MADDA WALABU UNIVERSITY

SCHOOL OF GRADUATE STUDIES, STREAM OF ENVIRONMENTAL RESOURCE MANAGEMENT IN ENVIRONMENTAL SCIENCE PROGRAM.

ESTIMATING WATER BALANCE OF TEGONA WATERSHED IN, SOUTH EASTERN ETHIOPIA, USING SWAT MODEL.

M.Sc THESIS

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A Thesis submitted to the School of Natural Science In Partial Fulfillment of the Requirements for the Master of Science (M.Sc) Degree in Environmental Science (Environmental Resource Management).

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APROVAL SHEET

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As thesis research advisor, we here by certify that we have read and evaluated this thesis prepared, under our guidance, by Meseret Woldeyohannes, entitled**: Estimating Water balance of Tegona watershed in south eastern Ethiopia, Using SWAT Model.**

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As a member of the Board of Examiners of the MSc, Thesis Open Defense Examination, we certify that we have read, evaluated the thesis prepared by Meseret Woldeyohannes and examined the candidate. We recommended that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Environmental Science (Environmental Resource Management).

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DEDICATION

I dedicate this thesis to my father **Woldeyohannes Kifle** and my mother **Askale**, who showed me the right way during my childhood and nurtured me with affection and care. And to my heart touched husband and to my lovely son Haniel for their continuous care and love.

STATEMENT OF THE AUTHORS

First of all, I declare that this thesis is a result of my genuine work. I have duly acknowledged all sources and materials used for writing up. I submit this thesis to Madda Walabu University in partial fulfillment for the Degree of Master of Science. The thesis is deposited at the library of the University to be made available to users for reference. I solemnly declare that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Meseret Woldeyohannes was born on 8 March 1990 in Addis Ababa, the capital city of Ethiopia. I attended my primary education at Dagmawi Birhan Elementary School, junior secondary school education at Eshet Elementary School, and Senior Secondary School at Addis Ketema Secondary and Preparatory School from 1998- 2010.

Following the completion of my high school education, I joined Haramaya University in January 2010 to pursue tertiary education and graduated with the degree of Bachelor of Science (BSc) in Natural Resource Management in July, 2012. Up on graduation, I worked for one year as a development expert in the Bureau of Agriculture of the Cheha District of Southern Nations Nationalities and Peoples Region. After this I joined School of Graduate studies of Madda Walabu University in 2014 for M.Sc in Environmental Science.

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LIST OF ACRONYMS

AGNPS	Agricultural Nonpoint Source Pollution Model
ANSWERS	Areal Nonpoint Source Watershed Environmental Response Simulation
Arc SWAT	SWAT Integrated with ArcGIS
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FAST	Fourier amplitude sensitivity test
GIS	Geographic Information System
HRU	Hydrologic Response Unit
LH	Latine Hypercube
LULC	Land Use / Land Cover
NSE	Nash-Sutcliffe Efficiency
OAT	One factor At a Time
PET	Potential Evapotranspiration
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nation Educational Scientific and Cultural Organization
USDA	United States Department of Agriculture
WXGEN	Weather generator in SWAT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIXES

ESTIMATING WATER BALANCE OF TEGONA WATERSHED IN, SOUTH EASTERN ETHIOPIA, USING SWAT MODEL

ABSTRACT

Water resource development is certainly the basic and crucial infrastructure for a nation's sustainable development. To utilize water resources in a sustainable manner, it is necessary to understand the quantity and quality in space and time. This study was initiated with the objective of evaluating the performance and applicability of the Soil and Water Assessment Tool (SWAT) in analyzing the influence of hydrologic parameters on the stream flow variability and estimation of monthly water yield at the outlet of Tegona river watershed in Bale mountainous area.. The total 468 km^2 *area of the watershed was subdivided into 12 sub-basins and 60 hydrologic response units (HRUs). Sensitivity analysis, model calibration and validation were made to evaluate the model performance for simulation of stream flow on monthly time step. The calibrated SWAT model performed well for simulation of monthly stream flow. Statistical model performance measures, coefficient of determination (*r^2*) of 0.71, the Nash-Sutcliffe simulation efficiency (ENS) of 0.77 and Percent difference (D) of 8.33, for monthly calibration and 0.86, 0.83 and -12.25 respectively for validation, indicated good to very good performance of the model simulation.*

Mean monthly and annual water yield simulated with the calibrated model were found to be 23.7 mm and 284.2 mm, respectively. The model slightly overestimated the flow on most of rainy months. The baseflow separation result indicated that subsurface flow was source of water in the study watershed. Overall, the model demonstrated good performance in capturing the patterns and trend of the observed flow series, which confirmed the appropriateness of the model for future scenario simulation. Therefore, it is recommended that SWAT model can be a potential tool for simulation of stream flow and water balance components of ungauged watershed in the highlands of Ethiopia with similar hydro-meteorological characteristics to Tegona watershed.

1. INTRODUCTION

1.1 Background of the study

Ethiopia can realize its food security and sustainable development not only by depending on rain fed agriculture but also by utilizing its plentiful water resources and conserving soil resources. Proper utilization of these resources necessitates assessment and management of the quantity and quality of the water resources both spatially and temporally.

By comparing water demand for food, the environment and industries and domestic use with the water supply available from precipitation, snow melt and aquifers, International Water Management Institute (IWMI) has predicted that more than twenty developing countries will experience chronic and physical water shortages in 2025 (Seckler *et al*., 1998). In the meantime, some countries especially in the Middle East and Africa are already confronted with a shortage in water supply (Al-Weshah, 2002). Such studies indicate the need of water resources management in a resourceful manner in order to meet future water demands. In this context, developing management plans would be certainly complimented by quantitative descriptions of spatial and temporal distribution of water resources and the processes influencing them (Dilnesaw, 2006).

Hence, for sustainable development, the estimation of water balance of the watershed is essential to assess the current status and trends in water resource availability in an area over a specific period of time. Further, the reliable estimates of the various hydrological parameters including runoff and precipitation for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that some suitable methods and techniques are used for quantifying the hydrological parameters from all parts of the watersheds. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices a hydrological cycle is a complex system. As a result, use of mathematical models and geospatial analyses tools for studying hydrological processes and hydrological responses to land use and climatic changes is the current trend (Sanjay, 2009).

1.2 Statement of the Problem

The Bale Mountain is relatively unmoved as compared to other areas. However, negative pressures on natural resources in the Bale Mountains are rapidly growing. Unsustainable natural resource exploitation and degradation throughout the area is increasingly threatening the sustainability of the environment, food security and sustainable livelihoods. Bale’s rural communities are seeking to meet their livelihood needs by expanding exploitation of local natural resources. Agricultural land is expanding rapidly, grazing areas are heavily degraded necessitating the search for new pasture, forest areas are being cut and cleared, and water systems disrupted. Unplanned and unrestricted settlement is a significant and mounting problem. Existing settlements are growing, and new settlements are appearing in previously unsettled and environmentally sensitive areas (Farm-Africa – SOS Sahel Ethiopia Report, 2007).

Watershed management has been recognized as a widely accepted approach for optimal use of water resources. Implementing watershed management offers opportunities to directly improve the livelihoods of Ethiopia’s rural communities through improved land productivity, increased food security, livelihood diversification as well as improvements in access to water and biomass fuels (ENTRO, 2007). However, in order to plan management of water resources it is important to assess the biophysical interactions, particularly the land degradation caused by land use and land cover change including effect of farming, deforestation and over grazing.

1.3 Significance of the study

For reliable prediction of the various hydrologic parameters including rainfall, runoff etc. for remote areas is very tough and time consuming by conventional methods. So it is very important to search suitable methods and techniques for quantifying the hydrological parameters. The fundamental objective of hydrology modeling is to gain an understanding of hydrological system in order to provide reliable information for managing water resources in a sustained manner. Distributed models are based on physical principles governing the movement of water within a catchment area, but they need detailed high-quality data to be used effectively. SWAT (Soil and Water Assessment Tool), MIKE-SHE, Variable infiltration Capacity (VIC) model, HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) are some of the semi-physical and physically based distributed hydrologic models(Tanmoyee Bhattacharya, et al.2013).

The sets of models are their own shortcomings when applied in data-scarce region. While empirical models need to be applied for environmental conditions they have been calibrated for mathematical models require intensive data for model calibration and validation. In this study, Soil and Water Assessment Tool (SWAT) was used to evaluate its applicability and to assess water balance component of the watershed of Tegona River in Southeastern, Ethiopia. This model is chosen considering its wider applicability to assess water balance of the watershed.

Tegona watershed as a whole receives a good amount of rainfall throughout the year, feeding into the Weib River which is a tributary of Genale River. Apart from the very high altitude in Bale Mountains (Sanate plateau) and hill topography, improper land use practices, and deforestation within the basin result in huge loss of water as runoff. Therefore, there is an urgent need for developing integrated watershed management plan based on hydrological studies using suitable modeling approach.

At the downstream parts of the river there are different water based projects which are attached to the flow of Tegona River. The projects include existing and proposed irrigation schemes, tourism and fish farming at the different parts of the river. Hence, computing seasonal and geographic patterns of irrigation demand, the prediction of stream flow and water-table elevations are useful for water resource management options in the area. Therefore, the output of this study can be utilized to plan and implement effective land and water resources development and management. Time series data on rain fall are available on gauging station of the watershed and these were used to calibrate and validate SWAT model and to assess its applicability and water balance of the Tegona watershed.

1.4 Research Objectives

1.4.1 General objective

The general objective of this study was to estimate stream flow variability in Bale mountainous region of Tegona watershed using the SWAT model

1.4.2 Specific objectives

The specific objectives corresponding to this study are:-

- To calibrate and validate of SWAT model on a monthly time step at the outlet of Tegona watershed in the Bale Mountainous region.
- To estimate the monthly, annual runoff yield and the water balance components of Tegona river watershed.

2. LITRATURE REVIEW

2.1 Factors Affecting Runoff

Apart from rainfall characteristic there are a number of site specific factors which have a direct bearing on the occurrence and volume of runoff. The major factors are reviewed below.

2.1.1 Soil type

Soil functions essentially as medium that provides a large number of passageways for water. Water flow in soil depends on the size and permanency of the pores. The size of the conduits depends on the size of the soil texture, the degree of aggregation and the arrangements of particles and aggregates (Silveira *et al*., 2000).The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have smaller infiltration capacities. The infiltration capacity depends further more on the moisture content prevailing in a soil at the onset of a rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated (Finkeland Sergerros, 1995).

2.1.2Vegetation

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. More significant is the effect the vegetation has on the infiltration capacity of the soil. Dense vegetation shields the soil from the raindrop impact and reduces the crusting effect as described earlier. In addition, the root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving more time to infiltrate and to evaporate (Finkel and Sergerros, 1995).

2.1.3 Slope and catchment characteristics

In general, the volume and peak rate of runoff increases with catchment area. However, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. In the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet (Carey *et al*., 2004). The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency. Investigation on experimental plots has shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it was observed that the quantity of runoff decreased with slope length to some extent (Ben Asher, 1988).

2.2 Impacts of Land Use on Stream Flow Regimes

2.2.1 Effect on mean flow

Afforestation and deforestation are two of the most important land use changes influencing the hydrological response of catchments. Catchment experiments worldwide have demonstrated that substantially altering the type and extent of vegetative cover on a catchments can significantly affect the interception and evapotranspiration (ET) processes, consequently cause a change in the runoff volume. Generally, land use changes that reduce ET increase annual runoff from catchments, whereas land use changes that increase ET decrease annual runoff. Coniferous forest, deciduous hardwood, brush and grass cover (in that order) have been found to have a decreasing influence on annual runoff of the source areas in which the land covers are manipulated (Brooks *et al*., 1997).

According to Brooks *et al*., (1997) the degree of change in annual runoff from catchments depends on the intensity and extent of land development. The generalized relationship based on catchments experiments worldwide is that a 10% reduction in coniferous forest (deciduous forest, shrub), being converted to grassland, causes an average increase of 40 mm (25 mm for deciduous forest, 10 mm for shrub) in annual runoff.

2.2.2 Effects on flood and low flows

Land use activities may affect storm flow response and in turn flood peaks through changes in vegetation cover, soil infiltration capacity, conveyance system, increased erosion and sedimentation (Brooks *et al*., 1997).

The potential impacts of land use changes on surface and near surface hydrological processes (fluxes or storages) under "normal" conditions in humid temperature zones. Forests and forest soils have popularly been thought to influence the timing of stream flow by storing water during wet periods and releasing water during dry periods because of their high infiltration and soil moisture storage capacities, and hence reduce flood peaks. Conversely, deforestation is generally accepted to be a cause of increased flooding downstream (Bronstert *et al*., 2002)

2.3GIS Applications in Hydrologic Analysis

Geographic Information Systems (GIS) provide a digital representation of watershed characteristics used for hydrologic modeling (Bruce and Arlen, 1993). Recent advances in GIS enabled planners, watershed managers, and hydrologic engineers to expand their capabilities for watershed management (De Barry, 2004). Several procedures have been developed to incorporate GIS into watershed application (De Barry, 2004). These GIS applications improve efficiency and accuracy and cut costs in the hydrologic parameter calculation methodology required by hydrologic models. Many subroutines have been developed to analyze the terrain and hydrologic processes from the grid cells of the Digital Elevation Models (DEMs). Some of the hydrologic subroutine includes: flow direction, sub basin or watershed boundary determination, flow accumulation and stream channel determination. The GIS hydrologic operations are based on the premise that water flows downhill in the direction of steepest descent, and the elevations of the grid cells dictate this direction (Maidment, 2002).

2.4Background of SWAT Model

The SWAT, Soil and Water Assessment Tool were developed at the U.S. Department of Agriculture (USDA) – Agricultural Research Service (ARS) Grassland, Soil and Water Research Laboratory in Temple, Texas (Arnold et al., 1998; Neitsch *et al*., 2002).It was developed to assist water resources managers in predicting and assessing the impact of management on water, sediment and agricultural chemical yields in large ungagged watersheds or river basins. SWAT has eight major components – hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The model is intended for long term yield predictions and is not capable of detailed single-event flood routing. It is an operational or conceptual model that operates on a daily time step (Neitsch *et al*., 2005).

As a robust interdisciplinary watershed modeling, SWAT has gained international acceptance in recent years. It is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman *et al*., 2005).

It is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungagged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-basins, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-basin area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-basins that are characterized by dominant land use, soil type, and management (Gassman *et al*., 2007).

SWAT simulates the hydrological cycle based on the water balance equation, in the land phase of hydrological cycle:

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) 2.1$$

where, SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

To reflect differences in evapotranspiration for various crops and soils the subdivision of the watershed enables by the model. To obtain the total runoff for the watershed Runoff is predicted separately for each HRU and routed. This gives a much better physical description of the water balance and increases accuracy.

