Q}_S$ is the average simulated discharge.

Major limitation of R^2 is that it describes the linear relationship between the two data sets, and one may obtain the large R^2 value with a poor model that consistently overestimates or underestimates the observations.

III. Ratio of Root Mean Square Error (RSR)

It incorporates benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistics and reported values can apply to various constituents. RSR varies from the optimal value of “0”, which indicate zero root mean square error (RMSE) or residual variation and therefore perfect the model simulation to a large positive value.

The criterion in the search for the optimal value was to minimize the root-mean-squared error (RMSE) as the objective function and given by**:**

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{n}}(Q_i^{obs}-Q_i^{sim})^2}}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{n}}(Q_i^{obs}-Q_i^{mean})^2}} \qquad 3.15$$

Where, Qobs is observed discharge [mm day-1], Qsim is simulated or modeled discharge [mm day-1] , Q_i^{mean} mean measured discharge and n is the number of data points.

IV. Percent Bias (PBIAS)

PBIAS is used as an additional model performance indicator and measures the average tendency of simulated to be larger or smaller than measured (Gupta et al., 1999). Optimal value of the PBIAS is 0 with lower absolute values indicating better model simulation (± indicates overestimation and underestimation bias of model) and computed as follows:

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n}(Q_i^{obs}-Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs})} * 100 \qquad 3.16$$

Where, PBIAS is the deviation of data being evaluated and it is expressed as a percentage. If PBIAS ± 25% for stream flow and PBIAS ± 55% for sediment the model simulation can be judged as satisfactory (Moriasi et al., 2007).

V. P-Factor

Goodness of calibration and prediction uncertainty is judged on the basis of the closeness of the p-factor to 100% (i.e., all observations bracketed by the prediction uncertainty). The average thickness of the 95PPU calculated by:

$$\mathrm{p} \quad \mathrm{factor} = \frac{1}{\mathrm{n}}\sum_{t_i}^{n}\left(\mathrm{Y}_{\mathrm{t_i,97.5\%}}^{\mathrm{M}} \quad \mathrm{Y}_{\mathrm{t_i,2.5\%}}^{\mathrm{M}}\right) \qquad 3.17$$

Where, $\mathrm{Y}_{\mathrm{t_i,97.5\%}}^{\mathrm{M}}$ and $\mathrm{Y}_{\mathrm{t_i,2.5\%}}^{\mathrm{M}}$ represents upper and lower boundaries of the 95ppu.

Generally; to decide the accuracy of the SWAT model the value of each index obtained by the model were compared with the value of hydrologic model performance ratings given by (Moriasi et al., 2007) in the following table 3.14.

Table 3. 14 Performance ratings of hydrologic SWAT Model

Performance Rating	RSR	NSE	PBIAS% Stream flow	PBIAS% Sediment
Very Good	0.00<RSR≤0.50	0.75<NSE≤1	PBIAS≤±10	PBIAS≤±15
Good	0.50<RSR≤0.60	0.65<NSE≤0.75	≤±10PBIAS≤±15	≤±15PBIAS≤±30
Satisfactory	0.60<RSR≤0.70	0.50<NSE≤0.65	≤±15PBIAS≤±25	≤±30PBIAS≤±55
Unsatisfactory	0.00<RSR>0.70	NSE≤0.50	PBIAS≥±25	PBIAS≥±55

3.8 PED-W model Sensitivity Analysis

Sensitivity analysis was carried out to obtain the most sensitive parameters of controlling the rainfall runoff process of the model. The study has three objective functions. These are; to maximize Nash-Sutcliffe efficiency coefficient and coefficient of determination and minimize Ratio of root mean square error. Sensitivity analyses were done for both water balance and sediment module manually increasing or decreasing each parameter by 10%.

Water balance module parameters are; portion of saturated area(%),portion of degraded area(%),portion of hill side(%),the maximum soil water storage(mm) in A_s, maximum soil water storage(mm) in A_d, maximum soil water storage(mm) in A_h, maximum storage for base (mm),base flow for half life time(days) and interflow(days) and sediment module parameters are; transport limit saturated area(AreaT$_{1)}$,transport limit degraded area(Area T2),PT, Source limit saturated area(AreaS1) and Source limit degraded area(AreaS2).

3.8.1 PED-W model Calibration and Validation

Model was calibrated using nine input parameters and initial values for calibration were done based on (Steenhuis et al., 2009; Collick et al., 2009;Engda et al., 2011and Moges et al., 2017). Values were changed during varying input parameters manually in order to get best fit with measured and simulated stream flow and sediment yield data. The data were divided into two to provide both calibration and validation. For calibration and validation of water balance and sediment module; the daily rainfall, potential evaporation, stream flow and sediment data were used. During model calibration and validation period and also the coefficient of determination, Nash-Sutcliffe coefficient and the Ratio of root mean square error were used to evaluate the model performance.

The general methodology of this study is indicated in the flow chart of figure 3.15.

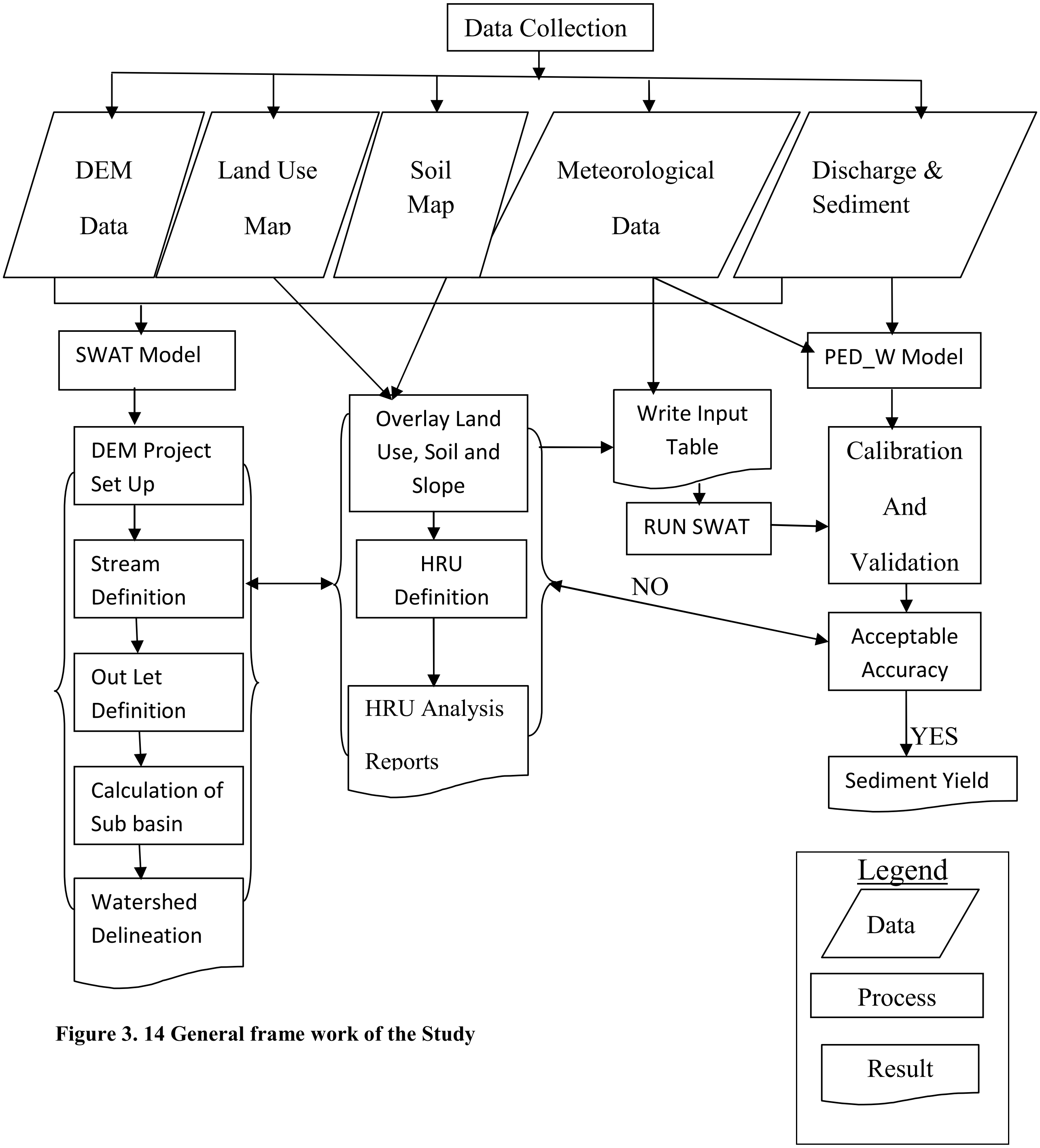


Figure 3. 14 General frame work of the Study

4. RESULTS AND DISCUSSION

4.1 Data Quality Analysis Result

In order to increase model efficiency, the data quality analysis is done by filling the data and checking consistency and homogeneity test for the study.

There were two areal rainfall potential stations as per Thiessen polygon developed in the methodology section within and around Temcha watershed and as it can be seen from the double mass curve, rainfall was consistent. Likewise; for Gumara watershed, four rainfall stations were used to check data consistency. In case of Andit Tid, the study cannot check the data consistency using single rainfall station. Since, only station that was represented for Andit Tid watershed was Andit Tid time series data. Catchment has better correlation because plot of cumulative annual rainfall of neighboring versus each station are aliened on single straight line. Observed precipitation data of the stations shows consistent and homogeneous. The plots of double mass curve for Temcha and Gumara watersheds were shown in figures (4.1& 4.2) respectively.

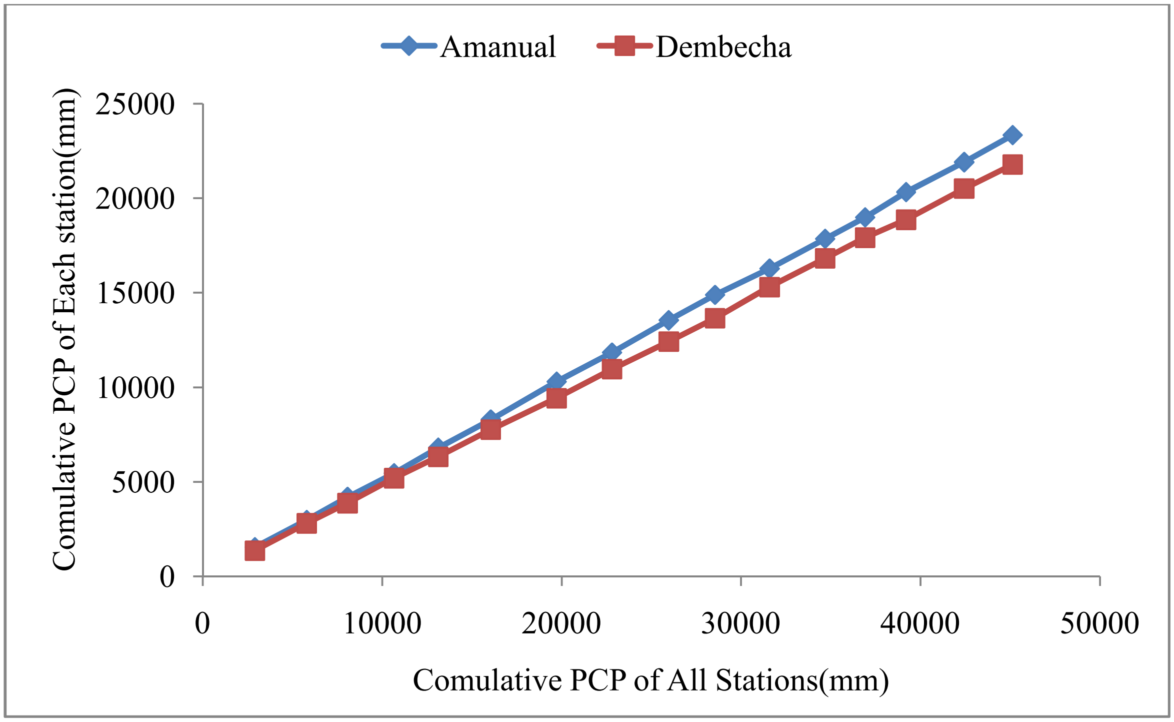


Figure 4. 1 Double mass curves for Temcha watershed

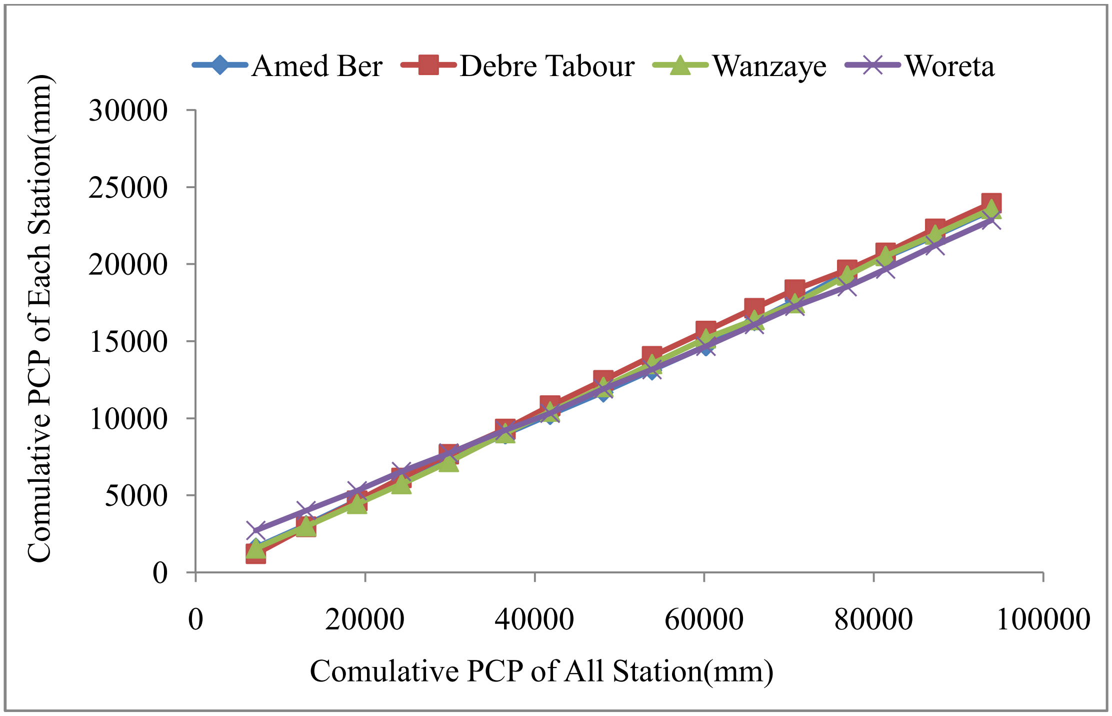


Figure 4. 2 Double mass curves for Gumara watershed

4.2 SWAT model Sensitivity Analysis Result

Prior to model calibration parameter sensitivity analysis was done using the SWAT-CAP, global sensitivity analysis suggested by Zhang et al.(2012) to consider seasonal sensitivity of stream flow and sediment parameters at the out let of the catchment.

Sensitivity analysis was based on the highest absolute value of t-stat and low p-value were selected as starting points for model calibration in both stream flow and sediment yield.

4.2.1 Stream Flow Sensitivity Analysis Result

The study carried out for Andit Tid watershed; Average slope steepness, ground water delay time, maximum canopy storage, moist soil bulk density and threshold depth of water in shallow aquifer for return flow to occur are the most sensitive flow parameters.

For Temcha watershed; surface runoff lag time, moist soil bulk density, threshold depth of water in shallow aquifer for return flow to occur, average slope steepness and maximum canopy storage are the most sensitive flow parameters.

In case of Gumara watershed; the moist soil bulk density ,average slope length, total soil depth, surface runoff lag time and hydraulic conductivity are the most sensitive parameters and unlike similar studies suitability of watershed models to predict distributed hydrologic response in Awramba watershed in the Lake Tana basin (Moges et al., 2017), performance and feasibility of the SWAT model for prediction of stream flow in the Lake Tana (Setegn et al., 2008) and sediment management modeling in Blue Nile basin using SWAT model (Betrie et al., 2011) curve number was less sensitive parameter. These could be various reasons for the flow mismatch. But, it is most likely quality precipitation data is the main constraint for accurate flow modeling in the Blue Nile basin.

Final global sensitivity analysis using SUFI-2 algorithm for one of the watershed bottom up rank was as shown in (Figure 4.3) and the three selected watersheds bottom up ranks of t-stat and p-value and final fitted values of the most sensitive parameters were as shown in the (Table 4.1) below.

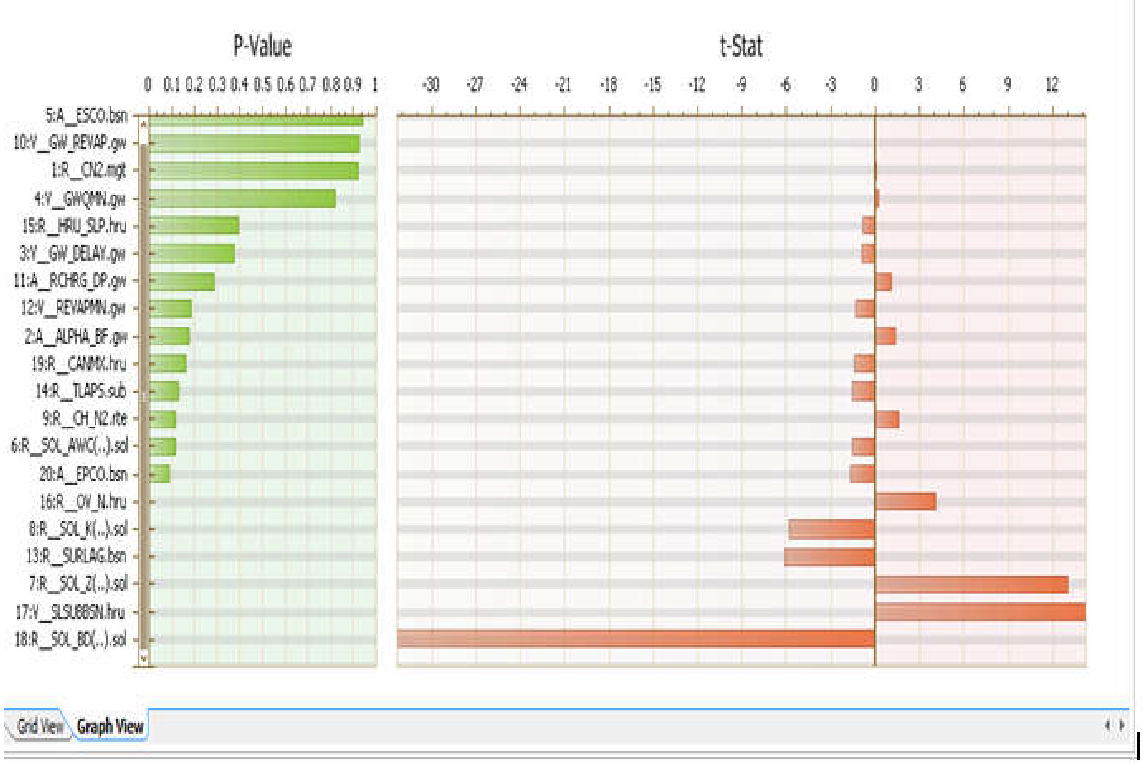


Figure 4. 3 Global Sensitivity output for stream flow of Gumara watershed sensitivity analysis showing rank of hydrological parameter from bottom up

Table 4. 1 Hydrological Sensitive Parameters and Fitted Values of SUFI-2 for selected watersheds

No.	Flow Sensitive Parameters	Description	Lower and Upper Bound	Final Fitted Values and Ranks(P & t-value)					
				Andit Tid		Temcha		Gumara	
1	CN2.mgt	SCS runoff curve number (%)	35-98	94.3145	6	37.3655	18	84.6969	18
2	ALPHA_BF	Base flow alpha factor	0-1	0.9585	19	0.00850	8	0.38682	12
3	GW_DELAY	Ground Water Delay Time	0-500	120.005	2	335.130	6	257.588	15
4	GWQMN.gw	Threshold depth of water in shallow aquifer for return flow to occur	0-5000	3272.5	5	236.750	3	100.625	17
5	ESCO.bsn	Soil evaporation compensation factor	0-1	0.7985	20	0.02050	7	0.35712	20
6	SOL_AWC.sol	Soil available water capacity	0-1	0.5235	12	0.55050	13	0.13456	8
7	SOL_Z.sol	Total soil depth (mm)	0-3500	1.75	7	50.7500	11	0.58100	3
8	SOL_K.sol	Hydraulic conductivity(mm/hr)	0-2000	535	16	1471.00	19	9.02688	5
9	CH_N2.rte	Manning roughness for main channel	0.01-0.3	0.0289	13	0.10548	17	0.09944	9
10	GW_REVAP	Ground Water revap Coefficient	0-0.2	0.0039	14	0.11010	14	0.06781	19
11	RCHRG_DP	Deep aquifer percolation fraction	0-1	0.4305	11	0.18850	16	0.39938	14
12	REVAPMN.gw	Threshold depth of H2o in the aquifer	0-20	804.5	9	427.500	15	4.86250	13
13	SURLAG.bsn	Surface runoff lag time	0.05-5	3.8045	10	20.9160	1	0.46147	4
14	TLAPS.sub		-10-10	6.33	15	1.48798	20	0.63750	10
15	HRU_SLP.hru	Average slope steepness	0-0.2	0.0685	1	0.17450	4	0.13688	16
16	OV_N.hru	Manning roughness for overland flow	0.1-30	17.248	18	12.5608	12	20.4594	6
17	SLSUBBSN	Average Slope length	10-150	87.91	17	75.8700	9	132.413	2
18	SOL_BD.sol	Moist Soil Bulk Density	0-0.25	0.2253	4	0.16038	2	0.00328	1
19	CANMX.hru	Maximum canopy storage (mm)	0-100	58.85	3	67.1500	5	0.86313	11
20	EPCO.bsn	Plant uptake compensation factor	0-1	0.7935	8	0.00250	10	0.96813	7

4.2.2 Sediment Yield Sensitivity Analysis Results

The study found out for Andit Tid watershed; Soil erodibility factor (USLE_K), peak rate adjustment factor for sediment routing in the sub basins (ADJ_PKR) and average width of main channel (CH_W$_2$) are the most sensitive sediment parameters.

