



JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

MSc PROGRAM IN HYDRAULIC ENGINEERING

ESTIMATION OF WATER BALANCE IN CHEMOGA WATERSHED  
USING SWAT MODEL, ABAY BASIN, ETHIOPIA

MSc THESIS

BY

DIRESS CHEKOL

A Thesis submitted to the School of Graduate Studies of Jimma University  
for partial requirement of Master of Science in Hydraulic Engineering.

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JIMMA UNIVERSITY, ETHIOPIA

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## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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## ***Abstract***

*Water resource development is the basic and critical infrastructure for a nation's sustainable development. To use water resource in optimum and effective way, it is necessary to understand the quantity or the distribution in space and time through different researches. Hence this study were conducted on hydrological process using SWAT model on Chemoga watershed located in Abbay basin. In this study calibration and validation of simulated versus measured flows of Chemoga river and estimation of Waterbalnce in the watershed were conducted after sensitivity of hydrologic parameters had been identified using SWAT-CUP model tool. Sequential uncertainly fitting algorithm (SUFI-2) of SWAT-CUP (Calibration and uncertainty program) were used with sets of hydrologic parameters. From those parameters, Evaporation Compensation factor (ESCO) is the most sensitive parameter in the watershed. The hydrological simulation performance evaluation using SWAT-CUP were achieved with the objective function of calibration ( $R^2=0.72$  and  $NS =0.65$ ) and Validation ( $R^2=0.82$  and  $NS =0.71$ ). This model evaluation was performed at monthly levels. The daily model evaluation performance did not fit with objective function due to poor model performance in daily levels of ( $R^2 =0.54$  and  $NS =0.42$ ). The change in soil water or Waterbalnce of the watershed is 24.5mm in the calibration period. The surface and subsurface flow contributions at the outlet of the watershed were resulted in the simulation from which 68% of the total yield of water from the watershed is base flow (ground water contribution).*

***Keyword: Calibration, Sensitivity, SWAT-CUP, SWAT model, Validation, Waterbalnce***

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## ACRONYMS

ArcGIS	Global Information System
BMC	Billion Metric Cube
BNRB	Blue Nile River Basin
ARS	Agricultural Research Service
CN	Curve Number
DEM	Digital Elevation Map
E <sub>NS</sub>	Nash Sutcliffe model efficiency
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GPS	Global position system
GWP	Global water partnership
HRU	Hydrologic Response Unit
IWMI	International Water Management Institute
LH-OAT	Latin hypercube sampling one at a time
LULC	Land Use Land Cover
MOWIE	Ministry Of Water Irrigation and Energy
NMA	National Meteorological Agency
PET	Potential evapotranspiration
95PPU	95% Percent level of uncertainty
R <sup>2</sup>	Coefficient of determination

SCS            Soil Conservation Service

SD    Standard deviation

SUFI        Sequential Uncertainty Fitting

STRM       Shuttle Radar Topographic Mission

SWAT       Soil and Water Assessment Tool

USDA       United States Department of Agriculture

# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 Background of the Study

Water is the universal need for humans life to exist .without water life could not be functional, hence it will simply cease if no water is available in the globe.in undisturbed environment water is always in process or in cycle which is called hydrological cycle. This cycle has been impacted by natural and artificial factors. Due to the hydrological cycle water is always in motion which requires different studies to determine the amount and the distribution of water with different location and time to plan proper water resource management plan. Establishing relationship between hydrological components' is the central focus in hydrological modeling that enables to investigate from simple to complex in dynamic flow equations. Hydrological models are used in studying different hydrological characteristics and influence of humans on watersheds of land use, deforestation and change of watershed management.

Ethiopia's primary water resource challenges are due to extreme hydrological variability and seasonality and the international nature of its significant surface water resources (Teshome, 2014).Fluctuating hydrological conditions have been observed to have very significant impacts on the livelihood of mankind through ages (Balek, 1983). Alternate wet and dry periods forced people to migrate from place to place in order to cope up with the problem. More than ever, challenges faced by many countries of the world in their struggle for socio-economic development today, are primarily related to water (GWP, 2000).

Hydrologic extremes (drought and flood) are the major negative outcomes of the alteration of hydrologic system. These challenges are severe in developing nations like Ethiopia, where agriculture is the primary steering system of the economy. The current food security, water supply and sanitation problems are the challenges that are directly related to water scarcity, whereas heavy storms causing flooding and land degradation due to soil erosion are related to water abundance. Areas of water scarcity cover much of the globe among which Middle, North and Eastern Africa are primarily raised (David, 2001).

Earth's water is constantly in motion, passing from one state to another and from one location to another, which makes its rational planning and management a very complex and difficult task under the best of circumstances (Turner, et al., 2004). The availability and use of water is therefore mainly constrained by its spatial quantity and quality distribution.

Sustainable water resource planning and management requires data to enable quantification of water quality and quantity (Oyebande, 2001). Information is required on the rates of transfers and storage of water within a catchment. Lack of adequate hydrological data introduces uncertainty in both the design and management of water resource systems. Water resource planning is complex since water is always in motion in hydrological process.

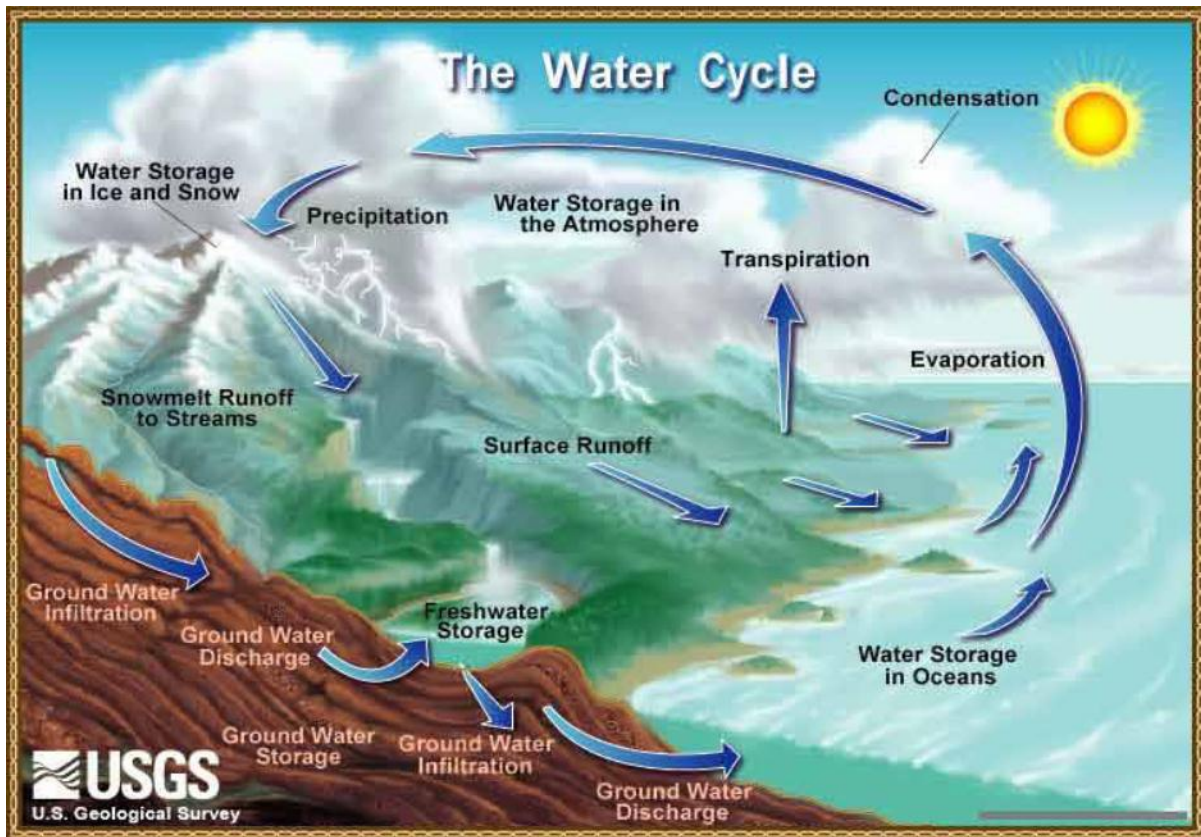


FIGURE 1 1. HYDROLOGICAL CYCLE (USGS)

To determine the variability of hydrologic parameters and flow of matter, a distributed watershed model with a high resolution of space and time is necessary. Human health and welfare, food security and industrial development are dependent on adequate supplies of suitable quality water. Conversely, too much water results in socioeconomic damages and loss of life due to flooding.

The liveliness of natural ecological systems is dependent on mankind's stewardship of water resources. Proper utilization of these resources necessitates assessment and management of the quantity and quality of the water resources both spatially and temporally (Dilnesaw, 2006).

Hence, the modeling of runoff, soil erosion and sediment yield are essential for sustainable watershed development. Furthermore, reliable estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas is 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, 2010) .

In the case of Chemoga sub basin catchment, improper land use practices, and deforestation within the watershed result in huge loss of productive soil and water as runoff. Therefore, there is an urgent need for developing integrated watershed management plan based on hydrological simulation studies using suitable modeling approach. Considering hydrological behavior of the watershed and applicability of the existing models for the solutions of aforementioned problems, this study will be conducted with the application of Soil and Water Assessment Tool (SWAT) model combined with remote sensing and ArcGIS to estimate the runoff yield of watershed of Chemoga River.

Mountains regions watersheds are the origin of the largest rivers in the world and represent the major source of water availability in many countries (Sanjay, 2010).Chemoga watershed is originated from Choke high lands of Ethiopia and enters to Abbay River, hence the catchment is mostly under good amount of rainfall. So, understanding hydrological characteristics is essential using soil and water assessment tool (SWAT) to investigate the runoff and base flow conditions in the catchment.



## **1.2. Statement of the problem**

Nowadays, natural resource conservation practices should be integrated with drafted strategic policies and laws to save the removal of basic environmental ingredients for safe life existence and to keep water resource projects from being extra exploited and to prepare optimum watershed management plan. Because, Water resource sector is the Primary government strategy to overcome poverty through constructing mega hydraulic projects which could change the standard of the life of the community (Ministry of Water Resource, 2010).

The agriculture which is low in productivity due to its rainfall dependency (Cheung, 2008) needs improvement by expanding irrigation schemes. The country also has to take the advantage of its immense hydropower potential from its rivers to meet the escalating energy demand. Water supply project is also another perspective of water resource development that is considered as an important issue to furnish the rural and rapidly urbanizing population, and expanding industries.

For all these projects, irrigation, hydropower and water supply, be it for preliminary or main design works, there should be clear estimation of hydrological situations of the project area. On the other hand, hydrology of Ethiopia is unstable mainly due to climate change and variability. Planning of any hydraulic structure (dams, irrigation canals, diversion structures, flood mitigation works etc.), is made based on the hydrological characteristics of the catchment (Koutsouris, 2010). Knowing hydrological condition or water cycles could be used to plan different water resource projects according to the runoff conditions of the basin.

Chemoga watershed covers from Choke high lands and ends through entering to the Blue Nile River where most of the catchment is highly erosion affected catchment (Bewket, 2003.). Hence, it is so necessary to determine the runoff which could be used to design hydraulic structures in the catchment and prepare watershed management plan.

## **1.3. Objective of the study**

### **1.3.1. Major objective of the study**

The general objective of this study is to estimate water balance in Chemoga watershed using SWAT (soil and water assessment tool).

### **1.3.2. Specific objectives**

- To perform calibration and validation of SWAT model on a monthly and daily time step at the outlet of Chemoga watershed.
- To estimate the monthly, seasonal and annual runoff yield of the model
- To determine ground water (base flow) contribution to the stream flow and to estimate the water balance of Chemoga river watershed.

### **1.4 Scope of the study**

The scope of this study is conducted to take consideration of hydrological components in the catchment. Hydrological modeling using parameters was the major task conducted in this thesis work. Determining the sensitivity of hydrological parameters had also considered to determine the water balance situation in the catchment of Chemoga River. The performance of the SWAT model in Chemoga watershed was evaluated using SWAT-CUP program. Different flow components or hydrological phases are determined. The annual and seasonal outlet flow is predicted. The water balance components are investigated. Hence, flow contributions to the outlet of the watershed is identified.

### **1.5. Significance of the study**

The thesis output is very important for different watershed management plans and would be a considerable input for design of different hydraulic structures on the Chemoga River. Estimating different hydrological and stream characteristics is very essential for multipurpose economical infrastructures to be constructed in the catchment. Hence it will be possible to design optimum hydraulic structures over the river considering the hydrological outputs of this thesis.

## CHAPTER TWO

### 2. LITRATURE REVIEW

#### 2.1. Related Previous works

In Ethiopian highlands the summer rainfall accounts for large percent of the total annual precipitation in the area. The intensity of this rain depends on the amount of moisture that enters and recycles in the region, and the degree to which it ascends to form cloud. According to Viste (2012), moisture transported from Red Sea contributes very importantly to the Ethiopian highland summer. However, moisture from south; coming from Atlantic and Indian oceans are also significant to the central Ethiopian rainfall although its transport to the region is affected by SST and pressure anomalies in Indian Ocean and Gulf of Guinea. Once the moisture is transported to the highland area, it recycles there as a result of the altitudinal feature that favors the process. It is this recycling of moisture along with transportation in to the region that gives summer season in Ethiopian highlands.

##### 2.1.1. Rainfall

The term precipitation as used in hydrology includes all forms of water deposited on the earth's surface and derived from atmospheric vapor. The principal forms are rain, snow, hail, sleet and mist. Unless otherwise specified, the terms precipitation and rainfall are often used indiscriminately to apply to any or all of the forms included in this group. Rainfall may be classified in accordance with the conditions that produce a rising column of unsaturated air, of which there are three: convectional, orographic and cyclonic. (Wisler, 1985) Convectional rainfall is most common type of rainfall in Tropics including Ethiopia.

Rainfall is extremely variable both in time and space. The variation is brought about by differences in the type and scale of development of precipitation-producing processes, and is also strongly influenced by local and regional factors, such as topography and wind direction at the time of rainfall. It is, however, assumed that each individual rain-gauge is representative of a very considerable area around it. This assumption is not correct. Because of the very considerable spatial variation of precipitation depth and intensity, particularly for short durations and for sever convectional storms as is the case in most parts of Ethiopia. There is no guarantee that point rainfalls will in any way provide a reliable guide to the rainfall of immediate surrounding areas (Wisler, 1985)

### **2.1.2. Runoff**

Runoff is that part of the rainfall, as well as any other flow contributions, which appears in surface streams of either in perennial or intermittent form. This is the flow collected from a drainage basin or watershed, and it appears at an outlet of the basin. According to the source from which the flow is derived, runoff may consist of surface runoff, subsurface runoff and ground water runoff.

For the practical purpose of runoff analysis, total runoff in stream channels is generally classified as base flow and direct flow which consists of all other types of flows. The direct runoff is that part of runoff which enters the stream promptly after the rainfall. It occurs only when the rainfall rate is greater than the infiltration rate. The base flow is defined as the sustained runoff composed of ground water runoff and delayed subsurface runoff ( (Buras, 1972).

### **2.1.3. Classification of Rainfall runoff models**

Several system of classification of hydrologic models have been used. In one system of classification, the models are classified according to three main criteria.

1. Randomness (deterministic or stochastic)
2. Spatial variation (lumped or distributed)
3. Time variability (time-dependent or time-independent)

In the other system of classification, hydrological models are divided into two main categories: physical models and abstract models. Physical models include scale models such. As hydraulic models of a spillway, and analog models which use another physical system having properties similar to those of the real system. Abstract models represent the system in mathematical form. The system operation is described by a set of equations and logical statements (Killingtveit, 1993).

In total a number of different model classes are classified in this system. The simplest type of model will be a deterministic lumped time-independent model. The most complex type of model would be a stochastic model with space variation in three dimensions and with time variation (Killingtveit, 1993)

The rational formula is, for instance, one of the simplest and oldest deterministic models in hydrology, more popular in the design of drainage systems. Although this formula is based on a number of simplifying assumptions which cannot be readily satisfied under actual circumstances, its simplicity has won it popularity (Chow, 1998).

#### **2.1.4. Land use land cover changes**

The applicability of recently developed landscape classification system using height above nearest drainage and slope was tested in Chemoga watershed. Using the threshold height above nearest drainage method and slope the catchment was grouped three distinct runoff generating units, i.e. Wetland, hill slope and plateau (Frehiwot, 2012).

Biruk, 2009 explained that the degree of change in annual runoff from catchments depends on the intensity and extent of land development. The generalized relationship based on catchments worldwide is that a 10% reduction in coniferous forest (Deciduous forest, shrubs), being converted to grassland causes an average increase of 40mm (25mm for deciduous forest, 10mm for shrubs) in annual runoff. Land use activities also affect storm flow response and in turn flood peaks through changes in vegetation cover, Soil infiltration capacity, conveyance system, increased erosion and siltation.

## **2.2. GIS APPLICATIONS IN HYDROLOGIC ANALYSIS**

Geographic Information Systems (GIS) provide a digital representation of watershed characteristics used for hydrologic modeling (Bruce & and F. D. 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) .

### **2.3. SWAT Model**

Soil and Water Assessment Tool (SWAT) is a distributed river basin or watershed scale model which was developed by Dr. Jeff Arnold at USDA-ARS. The model is used for predicting the impacts of land management on water, sediment and agricultural chemicals yield in complex watershed (Neitsch, et al., 2005). It is physically based, i.e., it uses physical data like weather data, soil data, vegetation data, land use and etc., from the watershed under consideration. SWAT is computationally efficient model because; it does simulation on a large basin within short period of time with less cost. The input data for SWAT is easily obtainable from local agencies. It combines empirically and physically based equations to simulate long term hydrologic events.