There are a few applications of SWAT model to Ethiopian conditions in relatively small watershed areas (e.g. Dilnesaw, 2006; Setegn, 2008; Ashenafi, 2009; Eyob, 2010; Alemayehu, 2013).

2.4.1SWAT strength and limitation

2.4.1.1 Strength

Key features that make the model applicable for a wide range of studies are: (Neitsch *et al*., 2005)

1. Modelling based on physical processes associated with soil and water interaction
2. Flexibility to incorporate crop characteristics, cropping stage and duration
3. Flexibility on input data requirement
4. Capability of modelling the changes in land use and management practices
5. Computational efficiency
6. Capability of long-term simulations
7. Capability of modelling catchments areas varying between few hectares to thousands ofsq.km.
8. The model is freely available and can be easily downloaded from the internet at http://swatmodel.tamu.edu

2.4.1.2 Limitation

Following are some of the limitations using SWAT for hydrological modelling:

1. Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to present the spatial variation in the hydro-meteorological characteristics in the area. The lack of adequate number of observation stations affects the model output.
2. In order to calibrate the model for the historic land use scenarios, the corresponding land use maps are needed. In order to get the real time picture of the land use pattern, this information can be extracted from the remote sensing satellite imageries by using digital image processing technique. However, acquisition of satellite imageries is expensive and also the expertise required for the image interpretation is another major limitation.
3. Though SWAT is a free software tool, in order to represent the spatial variation in the catchments characteristics, GIS software is the pre-requisite to run the model.

2.5. Sensitivity Analyses, Calibration and Validation of SWAT Model

The ability of a watershed model to sufficiently predict water quantity and quality for a specific application is evaluated through sensitivity analysis, model calibration, and model validation.

2.5.1. Sensitivity analyses

Sensitivity is measured as the response of an output variable to a change in an input parameter, with the greater change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model (White and Chaubey, 2005). It is a necessary process to identify key parameters and parameter precision required for calibration (Ma *et al*., 2000).

SWAT is a complex model with many parameters that makes manual calibration difficult. Hence, sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. Sensitivity analysis helps to determine the relative ranking of which parameters most affect the output variance due to input variability (Van Griensven *et al*., 2002) which reduces uncertainty and provides parameter estimation guidance for the calibration step of the model.

Spruill *et al*. (2000) performed a manual sensitivity analysis of 15 SWAT input parameters for a 5.5 km^2 watershed in Kentucky, which showed that saturated hydraulic conductivity, alpha base flow factor, drainage area, channel length, and channel width were the most sensitive parameters that affected stream flow.

Numerous sensitivity analyses have been reported in the SWAT literature, which provide valuable insights regarding which input parameters have the greatest impact on SWAT output. A two-step sensitivity analysis approach is described by Francos *et al*. (2003), which consists of: (1) a “Morris” screening procedure that is based on the One factor at a time (OAT) design, and (2) the use of a Fourier amplitude sensitivity test (FAST) method. The screening procedure is used to determine the qualitative ranking of an entire input parameter set for different model outputs at low computational cost, while the FAST method provides an assessment of the most relevant input parameters for a specific set of model output. Holvoet *et al*., (2005) presented the use of a Latin hypercube (LH) OAT sampling method, in which initial LH samples serve as the points for the OAT design. The LH-OAT method has been incorporated as part of the automatic sensitivity/calibration package included in SWAT 2005 (Gassman *et al*., 2007).

Therefore, sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, butalso for model validation and reduction of uncertainty (Hamby, 1994). The sensitivity analysis method in the Arc SWAT interface combines the Latin Hypercube (LH) and One factor-At-a-Time (OAT) sampling (Van Griensven, 2005).

2.5.2. Calibration approach

Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two. The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman *et al*., 2007). Coffey *et al*. (2004) presented nearly 20 different statistical tests that can be used for evaluating SWAT stream flow output during a manual calibration process. They recommended using the Nash-Suttcliffe simulation efficiency ENS and regression coefficientsr2 for analyzing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by Spruill *et al*. (2000).

Eckhartd and Arnold (2001) outlined the strategy of imposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT. Subsequently, an automatic calibration of the version SWAT-G of the SWAT model with a stochastic global optimization algorithm and Shuffled Complex Evolution algorithm is presented for a mesoscale catchment.

Automated techniques involve the use of Monte Carlo or other parameter estimation schemes that determine automatically what the best choice of values are for a suite of parameters, usually on the basis of a large set of simulations, for a calibration process (Gassman *et al*., 2007). Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is desirable as it is less subjective and due to extensive search of parameter possibilities can give results better than if done manually. The manual trial-and-error method of calibration is the most common and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite (Refsgaard and Storm, 1996). However, it is very cumbersome, time consuming, and requires experience.

2.5.3. Validation

In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable; parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios (Dilnesaw, 2006).

4. MATERIALS AND METHODS

3.1. Description of Study Area

3.1.1 Location

The Tegona watershed was found in South Eastern part of Ethiopia in Oromia Regional State, Bale Zone. The watershed was situated in Genale Dawa basin at the upper most parts of the Weib Sub-watershed, which was one of the sub basin of Genale Dawa River basins. The upper most part of Tegona watershed begins from Bale Mountains National Parks, hydrologically and environmentally the most sensitive parts that need a special treatment i.e. reserve the upper most part areas at least at present time condition and at most upgrade and rehabilitate what was lost in terms of resources from the areas. The Tegona watershed was located between 6° 53'N and 7°14'N latitudes and 39°46'E and 39°59'E longitudes. It can cover a total land area of 468km^2 in the Genale Dawa River basin. This watershed drains to Weib River, which was the tributary of Genale River. The river Tegona originates from an elevation of 4,345-meter mean above sea level (m.a.s.l), in the Bale Mountains National Park Locally called Senate Mountains to an elevation of 2,355m m.a.s.l. to the outlet of Tegona River basin.

3.1.2 Topography

There is high elevation change between the upstream and downstream of the watershed. The upper most part of the watershed topographically was the steepest parts which need a great attention to be protected because of its unique topographical steepness as well as hydrologically the most sensitive parts of Bale Mountains National Park. From the watershed, more than 4% of the area has a slope more than 30%, which is danger for the area if the land use and land cover of natural cover is disturbed. Next to the upper most part, the slope between 15% and 30% covers 11.84% of the areas. These areas are also not suitable for agricultural, and for other developmental issues unless necessary physical and conservation measures are taken. The areas in between the slope range of 0% to 15% cover about 84% of the watershed. This area is in between flat to the gentle slope of the watershed of the area. This area could be used for agricultural as well as for other developmental purposes, with a local management activates to protect the environmental and ecological degradation for sustainability (Ashenafi, 2009).

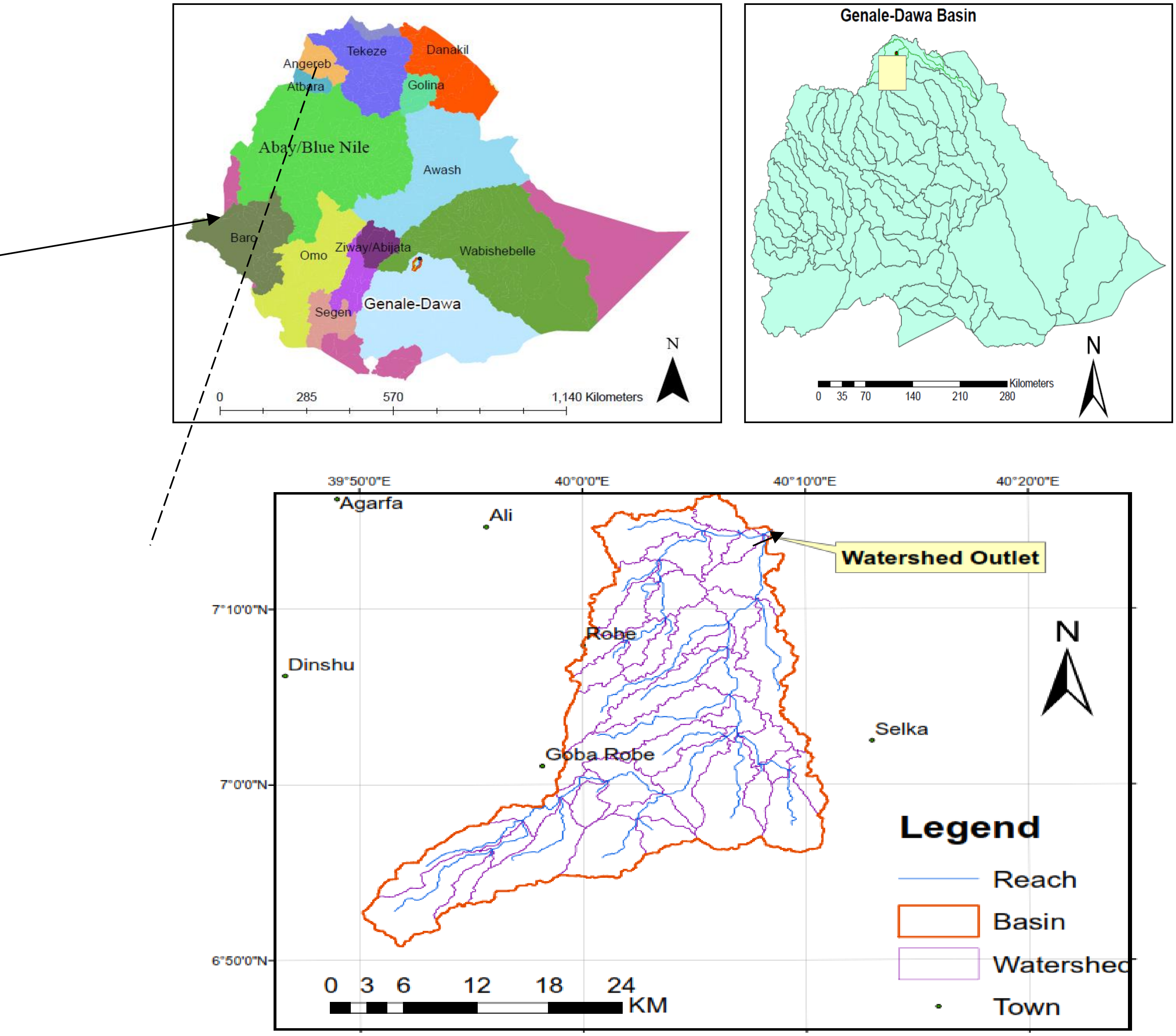


Figure 1Major River basins of Ethiopia and location map of the Tegona watershed.3.1.3 Climate

The climate of the Tegona watershed was in the range of frost (wurch) at the upper most part near Senate Mountains to humid highlands of Bale Mountains and Bale, respectively. The rainfall pattern was bimodal type, which divide the year into two main seasons: a main rainy season (summer) between July and mid of December and minor rainy season (spring) from April to end of June. The average annual rainfall range was 839mm to 1432mm in Robe and in Dinsho respectively. The annual maximum and minimum temperature of the area were about 19.7c°and 5.9c° respectively.

3.1.4 Soil

Soils in the study area were classified on the basis of the revised FAO/UNESCO-ISWC legend to soil Map of the world (1990) and the World Reference Base for Soil Resources (1998). There were more than six major soil types in the Tegona watershed, the Dystric Cambisols, Chromic Cambisols, Haplic Luvisols, Vertic Luvisols and Regosols. The Regosols and Dystric Cambisols are found in the upper most edge, chromic cambisols is found at upper most next to the earlier two, Eutric cambisols and Haplic Luvisol are found in the middle part and Vertic Luvisols is found at the downstream of the area.

Physical soil property calculator would be used to calculate the available soil moisture content, bulk density and saturated hydraulic conductivity and the default Value of the model.

3.1.5 Land use/Land coverThe land use land cover (LULC) of the study area includes the forest land; pasture land, woodland and agricultural land. This LULC category includes the vegetations of Erica arboria and Helic ryciumcitrispinum. The pasture type of LULC distributed in different parts of the watershed and it is what the community of the area uses as grazing land. Agriculture land is also the LULC type that covers from the middle to downstream parts of the watershed. It is the land cover under the crop cultivation of annual crops.

3.2. Methodology

3.3. Model Inputs

In order to get a satisfying outputs it was necessary to specify the parameters of static variables properly, especially the topography, soil layer and land use data. The other compulsory temporal inputs include, rainfall, minimum and maximum temperature, relative humidity, solar radiation, and wind speed.

3.3.1 Digital elevation model

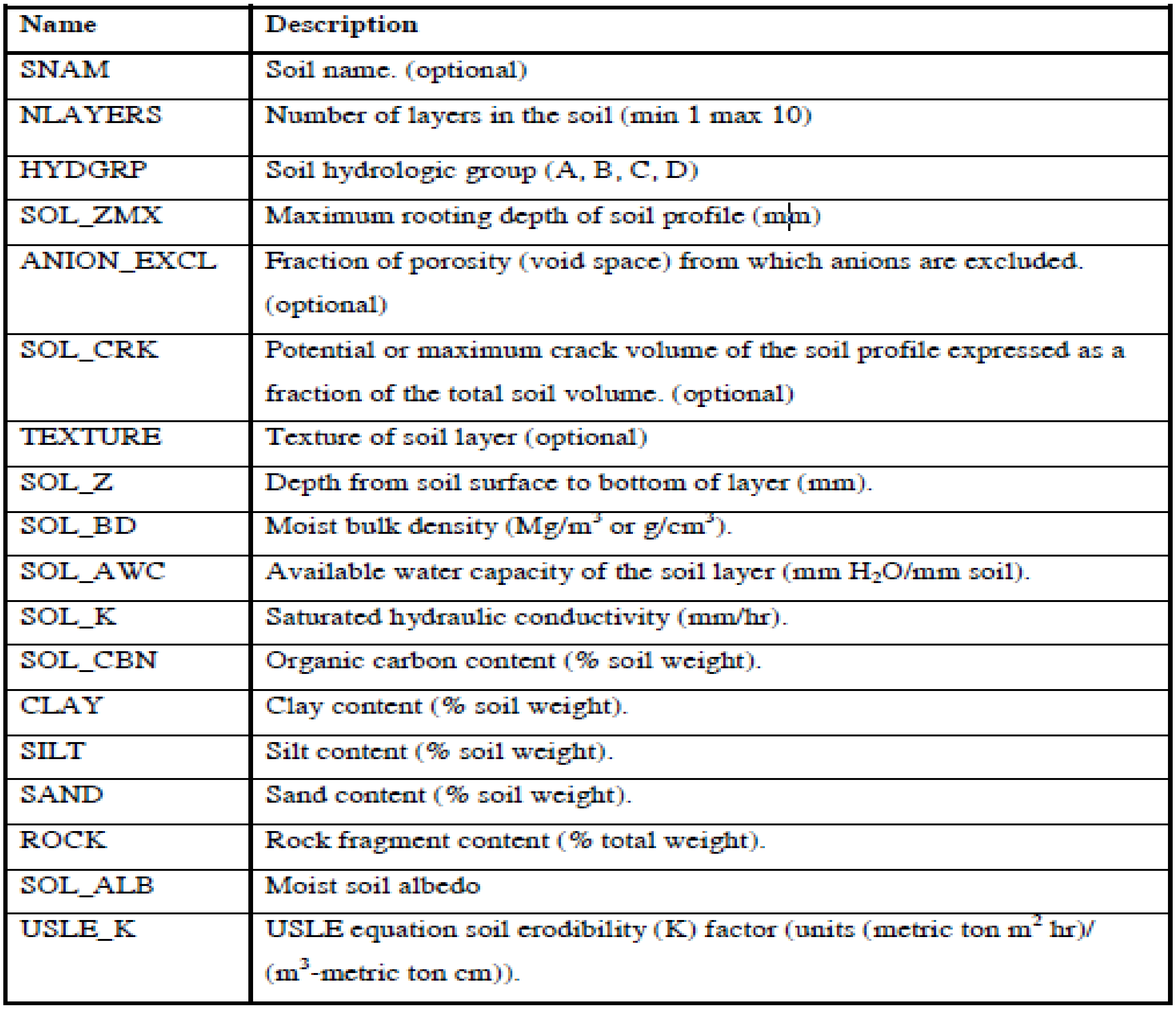
To delineate the watershed and sub basins and to determine drainage networks SWAT uses the digital representation of the topographic surface *i.e.* Digital Elevation Model (DEM). Topography would be defined by a DEM which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. The DEM was used to analyze the drainage patterns of the land surface terrain. And sub basin parameters such as slope, slope length, and defining of the stream network with its characteristics such as channel slope, length, and width will be derived from the DEM. For this study a DEM with a resolution of 30 m was used, which was obtained from SRTM.