For Temcha watershed; Erodibility factor (USLE_K), peak rate adjustment factor for sediment routing in the sub basins (ADJ_PKR) and an exponent parameter used in channel sediment routing (SPEXP) are the most sensitive sediment parameters.

In Gumara watershed; Average with of the main channel (CH_W$_2$), Erodibility factor (USLE_K) and peak rate adjustment factor for sediment routing in sub basins (ADJ_PKR) are top sensitive sediment parameters and results of sensitive parameters in three of the watersheds were similar as identified by Betrie et al.(2011) studies on Blue Nile basin for sediment management modeling using SWAT model.

Final global sensitivity analysis using SUFI-2 algorithm for one of the watershed bottom up rank was as shown in (Figure 4.4) and the three selected watersheds bottom up ranks of t-stat and p-value and final fitted values of the most sensitive sediment parameters were as shown in the (Table 4.2).

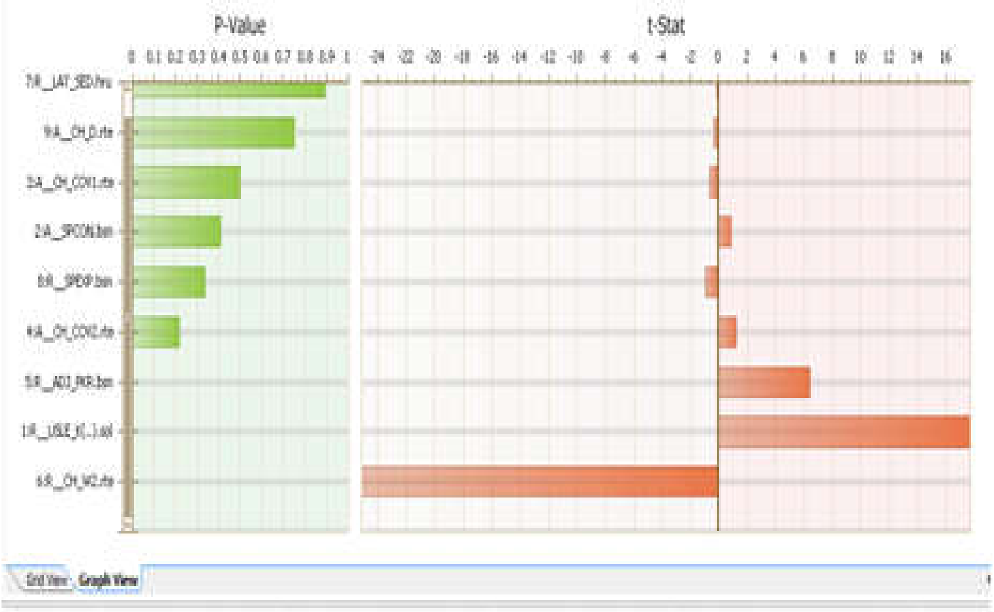


Figure 4. 4 Screen shot of Global Sensitivity output of Gumara watershed for sediment yield sensitivity analysis showing rank of hydrological parameter from bottom up

Table 4. 2 Hydrological Sensitive Parameters and Fitted Values of SUFI-2 for selected watersheds

No.	Sediment Sensitive Parameters	Description	Lower and Upper Bound	Final Fitted Values and Ranks(P & t-value)					
				Andit Tid Watershed		Temcha Watershed		Gumara watershed	
1	V__CH_W2.rte	Average width of main channel	0-.2.0	0.07500	3	0.0881	5	1.785	1
2	A__USLE_K.sol	USLE equation soil erodibility factor	0-0.20	0.00990	1	0.0021	1	0.0007	2
3	A__ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the sub basin	0-0.20	0.11510	2	0.0023	2	0.0183	3
4	A__CH_COV2.rte	Channel erodibility factor	0-0.20	0.07150	6	0.0499	4	0.1531	4
5	R__SPEXP.bsn	An exponent parameter used in channel sediment routing	1-1.50	1.8170	8	1.4963	3	1.875	5
6	V__SPCON.bsn	Linear parameter for channel sediment routing	0-0.001	0.00013	5	0.0063	7	0.00568	6
7	A__CH_COV1.rte	Channel cover factor	0-0.20	0.13910	4	0.1461	8	0.1429	7
8	A__CH_D.rte	Average depth of main channel	0.01-0.3	1.07225	9	26.415	6	1.02725	8
9	V__LAT_SED.hru	Sediment concentration in lateral flow and ground water flow	0-2.0	0.09890	7	0.6090	9	0.1621	9

4.3 PED-W model Sensitivity Analysis Results

The Sensitivity analysis to PED-W model for the study was carried out based on manual identification using (NSE) common model efficiency measuring criteria for water balance and sediment module as presented in the following section.

4.3.1 Water Balance Module Sensitivity Analysis Result

The study found out for Andit Tid watershed; portion of hillside area(Ah), the maximum storage for base(Bmax),maximum soil water storage($A_{s)}$and interflow(τ*) are top sensitive parameters.

For Temcha watershed; the portion of hillside area (Ah), base flow for half life time ($t_{1/2}$), maximum soil water storage ($A_{s)}$ and maximum storage for base(Bmax) are top sensitive parameters and in Gumara watershed; Portion of hillside area(Ah), maximum storage for base(Bmax),base flow half life time($t_{1/2}$) and interflow(τ*) are top sensitive parameters.

Based on the sensitivity analysis the most sensitive parameter for Andit Tid, Temcha and Gumara watersheds were portion of hillside area(Ah) and second most sensitive parameter was maximum storage of base flow(Bsmax), for Andit Tid and Gumara watershed. But, in case of Temcha watershed the second most sensitive parameter was the base flow of half life time ($t_{1/2}$) as shown in (Table 4.3-4.5 and Figure 4.5-4.7).

Identified sensitive parameters in the present study were similar with the past studies in suitability of watershed models to predict distributed hydrologic response in the Awramba Watershed in Lake Tana basin (Moges et al., 2017).

Table 4. 3 Water balance module sensitive parameters of NSE value for Andit Tid

10% change	-50	-40	-30	-20	-10	0	10	20	30	40	50	Rank
As	0.76	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74	0.73	0.73	3
Ad	0.75	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74	0.74	0.74	5
Ah	0.66	0.72	0.76	0.77	0.77	0.74	0.69	0.61	0.51	0.38	0.21	1
Smax,s	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	6
Smax,d	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	6
Smax,h	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	6
Bsmax	0.68	0.70	0.72	0.73	0.74	0.74	0.75	0.75	0.75	0.75	0.75	2
$t_{1/2}$	0.71	0.73	0.74	0.74	0.75	0.74	0.74	0.74	0.73	0.73	0.73	3
τ*	0.73	0.74	0.74	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.75	4

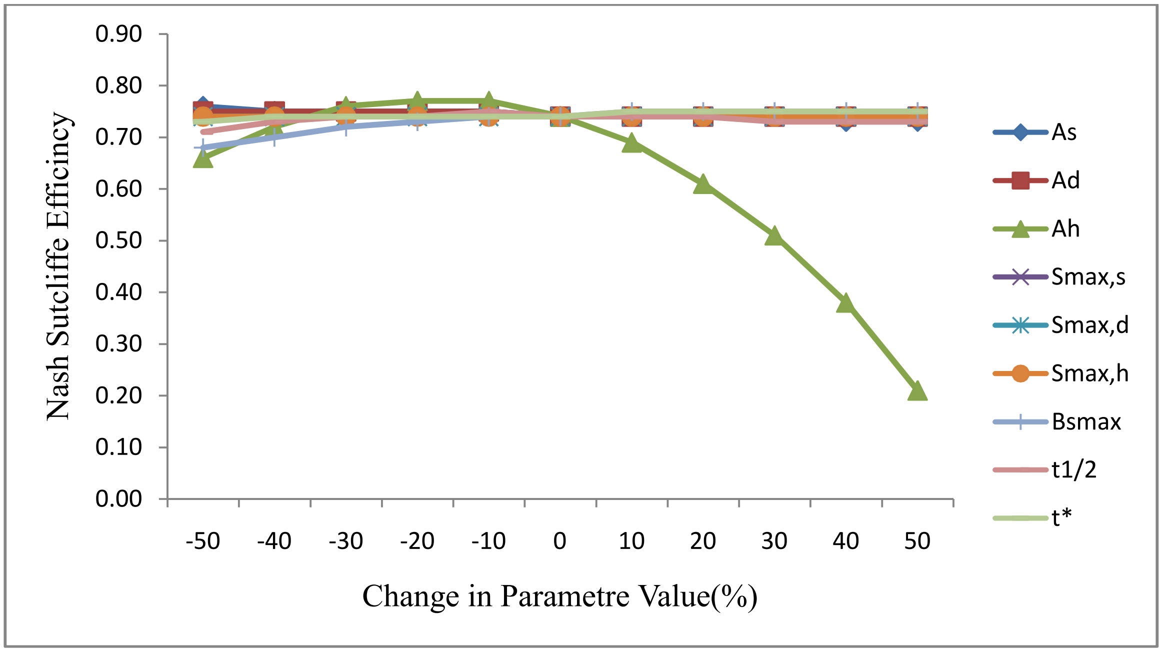


Figure 4. 5 Water balance module sensitivity Analysis of NSE value for Andit Tid

Table 4. 4 Water balance module sensitive parameters of NSE value for Temcha

10% change	-50	-40	-30	-20	-10	0	10	20	30	40	50	Rank
As	0.60	0.59	0.59	0.58	0.58	0.58	0.58	0.57	0.57	0.56	0.56	3
Ad	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	6
Ah	0.62	0.65	0.67	0.66	0.63	0.58	0.50	0.40	0.27	0.11	0.00	1
Smax,s	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	6
Smax,d	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	6
Smax,h	0.57	0.57	0.57	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	5
Bsmax	0.47	0.52	0.55	0.57	0.58	0.58	0.58	0.58	0.58	0.58	0.58	4
t1/2	0.51	0.53	0.55	0.57	0.58	0.58	0.58	0.59	0.58	0.58	0.58	2
τ*	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	6

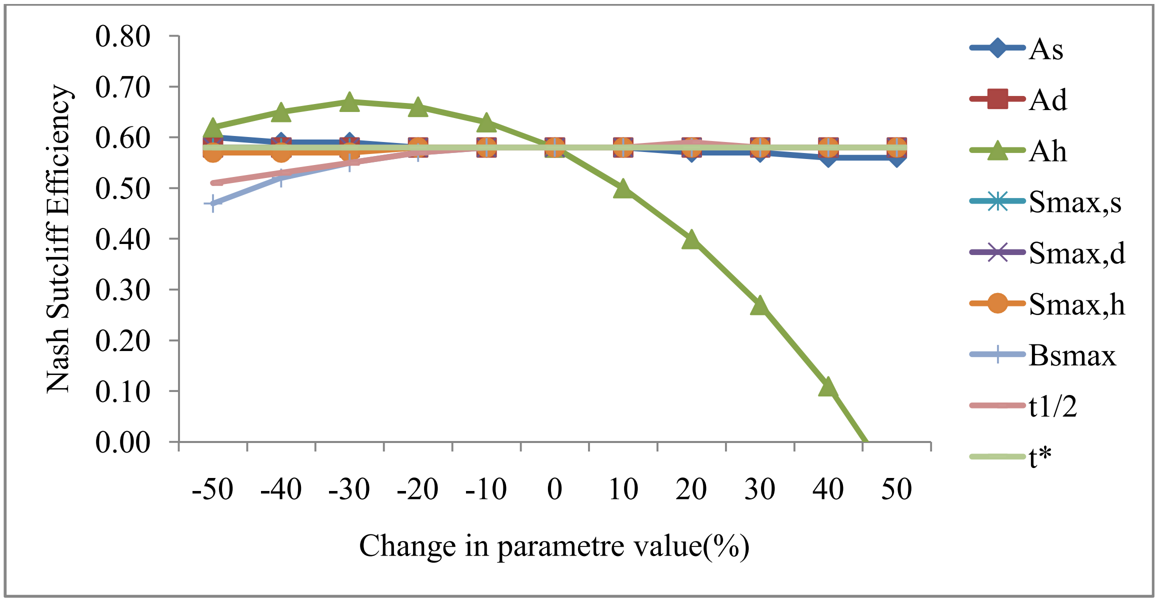


Figure 4. 6 Water balance module sensitivity Analysis of NSE value for Temcha

Table 4. 5 Water balance module sensitive parameters of NSE value for Gumara

10% Change	-50	-40	-30	-20	10	0	10	20	30	40	50	Rank
As	0.81	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.79	0.79	0.79	5
Ad	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	7
Ah	0.73	0.79	0.83	0.85	0.84	0.80	0.74	0.65	0.53	0.38	0.20	1
Smax,s	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	7
Smax,d	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	7
Smax,h	0.79	0.79	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	6
Bsmax	0.71	0.73	0.76	0.77	0.79	0.80	0.81	0.82	0.83	0.84	0.84	2
t1/2	0.78	0.80	0.81	0.81	0.81	0.80	0.79	0.78	0.78	0.77	0.76	3
τ*	0.77	0.78	0.79	0.79	0.80	0.80	0.80	0.81	0.81	0.81	0.81	4

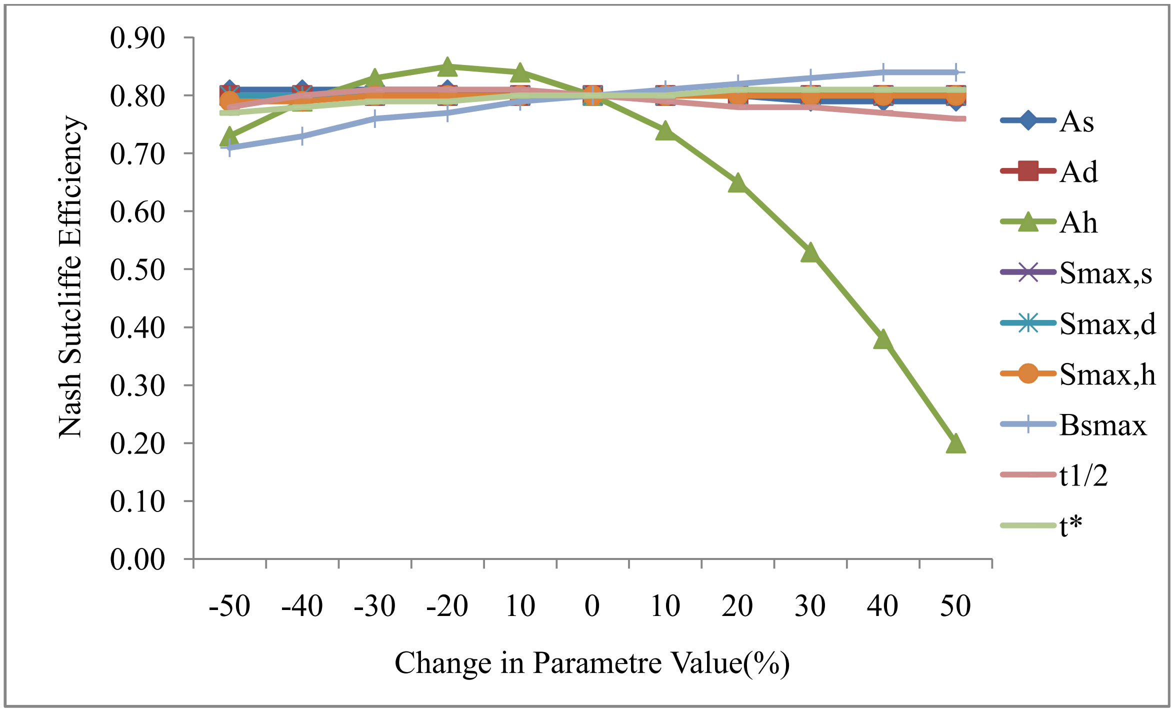


Figure 4. 7 Water balance module sensitivity Analysis of NSE value for Gumara

4.3.2 Sediment Module Sensitivity Analysis Result

Sediment module sensitivity analysis was done as water balance module for Andit Tid; the transport limit saturated area (AreaT1), source limit saturated areas (AreaS1) and transport limit degraded areas (AreaT2) are top sensitive parameters.

For Temcha watershed; the transport limit saturated area (AreaT1), source limit saturated areas (AreaS1) and PT are the most sensitive parameters. And for Gumara watershed: the transport limit saturated area (AreaT1), source limit degraded area (AreaS2) and source limit saturated areas (AreaS1) are the most sensitive parameters

Therefore, transport limit saturated area (AreaT1) is the most sensitive sediment module parameter from the selected watersheds as shown in (Table 4.6 -4.8 and Figure 4.8-4.10).