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch, et al., 2005).

#### **2.3.1 Literatures Using SWAT model in Abay Basin**

In recent years, SWAT model developed by Arnold et al. (1998), has gained international acceptance as a robust interdisciplinary watershed modeling. SWAT 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., 2007). The review of SWAT model applicability to Ethiopian situations (Setegn & Dilnesaw, 2010) at relatively larger watersheds and (Ashenafi, et al., 2009. ) Indicated that the model is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged watershed. SWAT model can be a potential monitoring tool for watersheds in mountainous catchments of the tropical regions (Birhanu, et al., 2007.).

SWAT 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 ungauged 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., 2005.).

SWAT model requires a watershed divided into sub watersheds. Sub watersheds are connected through stream channels. The assessment work by SWAT is done on units called Hydrologic Response Units (HRU). Hydrologic Response Units are unique combinations of soil and vegetation types in a sub watershed. SWAT then simulates hydrology, vegetation growth, and management practices at the Hydrologic Response Unit level. The results (water, nutrients, sediment, and other pollutants from each Hydrologic Response Units) are summarized for each sub watershed and then routed through the stream network to the watershed outlet.

### 2.3.2. Hydrological components of SWAT model

The Simulation of the hydrology of a watershed is separated into two divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet (Neitsch, et al., 2005).

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

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

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).

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

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter. When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will start. Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA, 1972.) And the Green and Ampt infiltration method (Green & G. A. Ampt, 1911). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is (SCS, 1972.) :

$$Q_{surf} = \frac{(R_{day}-0.2S)^2}{(R_{day}+0.8S)} \quad 2.2$$

Where,  $Q_{surf}$  is the accumulated runoff or rainfall excess (mm),  $R_{day}$  is the rainfall depth for the day (mm), S is the retention parameter (mm).

SCS defines three antecedent moisture conditions: I-dry (wilting point), II-average moisture and III-wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the equations 2.2 and 2.3, respectively.

$$CN_1 = CN_2 - \frac{20 \times (100 - CN_2)}{(100 - CN_2 + \exp\{2.533 - 0.0636 \times (100 - CN_2)\})} \quad 2.3$$

Where CN1 is the moisture condition I curve number, CN2 is the moisture condition II curve number, and CN3 is the moisture condition III curve number.



The retention parameter is defined by equation 2.4

$$S = 25.4 \left( \frac{1000}{CN} - 10 \right) \quad 2.4$$

SWAT 2005 version includes two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant evapotranspiration. The soil moisture method (equation 2.4) over-estimates runoff in shallow soils. But calculating daily CN as a function of plant evapotranspiration, the value is less dependent on soil storage and more depends on antecedent climate. Runoff will only occur when  $R_{day} > 0.2S$ .

The retention parameter varies with soil profile water content according to the following equation:

$$S = S_{MAX} \times \left( 1 - \frac{SW}{SW + \exp(W1 - W2 \times SW)} \right) \quad 2.5$$

Where S is retention parameter for given moisture content (mm).

$S_{MAX}$  is the maximum retention parameter which can achieve in a given day (mm)

SW is the soil water content of a given soil profile excluding the amount of water held at different wilting points.

W1 and W2 are shape coefficients

The maximum retention parameter  $S_{MAX}$  can be calculated using the following equation:

$$S_{MAX} = 25.4 \left( \frac{1000}{CN_1} - 10 \right) \quad 2.6$$

The shape coefficients are determined by solving equation 2.7 assuming that,

- 1) The retention parameter for moisture condition I curve number corresponds to wilting point soil profile water content,
- 2) The retention parameter for moisture condition III curve number corresponds to field capacity soil profile water content, and

3) The soil has a curve number of 99 ( $S = 2.54$ ) when completely saturated.

$$W_1 = \ln \left[ \frac{F_C}{1 - S_3 \times S_{MAX}^{-1}} - F_C \right] + W_2 \times F_C \quad 2.7$$

$$W_2 = \frac{\left( \ln \left[ \frac{F_C}{1 - S_3 \times S_{MAX}^{-1}} - F_C \right] - \ln \left[ \frac{SAT}{1 - 2.54 \times S_{MAX}^{-1}} - SAT \right] \right)}{(SAT - F_C)} \quad 2.8$$

Where  $w_1$  is the first shape coefficient,  $w_2$  is the second shape coefficient,  $F_C$  is the amount of water in the soil profile at field capacity (mm of water),  $S_3$  is the retention parameter for the moisture condition III curve number,  $S_{MAX}$  is the retention parameter for the moisture condition I curve number,  $SAT$  is the amount of water in the soil profile when completely saturated (mm of water), and 2.54 is the retention parameter value for a curve number of 99.

The daily curve number value adjusted for moisture content can be calculated by rearranging equation 2.5 and inserting the retention parameter calculated for that moisture content.

The moisture condition II curve numbers provided in the tables are assumed to be appropriate for 5% slopes. Williams (1995) developed an equation to adjust the curve number to different slopes:

$$CN_{2S} = \frac{(CN_3 - CN_2)}{3} \times [1 - 2 \times \exp(-13.86 \times slope)] + CN_2 \quad 2.9$$

Where  $CN_{2s}$  is the moisture condition II curve number adjusted for slope,  $CN_3$  is the moisture condition III curve number for the default 5% slope,  $CN_2$  is the moisture condition II curve number for the default 5% slope, and  $SLP$  is the average percent slope of the sub-basin. Runoff is calculated separately for each sub-basin and routed to obtain the total runoff for the basin.

SWAT calculates the peak runoff rate with a modified rational method. There are many methods that are developed to estimate potential evapotranspiration (PET). Three methods are incorporated into SWAT: the Penman-Monteith method (Monteith, 1965), the Priestley-Taylor method (Priestley & Taylor, 1972) and the Hargreaves method (Hargreaves, et al., 1985.) And the model will also read in daily PET values if the user prefers to apply a different PET methods.

Groundwater balance in SWAT model is calculated by assuming two layers of aquifers. SWAT partitions groundwater into a shallow unconfined aquifer and a deep confined aquifer and it

simulates two aquifers in each sub-basin. The shallow aquifer is an unconfined aquifer that contributes to flow in the main channel or reach of the sub-basin. The deep aquifer is a confined aquifer. Water that enters the deep aquifer is assumed to contribute to stream flow somewhere outside of the watershed (Arnold, et al., 1993). The water balance for a shallow aquifer in SWAT is calculated with:

$$aq_{sh,i} = aq_{sh,i-1} + W_{rchrq} - Q_{gw} - W_{revap} - W_{deep} - W_{pump,sh} \quad 2.10$$

Where  $aq_{sh,i}$  is the amount of water stored in the shallow aquifer on day  $i$  (mm),  $aq_{sh,i-1}$  is the amount of water stored in the shallow aquifer on day  $i-1$  (mm),  $W_{rchrq}$  is the amount of recharge entering the aquifer on day  $i$  (mm),  $Q_{gw}$  is the groundwater flow, or base flow, into the main channel on day  $i$  (mm),  $W_{revap}$  is the amount of water moving into the soil zone in response to water deficiencies on day  $i$  (mm),  $W_{deep}$  is the amount of water percolating from the shallow aquifer into the deep aquifer on day  $i$  (mm), and  $W_{pump,sh}$  is the amount of water removed from the shallow aquifer by pumping on day  $i$  (mm).

The steady-state response of groundwater flow to recharge is (Hooghoudt, 1940. ):

$$Q_{gw} = \frac{800 \times K_{sat}}{L_{gw}^2} \times h_{wtbl} \quad 2.11$$

Where,  $Q_{gw}$  is the groundwater flow or base flow into the main channel on day  $i$  (mm),  $K_{sat}$  is basin divide for the groundwater system to the main channel (m), and  $h$  height (m). The hydraulic conductivity of the aquifer (mm/day),  $L_{gw}$  is the distance from the ridge or sub-basin divide for the ground water divide to the main channel (m).  $h_{wtbl}$  is the water table height (m).

A water table fluctuation due to non-steady-state response of groundwater flow to periodic recharge is calculated (Smedema & D. W. Rycroft, 2003):

$$\frac{dh_{wtbl}}{dt} = \frac{W_{rchrq} - Q_{gw}}{800 \times \mu} \quad 2.12$$

Where  $\frac{dh_{wtbl}}{dt}$  is the change in water table height with time (mm/day),  $W_{rchrq}$  is the amount of recharge entering the aquifer on day  $i$  (mm),  $Q_{gw}$  is the groundwater flow into the main channel on day  $i$  (mm), and  $\mu$  is the specific yield of the shallow aquifer (m/m)

Assuming that variation in groundwater flow is linearly related to the rate of change in water table height, equations 2.11 and 2.13 can be combined to obtain:

$$\frac{dQ_{gw}}{dt} = 10 \frac{K_{sat}}{\mu \times L_{gw}^2} (W_{rchrq} - Q_{gw}) = \alpha_{gw} \times (W_{rchrq} - Q_{gw}) \quad 2.13$$

$\alpha_{gw}$  is the base flow recession constant or constant of proportionality. The base flow recession constant is a direct index of groundwater flow response to changes in recharge.  $\alpha_{gw}$  Varies from 0.1-0.3 for land with slow response to recession constant and Recharge to 0.9-1.0 for land with a rapid response (Smedema & Rycroft, 1983). Although the base flow recession constant may be calculated, the best estimates are obtained by analysing measured stream flows during periods of no recharge in the watershed.

### 2.3.2 The routing stage of the hydrological cycle

Open channel flow is defined as channel flow with a free surface, such as flow in a river or partially full pipe. SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. The details of the water routing methods and the descriptions of the different model components can be found in Neitsch et al. (2005).

The peak channel velocity,  $V_{ch,pk}$  is calculated:

$$V_{ch,pk} = \frac{Q_{ch,pk}}{A_{ch}} \quad 2.14$$

Where  $Q_{ch,pk}$  the peak flow rate (m<sup>3</sup>/s) and  $A_{ch}$  is the cross-sectional area of flow in the channel (m<sup>2</sup>).

### 2.4. Base flow Separation of the watershed

Base flow is one component of hydrological process that contributes for stream flow. Using the time-series record of stream flow to derive the base flow contributions in the study area.

The first step in hydrograph analysis entails separation of stream flow into the two major components: surface runoff and base flow (Arnold & Allen, 1999.). However, the exact separation of each component. All methods suffer from the lack of real knowledge of how the water moves through the watershed over time for a multitude of storm events and antecedent moisture conditions (Arnold & Allen, 1999.).

Numerous analytical methods have been developed to separate base flow from total Stream flow. Although most procedures are based on physical reasoning, elements of all separation techniques are subjective. Manual separation of stream flow hydrograph into surface flow and ground water flow is difficult and inexact; often results derived from such manual methods cannot be replicated among investigators (White & Chaubey, 2005) Attempts to automate the manual methods with the computer remove some of the subjectivity inherent in these methods and substantially reduce the time required analysis of stream flow records (White & Chaubey, 2005).

According to Arnold et al. (1995), an automated base flow separation technique has been developed and tested. Base flow is considered to be the ground-water contribution to stream flow. Estimates of the amount of base flow can be derived from stream flow records. Such estimates are critical in the assessment of low flow characteristics of stream for use in water supply, water management, and pollution assessment. An automated technique was developed to calculate the slope of the base flow recession curve from the stream flow records. This technique is an adaptation of the Master Recession curve procedure (Arnold & Allen, 1999.) The base flow filter can be passed over the stream flow data three times (forward, backward and forward), depending on the user's selected estimates of base flow from pilot studies of stream flow data.

## **2.5 Overview of SWAT-CUP**

It is a computer program which is an interface of SWAT to perform sensitivity, calibration and validation of SWAT model. SWAT-CUP is the deterministic approach to get the desired variable through adjusting parameters of that are sensitive in the study area. It is an approach of trial and error until the objective function is attained but in highly managed catchment the objective function has easily determined. In calibration process of SWAT-CUP, there is always uncertainties due to the input data or the error by the modeller (Abbaspour, 2015).

### **2.5.1 Sensitivity Analyses, Calibration and Validation using SWAT -CUP**

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. It is certainty analysis hydrological parameters of stream flow.

### **2.5.2. 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 & Chaubey, 2005). It is a necessary process to identify key parameters and parameter precision required for calibration (Ma, et al., 2000).

.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<sup>2</sup> 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 2009 (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, but also for model validation and reduction of uncertainty (Hamby, 1994). The sensitivity analysis method in the SWAT-CUP interface combines the global sensitivity and One- factor-At-a-Time (OAT) sampling (Abbaspour, 2015).

### **2.5.3. Calibration approach**

. Calibration refers to the adjustment or fine-tuning of model parameters to reproduce observations within acceptable levels of agreement. 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, Workman, Taraba, & A. W. Fogle, 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-Sutcliffe simulation efficiency ENS and regression coefficients  $R^2$  for analysing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by (Spruill, et al., 2000).

(Eckhardt & J. G. 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 meso-scale 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 & B. Storm, 1996). However, it is very cumbersome, time consuming, and requires experience.



#### **2.5.4. Validation**

. Following calibration, a validation test was conducted by applying the calibrated model to a second period of data not used in the calibration. This section of the report presents the process used to calibrate the model for both hydrology and water quality. 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).

#### **2.6. Weather Generator**

Lack of full and realistic long period climatic data is the problem of developing countries. Weather generators solve this problem by generating data having the same statistical properties as the observed ones (Danuso, 2002). SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The user may choose to read these input from a file or generate the values using monthly average data summarized over a number of years.

SWAT includes the WXGEN weather generator model (Sharpley & R.Williams, 2000) to generate climatic data or to fill in gaps in measured records. The occurrence of rain on a given day has a major impact on relative humidity, temperature and solar radiation for the day. The weather generator first independently generates precipitation for the day (Neitsch et al., 2005).

Once the total amount of rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green and Ampt method is used for infiltration. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently (Neitsch et al., 2005).

### **.2.6.1 Precipitation**

The daily precipitation generator is a Markov chain-skewed (Nicks, 1974) or Markov chain-exponential model (Williams, 1995). A first-order Markov chain is used to define the day as wet or dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount.

### **2.6.2. Occurrence of wet or dry day**

With the first-order Markov-chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.1 mm of rain or more.

The user is required to input the probability of a wet day on day  $i$  given a wet day on day  $i - 1$ ,  $P_i(W/W)$ , and the probability of a wet day on day  $i$  given a dry day on day  $i - 1$ ,  $P_i(W/D)$ , for each month of the year. From these inputs the remaining transition probabilities can be derived:

$$P_i(D|W) = 1 - P_i(W|W) \quad 2.15$$

$$P_i(D|D) = 1 - P_i(W|D) \quad 2.16$$

Where:  $P_i(D/W)$  is the probability of a dry day on day  $i$  given a wet day on day  $i - 1$  and  $P_i(D/D)$  is the probability of a dry day on day  $i$  given a dry day on day  $i - 1$ . To define a day as wet or dry, SWAT generates a random number between 0.0 and 1.0. This random numbers compared to the appropriate wet-dry probability,  $P_i(W/W)$  or  $P_i(W/D)$ . If the random number is equal to or less than the wet-dry probability, the day is defined as wet. If the random number is greater than the wet-dry probability, the day is defined as dry.

## **CHAPTER THREE**

### **3.0 MATERIALS AND METHODS**

#### **3.1. Description of the Study Area**

##### **3.1.1. General**

Upper Blue Nile (Abbay) River Basin is found between latitudes of 7° 45' N and 12° 46' N; and longitudes of 34° 05' E and 39° 45' E. It is the largest basin in terms of volume of its water and the second largest basin in terms of area covering a drainage area of about 199,800 km<sup>2</sup> with an annual yield of about 49 BCM (Awulachew, et al., 2007). This area is about 20 % of the total areal span of Ethiopia. The main stream of this basin and its tributaries deeply incise the Ethiopian plateau with general slope running north-west ward (Betrie, et al., 2011).

The elevation of the basin ranges from 500 m at Sudan border to 4620 m at the highest mountain of Ethiopia; the Ras Dashen. It has sub-basins: Tana, north Gojam, Beshilo, Welaka, Jemma, south Gojam, Muger, Guder, Finchaa, Dedesa, Anger, Wonbera, Dabus and Beles. The climate of Upper Blue Nile River basin ranges from humid to semi-arid; most percent of the annual precipitation being received in summer (June to September). The annual precipitation of the UBNRB ranges from 1200 to 1600 based on the period and region used (Soliman, et al., 2009).

##### **3.1.2. Location of Chemoga Sub-basin**

Chemoga watershed is located in Coke Mountains of north western Ethiopia in Blue Nile basin and it is about 298km far from Addis Ababa, the capital city of the country. This watershed is found between 37° 35' and 37° 54' E and between 10°17' and 10°39' S of the Blue Nile basin with the catchment area of 460km<sup>2</sup>. Chemoga river through the middle of the catchment drains the collected water to the River Abbay (Source; MOWIE shapfiles).