3.3.2 Soil properties

Soil physical and chemical properties were other inputs required by SWAT soil data base. The physical property of the soil in each horizon governs the movement of water, air through the soil profile and has major impact on cycling of water in hydrologic response unit (HRU) and was used to determine water budget for the soil profile.

Basic physico-chemical properties of major soil types in watershed were collected from the Ministry of Water and Energy (MoWE) of Genale Dawa river master plan and available data sources. Soil sampling from representative areas in the watershed was made to enrich the available soil map and datasets.

Table 1 Soil physical properties required by the SWAT model



Name	Description
SNAM	Soil name. (optional)
NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrologic group (A, B, C, D)
SOL_ZMX	Maximum rooting depth of soil profile (mm)
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded. (optional)
SOL_CRK	Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume. (optional)
TEXTURE	Texture of soil layer (optional)
SOL_Z	Depth from soil surface to bottom of layer (mm).
SOL_BD	Moist bulk density (Mg/m^3 or g/cm^3).
SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil).
SOL_K	Saturated hydraulic conductivity (mm/hr).
SOL_CBN	Organic carbon content (% soil weight).
CLAY	Clay content (% soil weight).
SILT	Silt content (% soil weight).
SAND	Sand content (% soil weight).
ROCK	Rock fragment content (% total weight).
SOL_ALB	Moist soil albedo
USLE_K	USLE equation soil erodibility (K) factor (units (metric ton m^2 hr)/ (m^3-metric ton cm)).

3.3.3 Land use and land cover maps

Land use and land cover was one of the most important spatial input data by SWAT model that affect water runoff, evapotranspiration, surface erosion and other hydrological process in a given watershed. The land use and land cover map and datasets were obtained from Ministry of Water and Energy (MoWE), Genale Dawa river master plan and together with field investigations.

Table 2 Land use and its respective SWAT codes

Land use	SWAT code
Forest-Deciduous	FRSD
Agricultural Land	AGRL
Agricultural Land (Row crops)	AGRR
Farm Village	FAVG
Moderately Cultivated	MoCU
Urban	URBN
Moderately Cultivated (Perennial)	MCUP
Forest-Evergreen	FRSE
Agricultural Land-Close-grown	AGRC
Intensively Cultivated	INCU
Range Grasses	RNGE
Moderately Cultivated (Smallholder farm)	MCSH

3.3.4 Meteorological data

The model SWAT requires daily meteorological data that could either be read from a measured data set or be generated by a weather generator model which include precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity. Meteorological data was collected from NMSA for Bale Robe, Goba, and Sinana meteorological stations; that were found inside the watershed and in close proximity to the watershed boundary. Homogeneity and trend test of time series data was undertaken using software Rainbow.

3.3.5 River discharge data

Daily river discharge data of the Tegona River basin were obtained from the Hydrology Department of the Ministry of Water and Energy for the year 1981 up to 2009. Daily river discharges of the gauging stations were used for performing sensitivity analysis, calibration and validation of the model.

3.3.6. Base flow Separation

An automated base flow separation and recession analysis technique (Arnold *et al.*, 1999) was employed to separate the base flow and surface runoff from the total daily stream flow records. This information was used in order to get SWAT to correctly reflect basic observed water balance at the outlet of the watershed.

3.4Model Set Up

3.4.1 Watershed delineation

The first step in creating SWAT model input was delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. The SWAT model provides three spatial levels: the watershed, the sub basins, and the hydrologic response units (HRUs). Each level was characterized by a parameter set and input data. The largest spatial level, the watershed, refers to the entire area being represented by the model.

For modeling purposes, a watershed was partitioned into 12 sub watersheds or sub basins. The use of sub basins in a simulation was particularly beneficial when different areas of the watershed were dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub basins, the user was able to reference different areas of the watershed to one another spatially. Moreover, the selection and implementation of appropriate conservation measure can be aided by reliable predictions of watershed response under different land use scenarios.

The watershed and sub watershed delineation was done using DEM data. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub basin. The ArcSWAT interface allows the user to fix the number of sub basins by deciding the initial threshold area. The threshold area defines the minimum drainage area required to form the origin of a stream.

The DEM was used to analyze the drainage patterns of the land surface. Moreover, DEM were used to determine slope, slope length, channel slope and length**.**

3.4.2 Hydrological response units

The land area in a sub basin was divided into Hydrologic Response Units (HRU). SWAT uses a concept of HRU: portions of a sub basin that possess unique land use/management/soil attributes. An HRU is not synonymous to a field. Rather it was the total area in the sub basin with a particular land use, management and soil. While individual fields with a specific land use, management and soil may be scattered throughout a sub basin, these areas were lumped together to form one HRU. HRUs were used in most SWAT runs since they simplify a run by lumping all similar soil and land use areas into a single response unit. It was often not practical to simulate individual fields in cases where the focus lies on entire basins.

Implicit in the concept of the HRU was the assumption that there was no interaction between HRUs in one sub basin. If the interaction of one land use area with another was important, rather than defining those land use areas as HRUs they should be defined as sub basins. It was only at the sub basin level that spatial relationships were specified. The benefit of HRUs was the increase in accuracy it adds to the prediction of loadings from the sub basin. The growth and development of plants could differ greatly among species. When the diversity in plant cover within a sub basin is accounted for the net amount of runoff entering the main channel from the sub basin was much more accurate. The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub watershed.

3.4.3 Sensitivity analysis

The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven, 2005). The inputs were the observed daily flow data, the simulated annual flow data and the sensitive parameter in relation to flow with the absolute lower and upper bound and default type of change to be applied (method application) were used.

LH-OAT combines the OAT design and LH sampling by taking the Latin Hypercube samples as initial points for OAT design. The LH-OAT sensitivity analysis method combines thus the robustness of the Latin Hypercube sampling that ensures that the full range of all parameters has been sampled with the precision of an OAT designs assuring that the changes in the output in each model run can be unambiguously attributed to the input changed in such a simulation leading to a robust and efficient sensitivity analysis method (Van Griensven, 2005).

3.4.4 Calibration

Calibration was the process whereby model parameter were adjusted to make the model output match with observed data. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested without further parameter adjustment against an independent set of measured data (validation).

Refsgaard and Storm (1996) categorize calibration methods as the manual trial-and-error method, automatic or numerical parameter optimization method; and a combination of both methods. They indicated that the manual trial-and-error method is most common and especially recommended for the application of more complicated models in which a good graphical representation was a prerequisite. However, it is very cumbersome, time consuming, and requires experience. Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. For this study manual and automatic calibration method were used.

For each calibration run and parameter change, the corresponding model performance statistics (r^2 and E_{NS}) were calculated. This procedure was continued until the acceptable calibration statics recommended by SWAT developer for hydrology was achieved. SWAT developers in (Santhi *et al.*, 2001) assumed an acceptable calibration for hydrology at a $D<15\%$, $r^2 >0.6$ and $E_{NS}> 0.5$. The flow chart for model calibration is presented in Figure 2.

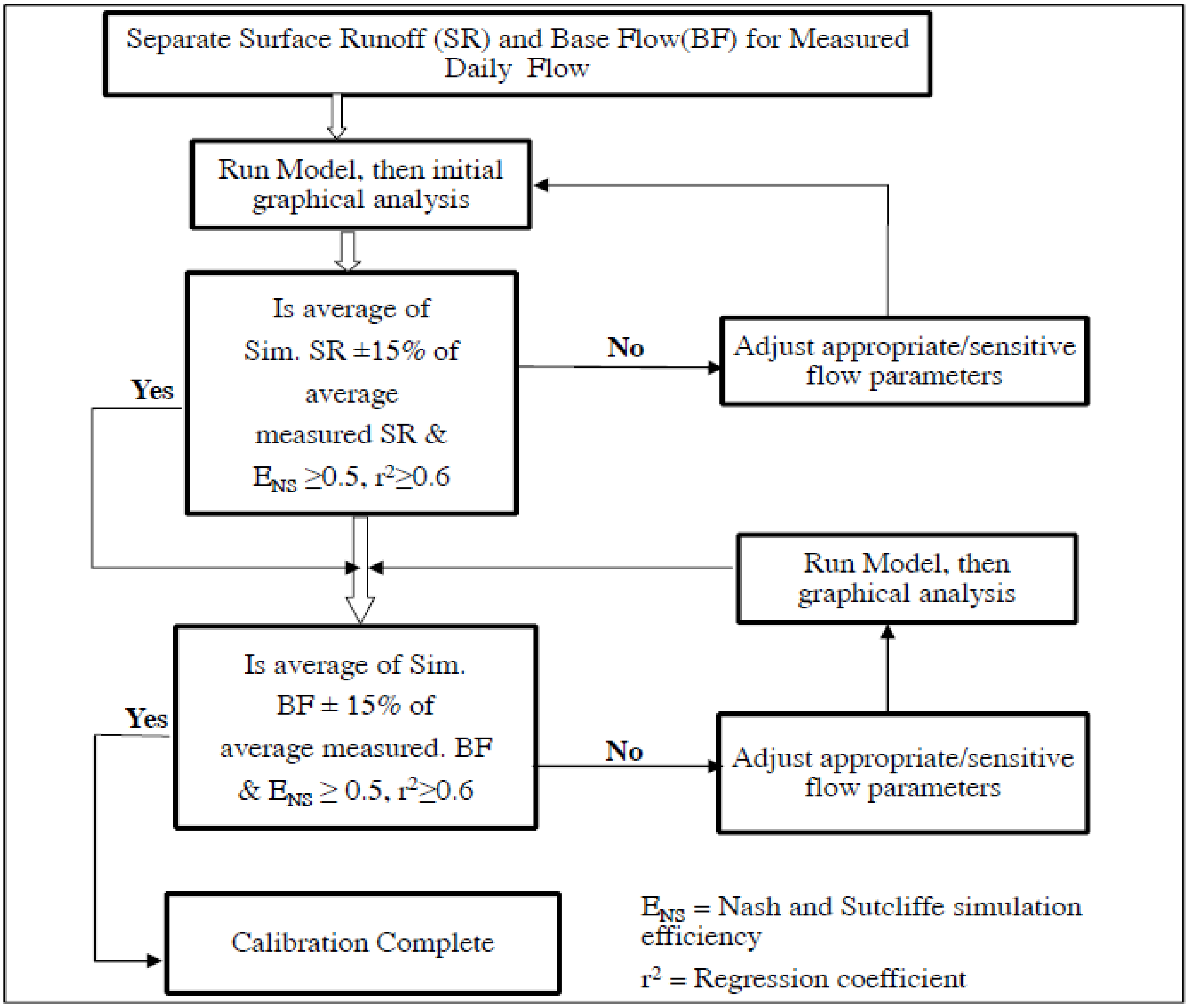


Figure 2 General calibration procedures for flow adapted from (Santhi *et al*., 2001).

3.4.5 Validation

Validation was comparison of the model outputs with an independent data set without making further adjustments. The three statistical model performance measures used in calibration procedure were used in validating stream flow.

3.4.6 Model performance evaluation

In order to evaluate the performance of SWAT model to determine the quality and reliability of prediction compared to the observed values the following methods for goodness-of-fit measures of model predictions were used: during the calibration and validation periods. These numerical model performance measures were coefficient of determination (R^2 coefficient), Percent difference between simulated and observed data (D) and the Nash-Suttcliffe simulation efficiency (E_{NS}) (Nash and Suttcliffe, 1970).

The regression coefficient (R^2) was the square of the Pearson product–moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to 1, the higher the agreement between the simulated and the measured flows and was calculated as

$$R^2 = \frac{(\sum[X_i - X_{av}]\,[Y_i - Y_{av}])^2}{\sum[X_i - X_{av}]^2 \sum[Y_i - Y_{av}]^2} \qquad 18$$

Where: X_i is measured value, $X_{av}$is average measured value, Y_i is simulated value, Y_{av} is average simulated value.

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

$$D = 100\left(\frac{\sum Y_i - \sum X_i}{\sum X_i}\right) \qquad 19$$

Where: Xi **is** measured value, Y_i is simulated value. A value close to 0% is best for D. However, higher values for D were acceptable if the accuracy in which the observed data gathered was relatively poor.

Nash and Sutcliffe simulation efficiency (E_{NS}) indicates the degree of fitness of observed and simulated data and given by the following formula

$$E_{NS} = 1 - \frac{\sum(X_{i-}Y_i)^2}{\sum(X_i - X_{av})^2} \qquad 20$$

The value of E_{NS} ranges from 1.0 (best) to negative infinity. The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value was the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions were very poor, and the average value of output was a better estimate than the model prediction (Nash and Sutcliffe, 1970).

4. RESULTS AND DISCUSSIONS

4.1. Watershed Delineations

As it is depicted in figure 3, 12 sub-basins were delineated in the Togona watershed area of 464 km^2 as it is outlined in Figure 1 and 3. Each sub basin boundary marks the end of reach, the end point of which the accumulation point for all flow from upstream which is then fed into downstream sub-basin and reach. Once the main reach and the longest paths/tributaries are formed, the model uses other physical parameters (soil, land use and land slope) to define HRUs.