Table 4. 6 Sediment module sensitive parameters of NSE value for Andit Tid

10% Change	-50	-40	-30	-20	-10	0	10	20	30	40	50	Rank
Area T1	0.68	0.71	0.72	0.73	0.73	0.73	0.71	0.68	0.65	0.60	0.55	1
Area T2	0.73	0.73	0.73	0.73	0.73	0.73	0.72	0.72	0.71	0.71	0.70	3
PT	0.73	0.73	0.73	0.72	0.72	0.73	0.73	0.73	0.73	0.73	0.73	4
Area S1	0.73	0.73	0.73	0.73	0.73	0.73	0.72	0.71	0.71	0.70	0.69	2
Area S2	0.73	0.73	0.73	0.73	0.73	0.73	0.72	0.72	0.72	0.72	0.72	4

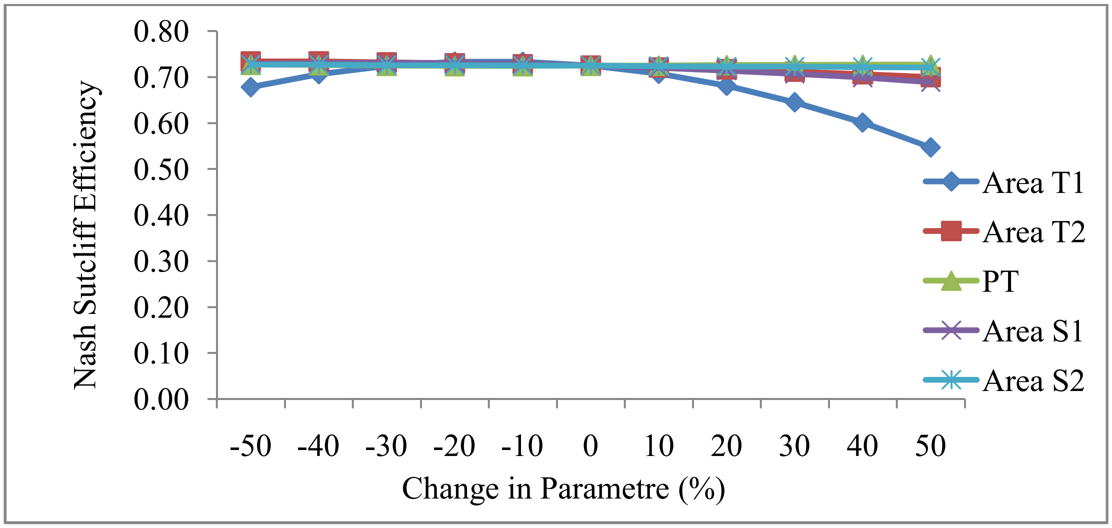


Figure 4. 8 Sediment module sensitivity Analysis of NSE value for Andit Tid

Table 4. 7 Sediment module sensitive parameters of NSE value for Temcha

10% Change	-50	-40	-30	-20	-10	0	10	20	30	40	50	Rank
Area T1	0.678	0.702	0.722	0.736	0.746	0.752	0.753	0.749	0.742	0.729	0.711	1
Area T2	0.744	0.746	0.748	0.749	0.751	0.752	0.753	0.753	0.753	0.753	0.752	4
PT	0.746	0.747	0.748	0.750	0.751	0.752	0.753	0.754	0.754	0.754	0.755	3
Area S1	0.713	0.724	0.734	0.742	0.748	0.752	0.755	0.755	0.754	0.752	0.745	2
Area S2	0.748	0.749	0.750	0.751	0.751	0.752	0.752	0.752	0.753	0.754	0.754	5

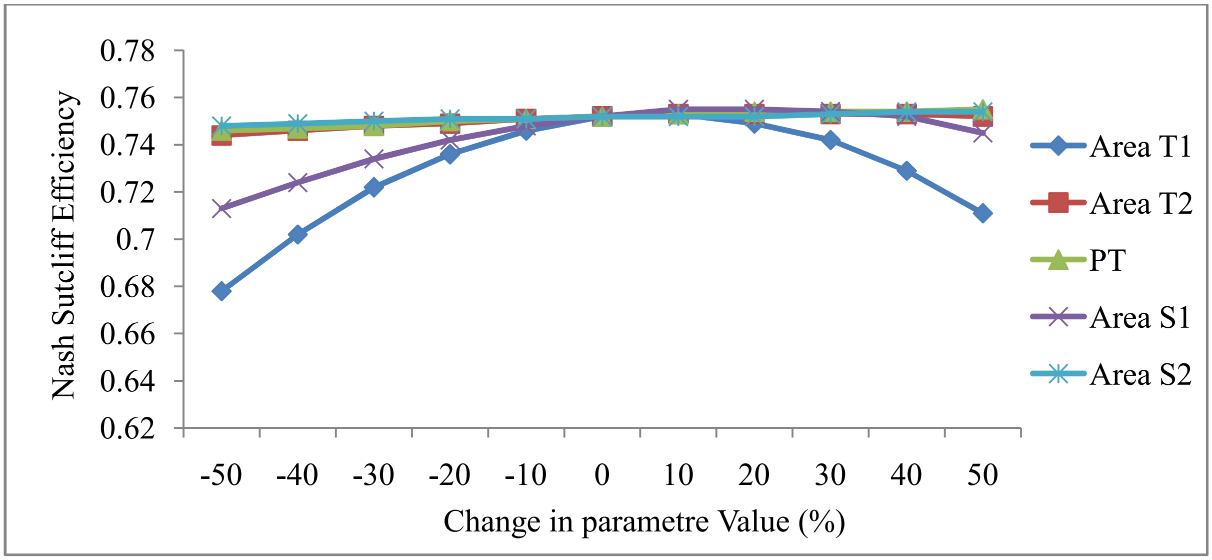


Figure 4. 9 Sediment module sensitivity Analysis of NSE value for Temcha

Table 4. 8 Sediment module sensitive parameter analysis NSE value for Gumara

10% Change	-50	-40	-30	-20	-10	0	10	20	30	40	50	Rank
AreaT1	0.65	0.69	0.73	0.76	0.79	0.81	0.83	0.83	0.83	0.83	0.83	1
AreaT2	0.78	0.78	0.79	0.79	0.80	0.81	0.82	0.82	0.82	0.83	0.83	2
PT	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	4
AreaS1	0.79	0.79	0.80	0.80	0.81	0.81	0.81	0.82	0.82	0.82	0.82	3
AreaS2	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	4

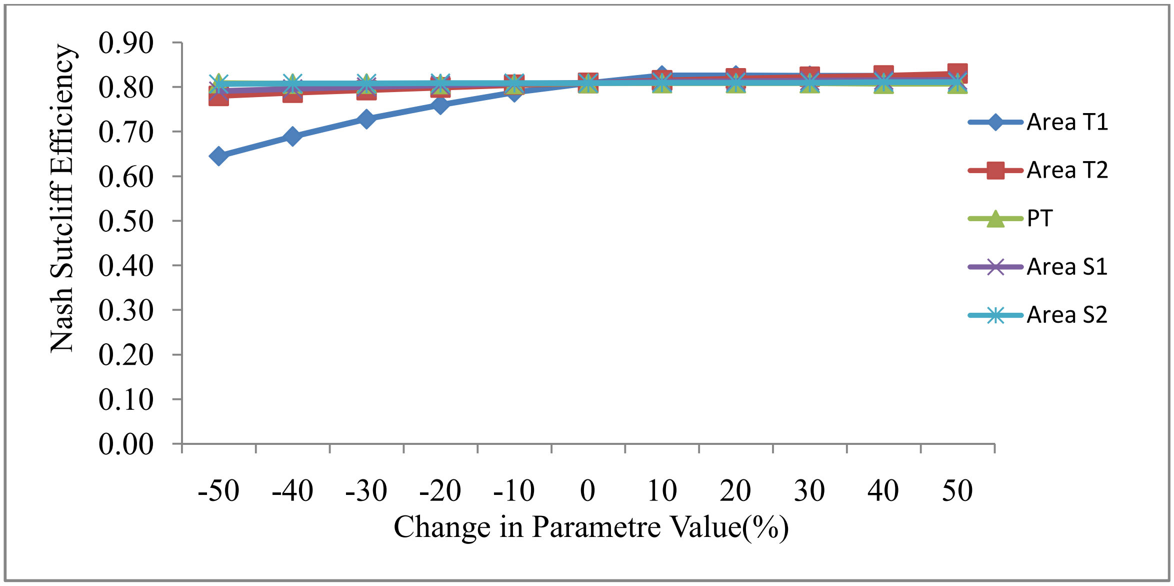


Figure 4. 10 Sediment module sensitivity Analysis of NSE value for Gumara

Ranks of the sensitivity parameter for each watershed were varying due to the variation of catchment characteristics or landscape proportion and rainfall distribution of arid region. Simplified watershed sediment model; coupled with hydrology model was developed and used to simulate the sediment concentrations and runoff at the two widely varying scales. Such simplified models that require very few calibration parameters to simulate runoff and sediment transport are important in data limiting environments (Tilahun et al., 2013).

Like, water Balance module based on the sensitivity analysis the most sensitive parameter in Andit Tid, Temcha and Gumara watersheds were the portion of transport limit saturated area (AreaT1) and the second most sensitive parameter for Andit Tid and Temcha was portion of source limit saturated area (AreaS1). But, in case of Gumara the second most sensitive parameter was the portion of transport limit degraded area (AreaT2) as shown in the above tables (4.4 -4.6) and also figures (4.10-4.12) too.

4.4 Hydrological Model Calibration and Validation

4.4.1 SWAT model Calibration and Validation

Calibration of models in the watershed size is the challenging task because of the possible uncertainties that may exist in the form of process simplification, processes not accounted for by the model and processes in the watershed that are unknown to modular (Abbaspour et al., 2007).

Calibration was performed using SUFI-2 algorism for both water balance and sediment module were resulted from selected watersheds both daily and monthly measured data from 2000 to 2010 leaving the first one year period (2000) for model warm-up and getting acceptable values of objective functions. Thus, validation was carried out without further adjustment of the calibrated parameters, but using input data independent of data sets.

4.4.1.1 Stream flow Calibration and Validation

The comparison made between measured and simulated stream flow indicated that, there was a good agreement between measured and simulated data. This was verified using both graphical technique and quantitative statistics.

Statistical values on the AnditTid watershed; monthly flow during calibration coefficient of determination (R^2 is 0.92),Nash Sutcliffe efficiency(NSE is 0.91) and during validation R^2 is 0.89, NSE is 0.89justify that the model is very good agreement between in measured and simulated data.

Statistical values on the Temcha watershed; monthly flow during calibration coefficient of determination (R^2 is 0.91),Nash Sutcliffe efficiency(NSE is 0.75) and during validation R^2 is 0.95, NSE is 0.93justify that the model is very good agreement between in measured and simulated data.

Statistical values on the Gumara watershed; monthly flow during calibration coefficient of determination (R^2 is 0.89),Nash Sutcliffe efficiency(NSE is 0.89) and during validation R^2 is 0.73, NSE is 0.71justify that the model is very good agreement between in measured and simulated data.

Similar studies in the other area supports the findings of this result. Setegn et al.(2008) monthly calibration results of SUFI-2 algorithm have good agreement between monthly observed and simulated flow in Tana basin for doing hydrological modeling both during calibration and validation processes coefficient of determinations (R^2) and Nash-Sutcliffe simulation efficiency (NSE) greater than 0.80.

Lists of the various performance statistics for the selected watersheds during calibration and validation was as shown in table 4.9 and graphical description in figure 4.11 to 4.16.

Table 4. 9 performance statistics during calibration and validation of water balance on selected watersheds for SWAT model

			SWAT			
			Calibration		Validation	
Watershed	Description of objective function		Daily	Monthly	Daily	Monthly
Andit Tid	Statistical Value	R^2	0.84	0.92	0.85	0.89
		NSE	0.70	0.91	0.84	0.89
		RSR	0.55	0.30	0.40	0.33
		p-factor	0.02	0.60	0.33	0.90
		PBIAS	-11.5	7.10	15.2	0.40
Temcha	Statistical Value	R^2	0.76	0.91	0.69	0.80
		NSE	0.62	0.75	0.65	0.93
		RSR	0.62	0.50	0.59	0.27
		p-factor	0.12	0.11	0.29	0.69
		PBIAS	-11.4	-0.32	26.7	26.7
Gumara	Statistical value	R^2	0.67	0.89	0.70	0.75
		NSE	0.64	0.89	0.68	0.71
		RSR	0.60	0.32	0.57	0.54
		p-factor	0.64	0.85	0.62	0.22
		PBIAS	-3.1	2.7	21.6	18.4

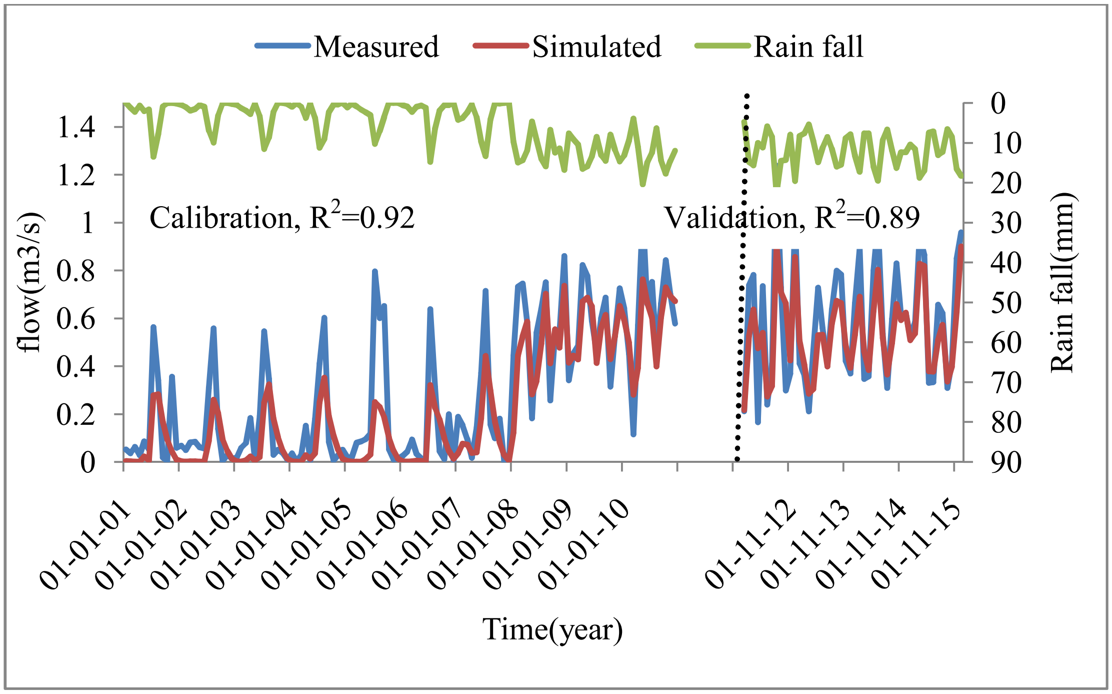


Figure 4. 11 Simulated and observed monthly stream flow during calibration (2001-2010) and Validation (2012-2015) of SWAT model for Andit Tid

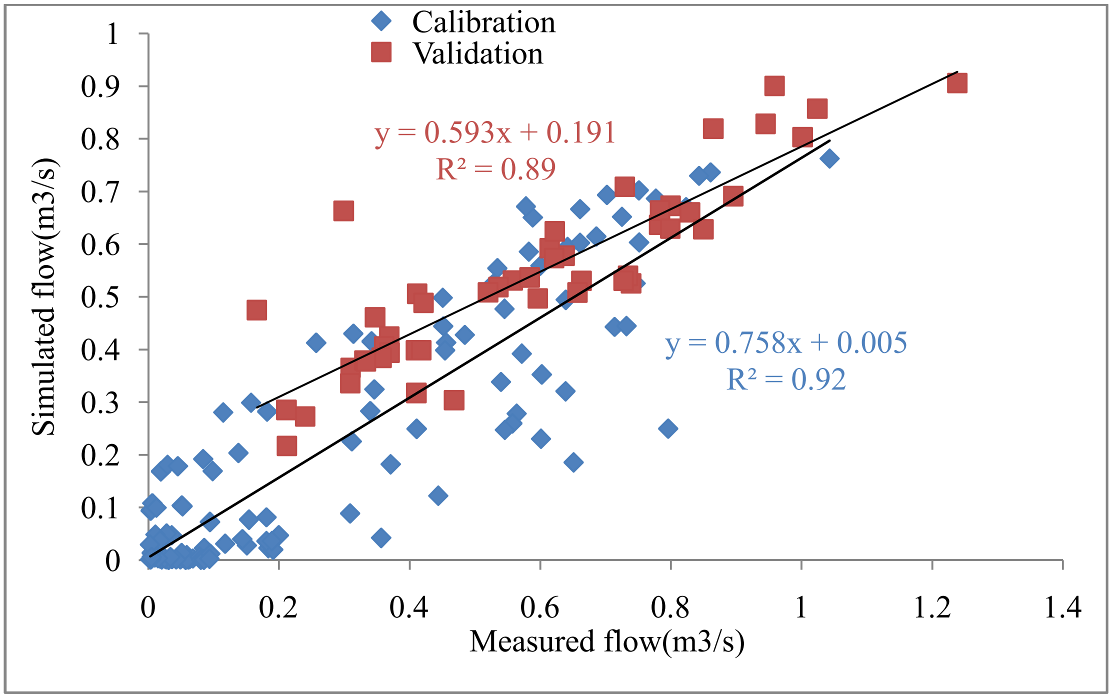


Figure 4. 12 Predicted vs measured and stream flow during calibration and validation of SWAT model for Andit Tid

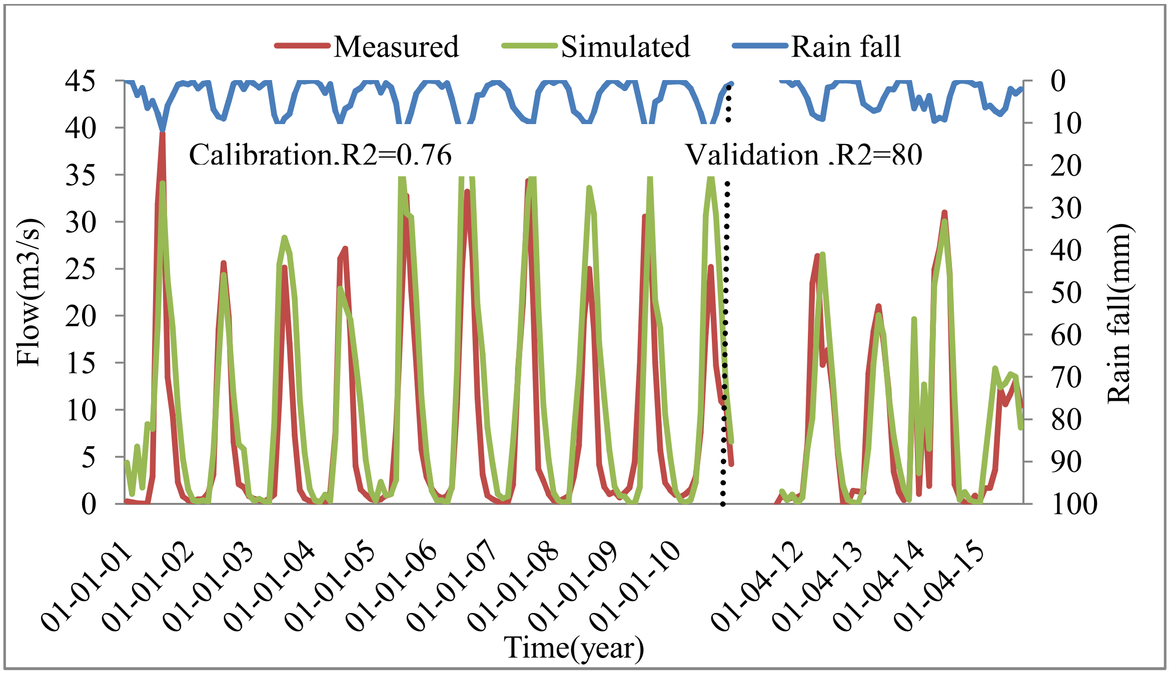


Figure 4. 13 Simulated vs observed monthly stream flow during calibration (2001-2010) and Validation (2012-2015) of SWAT model for Temcha

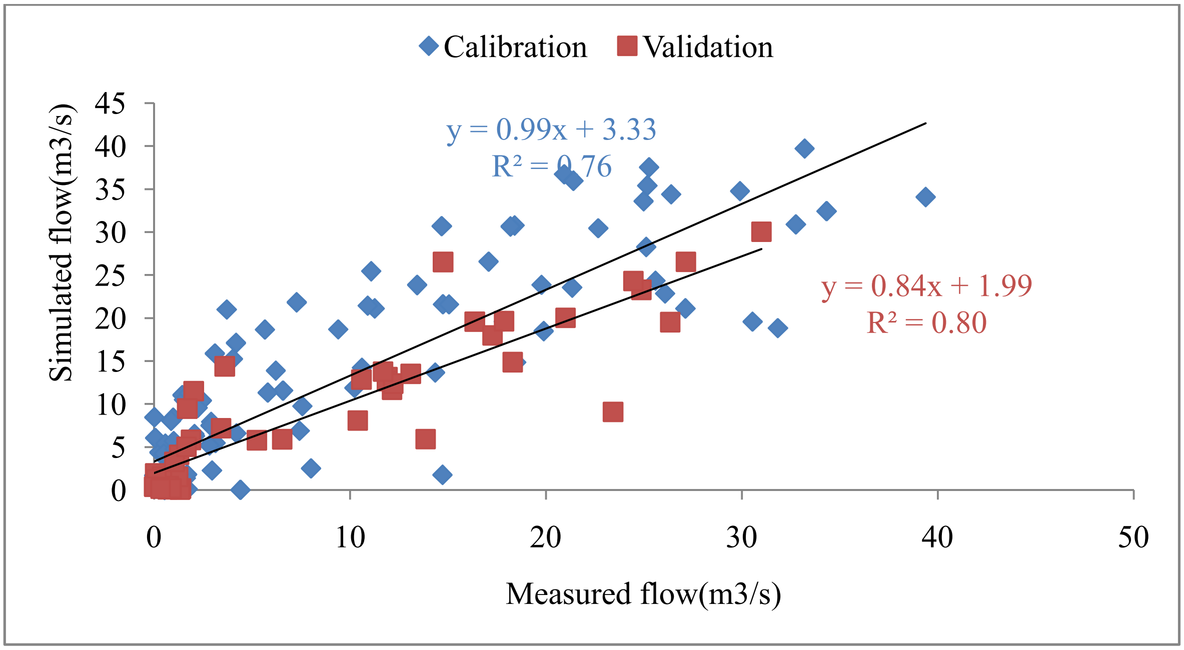


Figure 4. 14 Predicted vs measured stream flow during calibration and validation of SWAT model for Temcha