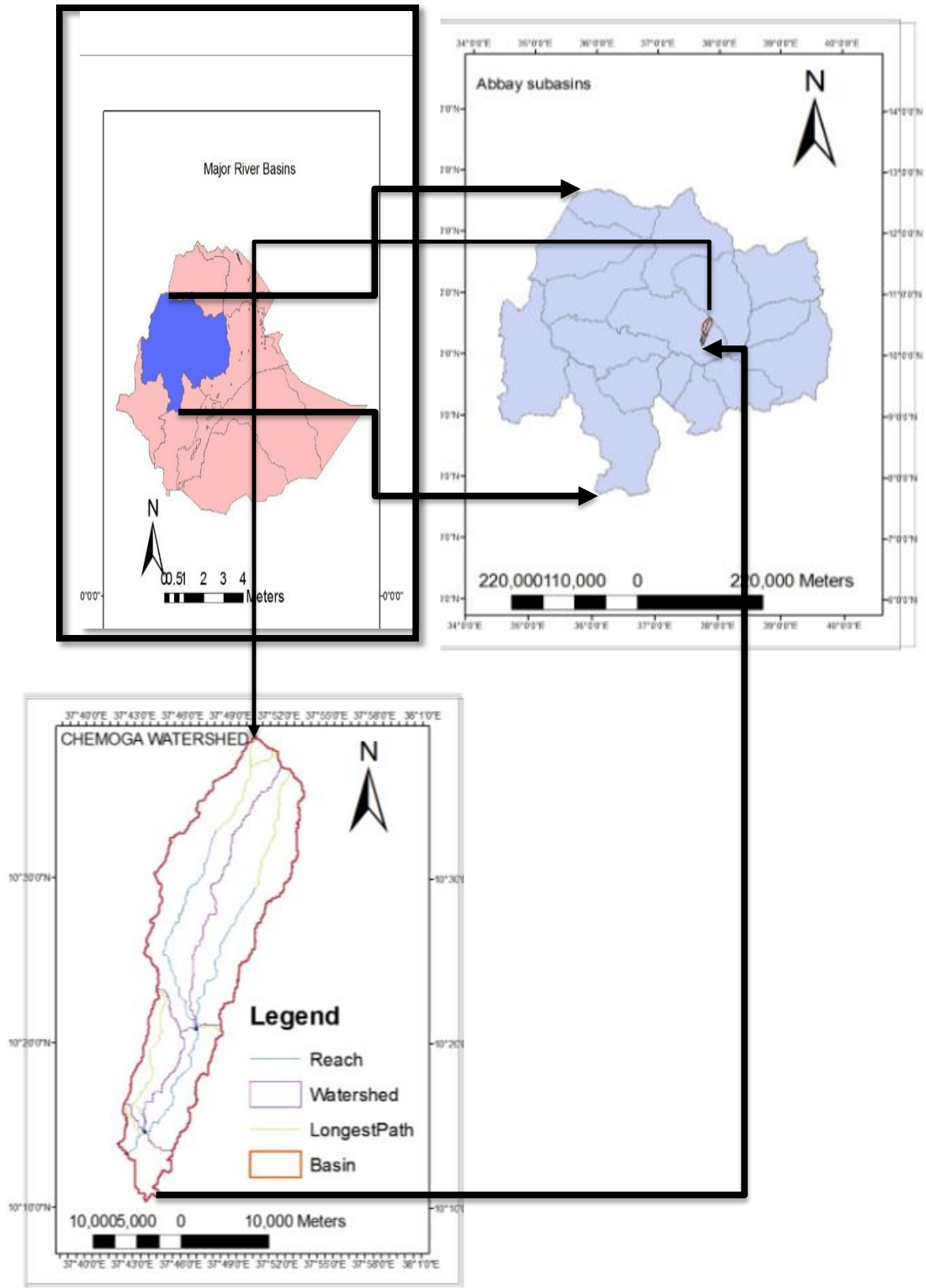


Figure 3 1. Location map of Chemoga watershed (MOWIE shapfiles)

### 3.1.3 Topography

Chemoga subbasin corresponds to north western Ethiopian high lands where the watershed originated from Choke high lands .The dominant land forms that form the watershed are flat land,gentle slope,hills,undulating surfaces and mountains regions.The watershed covers the elevation maximum of 3900m to minimum elevation of 2400m

### 3.2. Socio-economic Condition of The watershed

The livelihood of the majority of the inhabitants are based on agro-pastoral practice.these activities are mainly subsistence way of life leading.the main crops produced are Teff,potato,maize,barely,wheat,lentils,beans and peas.Most of these crops are totally depend on summer rainfall and some of the crops are produced using irrigation water (Frehiwot, 2012).

### 3.3. Data source, Data Collection and Analysis

Meteorological data was used to extrapolate hydrological condition of the catchment for hydrological analysis.hence,climatic condition was also used as input for SWAT model.This meteorological data was collected from National meteorological service of Ethiopia.The collected data is corresponded to the study area of the thesis.

Table 3 1 Weather stations in the watershed of Chemoga (National Meteorological Agency)

Station	Projected Latitude	Projected Longtude	Elevation(m )	Data available
DebreMarkos	1142577.936	363429.098	2455	All SWAT temporal data
Robgebiya	1165381.987	372189.189	3076	Precipitation Data
Amber	1143134.14	367461.52	2435	Precipitation Data

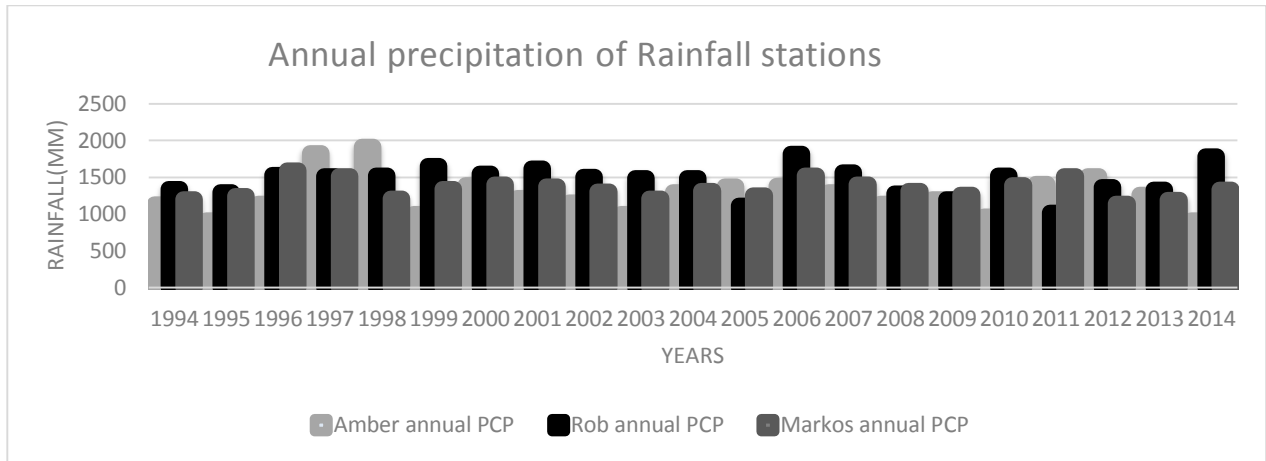


Figure 3 2. The annual rainfall of the study area recorded on rainfall stations

The meteorological data needed filling of missed data. The linear regression method was used for filling temperature data values. The following graph shows the maximum and minimum temperature recorded at Debremarkos gauging station.

### 3.3.1 Filling Missing Rainfall Data

Measured precipitation data are important for different hydrologic analysis, but due to failure of the observer to make necessary visit to the gauge or malfunctioning the gauge, missed data is occurred in rainfall stations. There are methods to fill missed values of precipitation data. For this study, arithmetic mean method was used to fill missed values. To fill the missed value of precipitations, Stations around the missed value station was used. This arithmetic method is used when the mean monthly rainfall error index of all stations are within 10% of the station under consideration (station x). The following formula is the arithmetic method for missed value which was used in this study.

$$P_x = \frac{1}{N}(P_A + P_B + P_C \dots \dots + P_N) \quad 3.1$$

Where  $P_x$  is the precipitation station with missed record,  $P_A, P_B, P_C \dots P_N$  are the corresponding precipitations at the index stations.

After, the missed data are fulfilled data consistency or the cumulative correlation of each station data has checked its linear co-linearity. The graph of correlation between each station and the

mean cumulative of the surrounding rainfall data are plotted which are located in the appendix at the end of all chapters of the thesis.

### 3.3.2 Rainbow homogeneity test of rainfall data

Frequency analysis of data requires that the data be homogeneous and independent. Hence, homogeneity test is required to check the data quality. Based on the cumulative deviation from the mean, homogeneity test were conducted for each of the rainfall station of rainfall data.

The restriction of homogeneity assures that the observations are independent. One of the tests of the homogeneity (Buishand, 1982) is based on the cumulative deviations from mean.

Once the data file is selected, an analysis on the data can be performed by selecting the 'Homogeneity test' or 'Frequency analysis'. After the analysis, one returns to the Main menu to select other data files or perform other tests on the same data file.

The homogeneity test for each rainfall station were performed as shown in the following graphs.

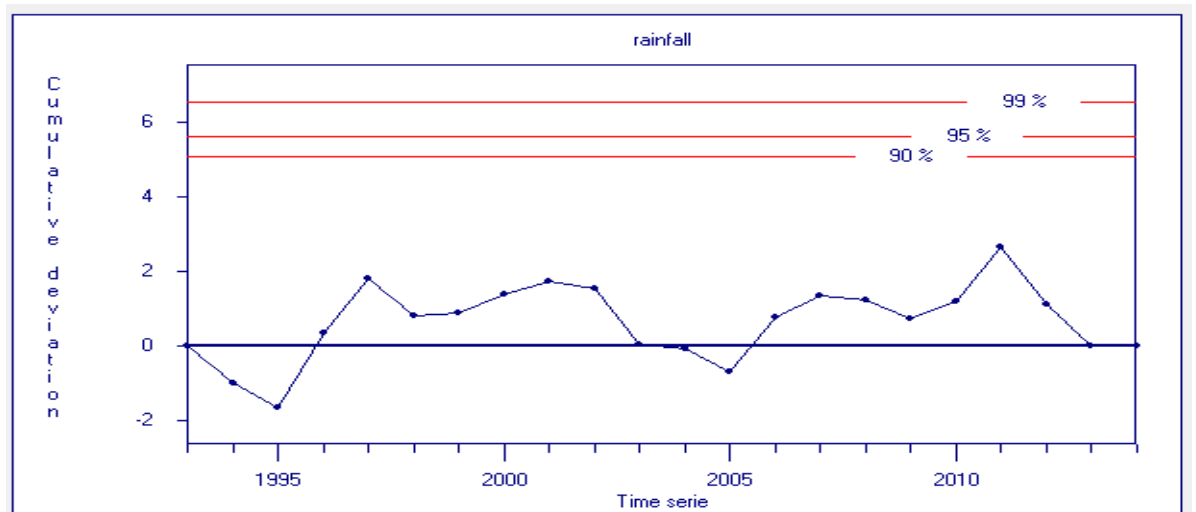


Figure 3 3. Cumulative deviation of rainfall data at DebreMarkos station.

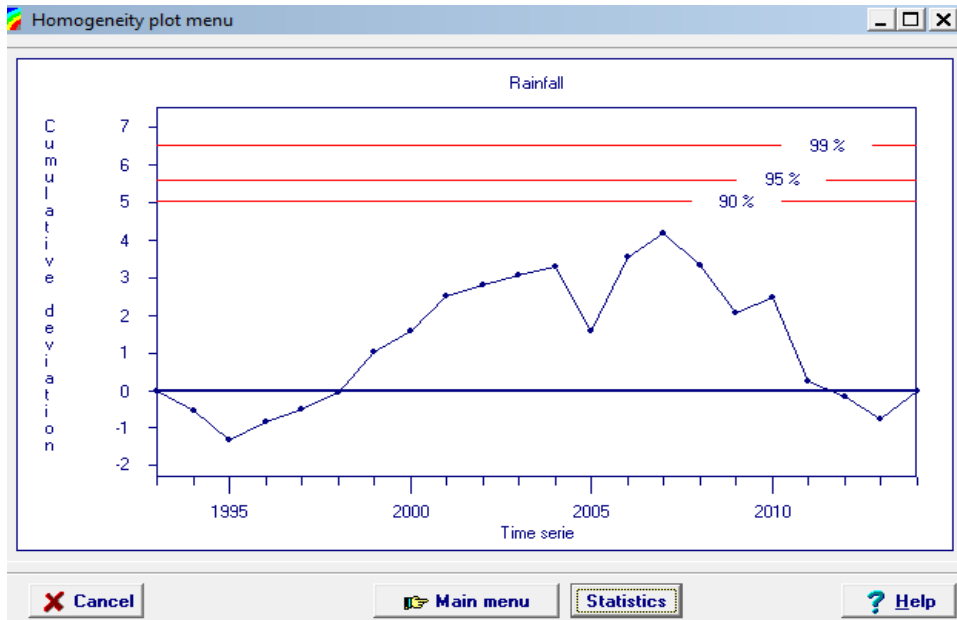


FIGURE 3 4 CUMULATIVE DEVIATION OF RAINFALL DATA AT ROBGEBIA STATION.

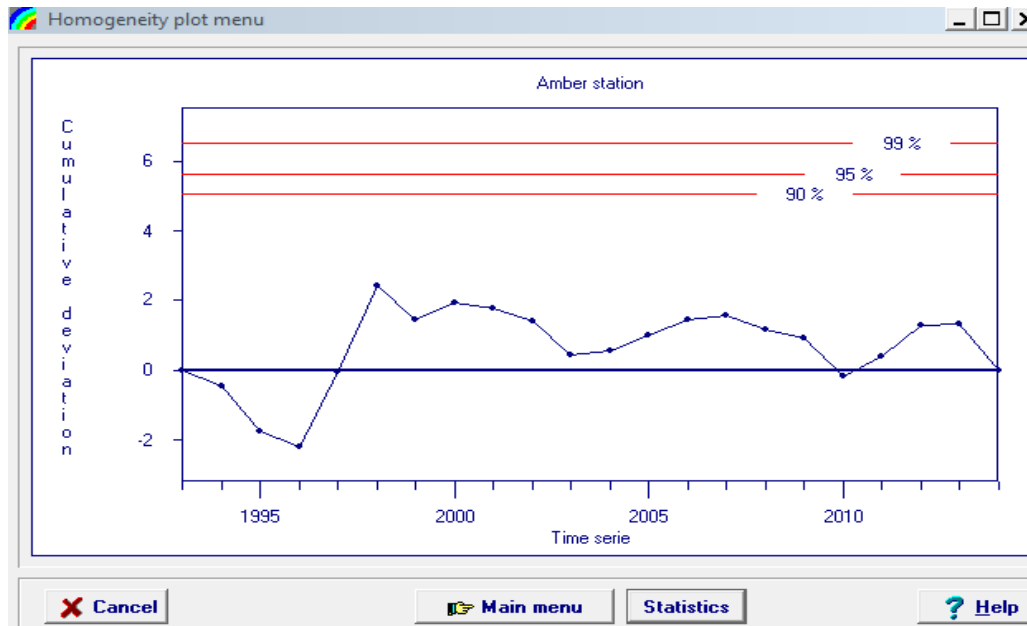


FIGURE 3 5 THE CUMULATIVE DEVIATION OF RAINFALL DATA AT AMBER STATION



### 3.3.3. Hydrological Data

SWAT requires daily temporal stream flow data for physical hydrological model flow estimation. This data was obtained from Ministry of Water, irrigation and Energy (hydrology department) which had been used as an input for SWAT process to investigate Hydrological characteristics of Chemoga watershed. Hence, the daily stream flow of Chemoga river was the required data.

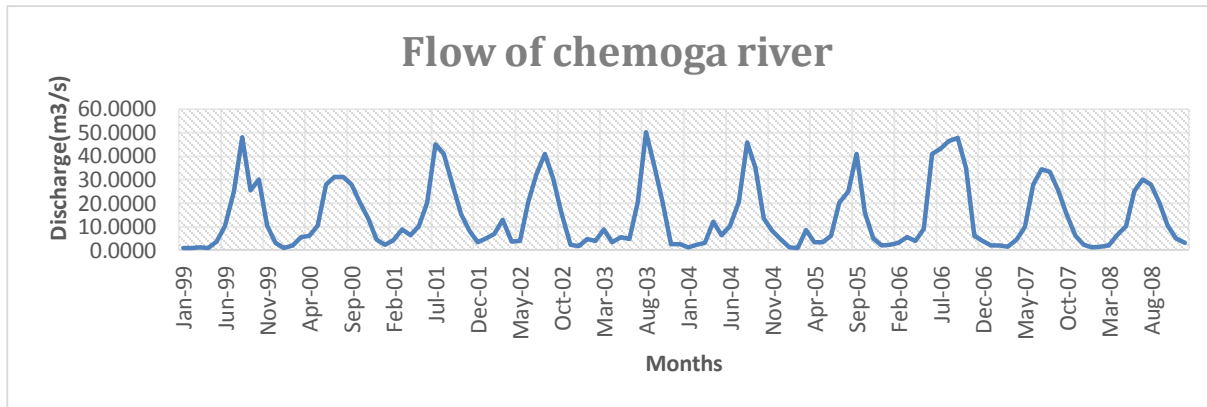


FIGURE 3 6 THE DISCHARGE DATA OF CHEMOGA RIVER (MOWIE)

### 3.3.4. Homogeneity test of river flow data

Homogeneity test had conducted for the flow data to check homogeneity and independence. The restriction of homogeneity assures assures that the observations are independent. The following charts show the cumulative deviation and the probability of rejecting homogeneity of the flow data.