From the assumed threshold values for HRU delineation, we have found 60 HRUs in 12 sub basins. Each HRU is composed of land use, soil type and slope parameters.

The areal coverage and percentage of watershed area covered by each land uses, soil types and slope ranges which were used for HRU definition are clearly presented below. A summary of the soil unit and its respective code with areal coverage in the watershed which was used for HRU definition is provided in Table 3 and the spatial distribution of each soil unit in the study watershed is also outlined in Figure 4.

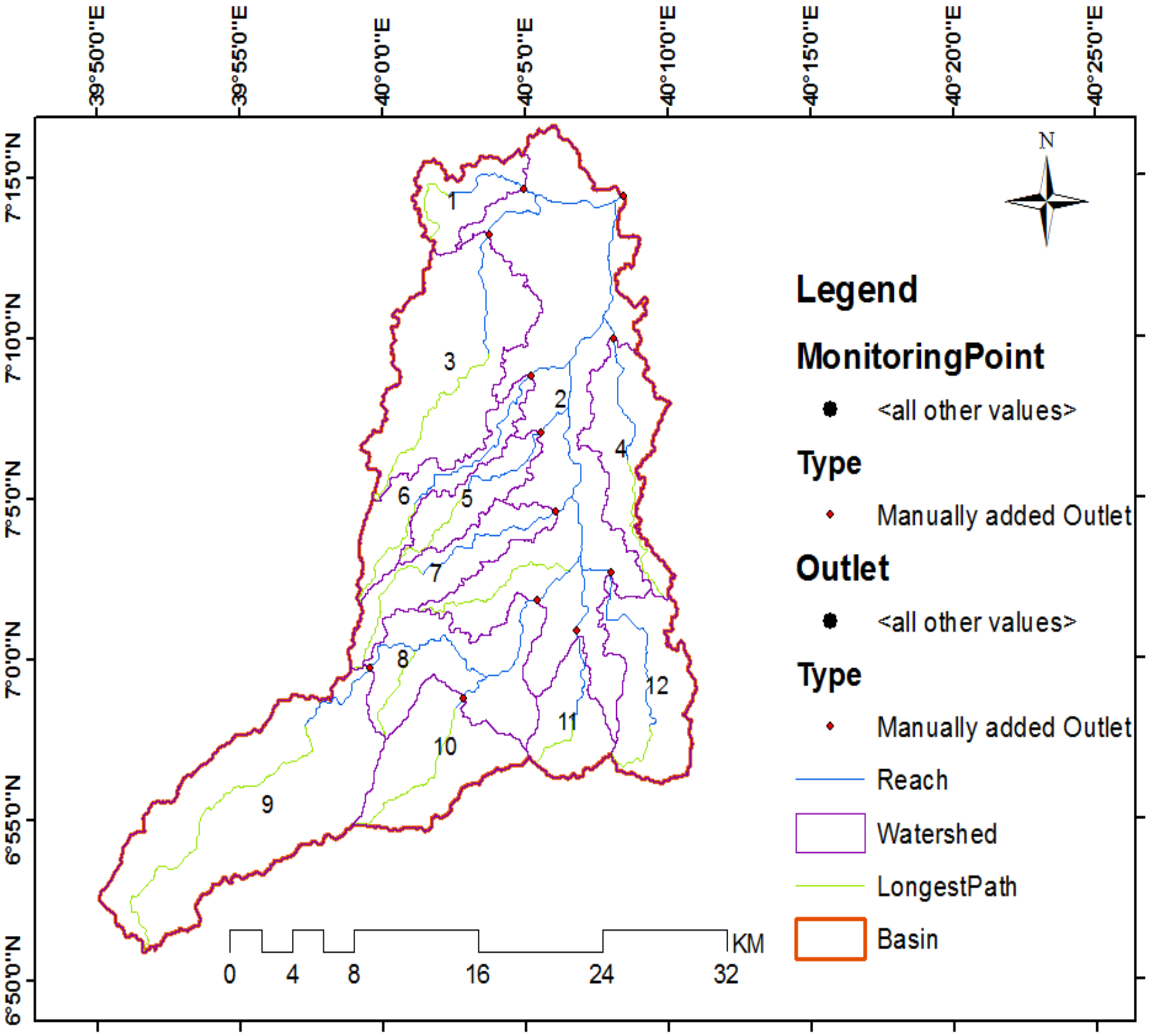


Figure 3 Sub-basin delineation in the Tegona watershed by SWAT model.

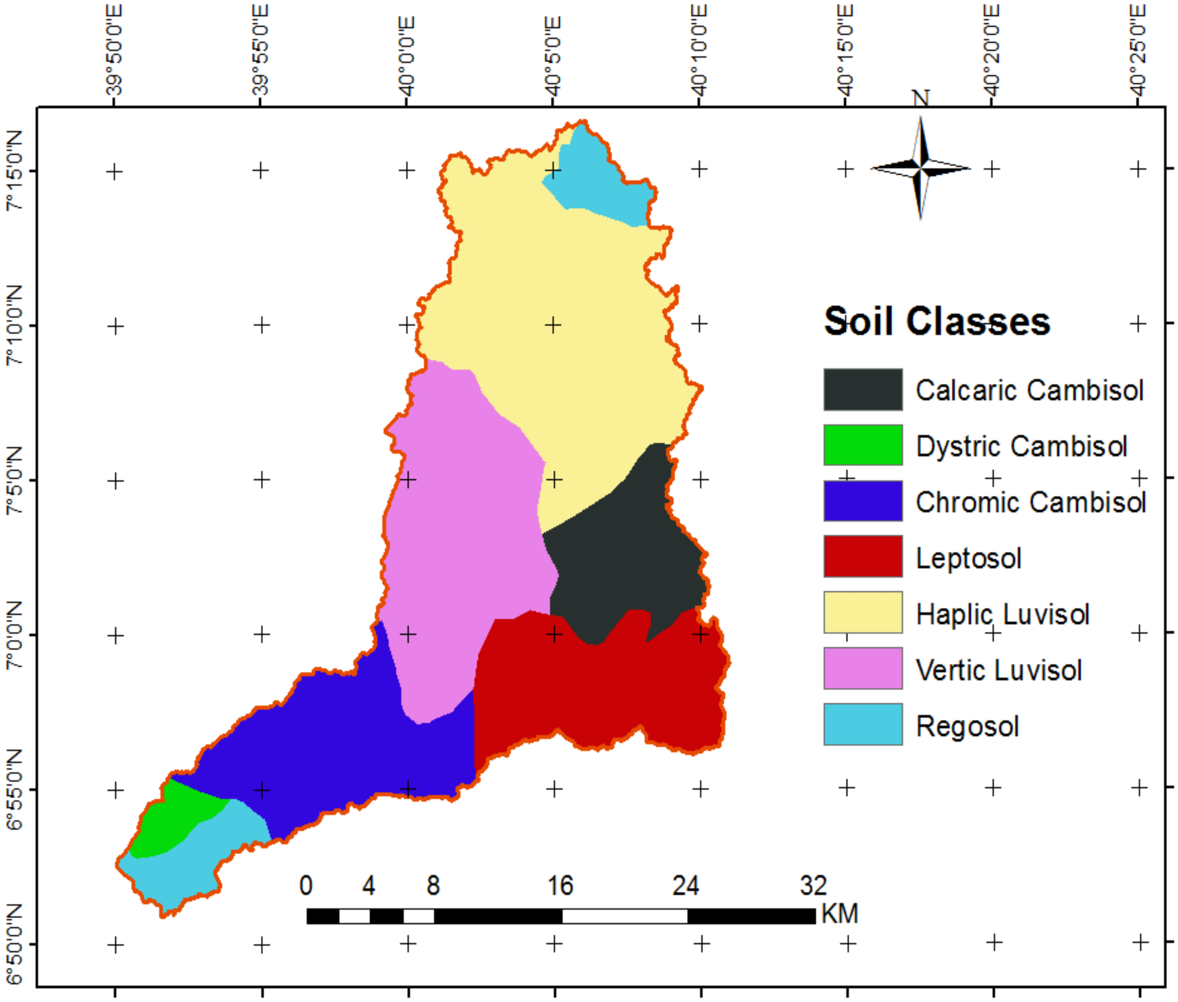


Figure 4 Soil map of the study watershed

Table 3 Major soil classes of Tegona watershed and their areal coverage

Soil class	Area (ha)	Watershed area (%)
Calaric Cambisol	46352	9.59
Daystric Cambisol	9647	1.99
Chromic Cambisol	73640	15.24
Leptosol	71651	14.83
Halplic Luvisol	147878	30.61
Vertic Luvisol	101695	21.05
Regosol	32255	6.68

A summary of the land use and its respective SWAT land use code with areal coverage in the watershed which was used for HRU definition is provided in Table 4 and the spatial distribution of each land use type over the study watershed is shown in Figure 5.

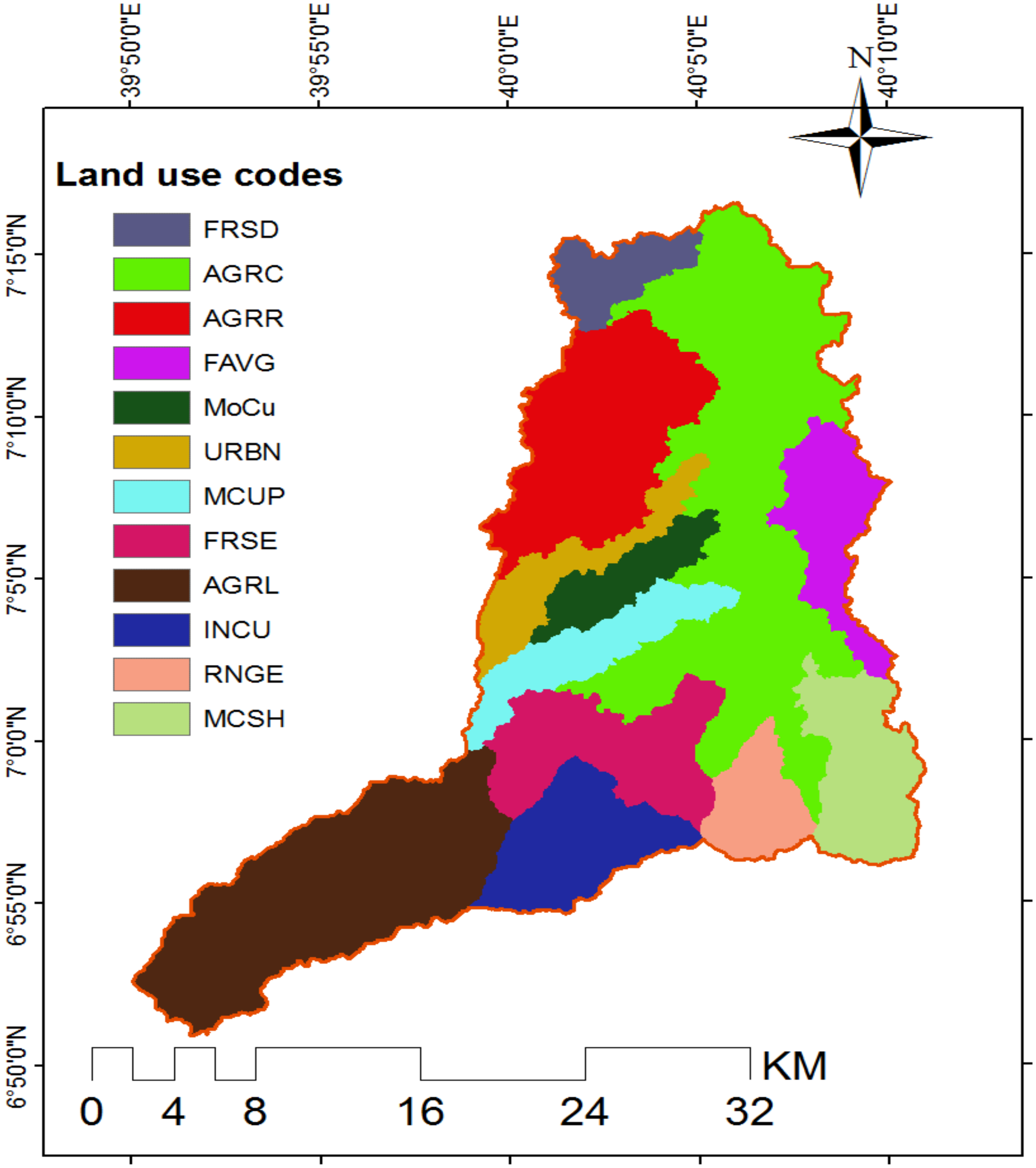


Figure 4 Land use map of the study watershed.

Table 4. Land use, SWAT codes and their areal coverage in the watershed

Land use	SWAT code	Area (ha)	Watershed area (%)
Forest-Deciduous	FRSD	14940	3.09
Agricultural Land	AGRL	126627	26.21
Agricultural Land (Row crops)	AGRR	58435	12.09
Farm Village	FAVG	25207	5.22
Moderately Cultivated	MoCU	15250	3.16
Urban	URBN	18900	3.91
Moderately Cultivated (Perennial)	MCUP	22444	4.65
Forest-Evergreen	FRSE	37324	7.73
Agricultural Land-Close-grown	AGRC	85003	17.60
Intensively Cultivated	INCU	31503	6.52
Range Grasses	RNGE	16779	3.47
Moderately Cultivated (Smallholder farm)	MCSH	30706	6.36

Depending on the maximum and standard deviation of land slope in the watershed, this study considered three slope classes, by dividing land slope classes as: class1: 0 to 5%, class 2: 5- 10%, class3:10-9999%. The maximum value of the slope ranges in SWAT database was assigned by default to be 9999%.

From land slope classifications, about 32.90% of the watershed area covered with a land slope of more than 10%, 42.06% of the watershed area covered with a land slope range of 0-5 %, and the remaining 25.04% of the area is covered with a land slope of 5-10%.

Figure 6 outlines the spatial distribution of land slope and indicated the upstream or most of the watershed part has a higher land slopes. Appendix Figure 1 in addition, shows the threshold values used for HRU delineation in ArcSWAT database.