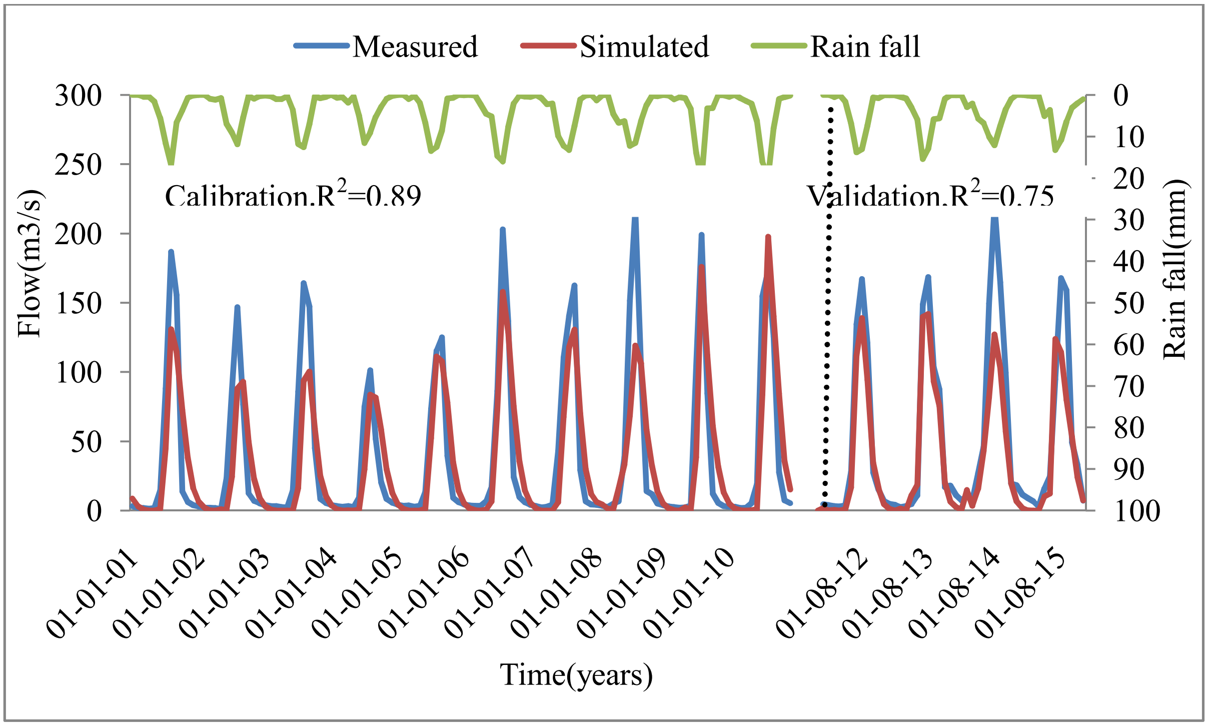


Figure 4. 15 Simulated and observed monthly Stream flow during calibration (2001-2010) and Validation (2012-2015) of SWAT model for Gumara

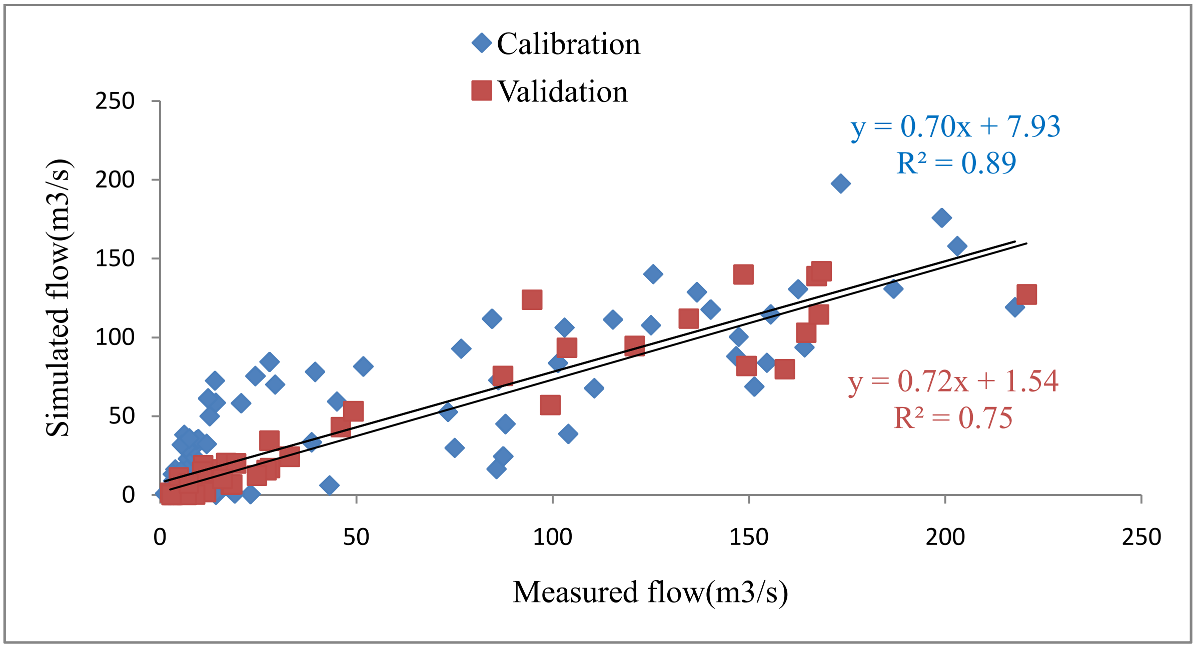


Figure 4. 16 Predicted vs measured and simulated stream flow during calibration and validation for SWAT model for Gumara

4.4.1.2 Sediment yield Calibration and Validation

The calibrated model using gagged rainfall could represent observed and simulated monthly sediment yield was very good agreement between modeled and observed data, except Temcha (0.65<NSE<0.86) for calibration and validation form AnditTid (0.88< NSE<0.92) and Gumara (0.79<NSE<0.86) was shown in daily and monthly summary table 4.11 and various performance statistics and also graphical description in (Figure 4.17 to 4.22) below.

The result obtained was within the range of similar studies on SWAT based runoff and sediment yield modelling in case of Gumara in Blue Nile basin(Asres and Awulachew, 2010) and runoff and sediment yield modelling using SWAT for management planning of MojoWatershed, Ethiopia (Gonfa, 2016), but different from the result obtained by (Yesuf et al., 2015) studies on modeling of sediment yield in Maybar(113.75ha) watershed. Hence, the results obtained confirm that SWAT model is more appropriate to be used for large watersheds.

Table 4. 10 Performance statistics during calibration and validation on sediment yield for selected watersheds for SWAT model

			SWAT model			
			Calibration (2001-2010)		Validation (2012-2015)	
Watershed	Description		Daily	Monthly	Daily	Monthly
Andit Tid	Statistical Value	R^2	0.46	0.68	0.51	0.53
		NSE	0.68	0.78	0.77	0.82
		RSR	0.56	0.35	0.48	0.29
		p-factor	0.90	0.72	0.87	0.69
		PBIAS	-15.4	-12.8	-20.8	-9.2
Temcha	Statistical Value	R^2	0.56	0.73	0.82	0.87
		NSE	0.56	0.65	0.72	0.86
		RSR	0.66	0.59	0.52	0.38
		p-factor	0.30	0.68	0.21	0.65
		PBIAS	6.8	-31.6	27.8	13.8
Gumara	Statistical Value	R^2	0.76	0.79	0.83	0.86
		NSE	0.63	0.78	0.73	0.85
		RSR	0.61	0.47	0.52	0.39
		p-factor	0.19	0.21	0.14	0.29
		PBIAS	-9.3	38.7	-35.1	37.8

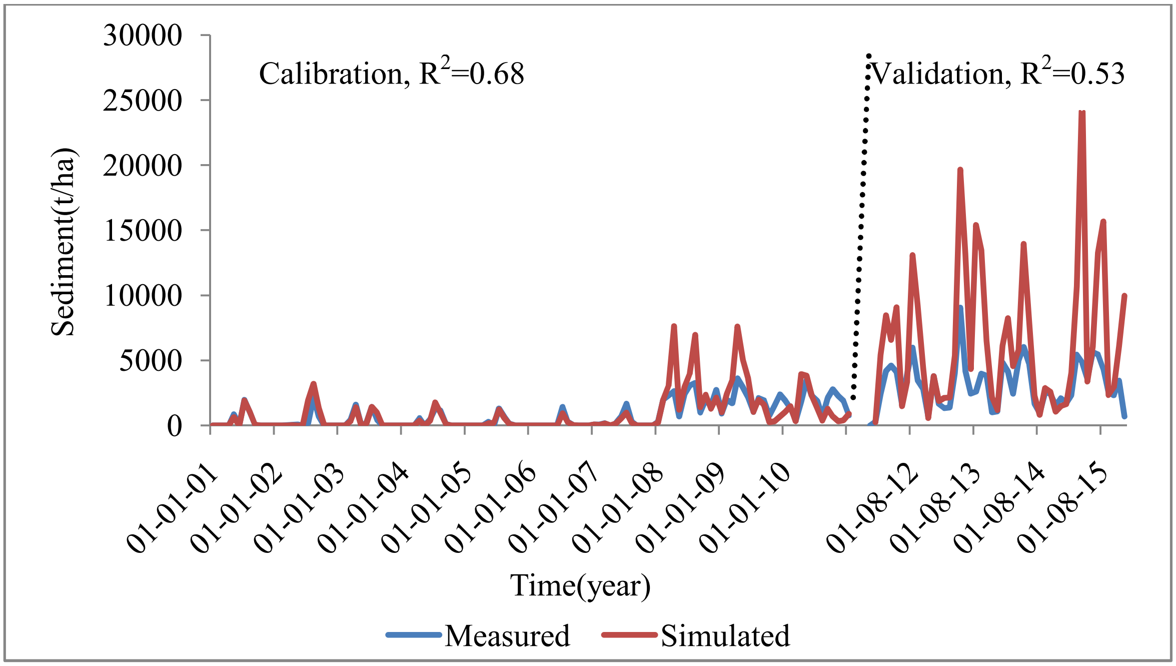


Figure 4. 17 Simulated and measured monthly Sediment yield during calibration validation of SWAT model for Andit Tid

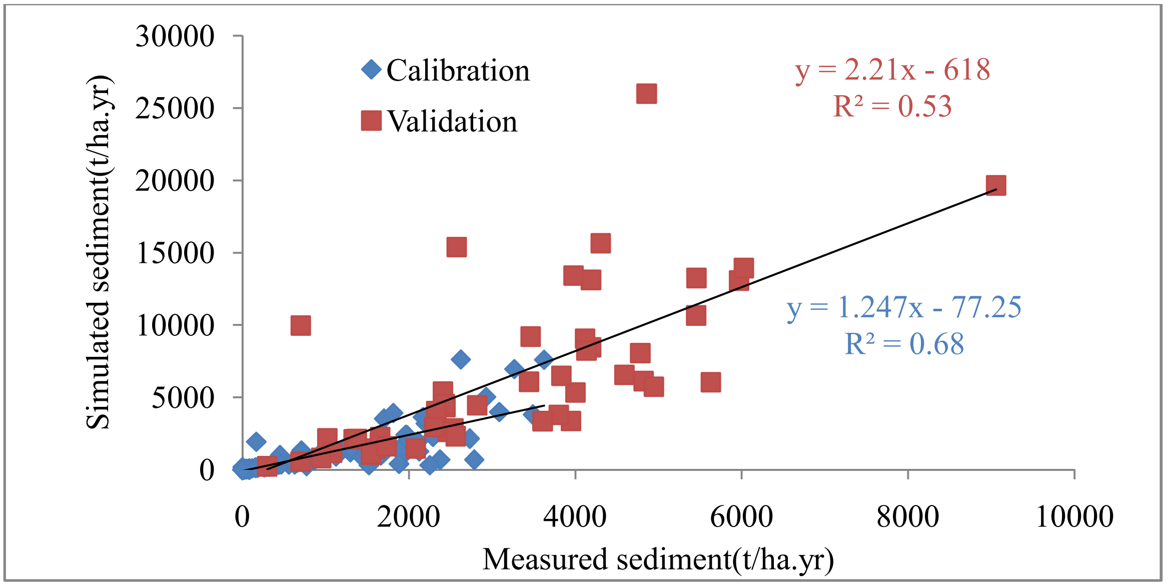


Figure 4. 18 Predicted vs measured Sediment yield during calibration and validation of SWAT model for Andit Tid

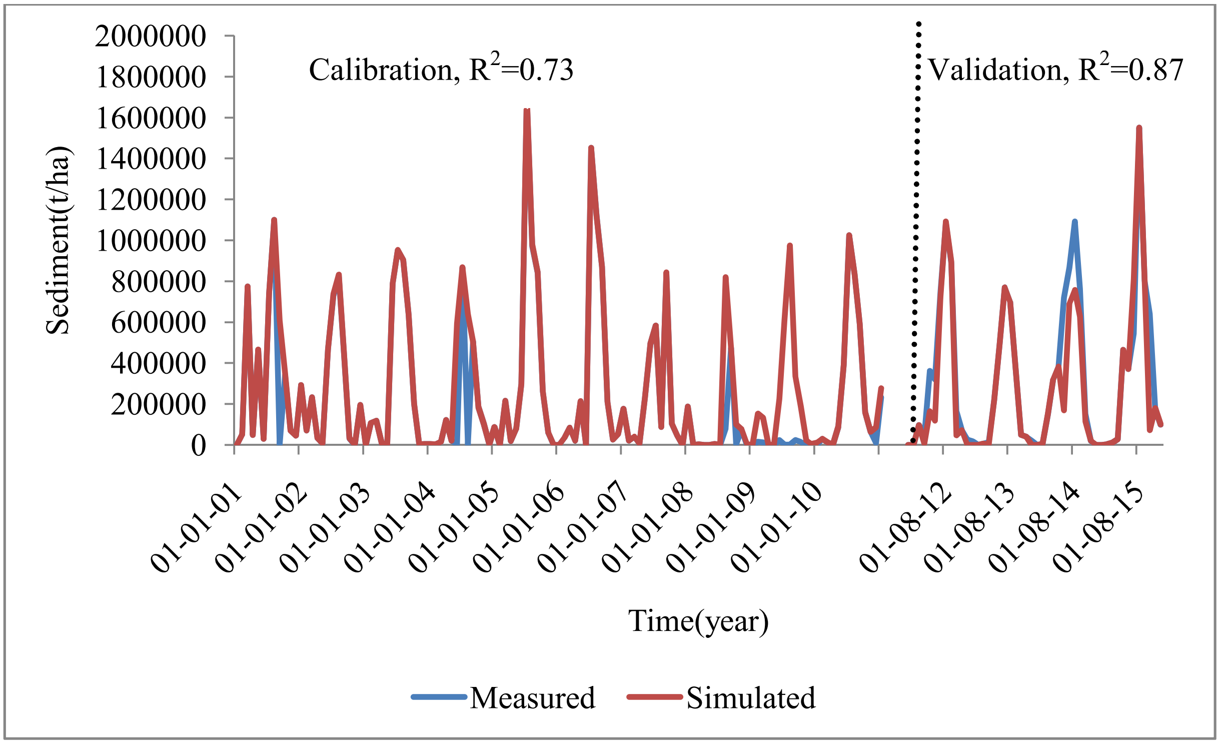


Figure 4. 19 Simulated vs Measured monthly Sediment yield during calibration and Validation of SWAT model for Temcha

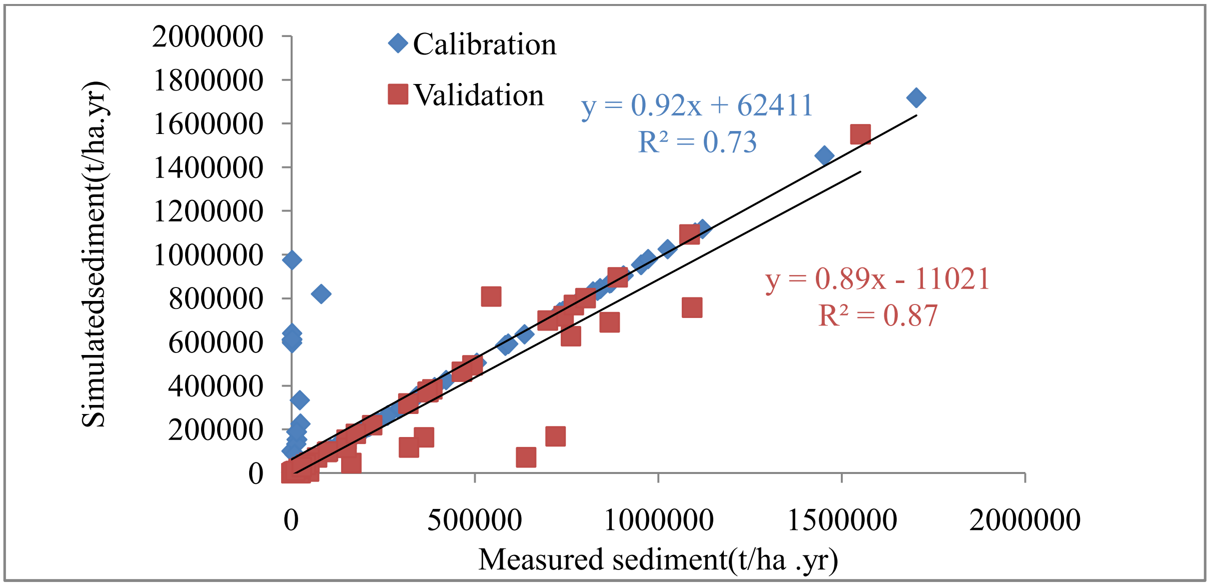


Figure 4. 20 Predicted vs measured Sediment yield during calibration and validation of SWAT model for Temcha

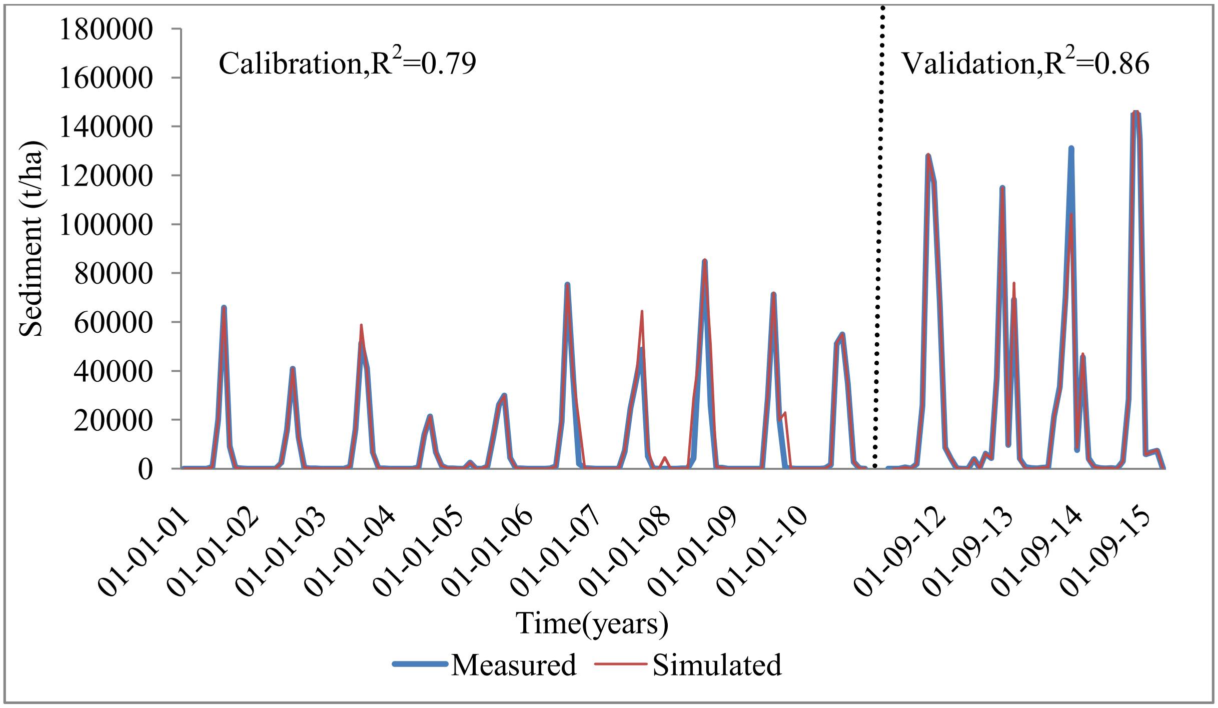


Figure 4. 21 Simulated and measured monthly Sediment yield during calibration and validation of SWAT model for Gumara