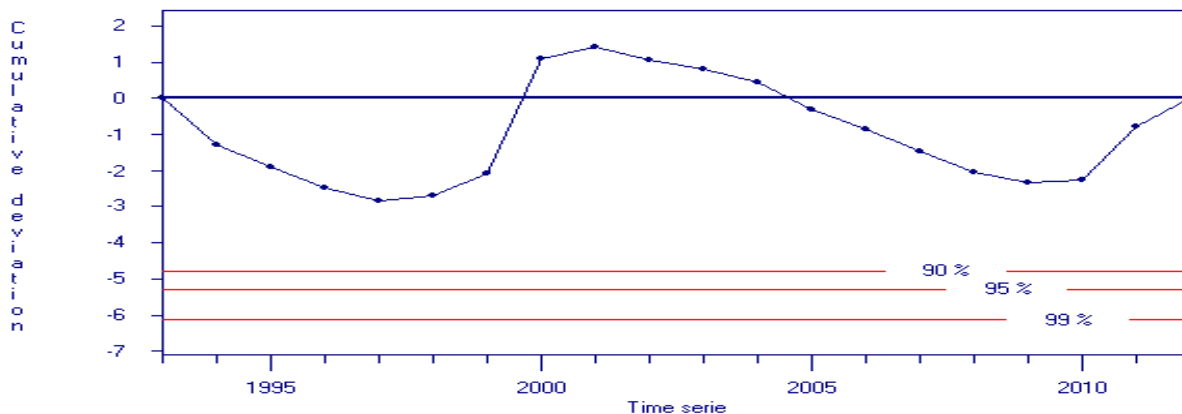


FIGURE 3 7 CUMULATIVE DEVIATION OF ANNUAL FLOW OF CHEMOGA OUTLET

### **3.3.5.Spatial Data**

Hydrological modeling directly or indirectly needs physical data of the study area such as elevation(digital elevation model),soil type,land use map,GPS location of the station.SWAT needs hydrological response unit(HRU) for simulation hydrological characteristics in Chemoga watershed based on digital elevation map,landuse,soil type map of the catchment.These data was collected from Ministry Of Water,Irrigation and Energy .The data is supplied in the form of digital elevation model of 90\*90m resolution,slope and land use/landcover maps from ministry shape files of the library.The physico-chemical properties of soil types were collected from MOWIE library documentation.

### **3.4. General procedures**

In data preparing process and inputting the daily weather data in down order of excel for each station and regression,corelation analysis were performed .Conditional processes were selected for precipitation considering the factors like,humidity,cloud cover and sunshine which determines the precipitation of the area.The spatial data that had gathered from MOWIE were primarily incorporated into SWAT before hydrological data was uploaded.watershed delination and masking the catchment was performed. the other hydrological and weather data were collected from NMA were not found in quality form to be used for SWAT software.Hence,it was reorganized using excel and othe supporting tools,like pcpstat.All weather stations do not have all necessary data.Only one station in the catchment has all meteorological data which is called the synoptic station .This serves as weather generator for other stations which do not have full data. After data preparation for SWAT were finished ,SWAT run proccess had started.then, SWAT reports were gathered in different forms,in dbf form or text form.from the report different runoff and base flow condition were collected. From different parameters that determine the characteristics of the watershed,sensitivity analysis were conducted.So,the parameter which is highly sensitive to change in the output based on the input physical variables were distinguished.ground water flow contribution could also read from SWAT output that enabled base flow separation from surface runoff. Calibration and validation approach had performed ,hence,SWAT outputs were compared with station observations.

3.4.1 The summerized sequence of the thesis outline had been shown in the following order.

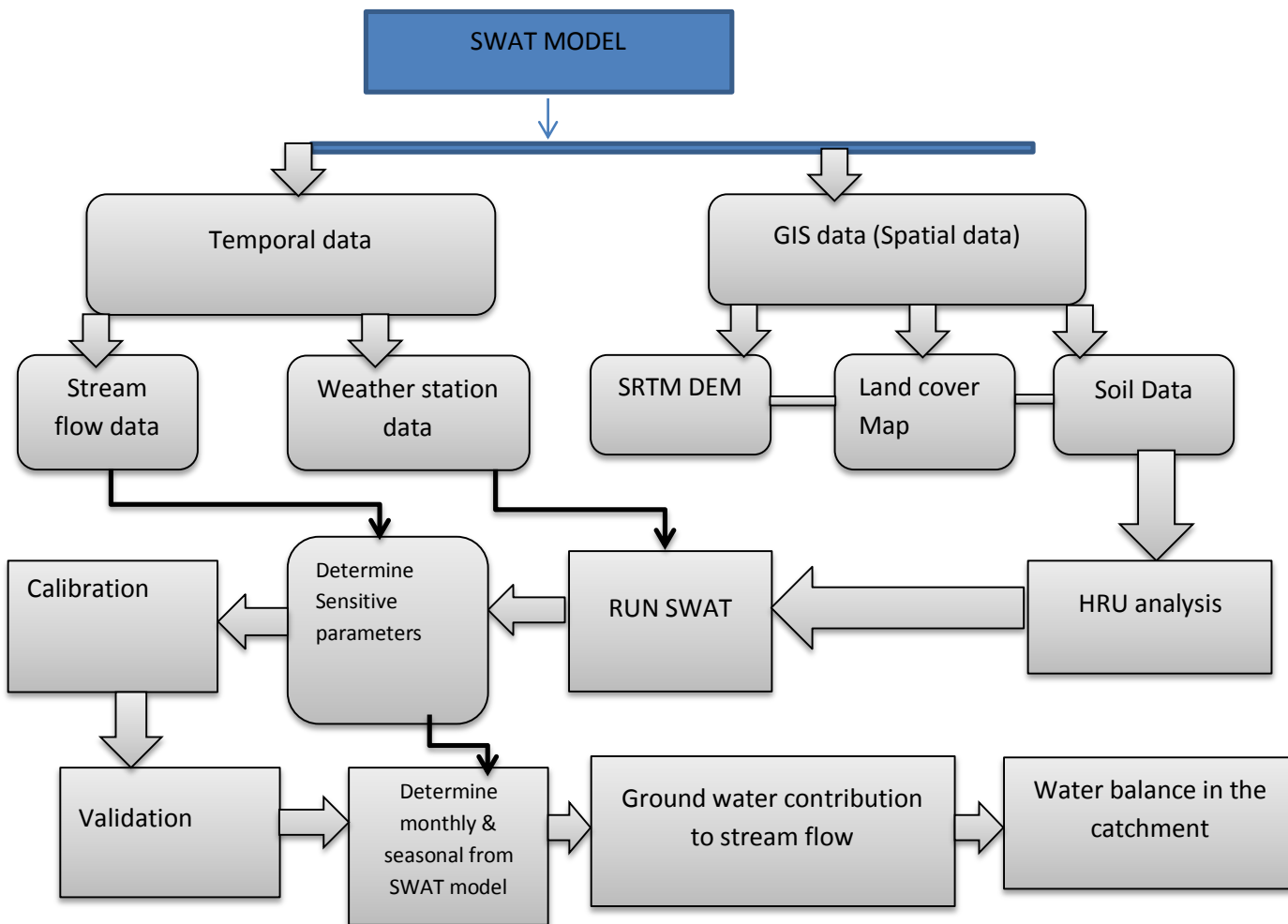


FIGURE 3 8 SUMMARIZED OUTLINE OF THE THESIS PROCEDURE.

### 3.5. Hydrological modelling

Simulation of rainfall runoff process is the most essential task in SWAT modelling to know hydrological characteristics of the watershed and water resource management in the catchment. SWAT requires specific information about the weather, soil property, topography, vegetation, and land management rather than simply incorporating regression equations to define the relation between input and output variables. In this study SWAT 2009 interfaced with ArcGIS 9.3 is used.

#### 3.5.1 Water balance Using SWAT Model

The simulation of hydrological cycle by SWAT is based the water balance equation which is incorporated in SWAT software.

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad 3.2$$

Where,  $SW_t$  = Final soil moisture content (mm)

$SW_o$  = initial soil moisture content, i (mm)

$R_{day}$  =The amount of precipitation on day i (mm)

$Q_{surf}$  =The amount of surface runoff on day, i (mm)

$E_a$  = the amount of evapotranspiration on day, i (mm)

$W_{seep}$  = The amount of water entering into vadose zone from the soil profile on day, I (mm) and

$W_{gw}$  = The amount of return flow on day, i (mm)

The daily climate variables required by SWAT include: precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity. These data have to be prepared into average monthly weather indices to be used by SWAT weather generator. But if the data is not available or missing values occur in the datasets, SWAT generates the data from monthly weather generator information as discussed below (Neitsch, et al., 2005).

Precipitation is generated using first order Marko chain developed by Nicks in 1974. This is done by comparing random number(0.0-1.0) generated by the model to the monthly wet-dry probabilities that if fed by the user. If the day is sensed as wet, then the amount of precipitation is determined from skewed distribution or modified exponential distribution.

Maximum and minimum temperatures as well as solar radiations are generated from normal distribution. This is done by incorporating continuity equation into the generator to account for variations in temperature and radiations caused by dry-wet conditions.

### 3.5.2. Surface runoff for SWAT model

SWAT provides two options for determination of surface runoff: The SCS curve method and the Green and Ampt infiltration method. In this study, the SCS curve method was used as it better provides a consistent basis for estimation of runoff under varying land use and soil types.

### 3.5.3 Potential evapotranspiration (PET)

One of water balance component in hydrological simulation is potential evapotranspiration (PET), the amount of water transpired from stomata and evaporated from green crop having uniform height which completely covers the field under no shortage of water. Potential evapotranspiration can be computed in three ways in SWAT unless recorded PET data is uploaded into the model. These are Penman-Monteith, Priestley-Taylor and Hargreaves method. In this study Penman-Monteith method was used in hydrological simulation.

Penman-Monteith method needs temperature, relative humidity, solar radiation and wind speed data. The Penman-Monteith equation is given as (Neitsch, et al., 2005)

$$\gamma E = \frac{\Delta * (H_{net} - G) + \rho_{air} * C_p * \frac{(e_z^0 - e_z)}{r_a}}{\Delta + \gamma * \left(1 + \frac{r_c}{r_a}\right)} \quad \text{----- 3.3}$$

$\gamma E$  is latent heat flux density (MJ/M<sup>2</sup>/day),  $\Delta$  is the slope of saturation vapour pressure versus temperature curve (kPa/°C),  $H_{net}$  is net radiation (MJ/M<sup>2</sup>/day),  $G$  is heat flux density to the ground (MJ/M<sup>2</sup>/day),  $\rho_{air}$  is density of air (kg/m<sup>3</sup>),  $C_p$  is specific heat at constant pressure (MJ/kg/°C),  $e_z^0$  is saturation vapour pressure of air at height  $Z$  (kPa),  $e_z$  is the water vapour pressure at height  $z$  (kPa),  $r_c$  is plant canopy resistant (s/m),  $r_a$  is aerodynamic resistance (s/m) and,  $\gamma$  is psychrometric constant (kg/°C).

Hargreaves method on the other hand needs only temperature data to compute potential evapotranspiration (PET). The Hargreaves formula is written as:

$$\gamma E_o = 0.0023 * H_o * (T_{max} - T_{min})^{0.5} * (\bar{T} + 17.8) \quad \text{----- 3.4}$$

Where,  $\gamma$  is latent heat of vaporization (MJ/kg/°C),  $T_{max}$  is maximum temperature of the day (°C),  $T_{min}$  is minimum temperature of the day (°C),  $\bar{T}$  is average temperature of the day (°C)

### 3.5.4. Inputs and SWAT model set up

Prior to the main watershed hydrological modelling steps the necessary spatial and hydro climatic data that are used as an input for were prepared into the form that is used by the model (SWAT2009). Accordingly, the spatial data, DEM of 90\*90m spatial resolutions for watershed delineation, soil map and land use land cover maps for analysis of hydrologic response units

were prepared into projected coordinate system. The climate data, rainfall, temperature, relative humidity and wind speed data of stations were prepared in .dbf formats. Weather generator data table is prepared using the climatic station of Debremarkos. The parameters of weather generator data table were calculated using supplementary softwares, like pcpSTAT and dew02 softwares which were downloaded at [http://www.brc.tamus.edu/swat/soft\\_links.html](http://www.brc.tamus.edu/swat/soft_links.html). Precipitation statistical and probability of parameters such as mean standard deviation, skewness coefficient, and probability of wet day and following a dry day and, average number of rainy days in the month were calculated using pcpSTAT and average daily dew point per month was calculated using dew02 software. After all necessary data were prepared arc SWAT project was setup for subsequent steps; watershed delineation, hydrologic response unit analysis and simulation.

### **3.5.5. Watershed delineation**

By watershed delineation operation, the watershed is segmented into hydrological connected sub-watersheds for use in watershed modelling. The first step of watershed delineation was importing DEM into the interface to simplify the time and space required for the watershed delineation, the working area reference (mask) was manually defined from loaded DEM data. The model enabled to propose maximum, minimum and contextually suggested drainage area for stream definition. Smaller drainage area provides more precise but the work takes more time. So the area suggested by the model was used to define flow direction, flow accumulation and others as it was sufficient to visualize the significant stream for the case (Chemoga River).

The whole surface flow from the catchment is generated from the catchment. Hence, there is no point source for the outlet. Due to this no inlet definition is required during the watershed delineation. One watershed outlet was selected to perform different calibration and validation for the catchment. The whole sub-watersheds in catchment were investigated using the outlet point.

### **3.5.6. Analysis of hydrologic response unit**

Arc SWAT characterizes the delineated watershed in terms the spatial data of land use, soil type and slope which were imported in combination. This is important for the SWAT to determine the hydrologic parameters of land use, soil and slope in combination for simulated of each sub-watershed with different characteristics. The combined interface does hydrologic response (HRU) analysis independently for each of the watershed parameters and finally overlays the results of analysis.

### **Land use definition**

A land use grid map in its projected form was loaded into the interface from the project data base. The code given for each land use in attribute table field of land use map was selected so that the model converts it to grid value on the map. A lookup table that defines this code for reclassification was prepared by referring to the actual land use in the study area and assimilating and/or writing them to land use/plant/urban table of data base of SWAT2009. The lookup table (user table) was then loaded and the land use layer reclassified to the defined land use.

### **Soil definition**

Soil is an important component of hydrologic response unit that is needed for hydrological simulation. All physico-chemical properties have to be contained in the user soil data base so that SWAT reads to define the spatial soil grids. Haplic Alisols are the dominant type of soils in Chemoga watershed. This spatial type of soil data were used to overlay HRU analysis with slope and land use/cover data of the watershed. Based on the overlay of these spatial data, the watershed hydrologic characteristics were determined into the smallest level watershed study called hydrologic response unit. Figure 3.9 shows the spatial distribution of major soils in Chemoga watershed.

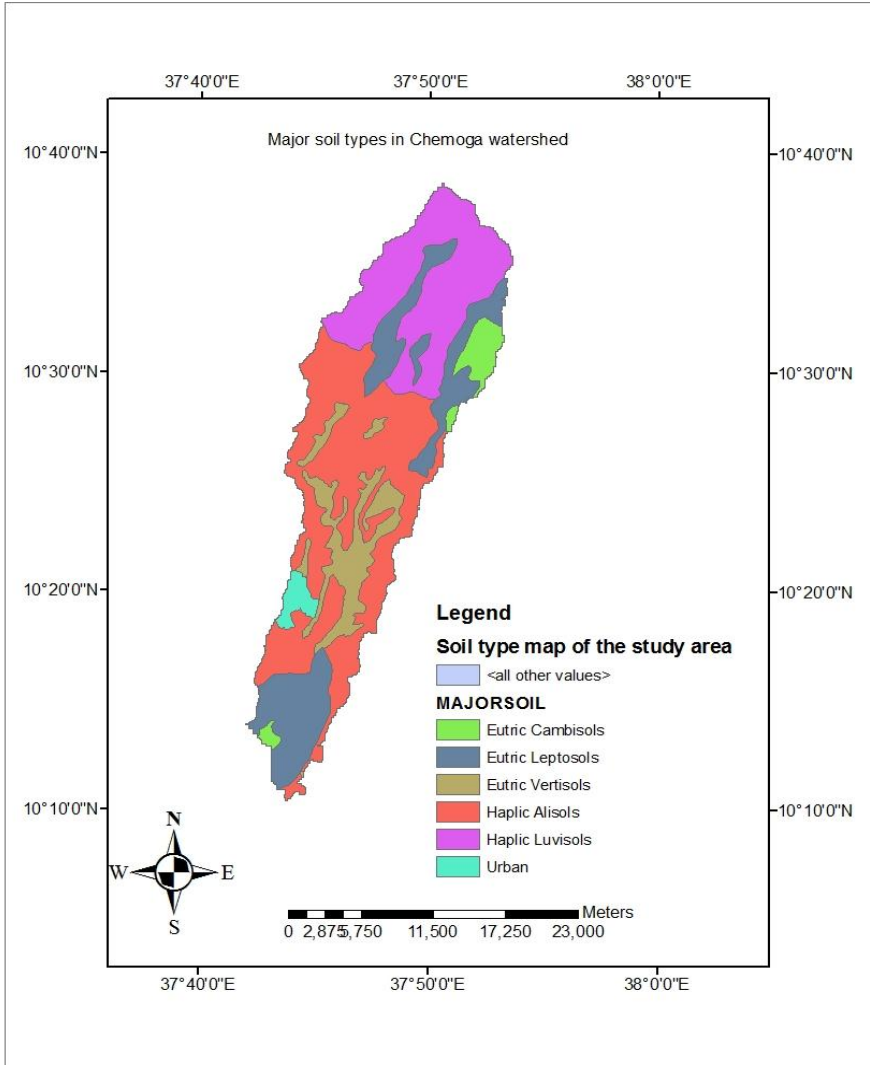


FIGURE 3 9 SOIL TYPES IN CHEMOGA WATERSHED (MOWIE SHAPFILES)

**Slope classification**

In this step the slope range in the defined watershed is determined. The terrain of Chemoga watershed has elevation difference of 2400-3900masl and over north to south it covers 80km .Multiple slope definition was selected in the slope discretization and therefore, five slope classes were used for classification. Finally, after land use, soil and slope were defined, the three layers are overlaid to produce the combined distribution of these watershed parameters for each of the delineated sub-watershed.