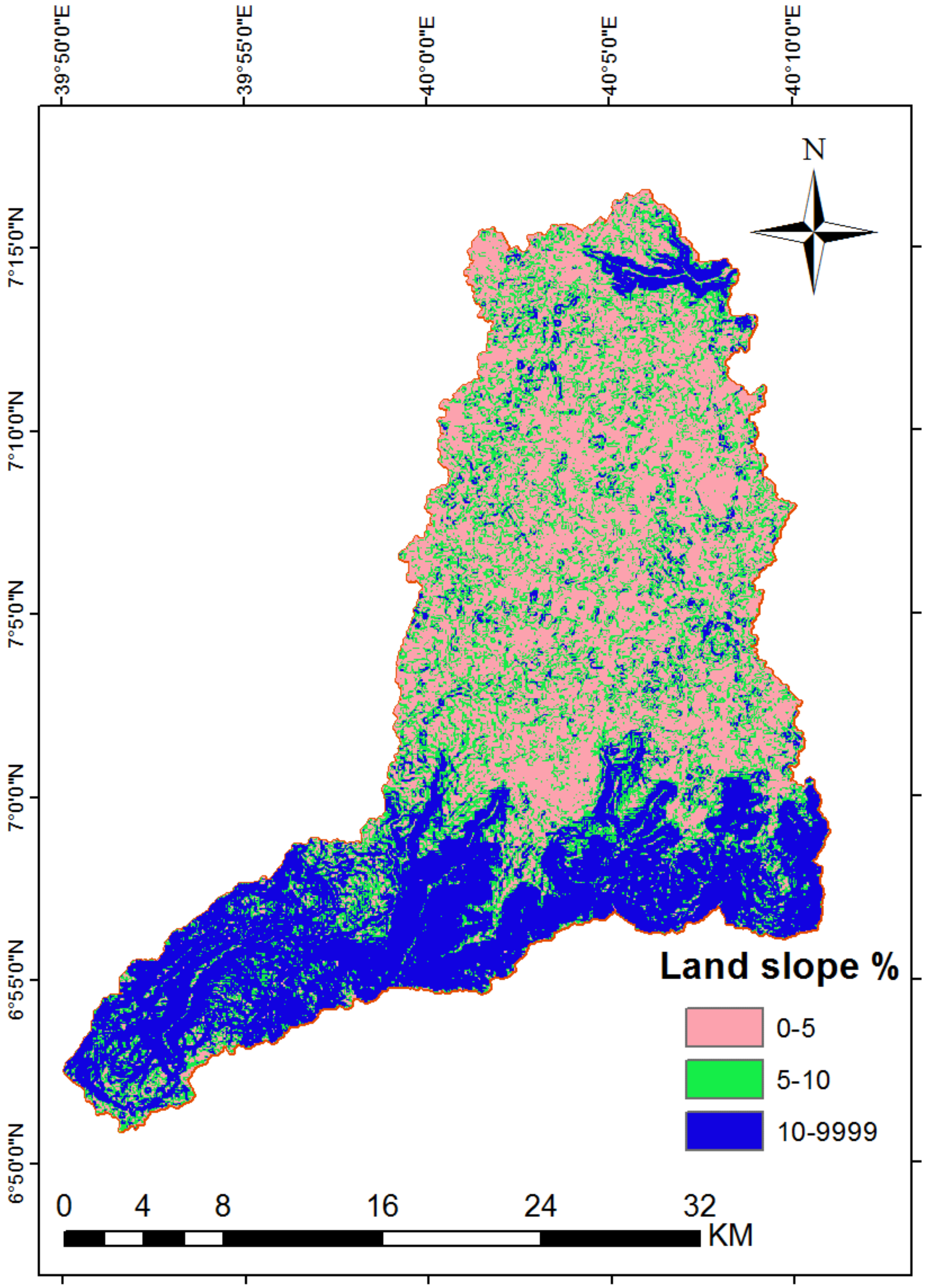


Figure 5 Slope map of the study watershed .

4.2. Sensitivity Analysis Outputs

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Even though 27 parameters were used for the sensitivity analysis, from which twenty one of them were found to be relatively sensitive with the category of sensitivity ranging from very high to small or negligible.

Among the sensitive flow parameters the ground water parameters were found to be the most sensitive. Deep aquifer percolation fraction; Rchrg_Dp, Base flow alpha factor [days]; Alpha_Bf, Threshold water depth in the shallow aquifer for flow [mm]; Gwqmn, Soil evaporation compensation factor; Esco, Initial curve number (II) value; Cn2, Soil depth [mm]; Sol_Z, Threshold water depth in the shallow aquifer for "revap" [mm]; Revapmin, Maximum potential leaf area index; Blai, Channel effective hydraulic conductivity [mm/hr]; Ch_K2, Available water capacity [mm water / mm soil]; Sol_Awc, Maximum canopy storage [mm]; Canmx and Surface runoff lag time [days]; Surlag were found to be the most effective hydrologic parameters for the simulation of stream flow. Sensitive flow parameters, relative sensitivity values, parameter ranking and their category were presented in the Table 5. A brief description of each hydrologic parameter is listed in the SWAT model user’s manual (Neitsch *et al*., 2004).

Table 5. Results of sensitivity analysis of flow parameters

Flow Sensitive Parameters	Rank	Mean Relative sensitivity	Category of sensitivity	Lower and upper bound
Deep aquifer percolation fraction; Rchrg_DP	1	1.840	Very High	0.0 to 1.0
Initial curve number (II) value; Cn2	2	1.060	Very High	±25.0
Baseflow alpha factor [days]; Alpha_Bf	3	0.689	High	0.0 to 1.0
Soil evaporation compensation factor; Esco	4	0.319	High	0.0 to 1.0
Maximum potential leaf area index; Blai	5	0.230	High	0.0 to 10.0
Channel effective hydraulic conductivity [mm/hr]; Ch_K2	6	0.166	Medium	0.0 to 150.0
Threshold water depth in the shallow aquifer for flow [mm]; Gwqmn	7	0.132	Medium	±1000.0
Soil depth [mm]; Sol_Z	8	0.127	Medium	±25.0
Available water capacity [mm water / mm soil];Sol_Awc	9	0.121	Medium	±25.0
Threshold water depth in the shallow aquifer for "revap" [mm]; Revapmin	10	0.106	Medium	±100.0
Maximum canopy storage [mm]; Canmx	11	0.097	Medium	0.0 to 10.0
Surface runoff lag time [days]; Surlag	12	0.081	Medium	0.0 to 10.0
Average slope steepness [m/m]; Slope	13	0.072	Medium	±25.0

Manning's n value for main channel ; Ch_N	14	0.067	Medium	0.0 to 1.0
Saturated hydraulic conductivity [mm/h]; Sol_K	15	0.066	Medium	±25.0
Groundwater Delay [days]; Gw_Delay	16	0.062	Medium	±10.0
Groundwater "revap" coefficient; Gw_Revap	17	0.034	Small	±0.036
Plant uptake compensation factor; Epco	18	0.005	Small	0.0 to 1.0
Moist soil albedo ; Sol_Alb	19	0.004	Small	±25.0
Average slope length [m]; Slsubbsn	20	0.0002	Small	±25.0
Maximum potential leaf area index; Biomix	21	0.0002	Small	0.0 to 10.0

4.3. SWAT Model Calibration and Validation Outputs

4.3.1. Model Calibration outputs

Base flow and surface flow was separated using the automated digital filter methods based on the daily flow data measured at the outlet of the Tegona watershed. The base flow separation technique indicated that about 55% of the total water yield was contributed from the subsurface water source which was more than surface runoff involvement for the total water yield at the outlet of the watershed. The model was run for a period of seven years January 1, 1994 to December 31, 2000. However, the first two years of the recording period were used for stabilization of model runs (warm up period). The calibration was therefore performed for a period of five years on monthly bases.

Table 6. Finally calibrated flow parameter values and variation methods (imet)

Flow Parameters	**Bounds/Ranges**	**Calibrated values**	**imet**
Alpha_Bf	0.0 to 1.0	0.96	1
Blai	0.0 to 1.0	0.27	1
Canmx	0.0 to 10.0	7.55	1
Cn2	±25.0	-15.90	3
Esco	0.0 to 1.0	0.16	1
Gw_Delay	±10.0	5.47	2
Gwqmn	±1000.0	854.02	2
Revapmin	±100.0	92.71	2
Rchrg_Dp	0.0 to 1.0	0.48	1
Sol_Awc	±25.0	15.43	3
Sol_K	±25.0	21.66	3
Sol_Z	±25.0	6.17	3
Surlag	0.0 to 10.0	5.09	1

Note from the above Table 6, 1 stands for Replacement of initial parameter by value, 2 for Adding value to initial parameter and 3 for Multiplying initial parameter by value (in percentage).

Model parameters were first calibrated manually which was very time consuming process, followed by automatic calibration using ParaSol (Parameter Solutions), an auto calibration tool which is embedded in SWAT 2005. The calibration processes considered 13 flow parameters (Table 6) and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The auto calibration processes significantly improved model efficiency. Table 8 illustrates the final calibrated and fitted values. The result from different statistical method of model performance evaluation met the criteria of ENS > 0.5, $r^2 > 0.6$ and D ≤ ±15%.

The statistical results of the model performance for calibration periods on monthly time steps are summarized in Table 7.The calibration results in Table 7 show that there is a good agreement between the simulated and measured monthly flows. Percent of error of the observed and simulated monthly flows at Tegona gauge station is 8.33% which is well within the acceptable range of

±15%. Further a good agreement between observed and simulated monthly flows are shown by the coefficient of determinations (R^2=0.71) and the Nash-Suttcliffe simulation efficiency (ENS=0.77) and thus fulfilled the requirements suggested by Santhi., *et al*. (2001) for R^2 >0.6 and ENS> 0.5.

Table 7. Calibration statistics for measured and simulated flows at Teona flow gauge station.

Period	Total flow (m^3/s)		Mean monthly flow (m^3/s)		% difference	R^2	ENS
1996-2000	Observed	Simulated	Observed	Simulated			
	693.95	751.72	11.57	12.53	8.33	0.71	0.77

The graphical representation of the simulated and observed monthly flows (figure 7.) shows a reasonable agreement.

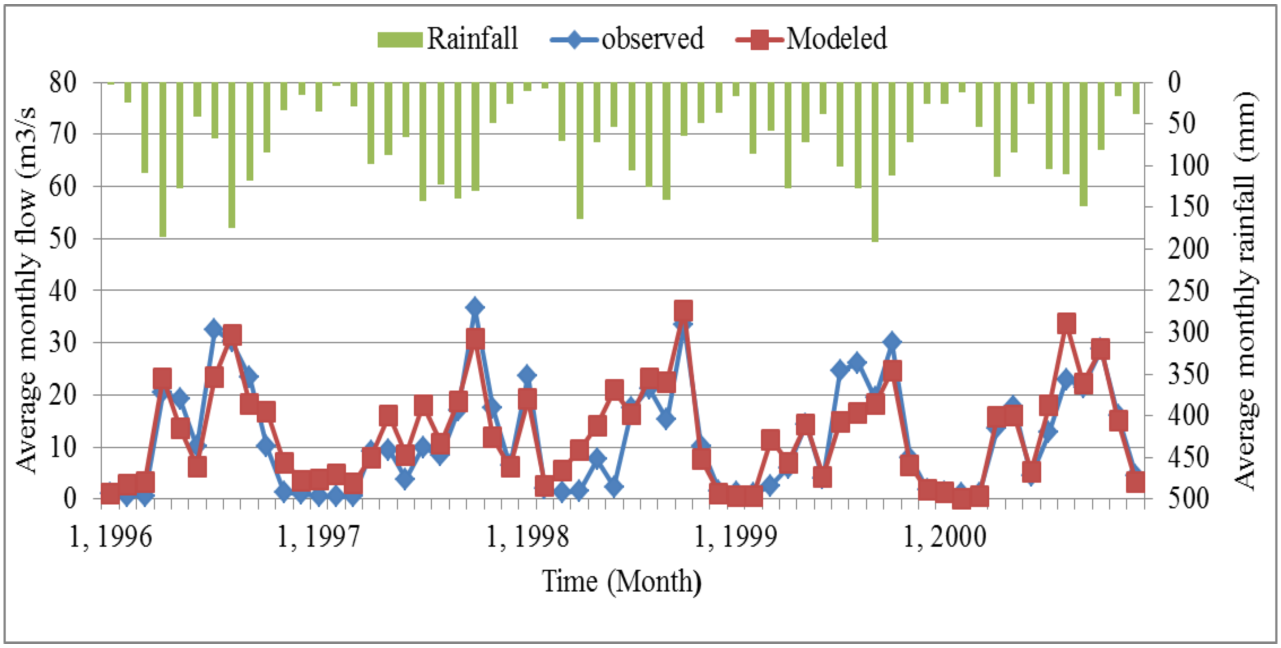


Figure 6 Hydrograph of the observed and simulated monthly flows for the calibration period at Tegona River gauge station.

Even though the model slightly over estimates the peak values in the year 1998 and 2000 and under estimates in remaining part of the calibration period, the overall flow is well simulated and the trend shows good patterns. Figure 8 also shows the scatter plots between observed and simulated flows and the equations showed positive relations between observed and simulated flows.

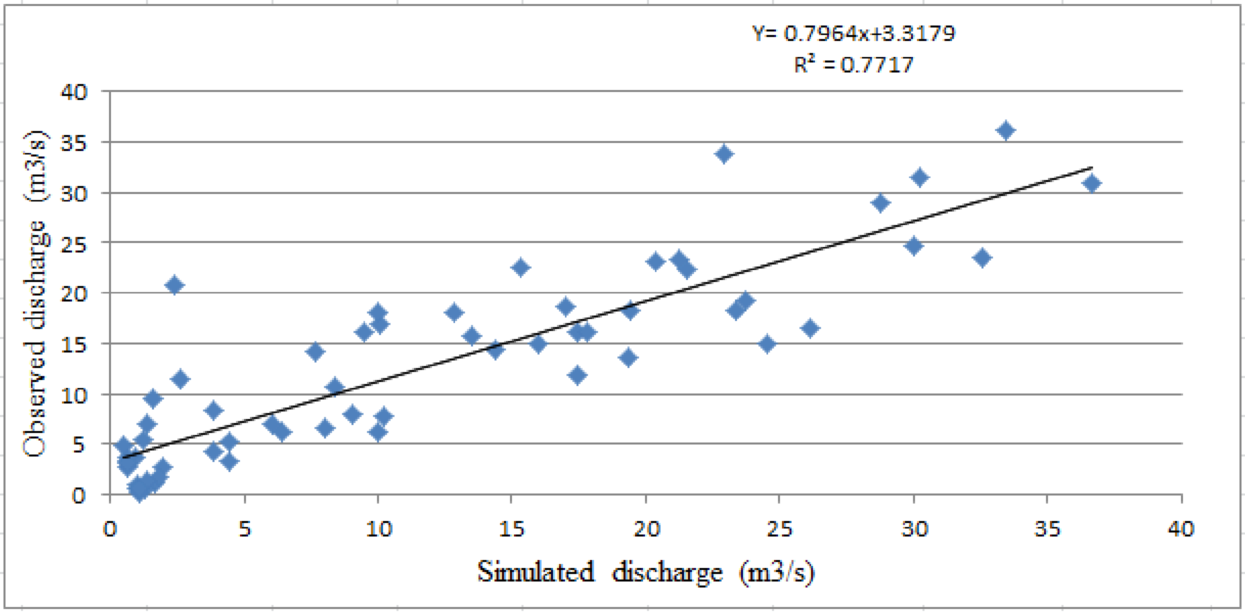


Figure 7 Scatter plots of monthly simulated versus observed flow at Tegona River gauge station after calibration.