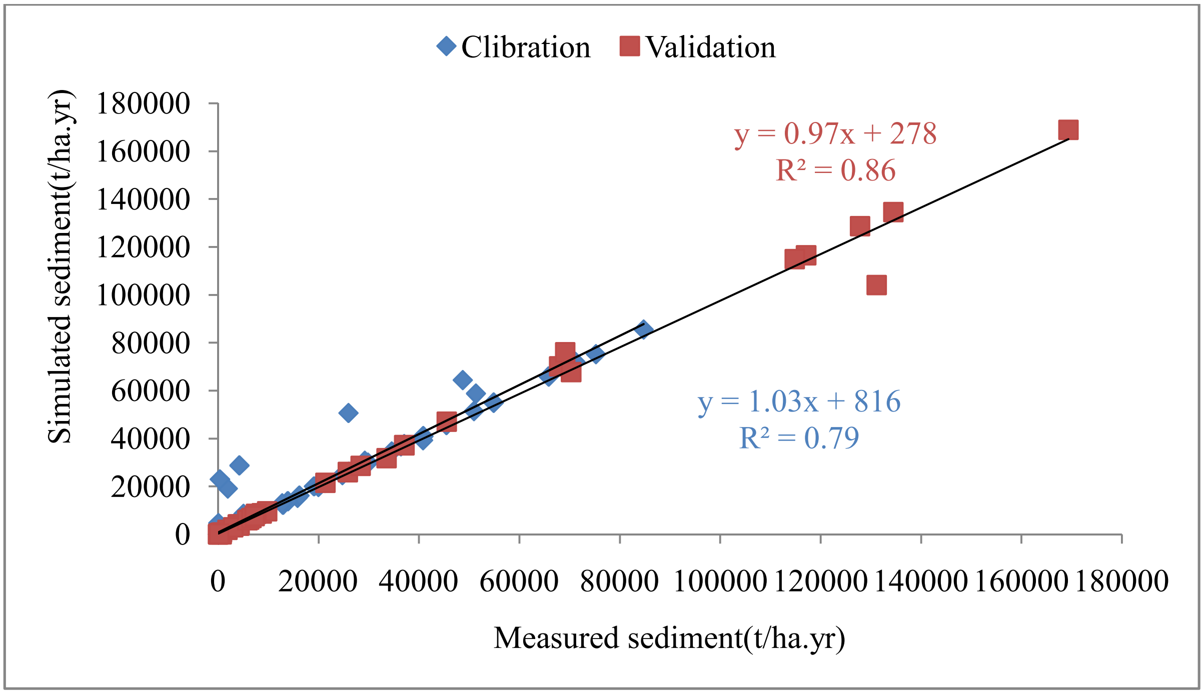


Figure 4. 22 Predicted and simulated Sediment yield during calibration and validation of SWAT model for Gumara

4.4.2 PED-W model calibration and validation

4.4.2.1 Water balance module calibration and validation

Model has nine input parameters during model development and all of them calibrated based on Steenhuis et al.(2009) and Collick et al.(2009). These initial values of the model were changed manually through randomly varying objective function in order to found best "closeness" or "goodness-of-fit" was achieved between simulated and observed subsurface flow and overland flow in the watershed.

The calibrated parameters in the model showed that saturation excess is the maim direct runoff process at outlet and could predict the maximum extent of runoff generation are from saturated area (constituting 5 % of the watershed) and degraded slopes (1%) and remaining part of the watershed was rain infiltrated contributing to inter flow and base flow as shown (Table 4.11). This was in accordance with measured data of interflow draining most of the watershed with limited overland flow on the hill slopes.

Table 4. 11 Calibrated parameters of water balance for selected watersheds

Parameters	Description of the parameters	Watersheds and Ranks			Optimal Fitted Value
		Andit Tid	Temcha	Gumara	
As	Portion of saturated area (%)	3	3	5	5
Ad	Portion of degraded area (%)	5	6	7	1
Ah	Portion of hill side (%)	1	1	1	94
Smax,s	Maximum soil water storage(mm) in A_s	6	6	7	73
Smax,d	Maximum soil water storage(mm) in A_d	6	6	7	15
Smax,h	Maximum soil water storage(mm) in A_h	6	5	6	150
Bmax	Maximum storage for base (mm)	2	4	2	210
t1/2	Base flow half life time(days)	3	2	3	12
τ*	Interflow(days)	4	6	4	6

A model efficiency coefficient (E) commonly used to assess the predictive power of hydrological model developed by Nash and Sutcliffe (1970) was optimized. For each watershed, inefficiency coefficient closest to one was sought because it indicated a good match between modeled and observed data.

The calibrated model using gagged rainfall could represent the observed and simulated monthly stream flow reasonable well, except Temcha (0.80<NSE<0.57) during calibration and validation form AnditTid (0.90< NSE<0.94) and Gumara (0.91<NSE<0.94) was shown in table 4.12 and the various performance statistics and also graphical description in (Figure 4.23 to 4.28) below.

Table 4. 12 performance statistics during calibration and validation of water balance on selected watersheds for PED-W model

			PED-WM			
			Calibration		Validation	
Watershed	Description of objective function		Daily	Monthly	Daily	Monthly
Andit Tid	Mean	Predicted	2.292	69.76	2.39	72.70
		Observed	0.288	65.72	3.06	93.37
	Statistical Value	R^2	0.71	0.91	0.79	0.94
		NSE	0.74	0.90	0.85	0.94
		RMSE	0.51	0.31	0.39	0.24
Temcha	Mean	Predicted	1.964	59.77	1.112	33.85
		Observed	1.70	51.731	3.077	93.66
	Statistical Value	R^2	0.55	0.83	0.61	0.76
		NSE	0.58	0.80	0.51	0.57
		RMSE	0.65	0.44	0.70	0.65
Gumara	Mean	Predicted	2.648	75.12	2.59	79.03
		Observed	2.303	70.11	3.06	93.37
	Statistical value	R^2	0.78	0.89	0.76	0.91
		NSE	0.80	0.91	0.83	0.94
		RMSE	0.45	0.30	0.41	0.24

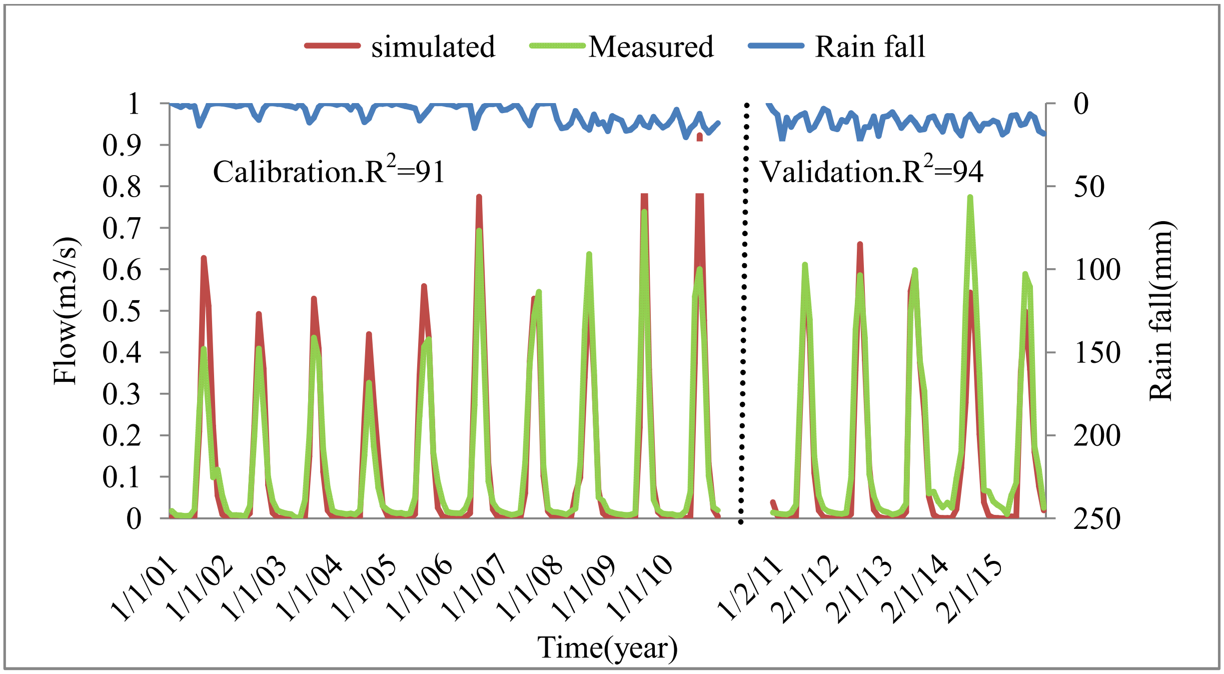


Figure 4. 23 Simulated and measured monthly Stream flow watershed during calibration (2001-2010) and Validation (2012-2015) of PED-WM for Andit Tid

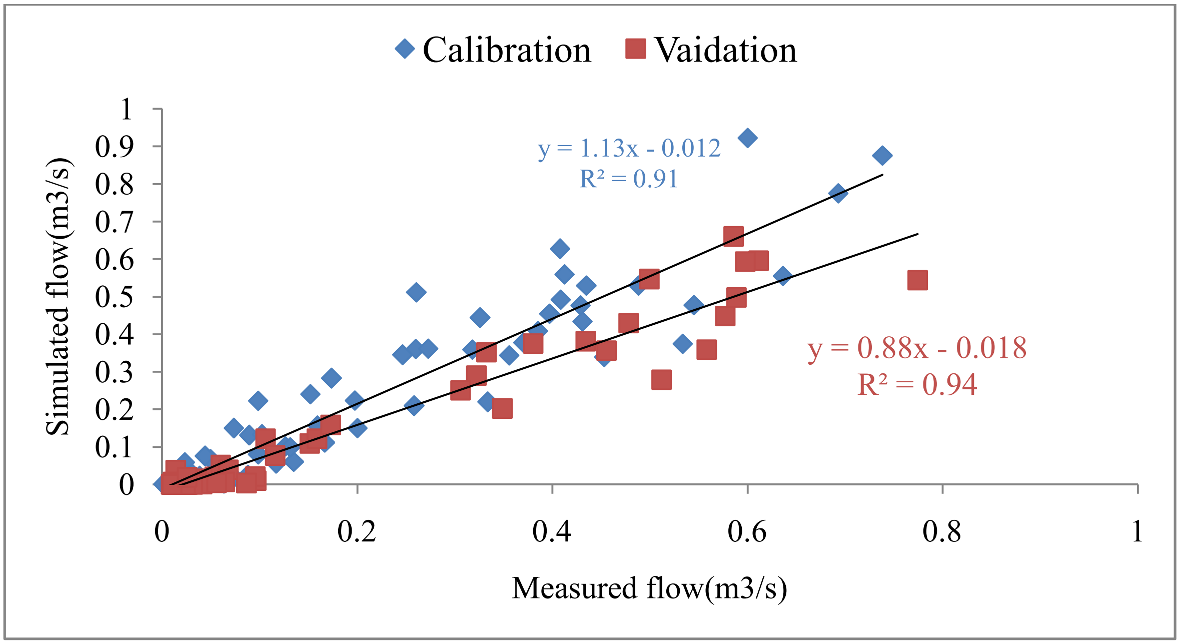


Figure 4. 24 predicted vs measured stream flow during calibration and validation of PED-WM for Andit Tid

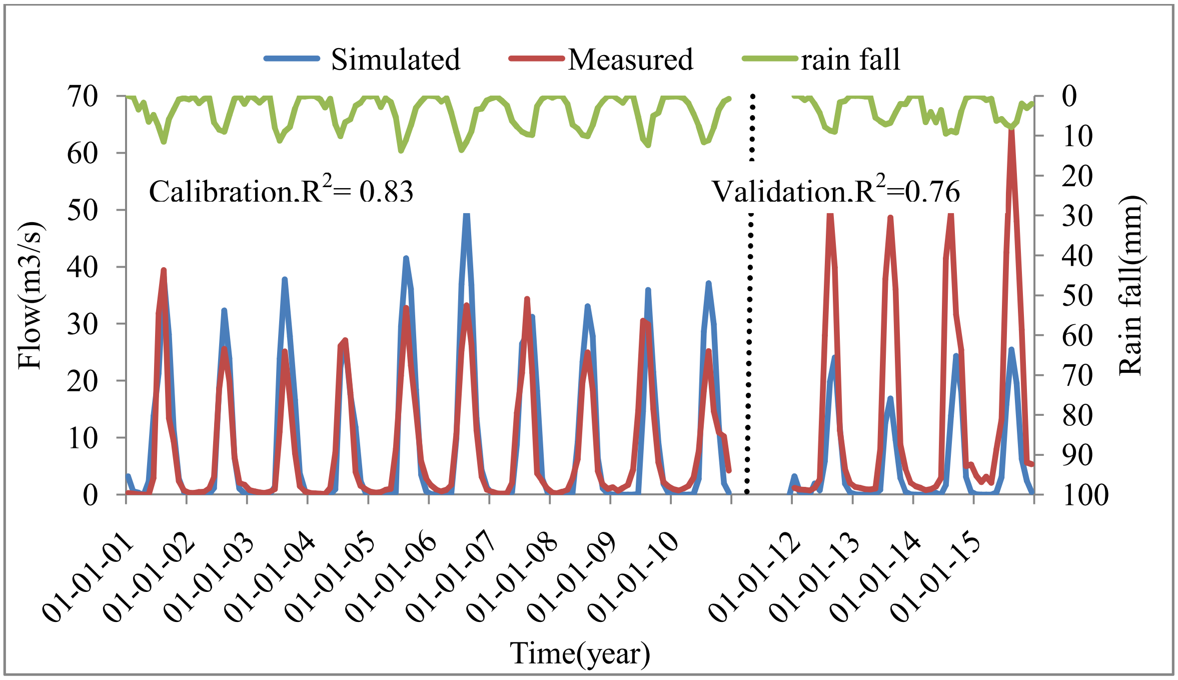


Figure 4. 25 Simulated and measured monthly Stream flow during calibration (2001-2010) and Validation (2012-2015) of PED-WM for Temcha

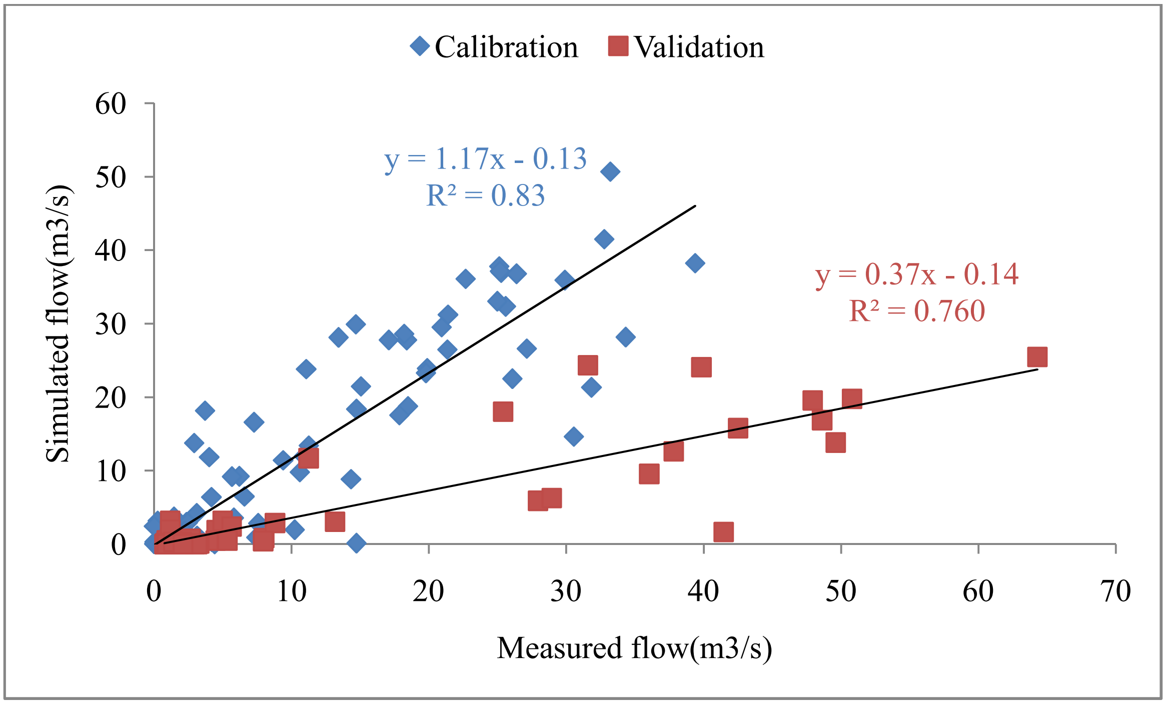


Figure 4. 26 Predicted vs measured stream flow during calibration and validation of PED-WM for Temcha

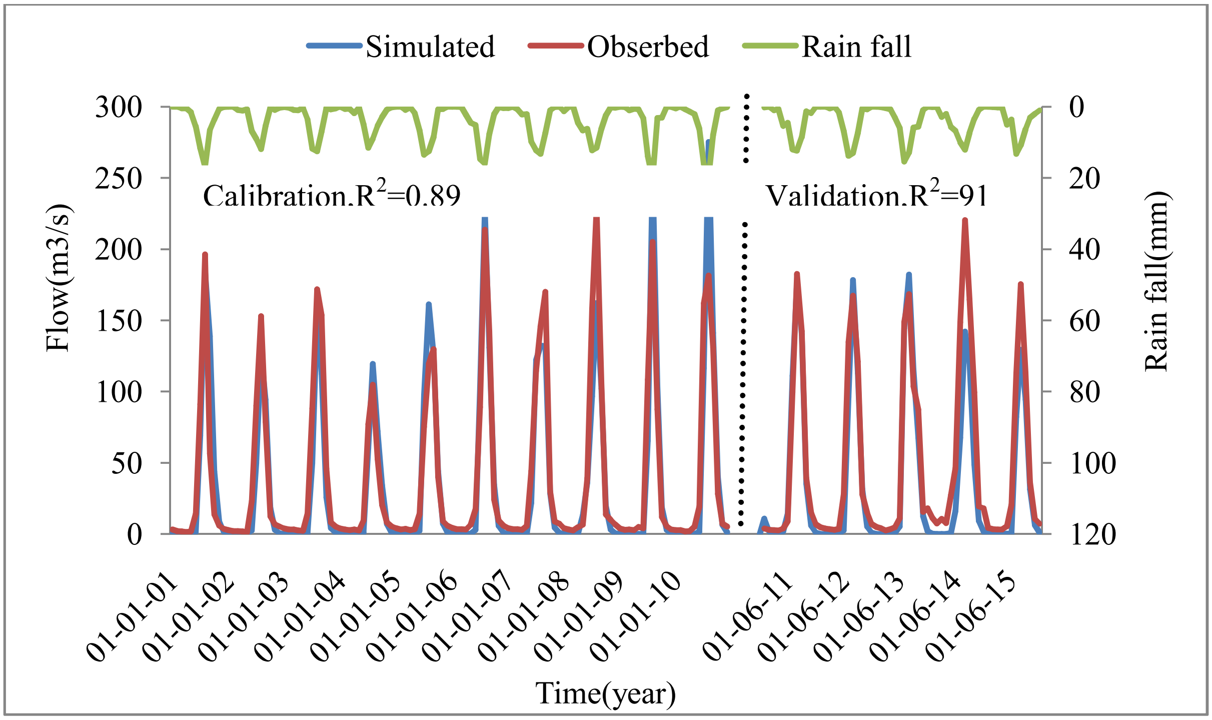


Figure 4. 27 Simulated vs measured monthly Stream flow during calibration (2001-2010) and Validation (2012-2015) of PED-WM for Gumara

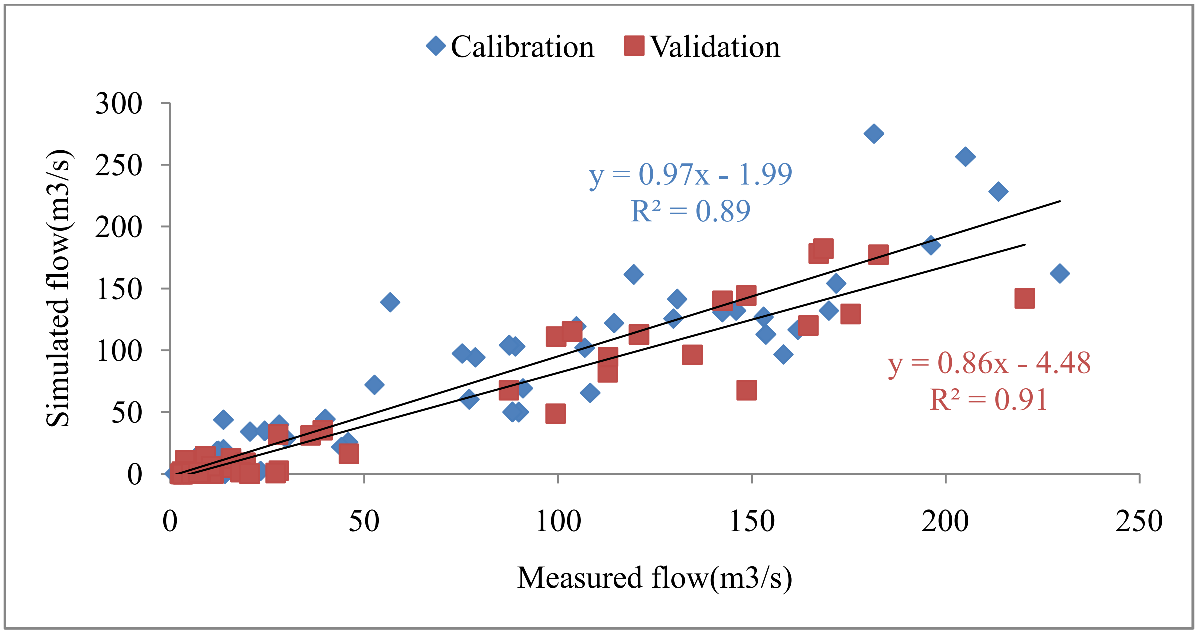


Figure 4. 28 Predicted vs measured stream flow during calibration and validation of PED-WM for Gumara

4.4.2.2 Sediment module calibration and validation

Calibration and validation was done based on studies in sub-humid Ethiopian highlands from Debre Mawi watershed to predict distributed discharge and sediment concentration (Tilahun et al., 2015) and budgeting suspended sediment fluxes in tropical monsoonal watersheds with limited data in Lake Tana basin (Zimale et al., 2018).