**HRU definition**



HRUs were defined such that land use/cover, soil and slope are all together considered during sub-basin modelling. This needs setting of HRU thresholds eliminate minor land uses/covers, soil groups and slope classes in each sub-watershed during simulation. Arc SWAT reapportions the remaining HRUs to 100% and considers them for simulation. The threshold level to be set for an HRU depends on the objective and scope of the modelling project. It is recommended (Winchell et al 2010) that for most applications default threshold settings of 20% for land use land cover, 10% for soil and 20% for slope is sufficient. For this case threshold levels were set to 20% for land uses ,15% for soil and 20% for slope .These thresholds were appropriate excluded spatially in significant land uses, soils and slopes to save simulation time and file storage space as reducing thresholds would incredibly boosts the number of HRUs.

### **3.5.7. Uploading weather Data**

SWAT needs physical information of the catchment or energy and moisture information to determine different components that make up hydrological process. The most necessary climatic data for SWAT model hydrological analysis are; temperature, precipitation, relative humidity, wind speed and solar radiation. Weather data of the study areas in the catchment were projected into SWAT data base for energy and moisture information. All station did not have complete weather data; SWAT needs a station of full weather data which serves as weather generator for other stations that did not have complete weather data. The absolute location of weather stations is also necessary to the model to link each sub-watershed to the appropriate station. After the location of weather stations were imported to the interface, and then the weather data of the stations were written for further simulation.

### **3.5.8. Selection of Potential evapotranspiration computation and SWAT edit**

SWAT (soil and water assessment tool) computes different watershed water balance components from model data and watershed inputs from weather stations. The edit SWAT inputs' menu allows as for making contextual changes to the model databases and watershed current files.one of the watershed water balance component is potential evapotranspiration (PET).The three methods of potential evapotranspiration computation are; the penman-Monteith method, Priestley- Taylor method and Hargreaves method. The Penman-Monteith method was used to compute potential evapotranspiration (PET) for SWAT simulation as it accounts for more

climatic elements than other methods (Neitsch, et al., 2005). However Hargreaves method requires only air temperature for potential evapotranspiration computation in SWAT database.

### **3.5.9. Sensitivity Analysis of Hydrological parameters**

Flow simulation considers a number of hydrological input parameters of ground water(.gw),management(.mgt),soil(.sol),hydrological response unit(.hru),routine(.rte) and sub-basin(.sub) and other hydrological and catchment practices. In order to assign value to these parameters, the significance of the effect on the flow was examined by sensitivity analysis. Sensitivity analysis shows the response of the watershed flow value due to change in the input parameters. A global sensitivity and One-factor-At-a-Time (OAT) method of sensitivity analysis is found in SWAT-CUP 2012 of which global sensitivity were used for this case to identify the most determinant parameters in the watershed for further modelling. OAT assures that the change in output in each model run can be correctly attributed to the input changed in such a simulation leading to robust and efficient sensitivity analysis method. Sensitivity analysis enabled to identify the major parameters that big difference in model output. Each parameter has its own influence in the result of simulation output but some parameters are highly sensitive for the change of the watershed condition.

### **3.5.10. Sensitivity Measurements in SWAT-CUP**

t-stat is the coefficient of parameter divided by its standard error. It is a measure of precision with which the regression coefficient is measured. If the coefficient is large compared to its standard error, then it is probably different from zero and the parameter is sensitive .p-value indicates or describes how the mean of the sample with the certain number of observations is expected to behave-value for each term would have null hypothesis if the coefficient is equal to zero or the parameter has no effect in the watershed. Hence, if the p-value is less than 0.05 it would be rejected as null parameter which have insignificant change in the output of simulation. A large p-value suggests that change in the predictor are not associated with change in the response so that the parameter is not very sensitive .A p-value less than 0.05 is generally accepted boundary to reject null hypothesis (The coefficient of the parameter is different from zero) with p-value of 0.05 there is only 5% chance that the results will come up in random distribution (Abbaspour, 2015).

In the following table, different hydrological parameters and their sensitivity expression are elaborated in detail

Table 3 2 SWAT-CUP parameters selected for sensitivity analysis

parameter	description	Default range	Category
ALPHA_BF	Base flow alpha factor(days)	0 to 1	.gw
BIOMIX	Biological mixing efficiency	0 to 1	.mgt
CANMAX	Maximum canopy index(mm)	0 to 10	.hru
CH_K2	Hydraulic conductivity in main canals(mm/hr)	0 to 150	.rte
CH_N2	Manning coefficient of tributary channels	0 to 1	.rte
CN2	SCS curve number for moisture condition	35 to 98	.mgt
ESCO	Soil evaporation compensation factor	0 to 1	.hru
GW_DELAY	Ground water delay(day)	-10 to 10	.gw
GW_REVAP	Ground water evaporation coefficient	-0.036 to 0.036	.gw
GWQMN	Threshold depth of water in shallow aquifer required for return flow to occur	-1000 to 1000	.gw
REVAPMN	Threshold depth of water in shallow aquifer for ground water evaporation to occur(mm)	-100 to 100	.gw
SOL_ALB	Soil albedo	-25 to 25	.sol
SOL_AWC	Availability of water capacity of the soil layer(mm/mm)	-25 to 25	.sol
SOL_K	Soil hydraulic conductivity(mm/hr)	-25 to 25	.sol
SOL_Z	Soil depth(mm)	-25 to 25	.sol
SURLAG	Surface runoff lag coefficient	0 to 10	.sub
SLSUBBSN	Average slope lengiga tonh	10 to 150	.hru

.crop=crop, .gw=ground water,.hru=hydrologic response unit,.mgt=management,.rte =routine, .sub =subbasin, .sol =soil.

Accordingly the sensitivity analysis was made by Sufi-2 technique total number of 22 parameters were considered for sensitivity analysis with the ending simulation number of 1000 starting from

simulation 500 .The analysis was made with observed flow data measured at the outlet of Chemoga hydrometric gauging station with the number of delineated sub basins in the watershed. Finally sensitivity analysis levels of parameters was identified based on the sensitivity indices of grid view or graph view which is expressed in P-value and t-stat value .The most sensitive parameter had values of highest negative t-stat value and lowest p-value.

### **3.5.11. Model Calibration and Validation**

Calibration of SWAT model involves adjusting the input parameters of the model as perfect as possible with the desired output of the flow. To verify that the model performs with sufficient, accurate data from gauged station flow data. The data used for calibration and validation was temporally independent. The model was calibrated for the period of 1999-2008 with three years warming up period and validated from 2009-2012 for flow data of Chemoga main stream using the data taken from river gauging station at monthly level. Daily calibration model performance were conducted in the daily flow period of 1998-2001.

Surface flow and subsurface flow had elaborated from the output of SWAT model. Hence, the base water and lateral flow to the stream outlet had known from the model.

The SWAT-CUP model performance evaluation procedure followed has been shown in figure 3.

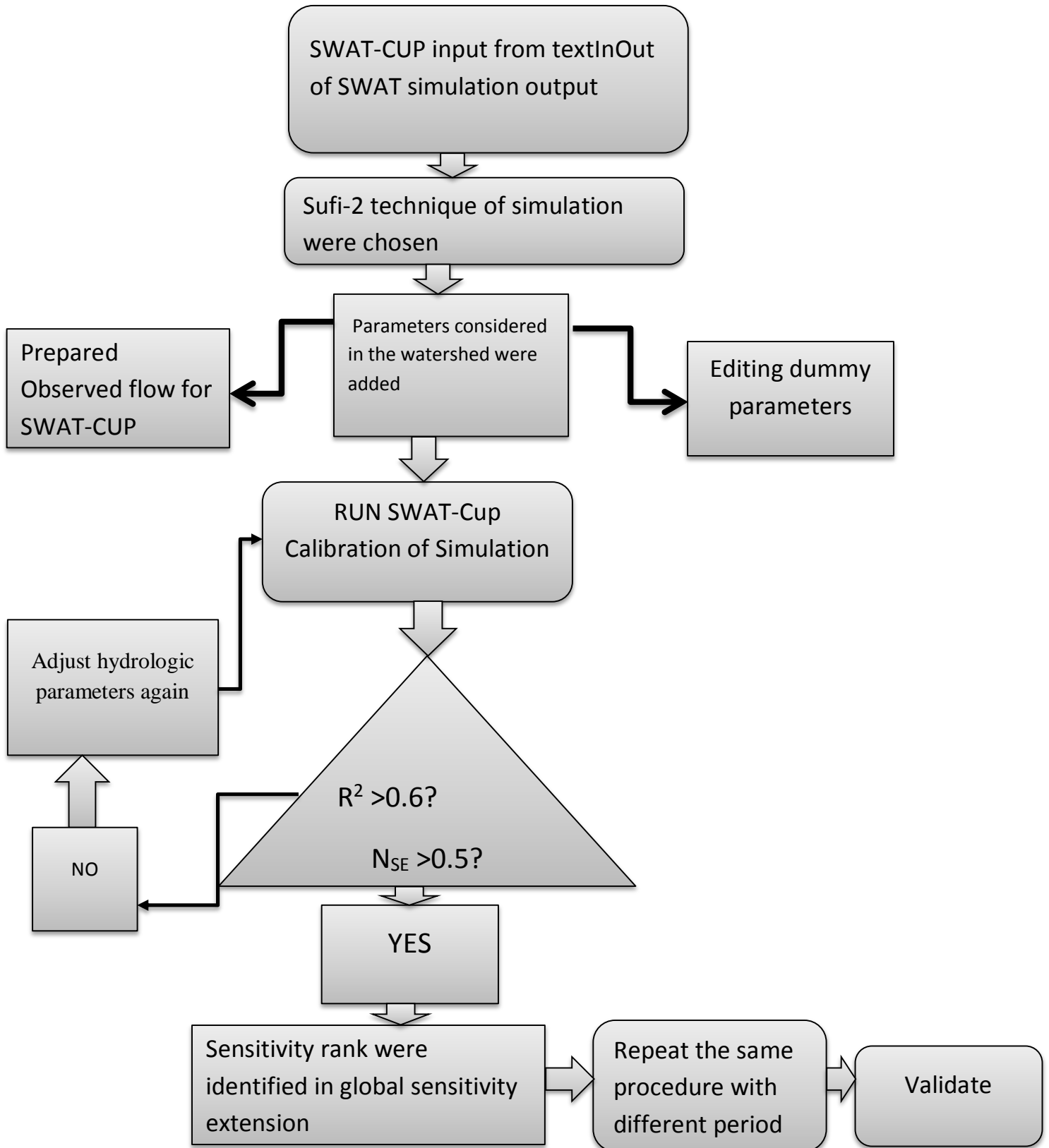


FIGURE 3 10 SWAT-CUP BASED EVALUATION STEPS

There are different calibration techniques available in SWAT-CUP: Sufi-2 type of calibration technique were used .The calibration was performed using the flow data of the watershed. Calibrated parameters are conditioned on the objective function of data points and location of variable parameter for the model.

### 3.6. Model performance evaluation

To evaluate model simulation output in relative to the observed data, model performance evaluation is necessary. There are various methods to evaluate model performance. For the case of this study two methods were used: Coefficient of determination ( $R^2$ ) and Nash Sutcliffe simulation efficiency (ENS)

The determination of coefficient of determination ( $R^2$ ) describes the proportion of variance in measured data in model.it is the magnitude of linear relationship between observed and simulated values.  $R^2$  ranges from 0 which is poor model performance to 1 of good model performance. Hence, with higher value indicates less error variance of observed and simulated values. So, the  $R^2$  of the model result above 0.6 is an acceptable (Santhi, et al., 2001).

$E_{NS}$  and  $R^2$  are calculated using the following equations:

$$NS = 1 - \frac{\sum_i^n (X_m - Y_s)^2}{\sum_i^n (X_m - \bar{X}_m)^2} \quad 3.4$$

$X_m$  is the measured value,  $\bar{X}_m$  is the average measured value and  $Y_s$  is the simulated value

The value of  $E_{NS}$  ranges from best fitting (1:1) to negativity. So  $E_{NS}$  measures the computability of SWAT simulated and measured values. If the value of  $E_{NS}$  is 1 the measured value fits completely with simulated values, hence the result achieves the objective function exactly. If the  $E_{NS}$  becomes the negative number, the model prediction is poor (Nash & J. V. Sutcliff, 1970). The coefficient of determination ( $R^2$ ) or the regression coefficient which describes the total variance between the observed and simulated flow values is calculated using the following formula.

$$R^2 = \frac{(\sum [X_m - \bar{X}] [Y_m - \bar{Y}])^2}{\sum [X_m - \bar{X}]^2 \sum [Y_m - \bar{Y}]^2} \quad 3.5$$

Where:  $X_m$  is the measured value,  $\bar{X}$  is the average measured value,  $Y_m$  is the simulated values and  $\bar{Y}$  is the average simulated values

The percent difference (D) measures the average difference between simulated results of SWAT and measured values of the stream hydrometer gauged is calculated using the following formula;

$$D = 100 \left( \frac{\sum Y_m - \sum X_m}{\sum X_m} \right) \quad 3.6$$

Where:  $Y_m$  is the simulated flow and  $X_m$  is the measured values. As the value of D approaches to zero the difference of percentage is very small and the simulation is in acceptable range

Table 3.2 performance ratings recommended for monthly time scale values (Moriassi, et al., 2007).

Table 3 3 Performance scale measurements of SWAT model

Performance ratings	$E_{NS}$	D (%)
Very Good	$0.75 < NS < 1.00$	$D < \pm 10$
Good	$0.65 < NS < 0.75$	$\pm 10 < D < \pm 15$
Satisfactory	$0.50 < NS < 0.65$	$\pm 15 < D < \pm 25$
Unsatisfactory	$NS < 0.50$	$D > \pm 25$

### **3.7. Watershed Delineation Using SWAT**

SWAT based watershed delineation had resulted with Catchment area of 466km<sup>2</sup> and 66 hydrologic response units had obtained based on the spatial input data of SWAT. The accumulation of HRUs were grouped into 5 sub basins based on the physical condition of the study area (Soil map, Land cover, slope and elevation).

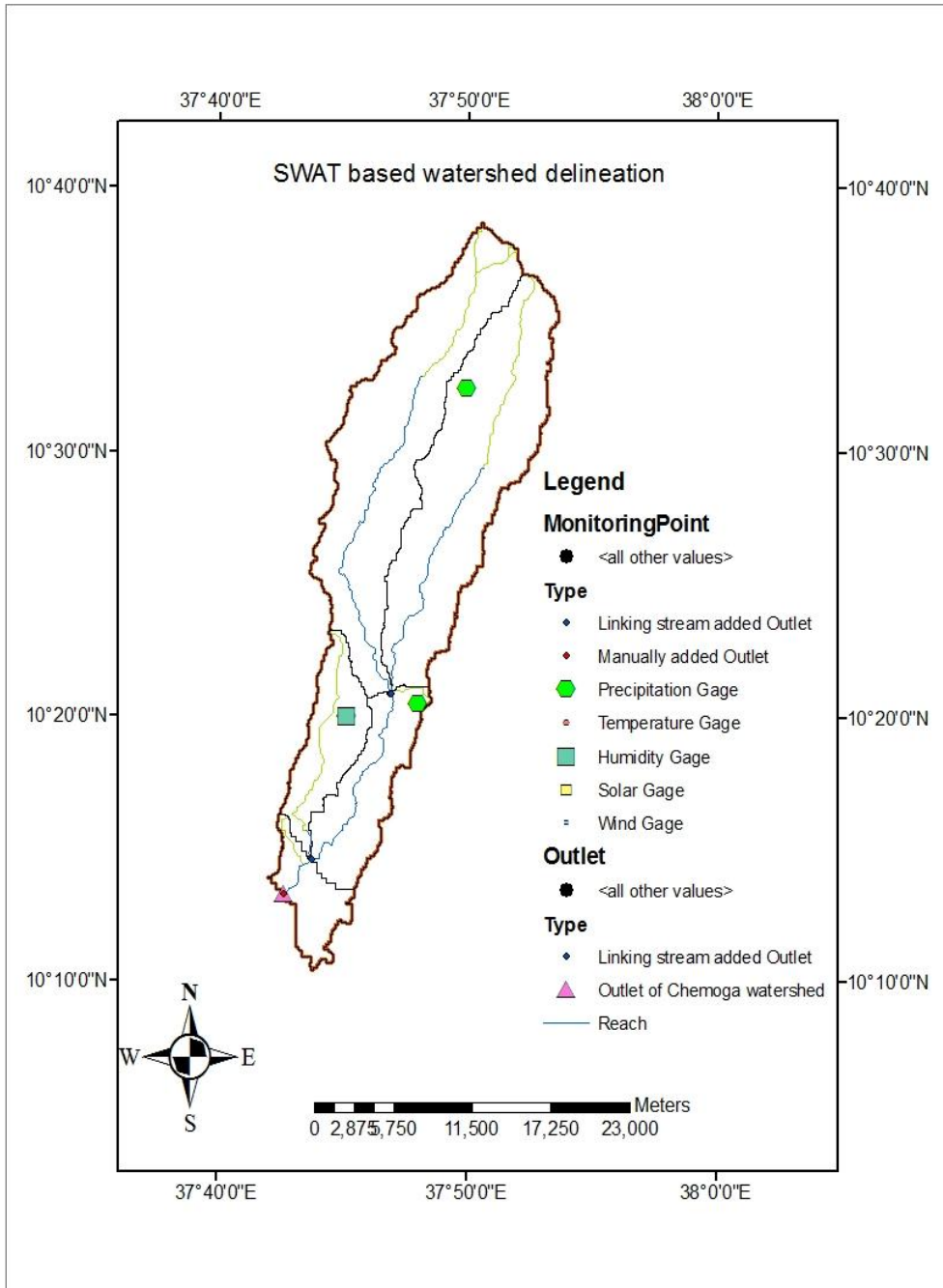
HRU definition of SWAT processing is based on soil, land use and slope thresholds were overlaid in the catchment and resulted the physical conditions in HRU definitions. Hence, from assumed threshold values, we had obtained 66 HRUs and 5 sub-basins based on the above spatial data. The major streams and longest flow path is also the part of the result in HRU analysis.