4.3.2. SWAT Model Validation of Flow Outputs

Validation of the model was carried out using an independent data set for five years from 2001-2005 without making further adjustments of sensitive parameters. The validation results are shown in the Table 8.

Table 8. Validation statistics for measured and simulated flows at Tegona flow gauge station.

Period	Total flow (m^3/s)		Mean monthly flow (m^3/s)		% difference	R^2	ENS
2001-2005	Observed	Simulated	Observed	Simulated			
	994.73	872.88	16.58	14.55	-12.25	0.86	0.83

As it can be seen from the Table 8 there is good agreement between monthly observed and simulated flows at Tegona River gauge station. The percent of error between the observed and simulated monthly flow is -12.25% and it is found within the tolerable range of ±15%. The coefficient of determinations (R^2) and Nash-Suttcliffe simulation efficiency (ENS) were found to be 0.86 and 0.83 respectively and these shows a very good correlation of the simulation results with the observed values.

Furthermore, figure 9 shows the hydrograph of monthly observed and simulated flows. Even though the model slightly overestimates the peak values in the year 2004 and under estimates from the year 2001 - 2002, the general trend was more or less similar.

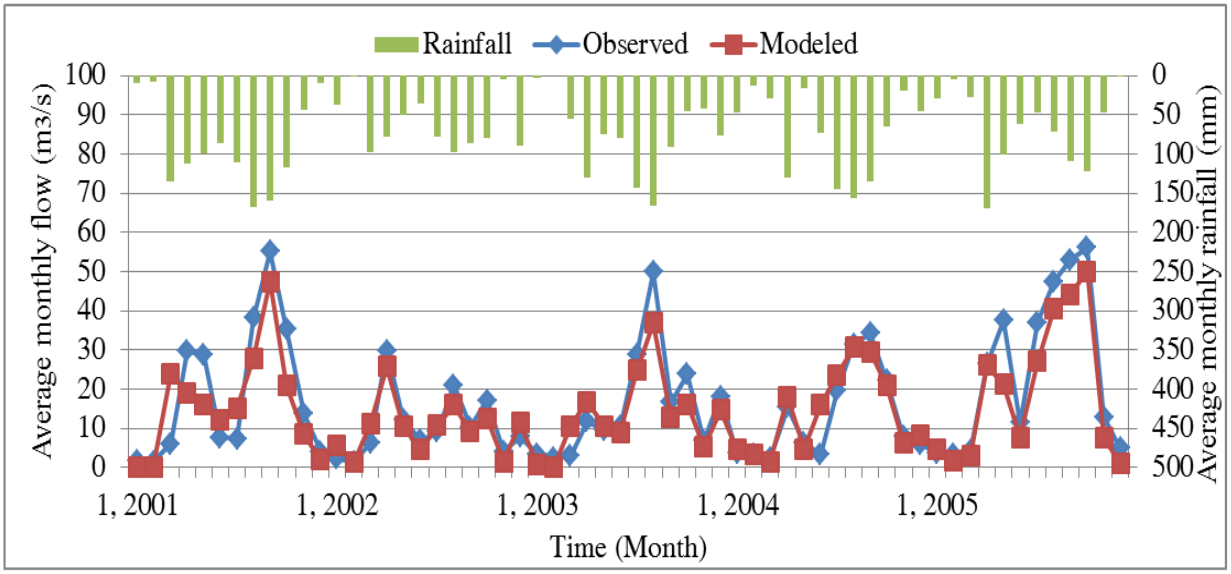


Figure 9. Hydrograph of the observed and simulated monthly flows for the validation period at Tegona River gauge station.

Generally there is a good fit between measured and simulated output and a slight over estimation of the low flows and under estimation of the peak flows were observed at the validation period. Since the model performed as well in the validation period, as for the calibration period hence, the set of optimized parameters listed in Table 7 during calibration process for Tegona watershed can be taken as the representative set of parameters for the watershed. The scatter plots between simulated and observed flows also showed positive relations (figure 10).

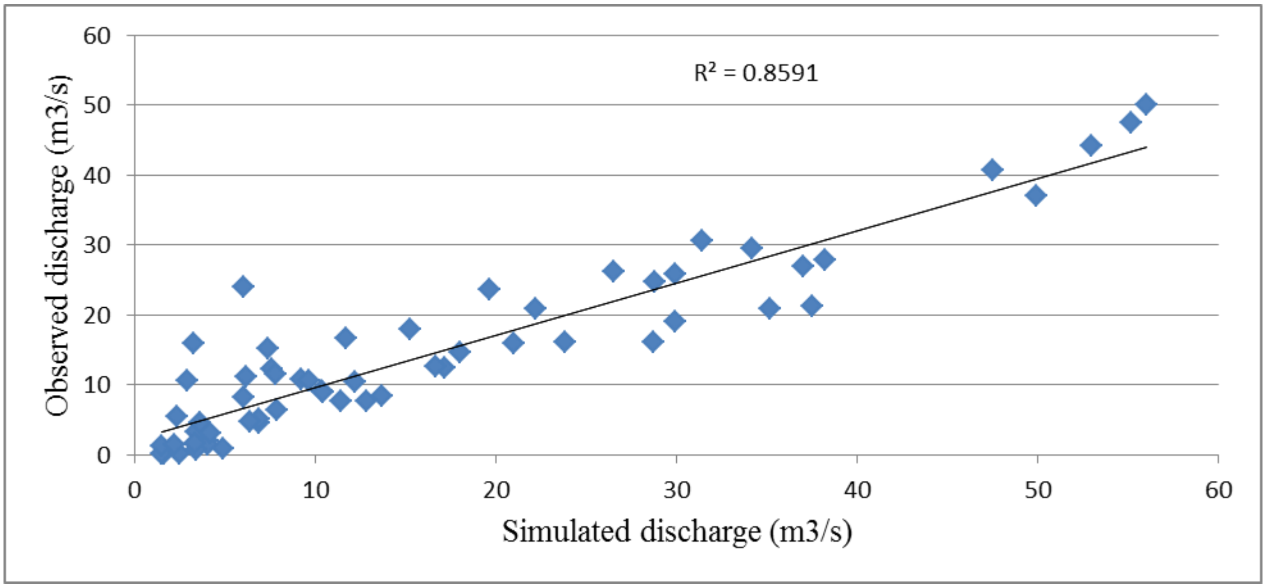


Figure 10. Scatter plots of monthly simulated versus observed flow at Tegona River gauge station after Validation.

Thus, the validation check illustrates the accuracy of the model for simulating time-periods outside of the calibration period. The model performed as good in the validation period (2001- 2005), as for the calibration period (1996-2000) at Tegona gauge station as indicated in Table 7. Hence, the set of optimized parameters used during calibration process can be taken as the representative set of parameter to explain the hydrologic characteristic of the Tegona watershed and further simulations using SWAT model can be carried out by using these parameters for any period of time.

4.4. Water Yield Simulation

4.4.1. Monthly water yield simulation

The water yield was simulated for the year 1994 to 2001 on monthly time step at the outlet of Tegona watershed. Moreover, the result was summarized in monthly bases after an intensive model calibration for sensitive flow parameters.

Comparison of the monthly simulated vs. observed total water yield proved that SWAT model can be a potential tool for simulation of streamflow and water balance components of ungauged watershed in the highlands of Ethiopia, despite the fact that the model slightly overestimation on the main rainy. As shown in Figure 11, model simulation slightly overestimated the observed discharge on the month of April, May, June, July, August, September and underestimated on October and November otherwise; the simulated flows have good similarity with observed values.

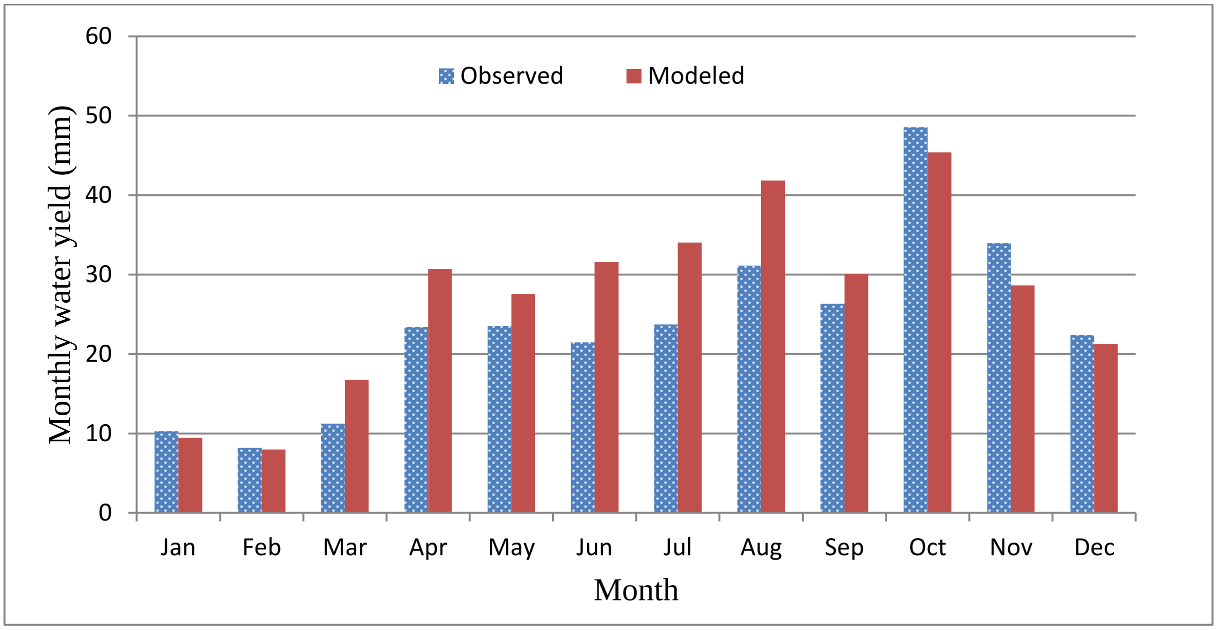


Figure 11. Mean monthly measured vs. simulated water yield for a base period of 1994-2001.

4.4.2. Average annual water balance components of the watershed

The SWAT model estimated other relevant water balance components in addition to monthly discharge. Average annual basin values for different water balance components during a base simulation periods presented in Figure 12 and Table 9 shows average annual watershed gain and losses with change in soil water storage. From these components total water yield is the amount of stream flow leaving the outlet of watershed during the time step.

The total water yield mathematically can be expressed as surface runoff plus lateral soil flow contribution to stream flow plus ground water contribution to stream flow minus water lost from tributary channels in the HRU via transmission through the bed.

Table 9. Average annual water balances simulated for a base periods of 1994-2001.

Water balance components	Amounts in (mm)
Precipitation; Precip	930.8
Surface runoff ; Sur_Q	142.19
Lateral soil flow contribution; Lat_Q	187.11
Ground water contribution to streamflow; Gw_Q	239.19
Revap or shallow aquifer recharges	6.55
Deep Aquifer Recharges	12.91
Total water yield; Twyld	568.49
Percolation out of soil; Perc	257.7
Actual evapotranspiration; ET	307
Potential evapotranspiration; PET	478
Transmission losses; Tloss	0
Change in soil water storage	35.85

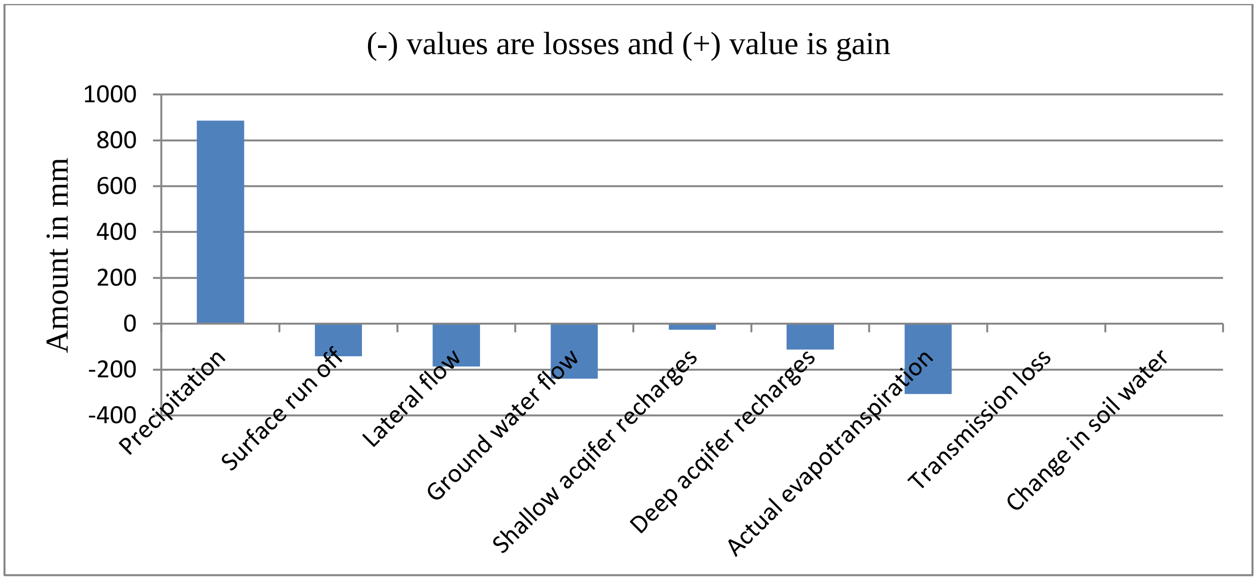


Figure 12. Average annual water balances for Tegona watershed.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Understandings on hydrological processes and develop suitable models for a watershed is the most important aspect in water resources development and management programmes. Watershed based hydrologic simulation models are likely to be used for the assessment of the quantity and quality of water. The performance and applicability of SWAT model was successfully evaluated through sensitivity analysis, model calibration and validation.

According to the result obtained from sensitivity analysis with measured discharge, subsurface flow parameters were found to be more sensitive to the stream flow of the watershed. Consequently, base flow was an important component of the hydrology of the study watershed, signifying the watershed is rich in ground water as a result of good recharge capacity. The stream flow simulation performance of the model for calibration and validation periods was evaluated using graphical and statistical methods. Model efficiency criteria were fulfilled the requirements of $r^2 > 0.6$, ENS > 0.5 and $D \leq \pm 15$, for both monthly flow calibration and validation periods.

Accordingly, SWAT model was found to produce a reliable estimate of monthly runoff for Tegona watershed. However, the model was weaker for the simulation of monthly stream flow in both calibration and validation periods, particularly, the monthly peak events were underestimated and low flows were overestimated. Nevertheless, additional weather station on the upstream area may produce more accurate prediction on a daily time step. Overall, the simulated and measured discharge followed similar patterns and trend, thus, SWAT model can be used for hydrologic simulation of mountainous watershed with similar characteristics to Tegona river watershed. However, for a more accurate modeling of hydrology, a large effort will be required to improve the quality of available input data.