There are two calibration parameters consisting of the constants for each of the two runoff source areas (transport limit) and source limits. Having constants and they are changed manually in order to get a best fit between measured and simulated daily sediment load.

Calibrated parameters were transport limit (at) and source limit (as*)* surface runoff source areas and transport limit coefficients for the saturated areas form selected watersheds were similar at (AreaT1=6.5) and final fitted source and transport limits areas were as shown (Table 4.13) and the various performance statistics and also graphical description in (Figure 4.29 to 4.34).

Table 4. 13 Calibrated parameters of Sediment module for selected watersheds

Parameters	Description of the parameter	Watersheds and Ranks			Optimal Fitted Value
		Andit Tid	Temcha	Gumara	
Area T_1	transport limit saturated area	1	1	1	6.5
Area T_2	transport limit degraded area	3	4	2	16
PT	total precipitation (PT)	4	3	4	595
Area S_1	Source limit saturated area	2	2	3	8.5
Area S_2	Source limit degraded area	4	5	4	12

Table 4. 14 Performance statistics during calibration and validation of sediment module on selected watersheds for PED-W model

			PED-WM			
			Calibration (2001-2010)		Validation (2012-2015)	
Watershed	Description		Daily	Monthly	Daily	Monthly
Andit Tid	Mean	Predicted	0.95	29.14	0.83	25.79
		Observed	0.94	28.77	0.84	26.04
	Statistical Value	R^2	0.71	0.90	0.73	0.92
		NSE	0.73	0.90	0.75	0.92
		RMSE	0.52	0.31	0.50	0.28
Temcha	Mean	Predicted	0.80	24.39	0.70	21.27
		Observed	1.41	42.92	0.93	28.19
	Statistical Value	R^2	0.74	0.91	0.64	0.71
		NSE	0.75	0.82	0.65	0.80
		RMSE	0.50	0.42	0.59	0.45
Gumara	Mean	Predicted	1.02	3.27	0.85	26.73
		Observed	1.55	47.56	1.07	33.41
	Statistical Value	R^2	0.83	0.95	0.90	0.92
		NSE	0.81	0.83	0.91	0.90
		RMSE	0.44	0.41	0.30	0.32

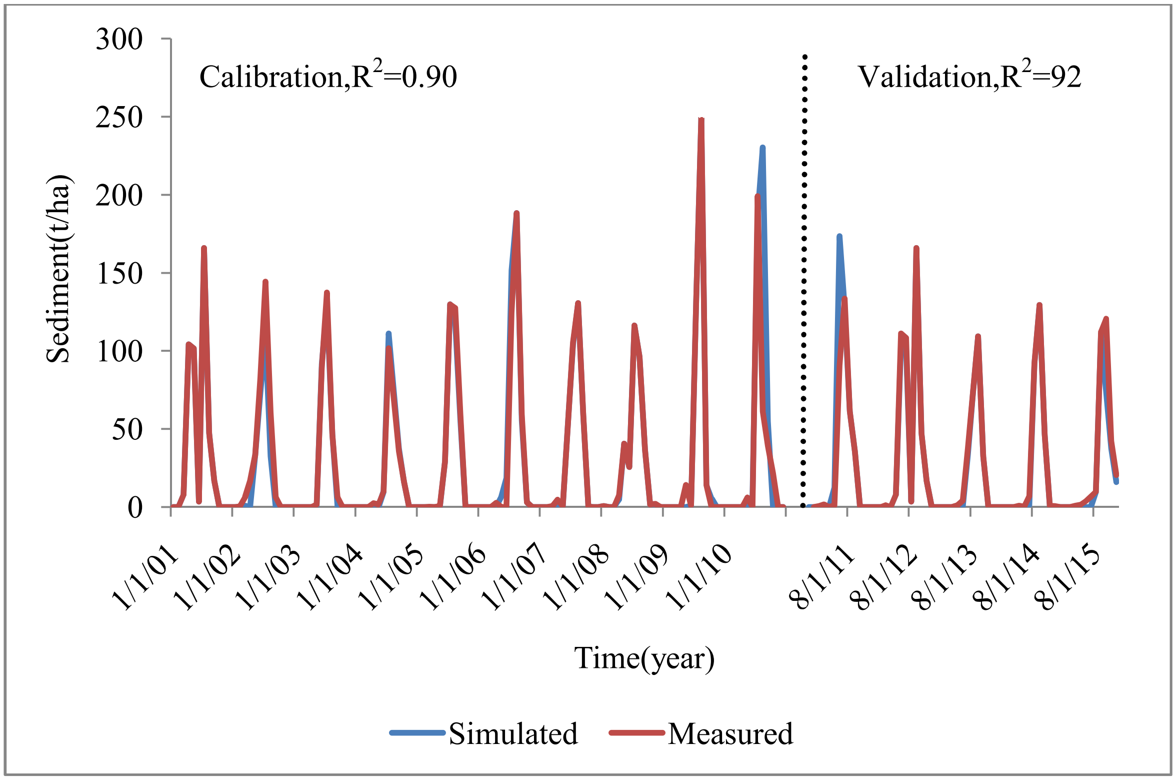


Figure 4. 29 Simulated and measured monthly Sediment yield during calibration Validation of PED-WM for Andit Tid

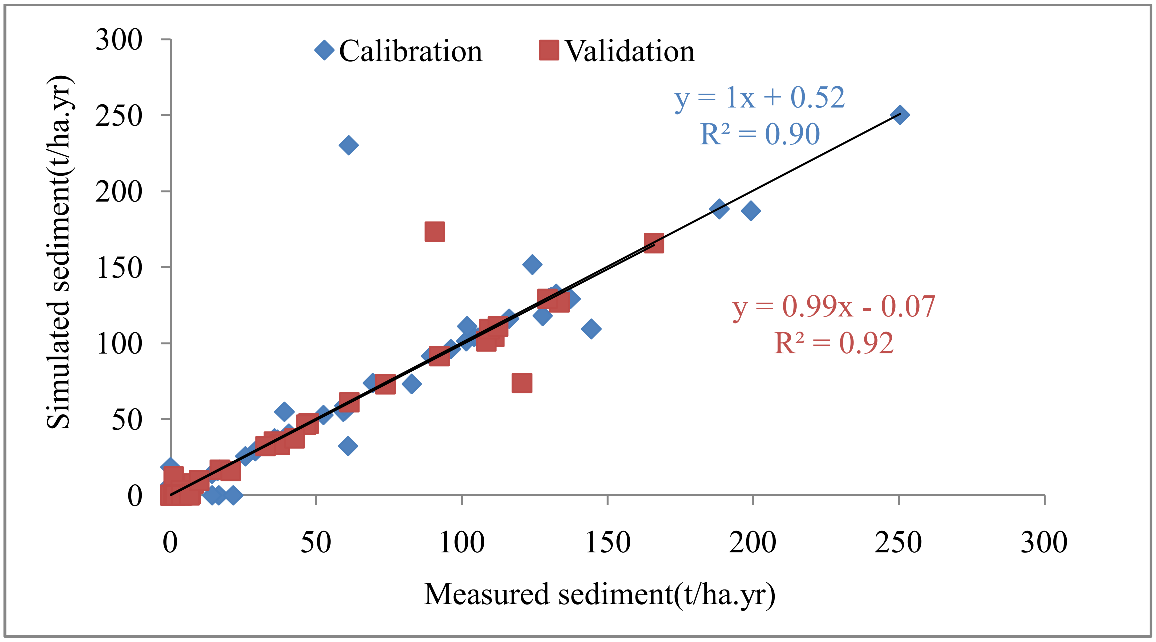


Figure 4. 30 Predicted vs measured Sediment yield during calibration and Validation of PED-WM for Andit Tid

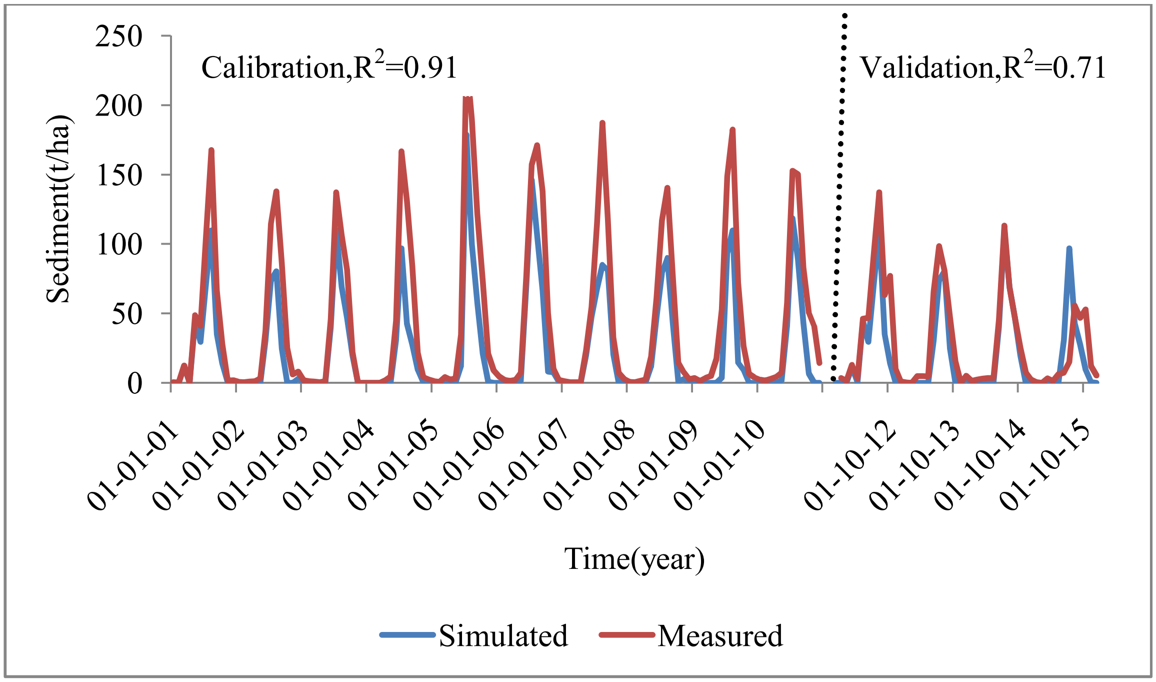


Figure 4. 31 Simulated and measured monthly Sediment during calibration and Validation of PED-WM for Temcha

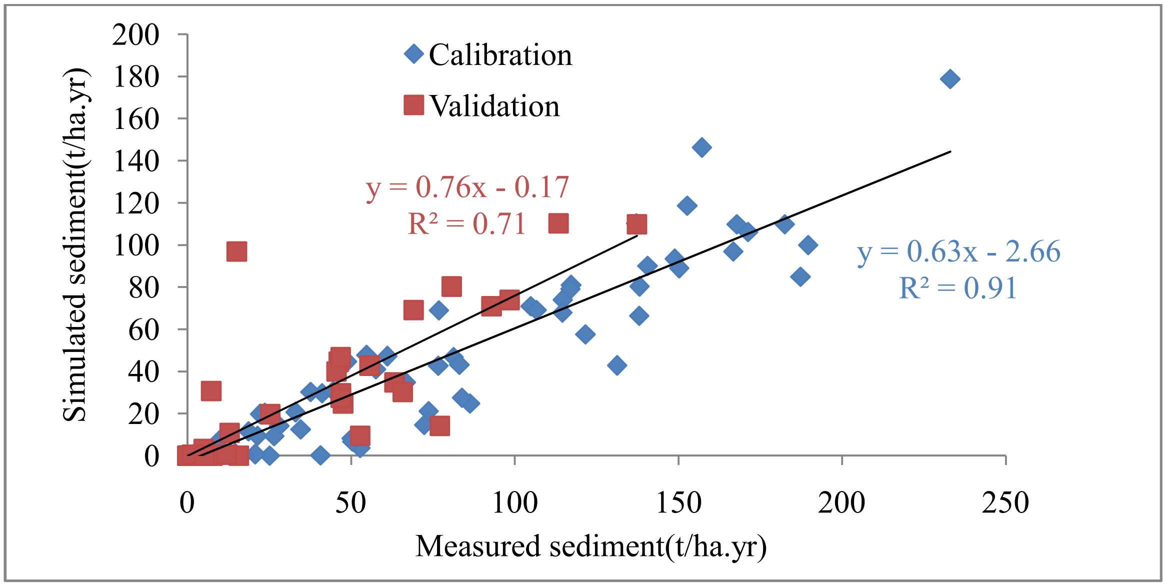


Figure 4. 32 Predicted vs measured Sediment yield during calibration and validation of PED-WM for Temcha

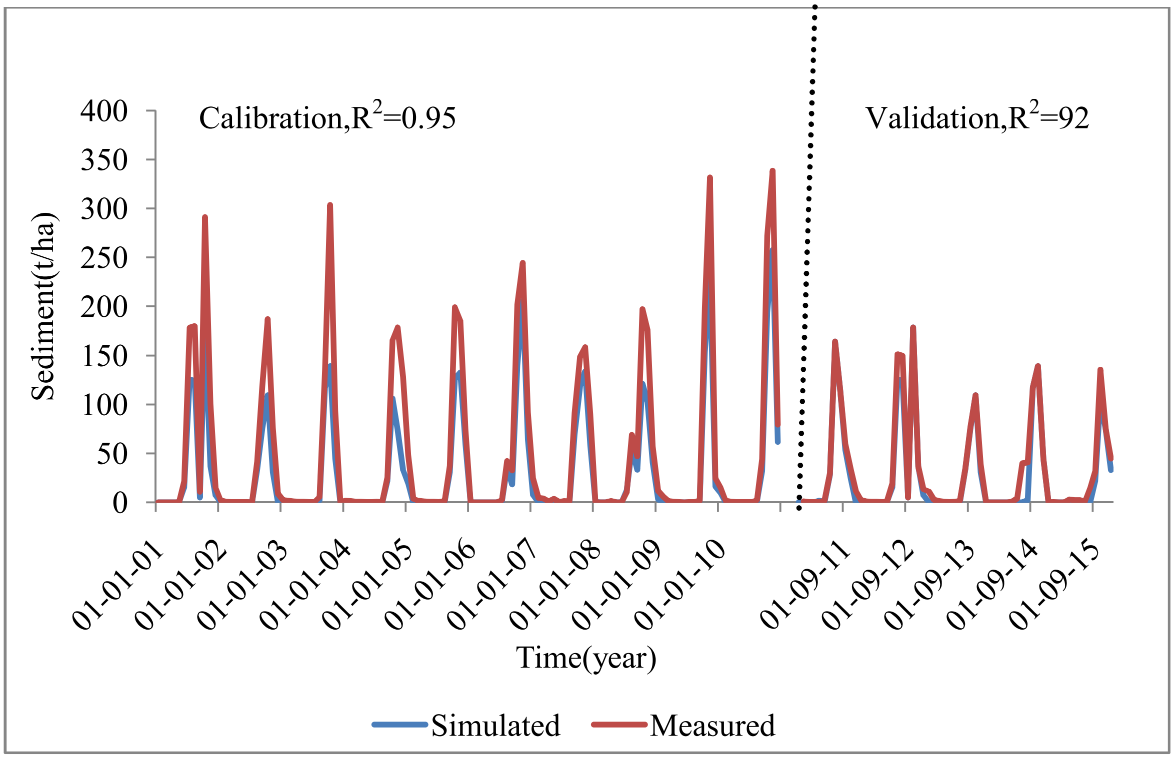


Figure 4. 33 Simulated and measured monthly Sediment yield during calibration and Validation of PED-WM for Gumara

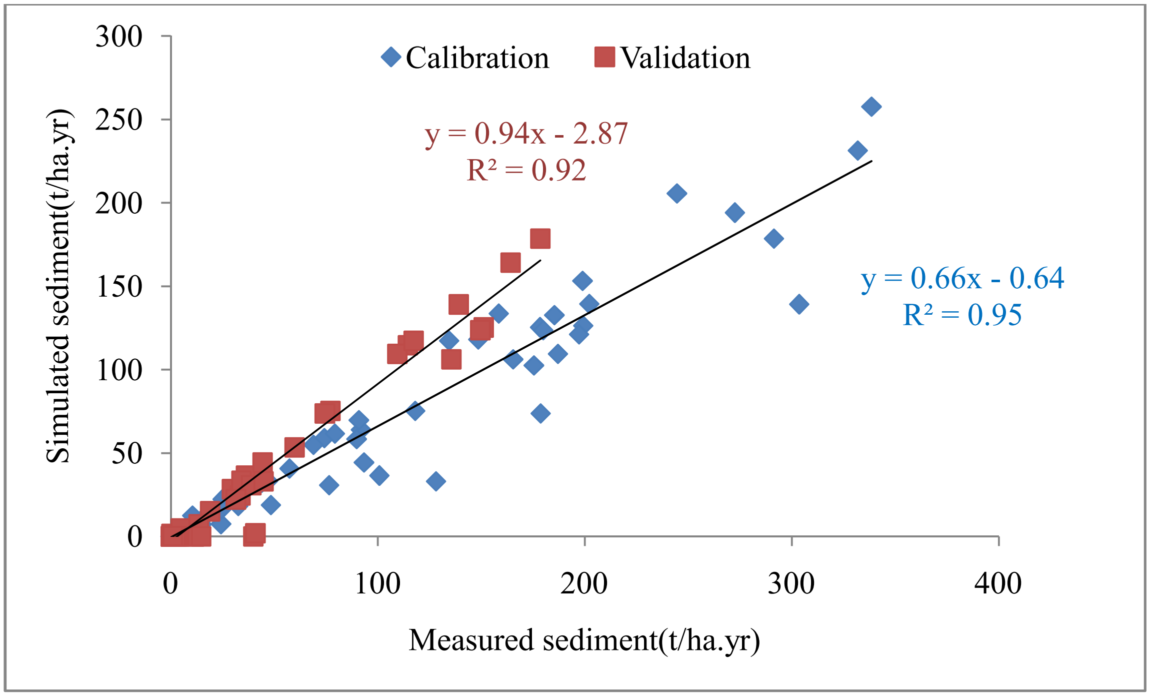


Figure 4. 34 Predicted vs measured Sediment yield during calibration and validation of PED-WM for Gumara

4.5 Hydrological Model Performance and Comparison

Both daily and monthly time steps of the measured stream and sediment load data were simulated through capability of SWAT and PED-W models form Andit Tid, Temcha and Gumara watersheds.