Since the location of all weather stations except Rob station were displayed together overlapped in weather generator station of Debremarkos.

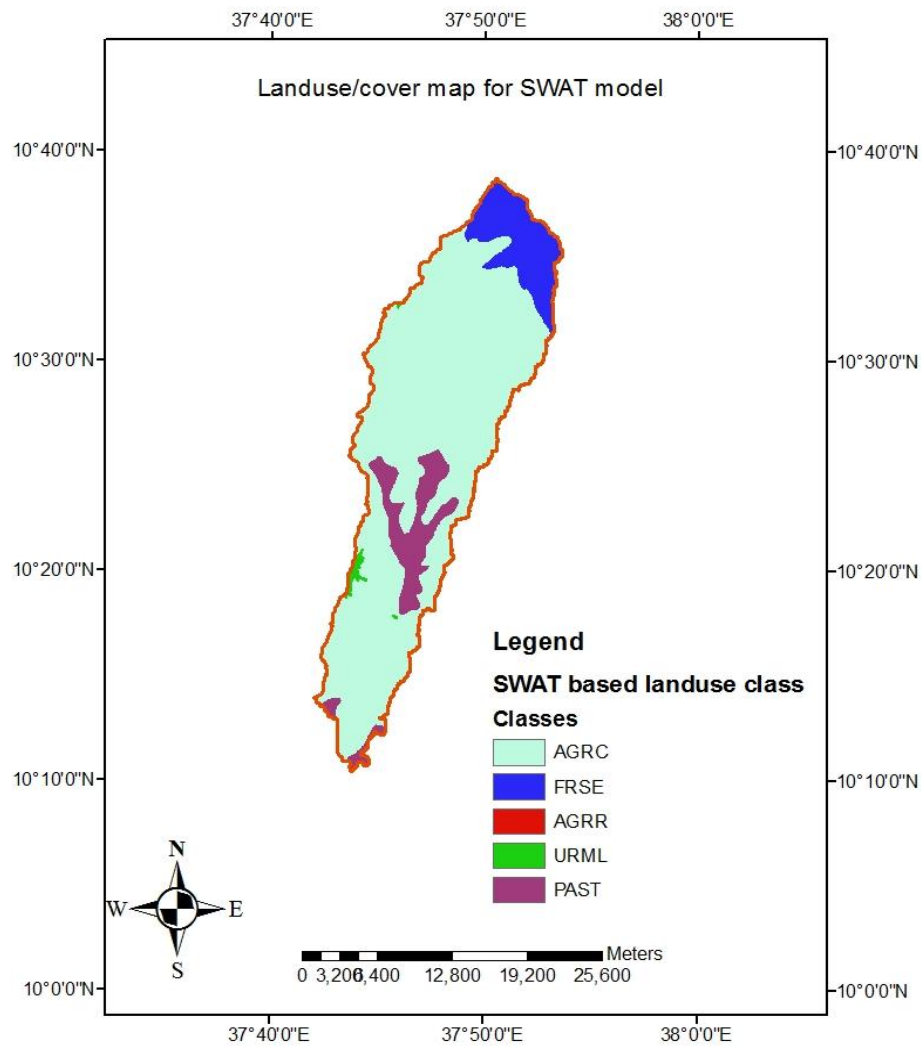
The size and distribution of HRU input spatial data is shown with maps in the following tables and figures.

Notice; Due to overlapping of gauge locations Temperature, solar radiation, humidity and wind speed of weather generator station are located over precipitation station (NMA).





**FIGURE 3 11 WATERSHED DELINEATION USING SWAT MODEL AND CLIMATE STATIONS OF CHEMOGA WATERSHED.**



**FIGURE 3 12 LAND USE/LAND COVER MAP OF SWAT MODEL**

**TABLE 3 4 LANDUSE COVERAGE AND SWAT CODE NAME CLASSIFICATION OF THE WATERSHED STUDY AREA.**

<i>Landuse/cover</i>	<b>SWAT Code</b>	<b>Area coverage(%)</b>
<i>Agricultural Close crops</i>	AGRC	80.045%
<i>Afro-Alpine Forest</i>	FRSE	10.176
<i>Agricultural row Crops</i>	AGRR	0.021
<i>Urbuan low populated</i>	URML	0.737
<i>Grass land(pasture)</i>	Past	9.02

**TABLE 3 5. THE MAJOR SOIL TYPES OF SWAT MODEL AND THEIR SPATIAL DISTRIBUTION COVERAGE IN THE STUDY AREA**

Soil Name	Area(Ha)	Watershed area(%)
Eutric cambisols	1705.86	3.66
Eutric leptosols	9093.87	19.52
Eutric vertisols	4864.05	10.44
Haplic Alisols	18616.23	39.95
Haplic luvisols	11447.73	24.57
Urban land	867.51	1.86

The spatial distribution of Soil class had shown in the following map from HRU analysis of SWAT model that had been used to overlay HRU definations. The majority of the soil in the watershed is Haplic Alisols with 39.95% coverage in the watershed.

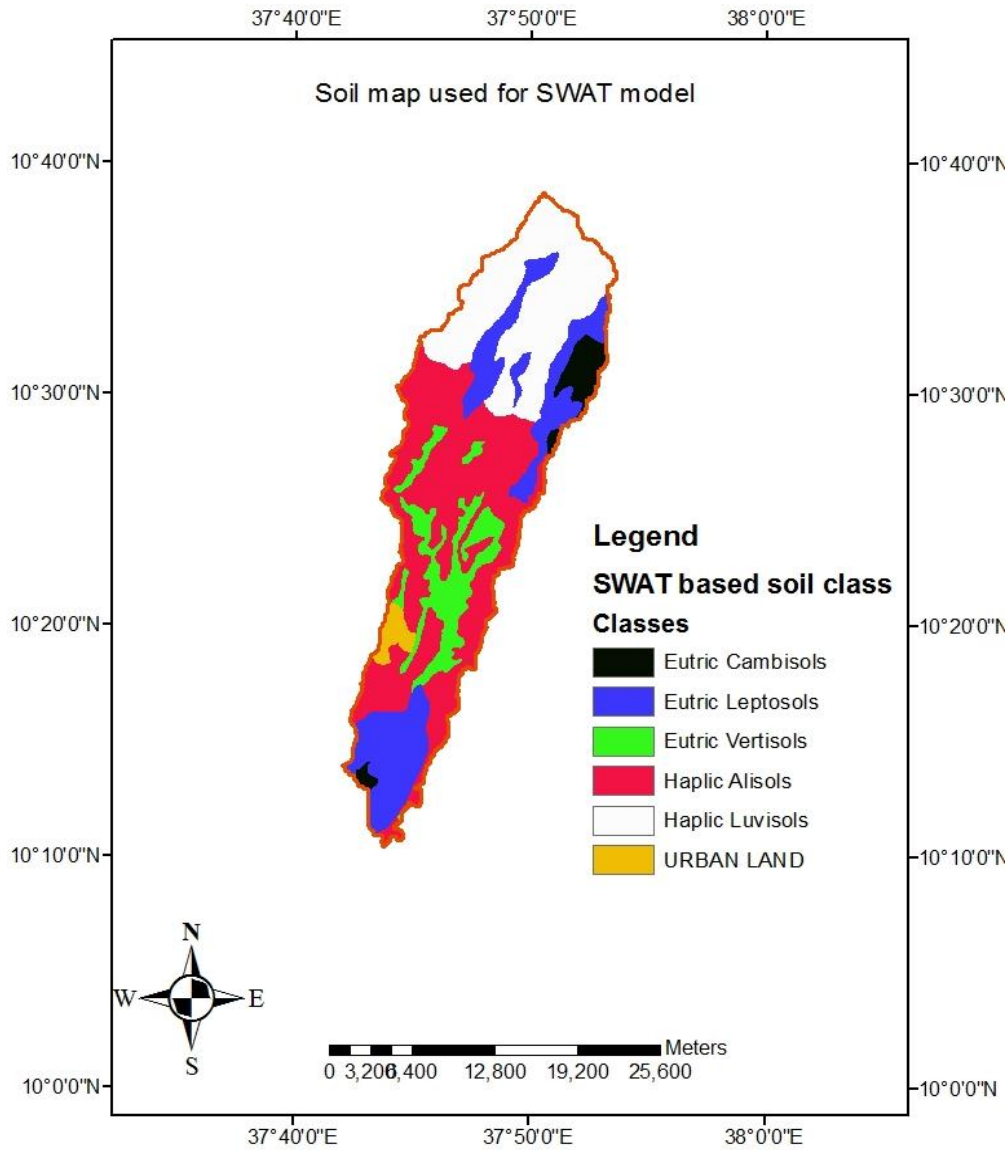


FIGURE 3 13 MAP OF SOIL IN CHEMOGA WATERSHED FOR SWAT MODEL.

### Slope class classification for SWAT model

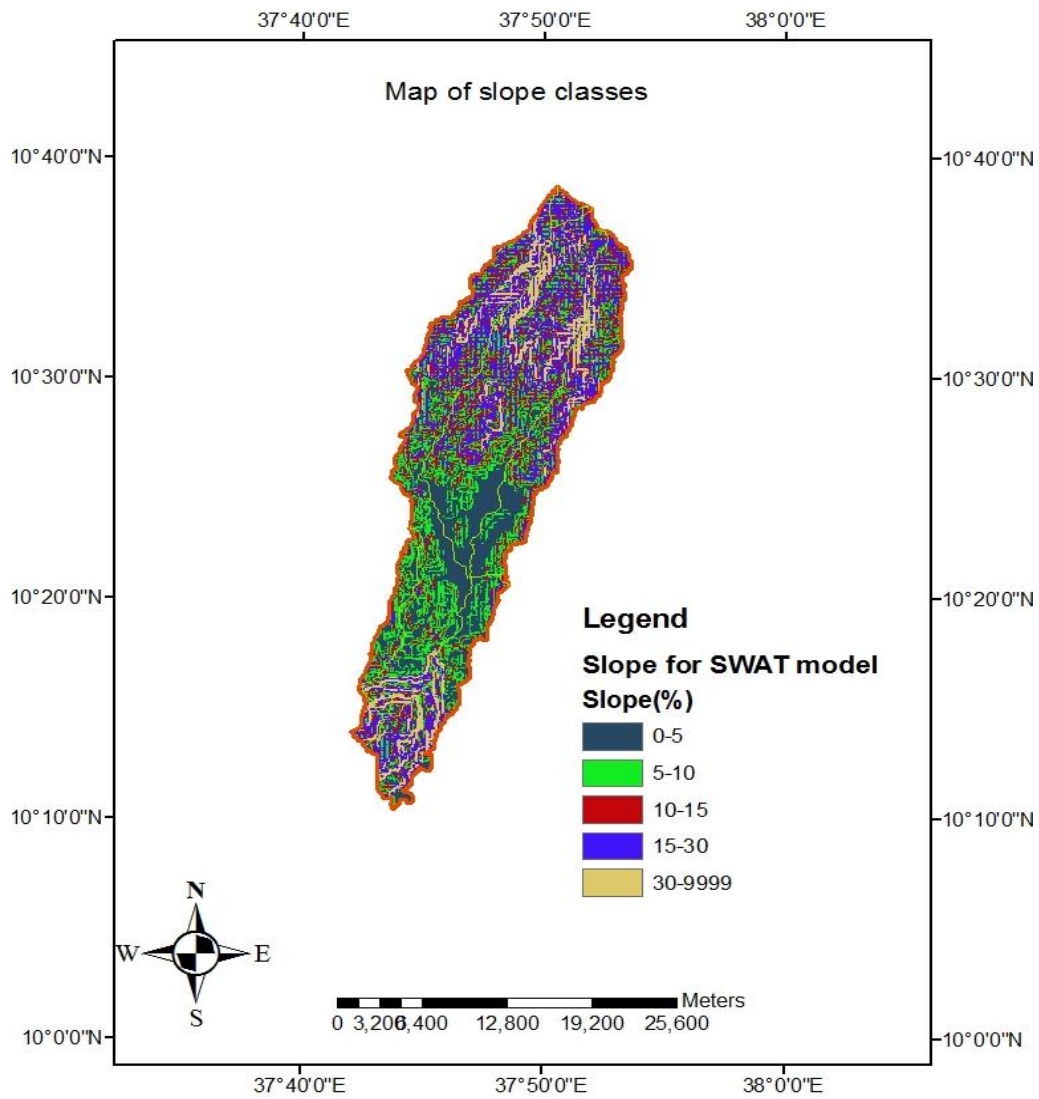
Due to the high elevation difference in the watershed ,slope had been classified into five classes in HRU analysis:

- Class-1:0-5%
- Class-2:5-10%
- Class-3:10-15%
- class-4:15-30%
- Class-5: >30%

**TABLE 3 6 SLOPE CLASS USED IN HRU DEFINITION OF SWAT MODEL**

Slope class	Slope range(%)	Coverage area(Ha)	Area coverage(%)
Class-1	0 -5	10700.1	22.96
Class-2	5-10	11438.01	24.55
Class-3	10-15	8662.95	18.59
Class-4	15-30	11399.13	24.46
Class-5	30-9999	4395.06	9.43

Spatial distribution of slope classes in the watershed had resulted in the following map 4.4. The higher slopes are observed in the upstream side of the watershed and lowest slopes are found in the middle of the watershed. Due to the elevation gap is very large the slope class were divided into five section for SWAT modeling to be considered.



**FIGURE 3 14 MAP OF SLOPE CLASS IN HRU DEFINITION**

## CHAPTER FOUR

### 4.0. RESULT AND DISCUSSION

#### 4.1. Sensitivity of Hydrologic Parameters

The model considered 17 parameters using SWAT-CUP program .As it had already stated in in HRU analysis, HRU is the smallest unit of disaggregation. HRU is divided based on the watershed condition of elevation, soil, land use, and distributed spatial and number parameters such as evaporation compensation factor, soil albedo, available soil moisture...etc. are the most sensitive parameters resulted from parameter sensitivity analysis using SWAT-CUP . The sensitivity scale of hydrologic parameters are expressed in t-stat and p-values.

##### 4.1.1. Sensitive parameters in the watershed

Their sensitivity range had been expressed in t-stat and p-value in global sensitivity of SWAT-CUP. In the grid view and map view of global sensitivity, parameters sensitivity were displayed from highly sensitive to lowest or negligible sensitive parameters in grid view and map view which is shown at the end of the chapter in the appendix of the thesis. The sensitivity of parameters with fitted value in the watershed and with the upper and lower bounds for each parameter have been shown in the following table. As indicated in the following below the most sensitive parameter in the watershed is evaporation compensation factor (ESCO).

In sensitivity analysis the larger, in the absolute value, the value of t-stat and the smaller the p-value the more sensitivity the parameter. Hence, soil-ALB followed by ESCO and SOIL-AWC are the most sensitive parameters in Chemoga watershed. The following table shows the t-stat and p-value of parameters in watershed sensitivity

**TABLE 4 1** THE SENSITIVITY RESULT OF PARAMETERS IN T-STAT AND P-VALUE OF SWAT-CUP

Parameter Name	Parameter Code Name	t-stat	p-value
Average slope length	SLSUBBS N.	0.00000	1.0000
Maximum Canopy storage	CANMX.	0.0049922120	0.996156171
Alpha base flow	ALPHA_B F	0.016025874	0.987660954
Snow pack temperature lag factor	TIMP	-0.140979785	0.891857186
Temperature lapse rate	TLAPS	0.185216647	0.858311430
SCS curve Number	CN2	0.212606303	0.837692707
Maximum melt rate for snow	SMFMX	0.217165780	0.834273117
Ground water revap coefficient	GW_REV AP	0.2517072766	0.8084972
Ground water delay	GW_DELA Y	0.34606387	0.73946
Saturated hydraulic conductivity	SOL-K	0.41055670	0.693673
Soil depth	SOL-Z	0.427084	0.682147
Threshold depth of water to occur return	GWQMN	0.635176	0.545508
Biological mixing efficient	BIOMIX	0.655350	0.5331799
Moist soil albedo	SOL-ALB	0.7146844972	0.49793910
Available water capacity of soil layer	SOL-AWC	0.8072293	0.4460917
Soil evaporation compensation factor	ESCO	1.01308532	0.34474920



#### 4.1.2. Sensitive Parameters used in Calibration evaluation of the Model

TABLE 4 2 SELECTIVE PARAMETERS FOR MODEL EVALUATION

Name of parameter	Parameter Code name	t-stat	p-value
SCS curve Number	CN2	0.212606303	0.837692707
Ground water revap coefficient	GW_REVAP	0.2517072766	0.8084972
Ground water delay	GW_DELAY	0.34606387	0.73946
Saturated hydraulic conductivity	SOL-K	0.41055670	0.693673
Soil depth	SOL-Z	0.427084	0.682147
Threshold depth of water to occur return	GWQMN	0.635176	0.545508
Moist soil albedo	SOL-ALB	0.7146844972	0.49793910
Available water capacity of soil layer	SOL-AWC	0.8072293	0.4460917
Soil evaporation compensation factor	ESCO	1.01308532	0.34474920

#### 4.1.3. Fitted value of sensitive parameters

The fitted value of sensitive parameter was observed between upper and lower bound of sensitivity ranges. The most sensitive parameter is soil evaporation compensation factor in Chemoga watershed. The fitted value of each parameter and its upper and lower bounds had been shown in Table 4.3.