5.2. Recommendations

Based on the finding the following recommendations were forwarded;

- The SWAT model performed well in simulating monthly flow of the Tegona watershed. Therefore, the calibrated parameter values can be considered for further hydrologic simulation of the watershed and the model can be taken as a potential tool for simulation of the hydrology of ungagged watershed in mountainous areas of Ethiopia which behave hydro-meteorologically similar with Tegona watershed.

- Proper recording and handling of time series data should be exercised for a better prediction efficiency of the watershed modeling. A hydrologic model is highly reliant on the input datasets so that, due attention need to be paid for the measurement and computation of the governing input such as meteorological and hydrological data otherwise, calibration and validation of SWAT model would be difficult.
- Future studies on Tegona watershed modeling should address the issues related to water quality including sedimentation, nutrients, and evaluate best management practices to address different water quality issues in the watershed, and baseline and future climate change impacts on water recourses availability. Similarly, accurate sampling and measurement of sedimentation and other water quality parameters have to be addressed by responsible bodies together with a better weather and flow datasets. It is only recommended to use the output of model simulation after proper model calibration and validation using measured datasets and subsequently, this hydrologic simulation model can be used to formulate strategies for soil and water conservation in a watershed.

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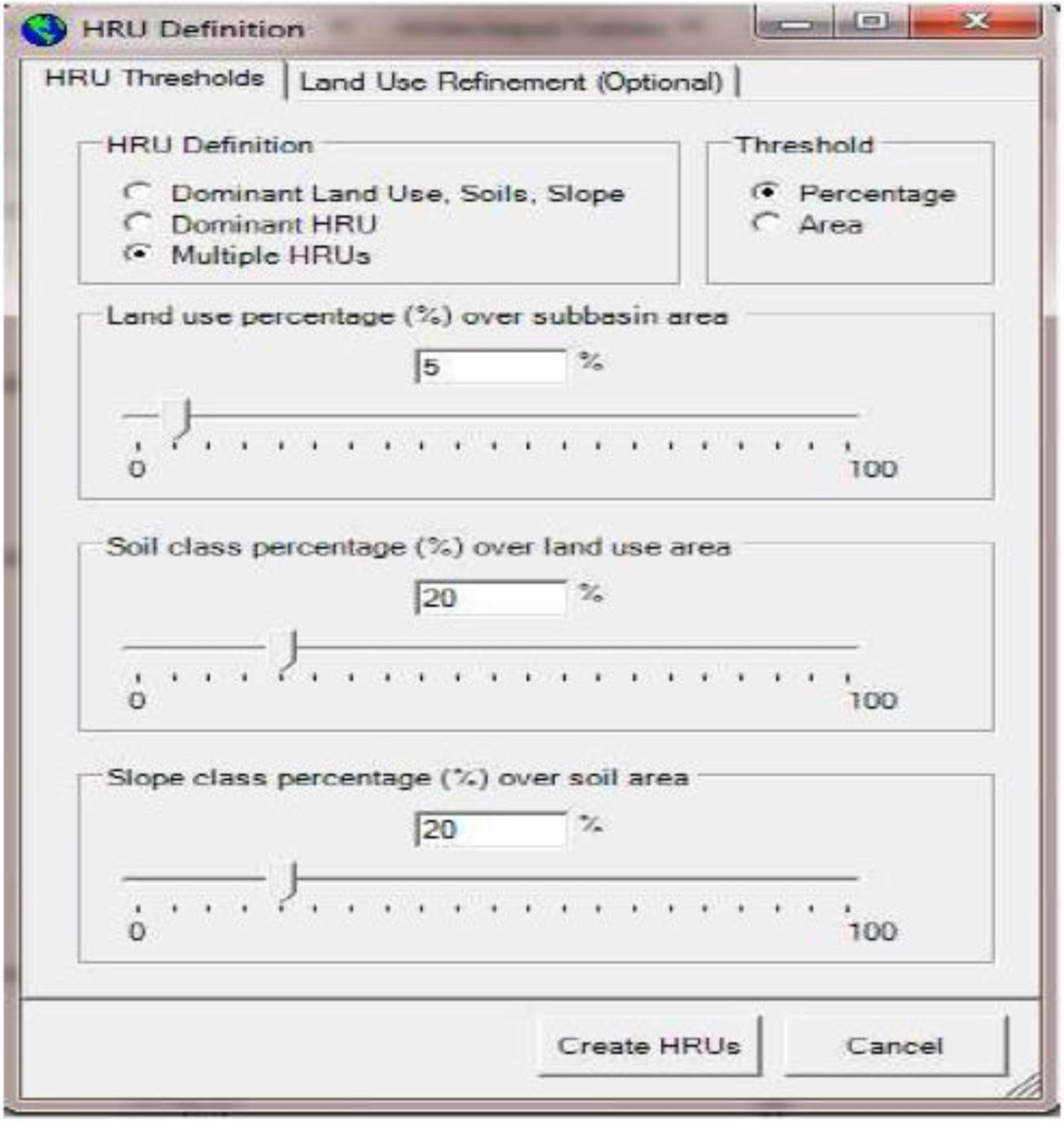
7. APPENDICES



HRU Definition

- ○ Dominant Land Use, Soils, Slope
- ○ Dominant HRU
- ● Multiple HRUs

Threshold

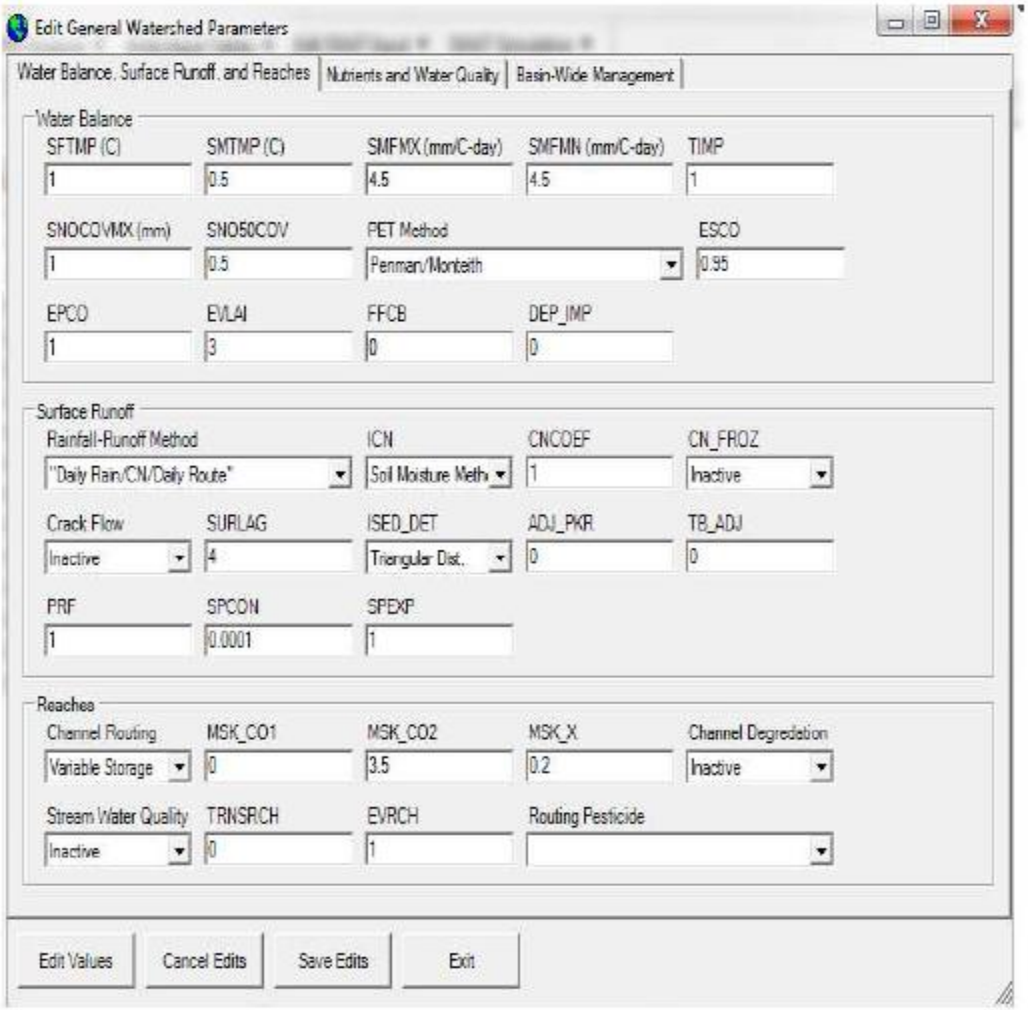
- ● Percentage
- ○ Area

Land use percentage (%) over subbasin area: 5 %

Soil class percentage (%) over land use area: 20 %

Slope class percentage (%) over soil area: 20 %

Appendix Figure 1 Threshold values used for HRU definition



Water Balance

SFTMP (C): 1
SMTMP (C): 0.5
SMFMX (mm/C-day): 4.5
SMFMN (mm/C-day): 4.5
TIMP: 1
SNOCOVMX (mm): 1
SNO50COV: 0.5
PET Method: Penman/Monteith
ESCO: 0.95
EPCO: 1
EVLAI: 3
FFCB: 0
DEP_IMP: 0

Surface Runoff

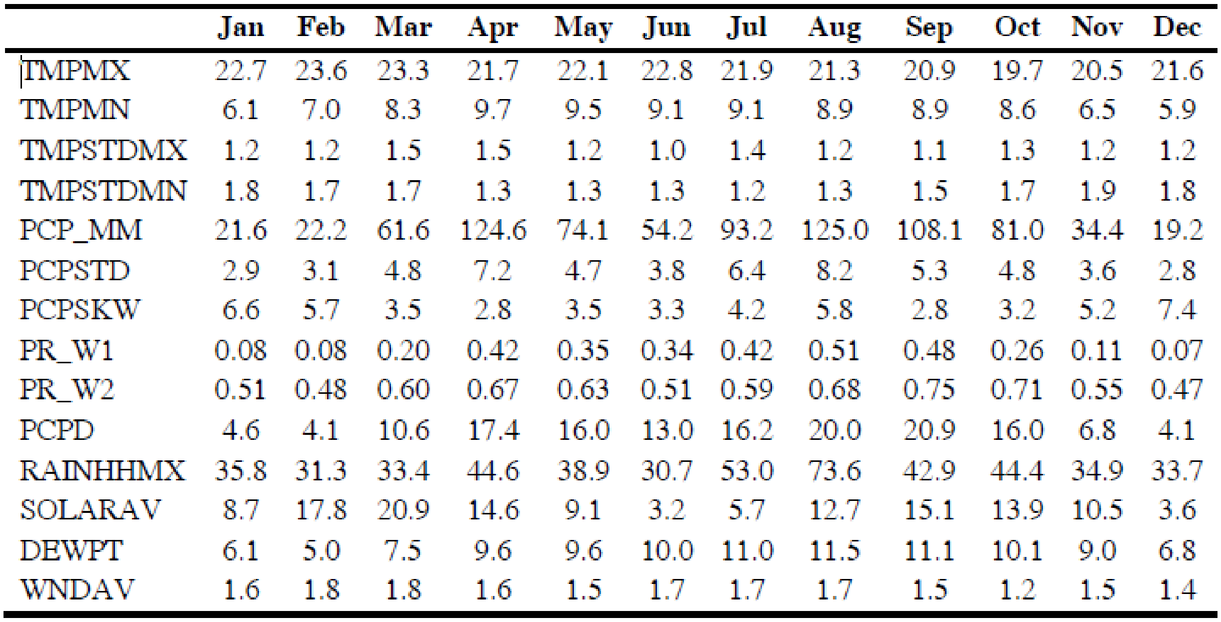
Rainfall-Runoff Method: "Daily Rain/CN/Daily Route"
ICN: Soil Moisture Meth
CNCOEF: 1
CN_FROZ: Inactive
Crack Flow: Inactive
SURLAG: 4
ISED_DET: Triangular Dist.
ADJ_PKR: 0
TB_ADJ: 0
PRF: 1
SPCON: 0.0001
SPEXP: 1

Reaches

Channel Routing: Variable Storage
MSK_CO1: 0
MSK_CO2: 3.5
MSK_X: 0.2
Channel Degredation: Inactive
Stream Water Quality: Inactive
TRNSRCH: 0
EVRCH: 1
Routing Pesticide:

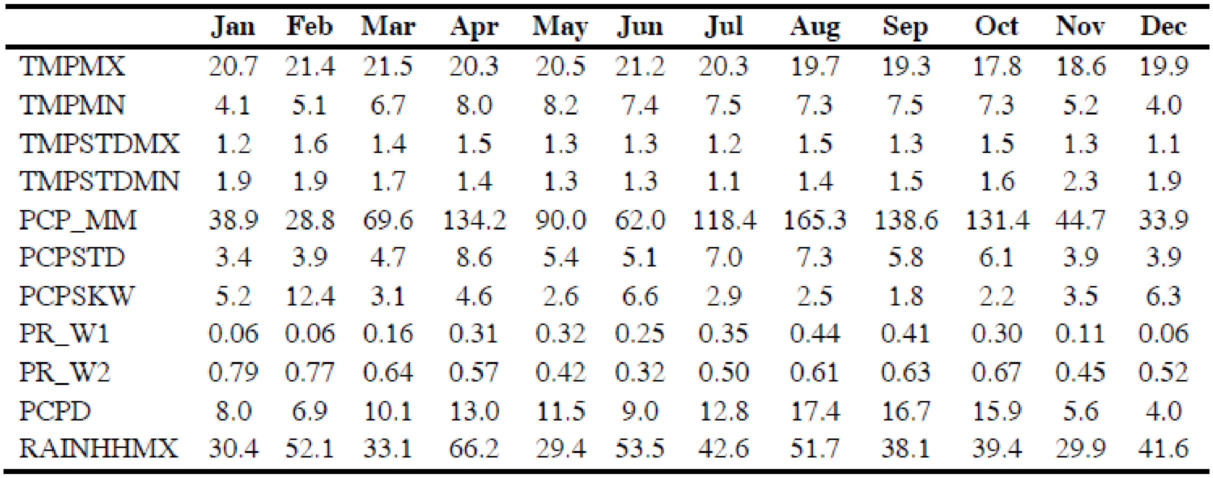
Appendix Figure 2 General watershed parameters used in SWAT database