Considering common model efficiency criteria (NSE) the water balance values were 0.70, 0.91and 0.84,0.89 during calibration and validation 0.74,0.90 and 0.85,0.94 for SWAT and PED-W models respectively for Andit Tid watershed.

For Temcha watershed has the values of (NSE) were 0.62, 0.75 and 0.65, 0.93 in daily and monthly time during calibration and validation 0.58,0.80 and 0.51, 0.57 for SWAT and PED-W model respectively.

Lastly, Gumara watershed has (NSE) values were for the SWAT model in the daily and monthly bias 0.64,0.89 and 0.68, 0.71 during calibration and validation respectively and also 0.80, 0.91 and 0.83, 0.94 calibrations and validation respectively for PED-WM.

The water balance module result of SWAT model were within the range of similar studies by (Setegn et al., 2008, Wale et al., 2008 and Awulachew et al., 2009) and Similarly, PED-WM the past studies in the Blue Nile basin by (Collick et al., 2009;Steenhuis et al., 2009, Tesemma et al., 2010;Tilahun et al., 2013 and Moges et al., 2017).

The sediment module SWAT model for Andit Tid; NSE value were during calibration and validation 0.68, 0.78 and 0.77,0.82 daily and monthly times step. For Temcha; 0.56, 0.65 and 0.72, 0.86daily and monthly times step. Lastly, for Gumara watershed 0.63, 0.78 and 0.73,0.85 daily and monthly times step respectively. These results of SWAT model were in the range of similar studies on (Demirel et al., 2009; Betrie et al., 2011 and Wosenie et al., 2014).

The sediment module PED-W model for Andit Tid; NSE values were during calibration and validation was 0.73, 0.90 and 0.75, 0.92 daily and monthly times step. For Temcha; 0.75, 0.82 and 0.65, 0.80 daily and monthly times step. Lastly, for Gumara watershed 0.81, 0.83 and 0.91, 0.90 daily and monthly times step respectively. These results of PED-W model were within the range of similar studies by (Tilahun et al., 2015; Zimale et al., 2018).

The selected models have different runoff generation mechanism and also the model principles are differ each other. SWAT model to generate runoff mechanism is infiltration excess. PED-W model runoff mechanism depends on saturation excess and the parameters were similar for the Andit Tid, Temcha & Gumara watersheds; which contributes runoff generation area from 6% (5%saturated and 1% degraded) and an aquifer half life($t_{1/2}$) were 12days and 6 days inter flow(τ^*) period.

PED-W model was the most suitable model to predicate stream flow and sediment yield for selected watersheds. Since, the values of Nash Sutcliffe efficiency (NSE), coefficient of determination (R^2) and Root mean square error (RSME) of PED-W model indicated that good agreement between observed and simulated data.

The PED-W model analysis showed that the model could capture quite well the variability in discharge and sediment concentrations using parameter values that did not vary greatly between the scales. The model basically assumes in its simplest form that a watershed in a monsoon climate wets up after the dry season and produces increasing amounts of base and interflow as the rainy season progresses (Tilahun et al., 2013).

The overall model performance indicated that PED-W was accurate and suitable model to predict the stream flow and sediment yield due to its insufficient data environments and saturation excess runoff generation mechanism and as our country context the rain fall occurs at short time of summer season for stream flow occurrence.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Modeling of Ethiopian watershed is challenging because reliable long term data are not available and our understanding of hydrological responses to precipitation and monsoonal climate is limited due to little fundamental research carried out on these aspects.

Rainfall-runoff models are standard tools used for investigating hydrological processes. The numbers of models with different applications ranges from small catchments to global models have been developed and each model has got its own unique characteristics and respective applications.

SWAT and PED-W models are successfully calibrated and validated in the Andit Tid, Temcha and Gumara gauging stations of the Blue Nile basin using SUFI-2 algorithm and manually adjusting default values of the model development ranges respectively. These models are used for the modeling of the stream flow and sediment load.

Sequential uncertainty fittings verstion2 (SUFI-2) algorithm for SWAT model is effective method calibration and validation. But, it requires additional iterations as well as the need for the adjustment of parameter ranges. Despite data uncertainty; SWAT model produced good simulation results for daily and monthly time steps.

PED-W model Sensitivity analysis is carried out manually increasing or decreasing each parameter by(±10%)while, other landscape parameters were remaining constant and fixing lower and upper limits of the model(0.0-1.0).

The overall values of simulated and measured monthly and daily time step on the stream flow and sediment concentration in the AnditTid, Temcha and Gumara gauging stations as obtained using SWAT and PED-W models during calibration and validation have been found out good agreement.

The sediment module efficiency criteria on daily and monthly time step during calibration period were presented as follows; for SWAT (NSE=0.68, 0.78) and PED-WM (NSE=0.73, 0.90) were obtained for AnditTid. Similarly, for validation of SWAT model (NSE=0.77, 0.82) and PED-WM (NSE=0.75, 0.92).

For Temcha calibration of SWAT (NSE=0.56, 0.65) and PED-WM (NSE=0.75, 0.82) and validation of SWAT (NSE=0.72,0.86) and PED-WM (NSE=0.65,0.80). And also, Gumara calibration of SWAT (NSE=0.63, 0.78) and PED-WM (NSE=0.81, 0.83) and validation of SWAT (NSE=0.73,0.85) and PED-WM(NSE=0.91,0.90) were obtained.

Generally, SWAT model performs better with monthly time step simulations and shows good agreement between measured and simulated values of the stream flow and sediment yield as compared to daily simulations.

PED-W model is simplified watershed sediment model coupled with the hydrology model and used to simulate sediment concentrations and such simplified models that require very few calibration parameters to simulate the stream flow and sediment transport and also important in data limiting environments as compared to SWAT model data intensiveness.

5.2 Recommendations

It is better to understand rainfall-runoff modeling processes in the watersheds as well as a basin label for paramount planning and management of the water resources, particularly in data-scarce regions of Blue Nile basin, Ethiopia.

However, this should not tempt us to believe that a scientific knowledge of rainfall excess can easily be the applied to hydrologic problems in general.

Moreover; the output of the present study will support the planners and decision makers to take relevant soil and water conservation measures to diminish the alarming soil loss and land degradation troubles in this data-scarce region, Blue Nile Basin, Ethiopia.

There is the need for weather, stream flow and sediment concentration quality data for the investigation and improvement of the catchment management practice for the capability of hydrological model; specifically for the SWAT and PED-W models in the entire Blue Nile Basin, Ethiopia.

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APPENDIX

Annex I: A) Temcha watershed summary of rainfall data for selected Rain Gauge Station

Monthly Rain Fall of Each Station				Cumulative Monthly Rain fall Each Stations		
YEAR	AMAN	DEMBCH	Sum of Each St			CUM_ALL ST
2000	1549.520	1367.600	2917.120	1549.520	1367.600	2917.120
2001	1435.250	1446.900	2882.150	2984.770	2814.500	5799.270
2002	1214.280	1062.000	2276.280	4199.050	3876.500	8075.550
2003	1263.590	1325.200	2588.790	5462.640	5201.700	10664.340
2004	1345.670	1123.800	2469.470	6808.310	6325.500	13133.810
2005	1489.820	1436.100	2925.920	8298.130	7761.600	16059.730
2006	2002.040	1662.200	3664.240	10300.170	9423.800	19723.970
2007	1546.770	1537.800	3084.570	11846.940	10961.600	22808.540
2008	1705.900	1459.200	3165.100	13552.840	12420.800	25973.640
2009	1344.500	1231.700	2576.200	14897.340	13652.500	28549.840
2010	1387.900	1652.700	3040.600	16285.240	15305.200	31590.440
2011	1580.100	1516.420	3096.520	17865.340	16821.620	34686.960
2012	1134.400	1096.100	2230.500	18999.740	17917.720	36917.460
2013	1333.900	944.700	2278.600	20333.640	18862.420	39196.060
2014	1588.090	1649.640	3237.730	21921.730	20512.060	42433.790
2015	1426.900	1269.900	2696.800	23348.630	21781.960	45130.590

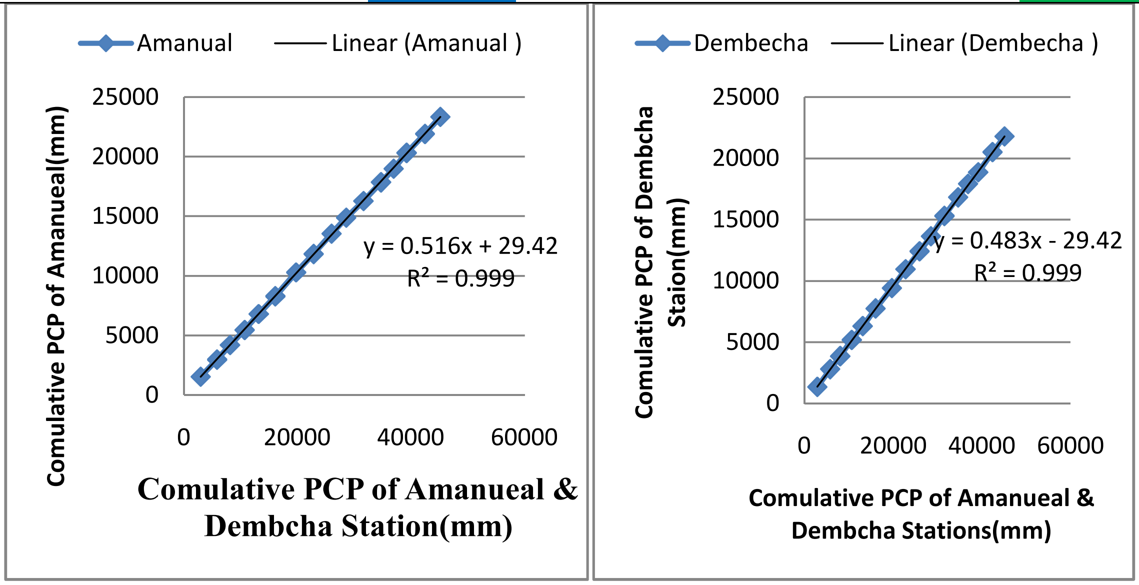


Figure 3.10 Double mass curves for Temcha watershed the selected stations (2000_2015)

Table 1: Mean annual rain fall station of Temcha watershed

	MONTHLY RF OF EACH STATION			
year	Amanueal	DEBRETABOUR	Average	
2000	1549.52	1367.6	1458.56	
2001	1435.25	1446.9	1441.075	
2002	1214.28	1062	1138.14	
2003	1263.59	1325.2	1294.395	
2004	1345.67	1123.8	1234.735	
2005	1489.82	1436.1	1462.96	
2006	2002.04	1662.2	1832.12	
2007	1546.77	1537.8	1542.285	
2008	1705.9	1459.2	1582.55	
2009	1344.5	1231.7	1288.1	
2010	1387.9	1652.7	1520.3	
2011	1580.1	1516.42	1548.26	
2012	1134.4	1096.1	1115.25	
2013	1333.9	944.7	1139.3	
2014	1588.09	1649.64	1618.865	
2015	1426.9	1269.9	1348.4	
Mean Annual RF	1459.289	1361.373		1410.331
			1410.331	

Annex II: B) Gumara watersheds summary of rainfall data for selected Rain Gauge Station

	Monthly Rainfall of Each Station						Cumulative Monthly Rain fall Each Stations			
Year	Amed Ber	Debre Tabour	Wanzaye	Woreta	Sum of All Station	Amed Ber	Debretabor	Wanzaye	Woreta	CUM_ALL STATION
2015	1612.500	1202.600	1567.100	2721.000	7103.200	1612.500	1202.600	1567.100	2721.000	7103.200
2014	1447.900	1749.900	1441.000	1279.200	5918.000	3060.400	2952.500	3008.100	4000.200	13021.200
2013	1595.300	1683.500	1442.900	1297.600	6019.300	4655.700	4636.000	4451.000	5297.800	19040.500
2012	1219.600	1489.400	1290.500	1241.100	5240.600	5875.300	6125.400	5741.500	6538.900	24281.100
2011	1423.800	1534.000	1427.900	1195.300	5581.000	7299.100	7659.400	7169.400	7734.200	29862.100
2010	1668.700	1634.400	1878.200	1478.700	6660.000	8967.800	9293.800	9047.600	9212.900	36522.100
2009	1269.400	1517.800	1399.200	1107.100	5293.500	10237.200	10811.600	10446.800	10320.000	41815.600
2008	1449.600	1647.100	1592.200	1588.700	6277.600	11686.800	12458.700	12039.000	11908.700	48093.200
2007	1441.900	1557.700	1488.400	1249.410	5737.410	13128.700	14016.400	13527.400	13158.110	53830.610
2006	1550.700	1638.200	1663.500	1515.500	6367.900	14679.400	15654.600	15190.900	14673.610	60198.510
2005	1637.620	1491.400	1198.400	1397.100	5724.520	16317.020	17146.000	16389.300	16070.710	65923.030
2004	1304.100	1198.100	1085.700	1186.500	4774.400	17621.120	18344.100	17475.000	17257.210	70697.430
2003	1818.220	1290.000	1798.000	1267.500	6173.720	19439.340	19634.100	19273.000	18524.710	76871.150
2002	1013.000	1097.530	1267.700	1141.900	4520.130	20452.340	20731.630	20540.700	19666.610	81391.280
2001	1381.900	1558.360	1381.200	1535.220	5856.680	21834.240	22289.990	21921.900	21201.830	87247.960
2000	1664.500	1663.370	1664.800	1645.530	6638.200	23498.740	23953.360	23586.700	22847.360	93886.160

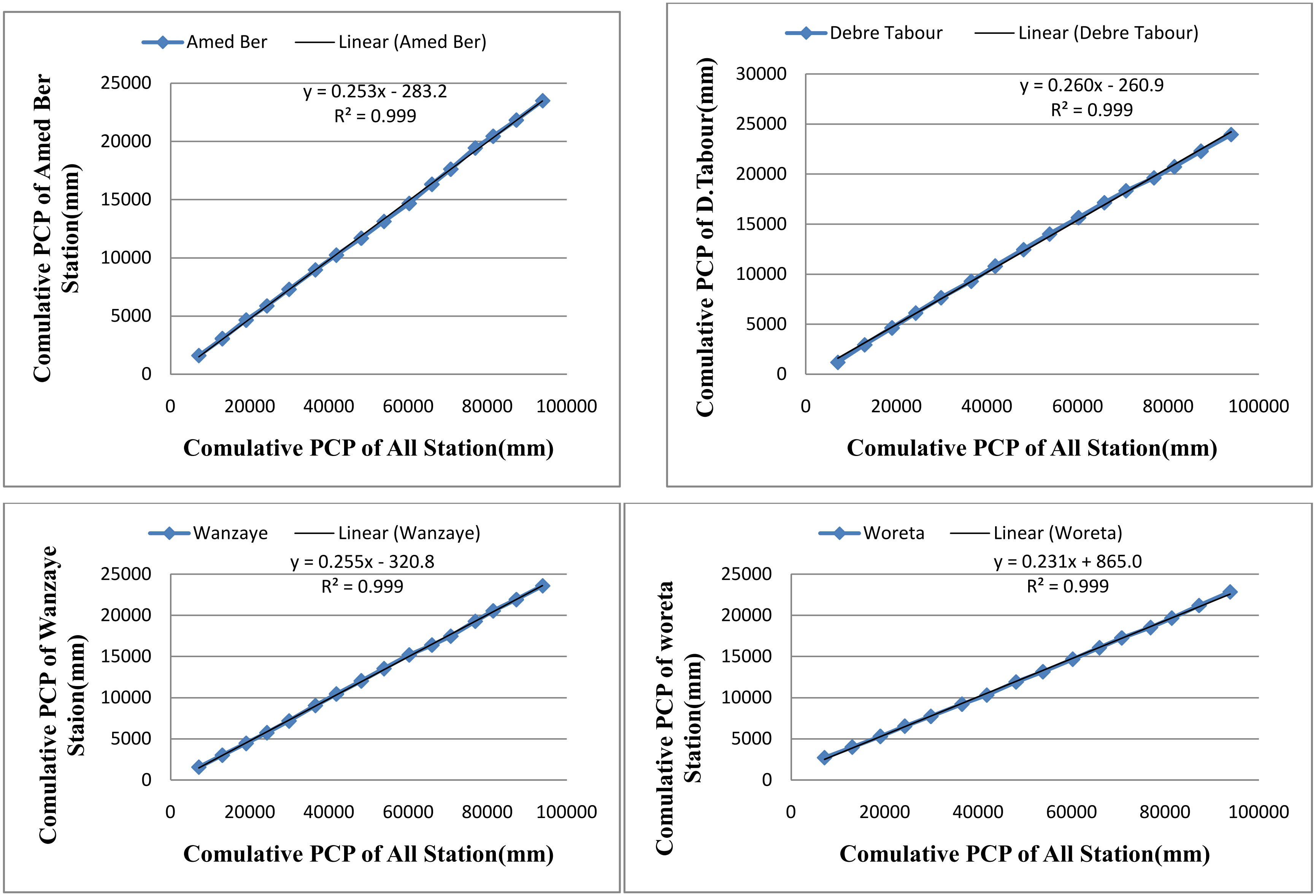


Figure 3.10 Double mass curves for Gumara watershed the selected stations (2000_2015)

Annex III: C) Statistical Parameters Calculation for Precipitation Data on Gumara watersheds

After the precipitation data was checked for quality and the appropriate station selected statistical parameters of precipitation data for Debre Tabour (synoptic stations) must be calculated before model set up.

The statistical parameters for precipitation were calculated using the programme *pcpSTAT.exe*. This programme calculates statistical parameters of daily precipitation data used by the weather generator of the SWAT model (userwgn.dbf) (Liersch, 2003).

The programme can be found at (http://swat.tamu.edu/software/links/).

MONTHLY RF OF EACH STATION

YEAR	Amed Ber	Debretabor	Wanzaye	Woreta	Average	
2000	1664.50	1663.37	1664.80	1645.53	1659.55	
2001	1381.90	1558.36	1381.20	1535.22	1464.17	
2002	1013.00	1097.53	1267.70	1141.90	1130.03	
2003	1818.22	1290.00	1798.00	1267.50	1543.43	
2004	1304.10	1198.10	1085.70	1186.50	1193.6	
2005	1637.62	1491.40	1198.40	1397.10	1431.13	
2006	1550.70	1638.20	1663.50	1515.50	1591.98	
2007	1441.90	1557.70	1488.40	1249.41	1434.35	
2008	1449.60	1647.10	1592.20	1588.70	1569.4	
2009	1269.40	1517.80	1399.20	1107.10	1323.38	
2010	1668.70	1634.40	1878.20	1478.70	1665	
2011	1423.80	1534.00	1427.90	1195.30	1395.25	
2012	1219.60	1489.40	1290.50	1241.10	1310.15	
2013	1595.30	1683.50	1442.90	1297.60	1504.83	
2014	1447.90	1749.90	1441.00	1279.20	1479.5	
2015	1612.50	1202.60	1567.10	2721.00	1775.8	
Mean Annual RF	1468.67125	1497.085	1474.169	1427.96		1466.97
					1466.97	

After precipitation data was checked for quality and the appropriate station selected the statistical parameters of precipitation data for Debre Tabour (synoptic stations) must be calculated before model set up.

The statistical parameters for precipitation were calculated using the programme *pcpSTAT.exe*. This programme calculates statistical parameters of daily precipitation data used by the weather generator of the SWAT model (userwgn.dbf) (Liersch, 2003).

The programme can be found at (http://swat.tamu.edu/software/links/).