TABLE 4 3 THE FITTED VALUES OF SWAT-CUP PARAMETERS

Simulation code Name	Fitted Value	Lower bound	Upper bound
CN2	76.58	35.000	98.00
ALPHA-BF	0.700	0.000	1.00
GW-DELAY	19.00	0.000	50.00
GWQMN	1500	0.0200	5000.00
GW-REVAP	0.09560	0.000	0.2000
ESCO	0.7800	0.000	1.000
SOL-K	50.00	0.000	100.00
SOL-Z	186.00	0.000	300.00
SFTMP	0.1000	0.000	5.00
SMFMX	7.800	0.00	10.00
TIMP	0.1400	0.00	1.00
BIOMIX	0.7400	0.00	1.000
SLSUBBSN	136.00	10.00	150.00
CANMX	0.600	0.00	10.00
TLAPS	25.00	0.00	50.00
SOL_ALB	0.2500	0.00	2.00
SOL_AWC	0.3000	0.00	1.000

## 4.2 Model Calibration and Validation Using SWAT-CUP

Model calibration follows the identification of best parameters in sensitivity analysis. Using best sensitive parameters, calibration had performed using SWAT-CUP. The model were calibrated using the average monthly and daily levels of flow values. Monthly calibration had conducted for the period of 10 years from 1999-2008 with three years warm-up period of 1995, 1996 and 1997. Daily calibration is conducted from 1998-2001. The calibration was done with fine adjustment of sensitive parameters as it had already discussed in sensitivity analysis. The objective function of model performance is achieved at monthly levels with statistical measures of  $R^2$  (Coefficient of determination) > 0.6 and  $E_{NS}$  (coefficient of Sutcliffe) > 0.5 (Moriassi, et al., 2007).

### 4.2.1 Model performance result from SWAT-CUP

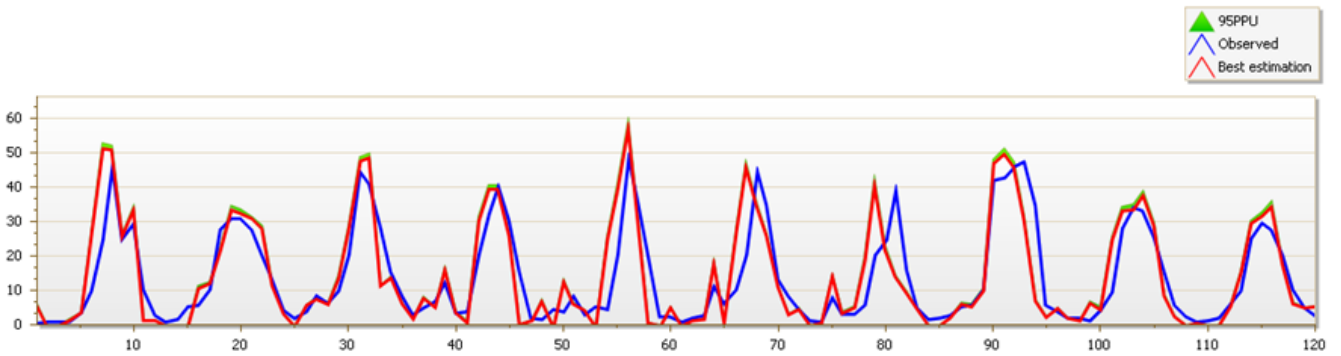
The calibration and validation performance using SWAT-CUP of Chemoga watershed had resulted in the following table.

TABLE 4 4 CALIBRATION AND VALIDATION PERFORMANCE OF SWAT-CUP

Simulation type	Period of simulation	Model efficiency		
		$R^2$	$E_{NS}$	D (%)
Calibration	1999-2008	0.71	0.65	4.47
Validation	2009-2012	0.83	0.71	2.13
Daily Calibration	1998-2001	0.56	0.42	27.56

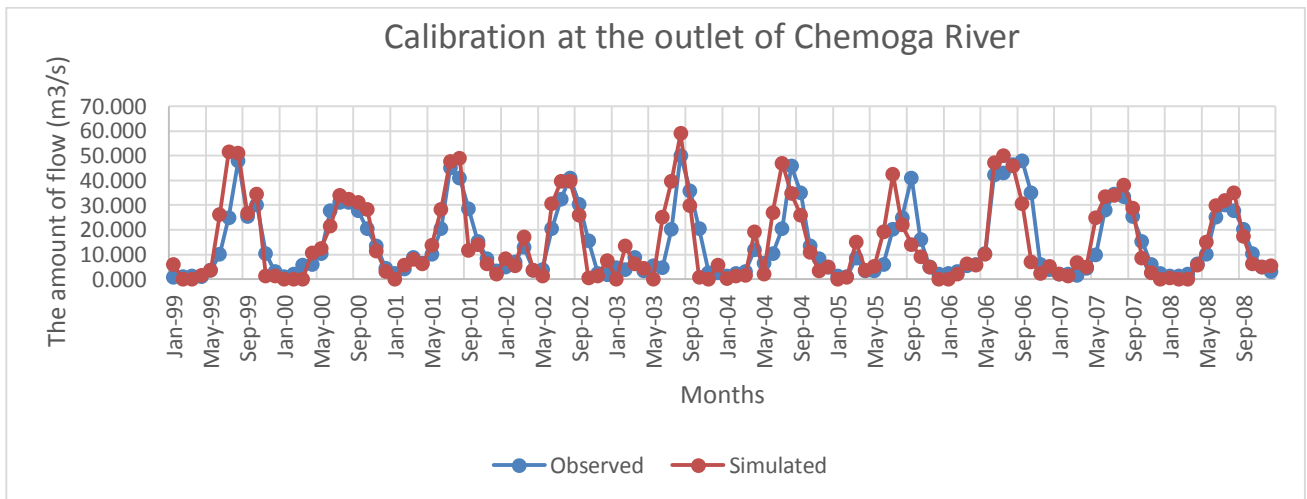
The SWAT-CUP model performance was effective and had resulted very good results in monthly scale. Hence, SWAT-CUP could to perform effective prediction of hydrological simulation of Chemoga watershed. Daily calibration using SWAT-CUP could not get could not get the objective model performance values with sensitive parameters of the watershed. This was due to the property of unmanaged catchment and the error of the modeler (Abbaspour, 2015). Figure 4.1 and 4.2 shows the calibration result in the chart.

### FLOW\_OUT\_5

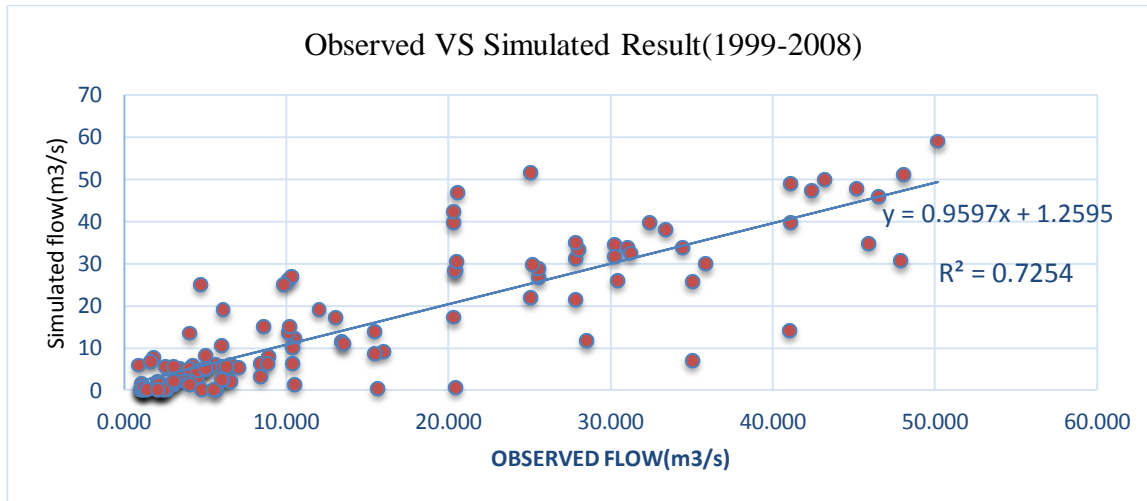


**FIGURE 4 1 THE MONTHLY CALIBRATION GRAPH USING SWAT-CUP (1999-2008)**

The next graph shows only the simulated and the observed flow values at the outlet of Chemoga watershed.



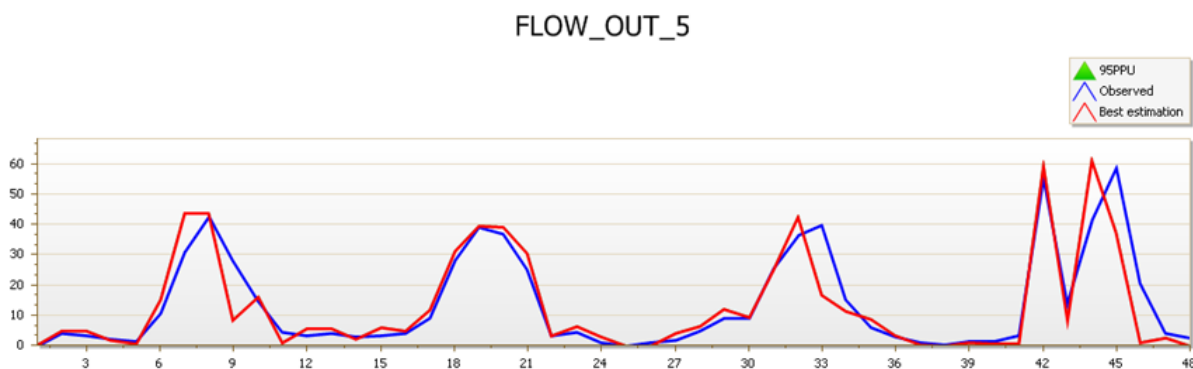
**FIGURE 4 2 CALIBRATION RESULT AT THE OUTLET OF CHEMOGA RIVER**



**FIGURE 4 3 THE SCATTERED PLOT OF OBSERVED VERSUS SIMULATED FLOW OF CALIBRATION PERIOD**

#### **4.2.2. Model Validation with SWAT-CUP**

The model was found with strong objective function of stastical performance in the watershed. The stastical performance values resulted from SWAT-CUP simulation are 0.83, 0.81 and 0.81 for stastical values of  $R^2$ ,  $E_{NS}$  and  $D$  respectively. Hence, SWAT-CUP model performance is strongly achieved with the model criteria of  $R^2 > 0.6$  and  $E_{NS} > 0.5$  (Santhi et al., 2001). The result for validation performance of Chemoga watershed shows that the parameters which were used for simulation using SWAT-CUP are highly sensitive to predict the hydrological characteristics in the basin. The following figure shows the model validation result using SWAT-CUP in the period of 2009-2012.



**FIGURE 4 4 MODEL VALIDATION OF CHEMOGA RIVER USING SWAT-CUP**

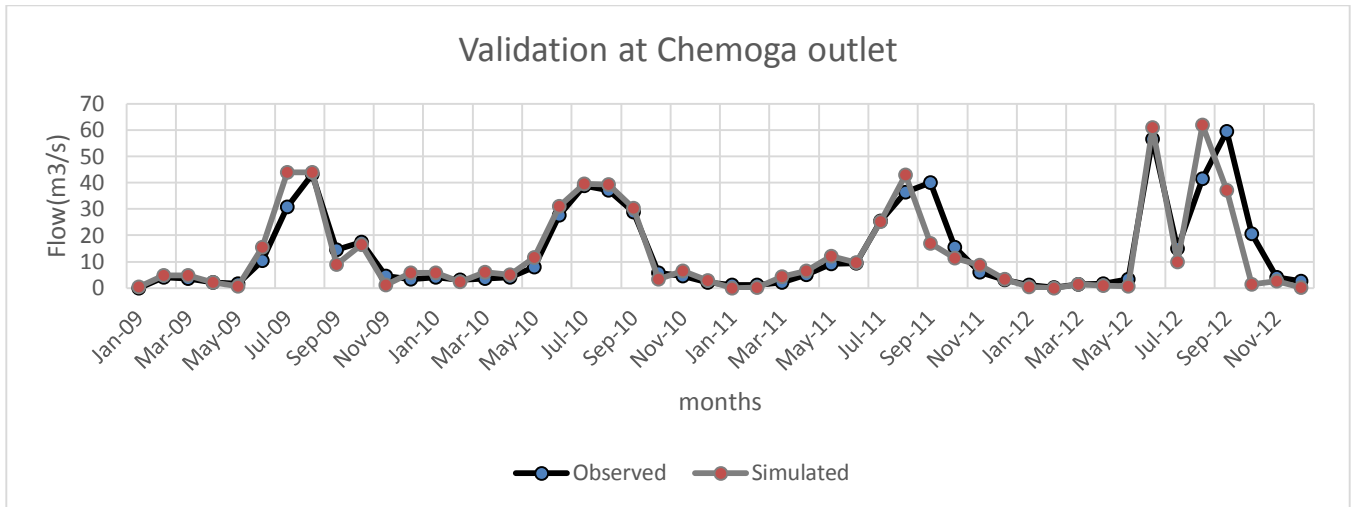


FIGURE 4 5 MODEL VALIDATION OF CHEMOGA RIVER AT OUTLET (2009-2012)

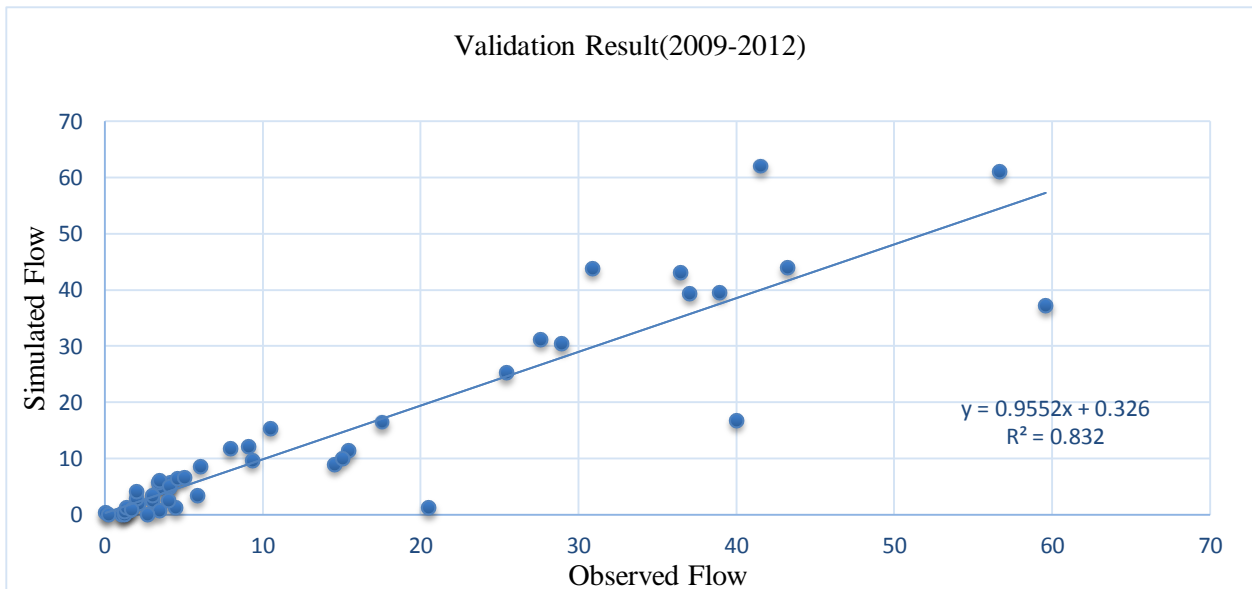
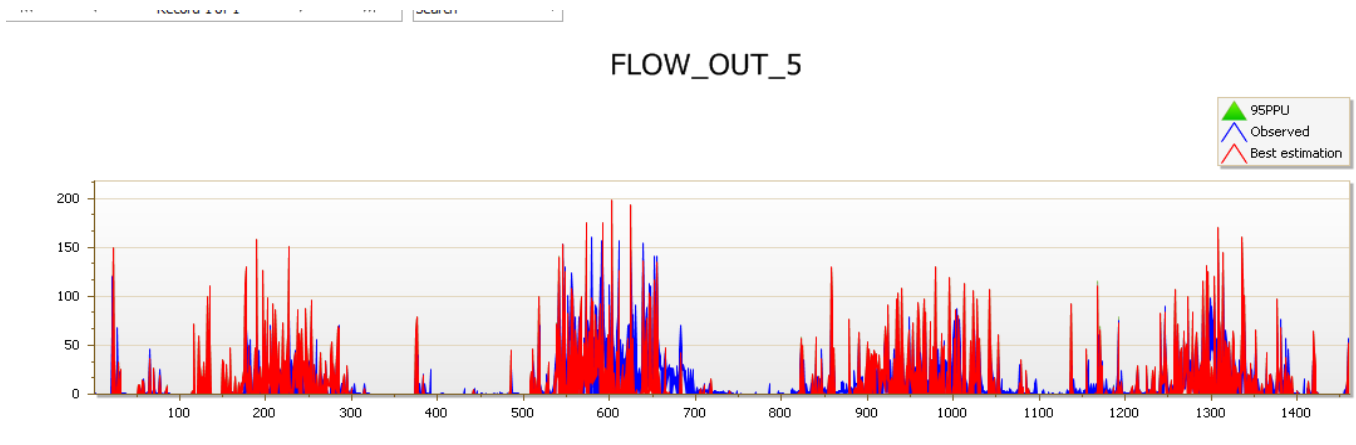