Appendix Table 1 Statistical values for Robe weather station



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPMX	22.7	23.6	23.3	21.7	22.1	22.8	21.9	21.3	20.9	19.7	20.5	21.6
TMPMN	6.1	7.0	8.3	9.7	9.5	9.1	9.1	8.9	8.9	8.6	6.5	5.9
TMPSTDMX	1.2	1.2	1.5	1.5	1.2	1.0	1.4	1.2	1.1	1.3	1.2	1.2
TMPSTDMN	1.8	1.7	1.7	1.3	1.3	1.3	1.2	1.3	1.5	1.7	1.9	1.8
PCP_MM	21.6	22.2	61.6	124.6	74.1	54.2	93.2	125.0	108.1	81.0	34.4	19.2
PCPSTD	2.9	3.1	4.8	7.2	4.7	3.8	6.4	8.2	5.3	4.8	3.6	2.8
PCPSKW	6.6	5.7	3.5	2.8	3.5	3.3	4.2	5.8	2.8	3.2	5.2	7.4
PR_W1	0.08	0.08	0.20	0.42	0.35	0.34	0.42	0.51	0.48	0.26	0.11	0.07
PR_W2	0.51	0.48	0.60	0.67	0.63	0.51	0.59	0.68	0.75	0.71	0.55	0.47
PCPD	4.6	4.1	10.6	17.4	16.0	13.0	16.2	20.0	20.9	16.0	6.8	4.1
RAINHHMX	35.8	31.3	33.4	44.6	38.9	30.7	53.0	73.6	42.9	44.4	34.9	33.7
SOLARAV	8.7	17.8	20.9	14.6	9.1	3.2	5.7	12.7	15.1	13.9	10.5	3.6
DEWPT	6.1	5.0	7.5	9.6	9.6	10.0	11.0	11.5	11.1	10.1	9.0	6.8
WNDAV	1.6	1.8	1.8	1.6	1.5	1.7	1.7	1.7	1.5	1.2	1.5	1.4

Appendix Table 2 Statistical values for Goba weather station (1998-2008)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPMX	20.7	21.4	21.5	20.3	20.5	21.2	20.3	19.7	19.3	17.8	18.6	19.9
TMPMN	4.1	5.1	6.7	8.0	8.2	7.4	7.5	7.3	7.5	7.3	5.2	4.0
TMPSTDMX	1.2	1.6	1.4	1.5	1.3	1.3	1.2	1.5	1.3	1.5	1.3	1.1
TMPSTDMN	1.9	1.9	1.7	1.4	1.3	1.3	1.1	1.4	1.5	1.6	2.3	1.9
PCP_MM	38.9	28.8	69.6	134.2	90.0	62.0	118.4	165.3	138.6	131.4	44.7	33.9
PCPSTD	3.4	3.9	4.7	8.6	5.4	5.1	7.0	7.3	5.8	6.1	3.9	3.9
PCPSKW	5.2	12.4	3.1	4.6	2.6	6.6	2.9	2.5	1.8	2.2	3.5	6.3
PR_W1	0.06	0.06	0.16	0.31	0.32	0.25	0.35	0.44	0.41	0.30	0.11	0.06
PR_W2	0.79	0.77	0.64	0.57	0.42	0.32	0.50	0.61	0.63	0.67	0.45	0.52
PCPD	8.0	6.9	10.1	13.0	11.5	9.0	12.8	17.4	16.7	15.9	5.6	4.0
RAINHHMX	30.4	52.1	33.1	66.2	29.4	53.5	42.6	51.7	38.1	39.4	29.9	41.6

Where:-

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

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

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

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

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

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

PCPSKW: Skew coefficient for daily precipitation in month.

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

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

PCPD: Average number of days of precipitation in month.

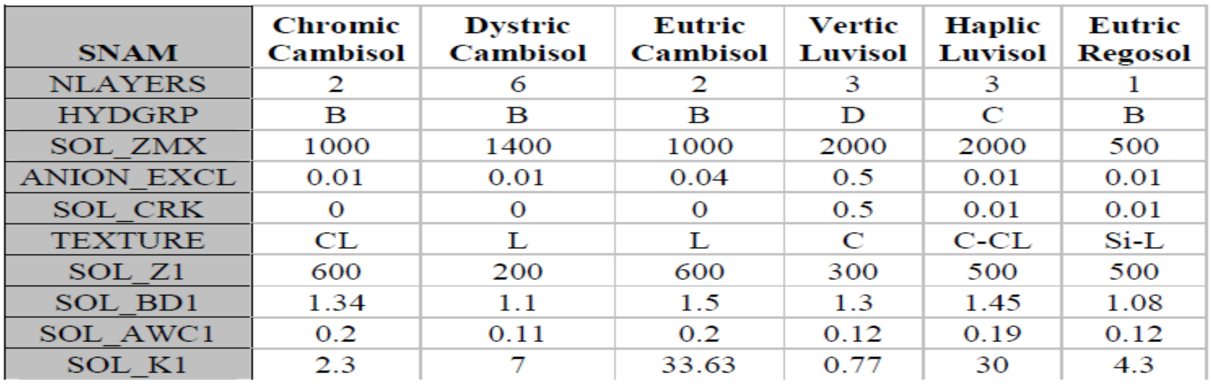
RAINHHMX: Maximum 0.5 hour rainfall in entire period of record for month (mm H2O).

SOLARAV: Average daily solar radiation for month (MJ/m

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

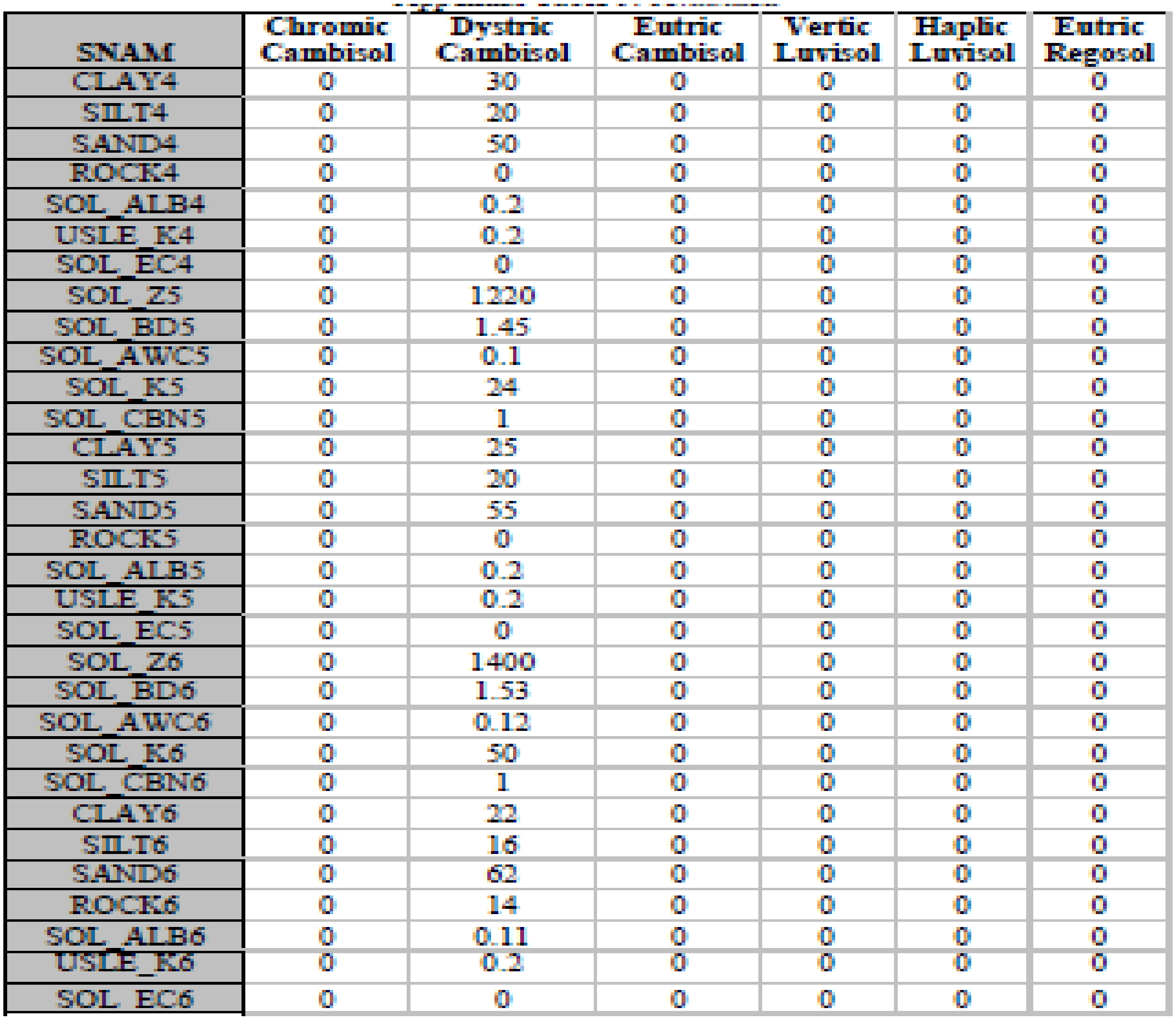
WNDAV: Average daily wind speed in month (m/s).

Appendix Table 3 Soil Parameters in SWAT database for each soil types.



SNAM	Chromic Cambisol	Dystric Cambisol	Eutric Cambisol	Vertic Luvisol	Haplic Luvisol	Eutric Regosol
NLAYERS	2	6	2	3	3	1
HYDGRP	B	B	B	D	C	B
SOL_ZMX	1000	1400	1000	2000	2000	500
ANION_EXCL	0.01	0.01	0.04	0.5	0.01	0.01
SOL_CRK	0	0	0	0.5	0.01	0.01
TEXTURE	CL	L	L	C	C-CL	Si-L
SOL_Z1	600	200	600	300	500	500
SOL_BD1	1.34	1.1	1.5	1.3	1.45	1.08
SOL_AWC1	0.2	0.11	0.2	0.12	0.19	0.12
SOL_K1	2.3	7	33.63	0.77	30	4.3

SNAM	Chromic Cambisol	Dystric Cambisol	Eutric Cambisol	Vertic Luvisol	Haplic Luvisol	Eutric Regosol
SOL_CBN1	1.7	1.5	1.63	1.2	4.1	1.6
CLAY1	35.1	50	21	50	25	22.2
SILT1	38.4	33	33	21	31	25.4
SAND1	26.48	17	46	29	44	52.4
ROCK1	0	5	0	0	0	0
SOL_ALB1	0.14	0.13	0.17	0.2	0.13	0.13
USLE_K1	0.25	0.22	0.31	0.12	0.3	0.23
SOL_EC1	0.15	0.04	0.04	0.3	0.06	0.05
SOL_Z2	1000	320	1000	900	1100	0
SOL_BD2	1.33	1.45	1.46	1.24	1.37	0
SOL_AWC2	0.18	0.13	0.18	0.11	0.09	0
SOL_K2	4.3	13	39.86	0.75	5.52	0
SOL_CBN2	1.3	1.1	1.1	0.7	1.6	0
CLAY2	30.5	32	13	66	44	0
SILT2	36	24	46	18	23	0
SAND2	33.47	44	41	16	33	0
ROCK2	0	0	0	0	0	0
SOL_ALB2	0.14	0	0.17	0.25	0.13	0
USLE_K2	0.13	0.34	0.34	0.13	0.11	0
SOL_EC2	0	0.02	0.02	1.1	0.05	0
SOL_Z3	0	650	0	2000	2000	0
SOL_BD3	0	1.45	0	1.28	1.42	0
SOL_AWC3	0	0.13	0	0.12	0.15	0
SOL_K3	0	25	0	0.56	10.56	0
SOL_CBN3	0	1	0	0.4	0.4	0
CLAY3	0	30	0	57	35	0
SILT3	0	20	0	23	35	0
SAND3	0	50	0	20	30	0
ROCK3	0	0	0	0	0	0
SOL_ALB3	0	0.2	0	0.25	0.13	0
USLE_K3	0	0.2	0	0.14	0.28	0
SOL_EC3	0	0	0	2.4	0.07	0
SOL_Z4	0	900	0	0	0	0
SOL_BD4	0	1.39	0	0	0	0
SOL_AWC4	0	0.13	0	0	0	0
SOL_K4	0	25	0	0	0	0
SOL_CBN4	0	1	0	0	0	0



SNAM	Chromic Cambisol	Dystric Cambisol	Eutric Cambisol	Vertic Luvisol	Haplic Luvisol	Eutric Regosol
CLAY4	0	30	0	0	0	0
SILT4	0	20	0	0	0	0
SAND4	0	50	0	0	0	0
ROCK4	0	0	0	0	0	0
SOL_ALB4	0	0.2	0	0	0	0
USLE_K4	0	0.2	0	0	0	0
SOL_EC4	0	0	0	0	0	0
SOL_Z5	0	1220	0	0	0	0
SOL_BD5	0	1.45	0	0	0	0
SOL_AWC5	0	0.1	0	0	0	0
SOL_K5	0	24	0	0	0	0
SOL_CBN5	0	1	0	0	0	0
CLAY5	0	25	0	0	0	0
SILT5	0	20	0	0	0	0
SAND5	0	55	0	0	0	0
ROCK5	0	0	0	0	0	0
SOL_ALB5	0	0.2	0	0	0	0
USLE_K5	0	0.2	0	0	0	0
SOL_EC5	0	0	0	0	0	0
SOL_Z6	0	1400	0	0	0	0
SOL_BD6	0	1.53	0	0	0	0
SOL_AWC6	0	0.12	0	0	0	0
SOL_K6	0	50	0	0	0	0
SOL_CBN6	0	1	0	0	0	0
CLAY6	0	22	0	0	0	0
SILT6	0	16	0	0	0	0
SAND6	0	62	0	0	0	0
ROCK6	0	14	0	0	0	0
SOL_ALB6	0	0.11	0	0	0	0
USLE_K6	0	0.2	0	0	0	0
SOL_EC6	0	0	0	0	0	0

(Source Alemayehu *et al*., 2012, Sintayehu *et al*., 2015).

Appendix Table 4 Simulated monthly water yield (mm) at the outlet of Tegona watershed.

Year **Month**	**1996**	**1997**	**1998**	**1999**	**Mean**
Jan	9.6	1.5	29.8	6.2	11.8
Feb	4.4	0.5	12.0	9.0	6.5
Mar	15.6	8.6	7.0	35.8	16.7
Apr	44.4	29.1	19.1	14.9	26.8
May	28.8	13.5	17.6	8.7	17.1
Jun	42.9	20.3	18.5	33.1	28.7
Jul	45.0	26.4	29.1	37.4	34.5
Aug	27.4	25.2	30.7	43.9	31.8
Sep	26.0	35.6	43.3	49.5	38.6
Oct	12.9	38.7	70.6	19.8	35.5
Nov	17.2	36.9	32.7	10.2	24.2
Dec	4.9	25.0	14.7	3.5	12.0
Total	279.1	261.2	324.9	271.8	284.2

Appendix Figure 3 The previous gauge station of Tegona River

Tegona Watershed

Tegona Watershed (All pictures are taken by the researcher).