Table 1) Statistical Analysis of Daily Precipitation Data Gumara (2000 - 2015)

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan	8.81	2.7414	16.3681	0.0364	0.3793	1.81
Feb	4.54	1.1355	11.1603	0.0395	0.2273	1.38
Mar	36.4	4.4039	8.3192	0.1313	0.45	6.25
Apr	48.4	4.1821	3.9159	0.157	0.5809	8.5
May	99.77	8.3188	6.5642	0.1921	0.6649	12.13
Jun	175.41	8.1001	3.0118	0.5333	0.7797	21.56
Jul	398.46	10.7678	1.3922	0.8889	0.9372	29.88
Aug	423.71	13.1133	2.161	0.7778	0.9065	28.75
Sep	200.38	9.1827	2.5116	0.4857	0.7559	21.25
Oct	60.69	5.6034	6.2318	0.1331	0.6772	9.88
Nov	30.24	3.9859	5.7601	0.0758	0.5211	4.44
Dec	9.26	1.4919	7.1361	0.0462	0.4146	2.56

Where*:*
PCP_MM=average monthly precipitation [mm]
PCPSTD = standard deviation
PCPSKW=skew coefficient
PR_W1= probability of a wet day following dry day
PR_W2 =probability of a wet day following a wet day
PCPD = average number of days of precipitation in month

(Written by Stefan Liersch,Berlin,August,2003)

According to Lee and Haque (2004) transition of the occurrence of daily precipitation consists of two transition probabilities. These are transition probability of a wet day, given that the previous day was a wet day P(W/W) and the transition probability of a wet day following a dry day P (W/D).Therefore, from statistical data, the probability of a wet day following a wet day (PR_W2) or P (W/W) and the probability of a wet day following a dry day (PR_W1) or P (W/D) can be calculated using the following relationship (Lee and Haque, 2004).

$$P(W/D) = a + bf$$

$$P(W/W) = (1-b) + P(W/D),$$

Where, f ,is perennial mean monthly precipitation frequency, being the ratio of the number of perennial monthly rainfall days and number of days of the month, while a,b are regression coefficients. This relationship is used in the programme written by Liersch (2003), to calculate the statistical parameters in the table above.

Table 2) Gumara watersheds summary of Temperature data for selected Rain Gauge Station

Month	Mean	Max	Min
Jan	18.1338	26.6063	9.65813
Feb	19.63	28.2825	10.9769
Mar	20.6725	28.9563	12.3919
Apr	20.9781	29.0344	12.9231
May	20.7175	28.0306	13.4013
Jun	19.1131	25.5344	12.69
Jul	17.7481	23.2125	12.2831
Aug	17.7181	23.075	12.3613
Sep	18.0313	24.1825	11.8819
Oct	18.5031	25.7006	11.3056
Nov	18.0588	25.965	10.1506
Dec	17.7175	26.0425	9.39313
	18.92	29.03	9.39

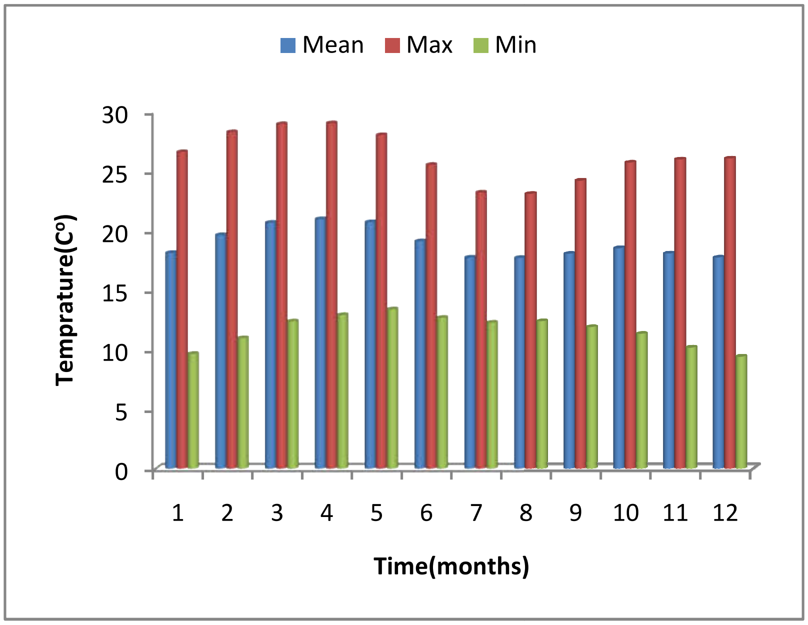


Table 3) Dew02 output using 2000-2015 daily max and min tmp and relative humidity and WGEN input data used by the SWAT model of Gumara

Average Daily Dew Point Temperature for period (2000_2015)

Month	Tmp_Max	tmp_Min	Hmd	Dewpt
Jan	17.22	5.94	61.94	5.02
Feb	18.18	7.11	53.56	3.84
Mar	18.36	7.92	60.32	5.91
Apr	18.75	8.63	58.36	5.96
May	19.58	9.16	52.87	5.14
Jun	20.22	8.96	55.9	6.13
Jul	17.67	7.87	74.42	8.78
Aug	17.37	7.46	74.00	8.36
Sep	17.40	7.87	66.94	7.16
Oct	16.73	6.88	59.13	4.52
Nov	16.14	5.55	59.13	3.76
Dec	16.18	5.25	61.53	4.25

tmp_max= Average daily maximum temperature in month[°C]

tmp_min= Average daily minimum temperature in month[°C]

hmd=Average daily humidity in month[%]

dewpt=Average daily dew point tempratue in month[°C]

(written By Stefan Liersch,Augst,2003)

Annex IV: D) Computations of Evapotranspiration (PET) as SWAT model requirement

Penman-Monteith equation combines the components that account for energy needed to sustain evaporation, the strength of the mechanism required to remove the water vapor and aerodynamic and surface resistance terms that account for water vapor atmosphere. The penman-Monteith equation is:

$$\lambda_E = \frac{\Delta(H_{net}-G)+\rho_{air}.c_p(e_z^0-e_{z)/r_a}}{\Delta+\gamma.(1+{}^{\mathrm{r_c}}/_{\mathrm{r_a}})} \qquad [1]$$

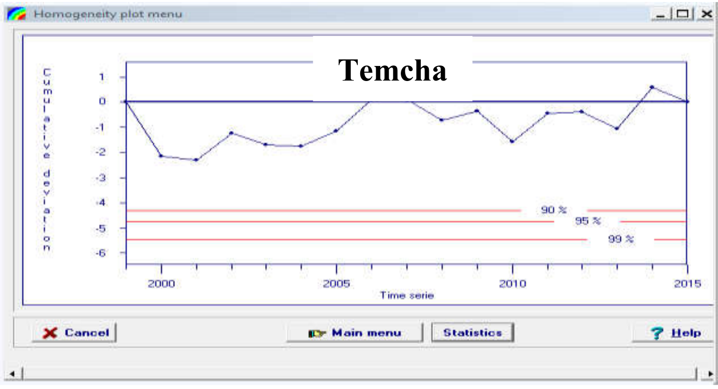
Where,E is the latent heat flux density (MJ m^{-2} d^{-1}), E is the depth rate evaporation (mm d^{-1}),   is the slope of the saturation vapor pressure-temperature curve, de/dT (kPa $°C^{-1}$), Hnet is the net radiation (MJ m^{-2} d^{-1}), G is the heat flux density to the ground (MJ m^{-2} d^{-1}), ρair is the air density (kg m^{-3}), cp is the specific heat at constant pressure (MJ kg^{-1} $°C^{-1}$), e_z^0 ,is the saturation vapor pressure of air at heat constant pressure(MJ kg^{-1} $°C^{-1}$),ez is the water vapor pressure of air at height z (kPa),γ is the psychometrics constant (kPa $°C^{-1}$), r_c is plant canopy resistance (sm^{-1}),and r_a is the diffusion resistance of the air layer(aerodynamic resistance) (sm^{-1}).

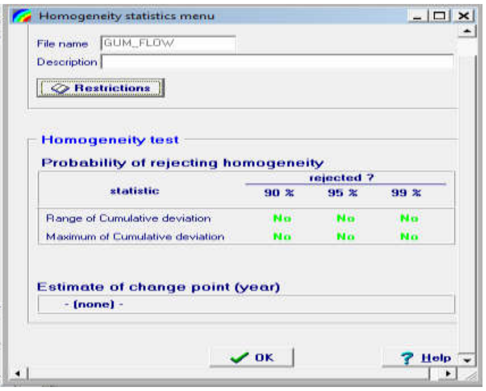
For well-watered plants under the neutral atmospheric stability and assuming logarithmic wind profiles, the Penman-Monteith equation may be written (Jensen et al., 1990)

$$\lambda_{Et} = \frac{\Delta(H_{net}-G)+\gamma.K_1\left(0.622\gamma.\frac{\rho_{air}}{\rho}\right).(e_z^0-e_{z)/r_a}}{\Delta+\gamma.(1+{}^{\mathrm{r_c}}/_{\mathrm{r_a}})} \qquad [2]$$

Where: λ is the latent heat of vaporization (MJ kg^{-1}), ET is the maximum transpiration rate (mm d^{-1}), K1 is a dimension coefficient needed to ensure the two terms in the numerator have the same units (for uz in m s^{-1},K1 = 8.64*104) and P is atmospheric pressure(kPa).

Annex V:E) Homogeneity and Frequency Histogram Expression of Gumara and Temcha Flow respectively.





File name GUM_FLOW

Description

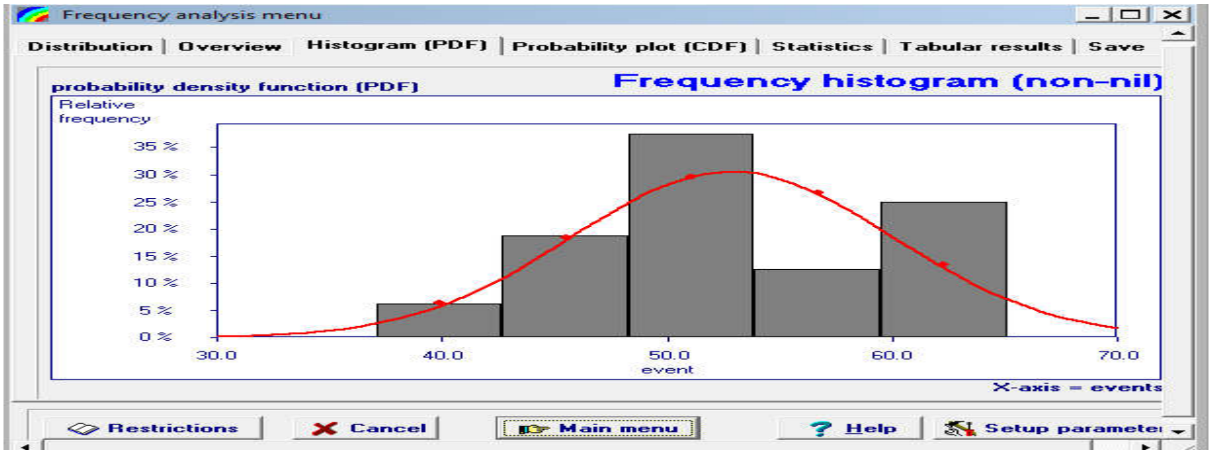
Homogeneity test

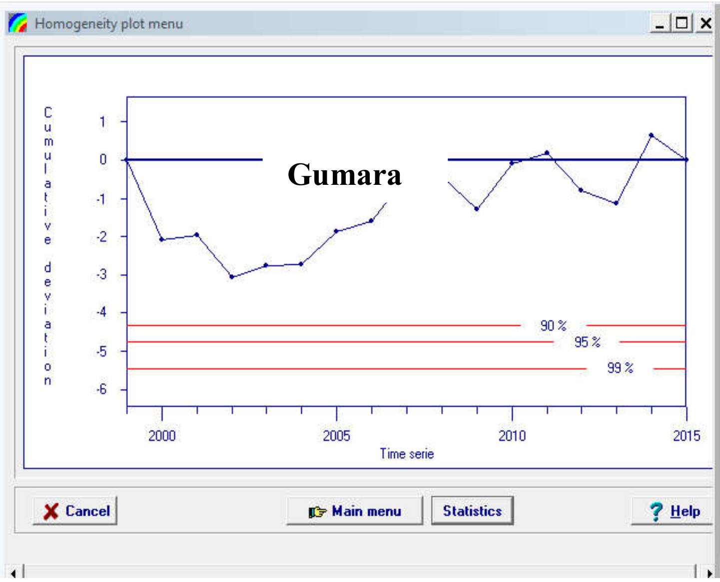
Probability of rejecting homogeneity

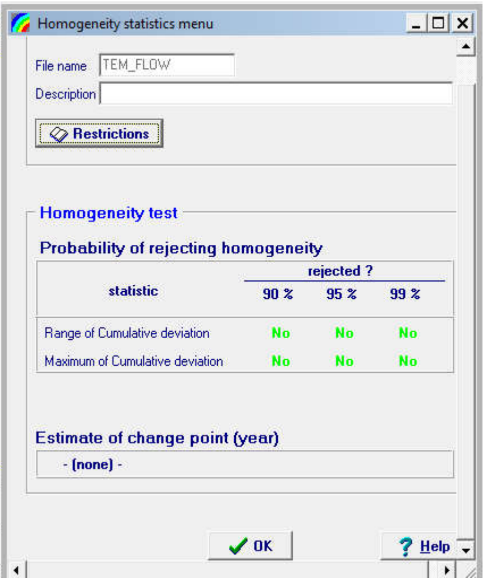
statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -







File name TEM_FLOW

Description

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

Estimate of change point (year)

- (none) -

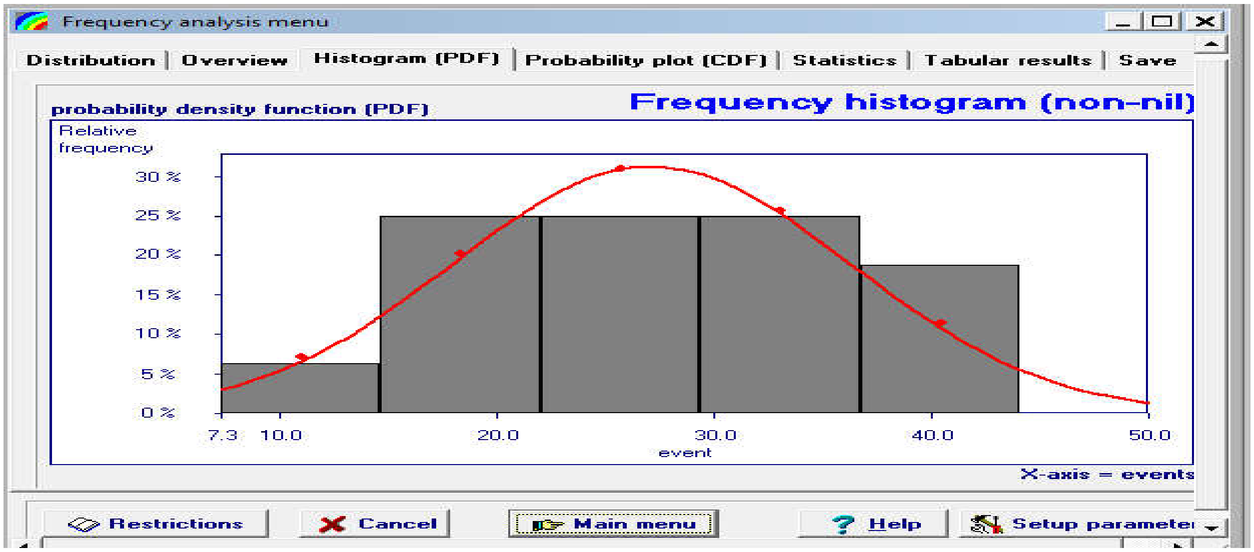
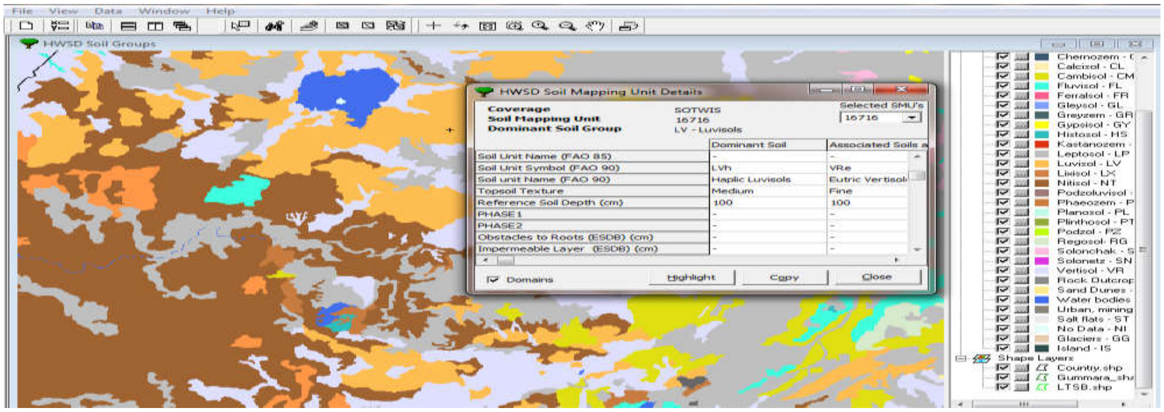


Table 4) Mean monthly flow (m^3/s) of the Gumara at River gauging station near Main road

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average	
2000	4.94	3.83	2.07	2.68	1.9	13.11	101.9	161.9	51.66	46.43	13.1	5.45	34.0792	
2001	3.29	2.05	1.82	1.39	1.9	14.43	87.97	186.82	55.51	13.97	6.15	3.86	31.5967	
2002	2.95	2.13	2.09	1.81	1.25	23.03	87.4	146.73	76.7	12.61	7.07	5.38	30.7625	
2003	4.01	3.27	3.31	2.51	2.37	14.2	85.68	164.15	147.4	45.03	8.27	5.32	40.4575	
2004	3.94	3.35	2.76	3.2	2.58	9.52	75.02	101.34	51.75	20.62	8.39	5.62	24.0075	
2005	4.16	3.42	3.76	2.72	3.57	13.96	73.33	115.34	125	39.46	9.24	6.05	33.3367	
2006	4.42	3.61	3.43	3.4	6.75	17.43	86.16	203.05	136.7	24.26	9.72	5.95	42.0767	
2007	4.17	3.18	2.43	2.88	4.14	43.13	110.6	140.23	162.5	29.3	6.66	4.32	42.7942	
2008	4.09	3.4	2.47	4.88	6.79	38.62	151.4	217.73	103	14.17	11.9	5.05	46.9525	
2009	3.87	3.05	2.57	2.03	2.3	3.4	104	199.1	84.55	12.21	5.51	3.25	35.4842	
2010	2.82	2.79	1.9	2.03	5.36	18.99	154.6	173.38	125.6	27.87	7.45	5.31	44.0058	
2011	3.95	3.13	2.83	2.61	4.05	9.15	95.94	174.45	136.8	38.61	15.6	6.89	41.17	
2012	4.71	3.95	3.31	3.03	3.7	28	134.7	167.21	120.9	27.83	15.1	6.98	43.2833	
2013	4.93	4.12	2.58	3.33	4.75	10.98	148.6	168.45	103.6	87.32	16.9	18	47.7933	
2014	11.2	7.36	10.7	7.72	27.1	46.05	149.1	220.74	164.6	99.39	19.4	18.3	65.1342	
2015	11.7	8.95	6.82	2.87	15.9	24.65	94.74	167.8	159.1	49.24	33	7.29	48.5042	
Mean Annual Flow	4.9	3.85	3.43	3.07	5.9	20.5	109	169.3	112.8	36.77	12.1	7.07		40.7149
													40.7149	

Annex VI: F) Soil Data HWSD -Viewer

The purpose of HWSD-Viewer is to provide a simple geographical tool to query and visualize the Harmonized World Soil Database. HWSD consists of a 30arc-second (or ~1 km) raster image and an attribute database in the Microsoft Access 2003 format. The raster image file is stored in binary format (ESRI Band Interleaved by Line - BIL) that can directly be read or imported by most GIS and Remote Sensing software. For advanced use or data extraction of the HWSD.



Coverage SOTWIS
Soil Mapping Unit 16716
Dominant Soil Group LV - Luvisols
Selected SMU's 16716

	Dominant Soil	Associated Soils a
Soil Unit Name (FAO 85)	-	-
Soil Unit Symbol (FAO 90)	LVh	VRe
Soil unit Name (FAO 90)	Haplic Luvisols	Eutric Vertisol
Topsoil Texture	Medium	Fine
Reference Soil Depth (cm)	100	100
PHASE1	-	-
PHASE2	-	-
Obstacles to Roots (ESDB) (cm)	-	-
Impermeable Layer (ESDB) (cm)	-	-

Figure 3. 18 Harmonized World Soil Database (HWSD) View