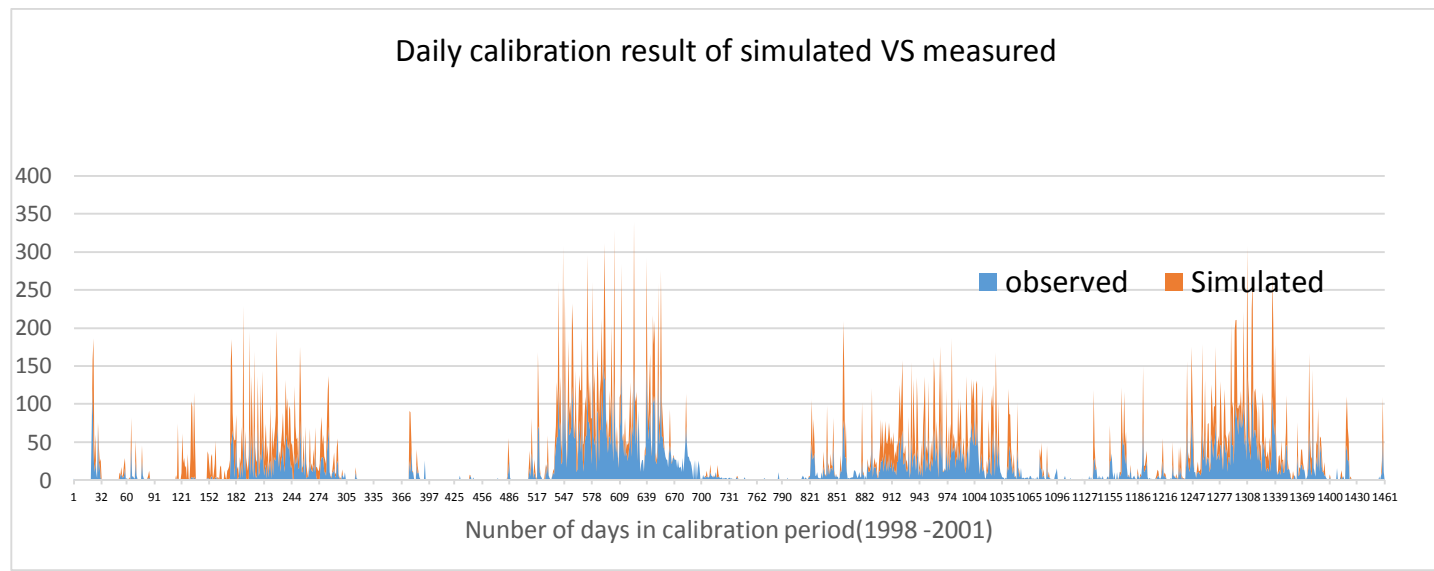
FIGURE 4 6. THE SCATTER PLOT OF OBSERVED VERSUS SIMULATED FLOW FOR VALIDATION PERIOD

#### 4.2.3. Daily Calibration

The daily evaluation model performance were not achieved in the objective function of the of Nash Sutcliffe coefficient of  $E_{NS} = 0.42$  but Coefficient of determination is obtained in the objective function range of good performance with  $R^2 = 0.56$ . The following graphs of 4.7 and 4.8 shows the result of daily calibration results of Chemoga watershed.



**FIGURE 4 7. DAILY CALIBRATION AT THE OUTLET OF CHEMOGA WATERSHED USING SWAT-CUP**



**FIGURE 4 8 DAILY CALIBRATION AT THE OUTLET OF CHEMOGA WATERSHED.**

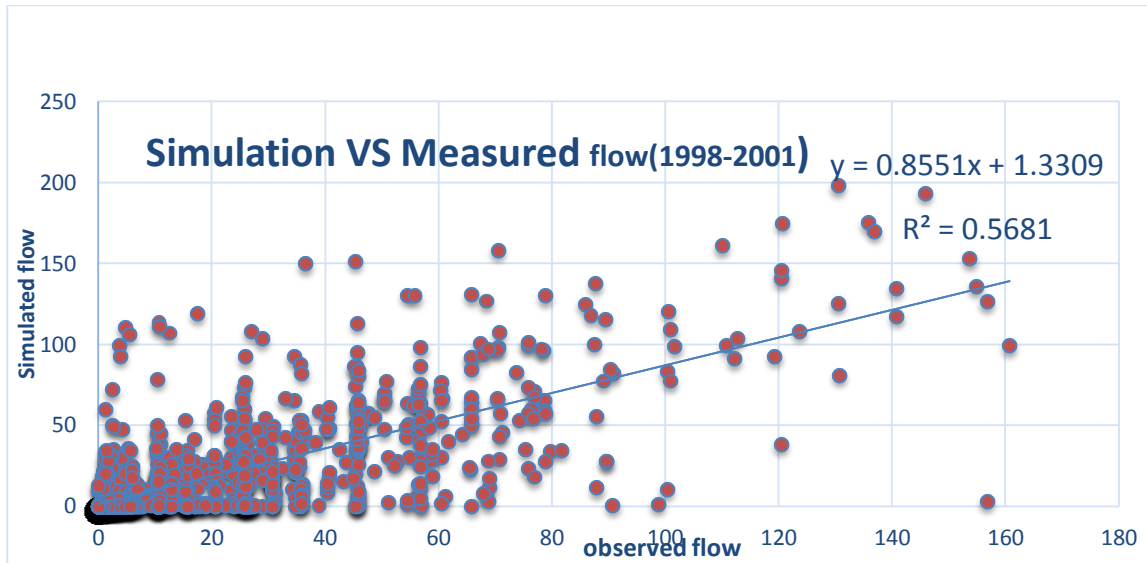


FIGURE 4 9. THE SCATTERED PLOT OF SIMULATED VERSUS MEASURED DAILY FLOW OF CHEMOGA RIVER

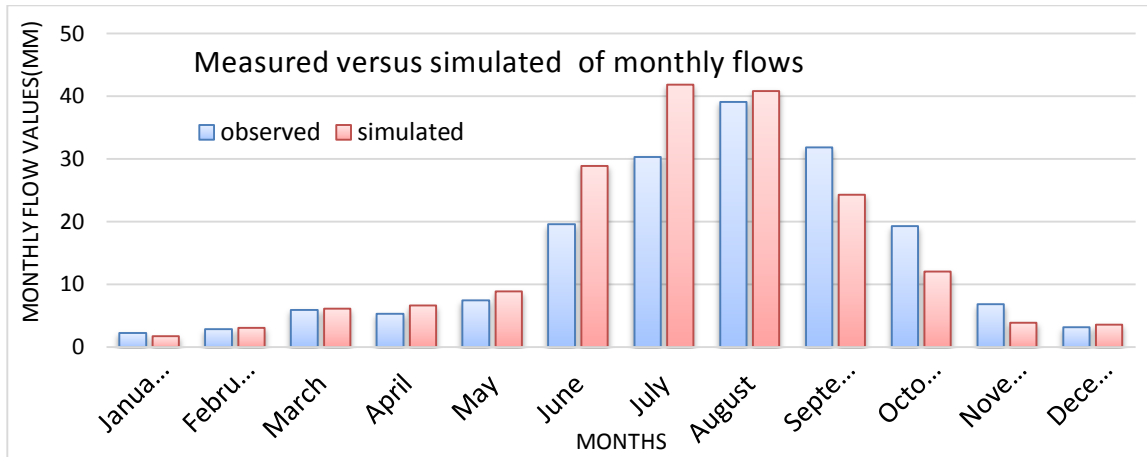
#### 4.3. Monthly, Seasonal and Annual Water yield From of SWAT Model

The monthly calibration results Chemoga watershed could be expressed in annual and seasonal bases in the simulation period of 1999-2008. The result of annual average observed flow yield in the outlet of Chemoga watershed is 144.5mm and the simulated flow yield in the calibration period is 152.3mm. Both the mean simulated and measured values in different seasons of the study years had resulted close values this shows the effective performance of the model.

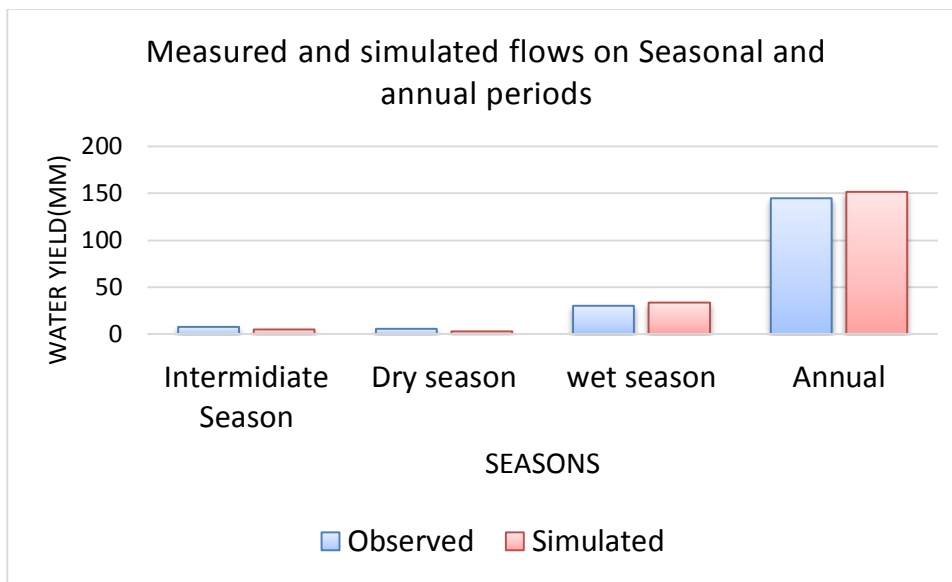
The result were summarized in three seasonal periods:

dry(February, March, April, May), wet(June, July, August, September) and intermediate(October, December, January, February). The model could effectively predict the hydrological characteristics of the watershed as compared the measured flow the river. Hence, SWAT model could determine the flow conditions in the catchment. The figure 4.10 and figure 4.11 shows the monthly and seasonal yield of simulated and observed flows in the simulation period of 1999-2008.





**FIGURE 4 10. MEAN MONTHLY MEASURED VERSUS SIMULATED FOR THE CALIBRATION PERIOD (1999-2008)**



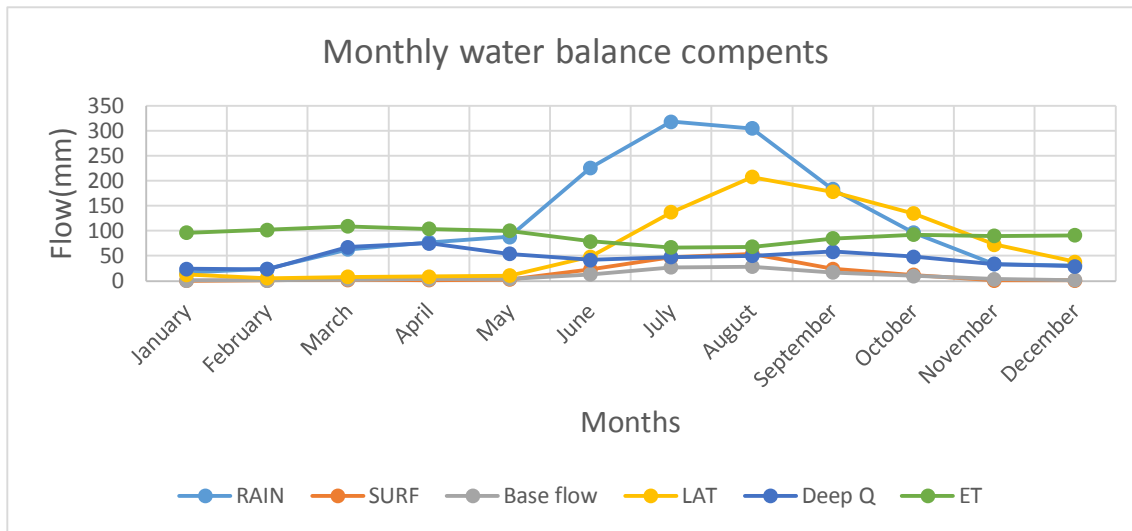
**FIGURE 4 11. SEASONAL AND ANNUAL MEASURED VERSUS SIMULATED FLOWS IN THE CALIBRATION PERIOD**

#### **4.4. Ground Water contribution and water balance in Chemoga watershed**

##### **4.4.1. SWAT simulated water balance components**

The main water balance components in the basin are: The total precipitation in the watershed during time step, the actual evapotranspiration from the watershed and the net amount of water

that leaves the basin and contributes to the rich (water yield). The following figure shows monthly surface water and subsurface water contributions in the watershed.

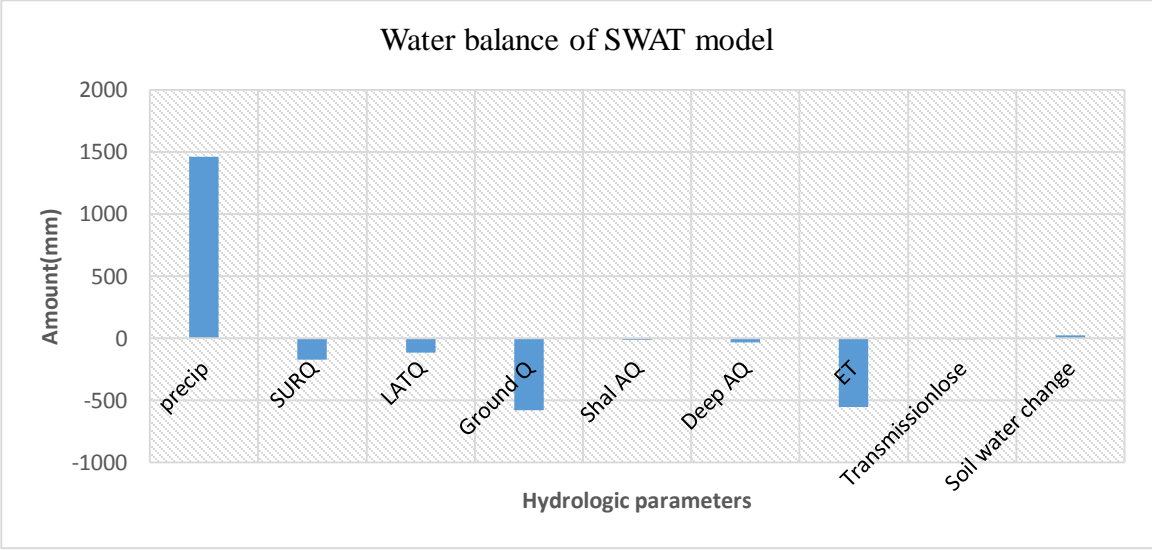


**FIGURE 4.12. MONTHLY FLOWS OF SURFACE AND SUBSURFACE HYDROLOGIC PARAMETERS**

The water yield includes surface runoff contribution to the stream flow, Lateral flow contribution to the stream flow, ground water contribution to the stream flow minus transmission losses. The result of calibration and validation analysis reveals that for the calibration period (1999-2008) and validation period (2009-2012). Various SWAT model water balance components for Chemoga watershed for calibration period are listed in table 4.4. The simulation result shows that 58% of the precipitation which is the main water source in the catchment flows as surface runoff in the watershed. Hence, 48% of the precipitation is lost through evapotranspiration. 68% of the water yield in the calibration period is from base flow contribution in the watershed, only 32% of water yield at the rich of the catchment is from surface runoff and lateral flows. The following table of 4.8 shows water balance components of the SWAT model which in Chemoga watershed.

**TABLE 4 5 HYDROLOGICAL MODEL RESULT OF WATER BALANCE COMPONENTS**

Hydrologic Parameter	Model result in calibration times(mm)
Precipitation(Precip)	1462
Surface runoff(SURQ)	170.5
Lateral flow(LATQ)	114.7
Groundwater(base flow)	577.6
Shallow aquifer recharge(Shal AQ)	12.22
Deep aquifer recharge(deepAQ)	31.06
Total Aquifer recharge	621.21
Total water yield	152.3
Percolation out of soil	621.68
Evapotranspiration(ET)	533.9
potential evapotranspiration	1081.8
Transmission losses	1.05
Change in soil water	24.5



(Water balance;  $SW_t + \sum_1^t (Precip - ET - Q_{surf} - Q_{seep} - Q_g)$ )

FIGURE 4 13. AVERAGE ANNUAL WATER BALANCE IN CHEMOGA WATERSHED

## CHAPTER FIVE

### 5.0. CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

Hydrological models greatly help in analyzing the spatial and temporal elements that directly or indirectly determines the hydrological process in any watershed. Hydrological models are the basic tools to study complex watersheds in managed and organized form using hydrologic parameters. Without hydrological models it could be complex to understand each of the parameters in the hydrological cycle because of hydrological cycle elements are always in motion. Hence, developing suitable hydrologic model is the key tool to study hydrological cycles of different watershed conditions. The basic tool to conduct this research was soil and water assessment tool (SWAT) which was enabled to study the hydrological characteristics in Chemoga watershed located in Abbay basin. The performance of SWAT model was evaluated using different hydrologic parameters that were resulted during simulation periods of the study. After major simulation had performed using the main arc SWAT tool, parameter evaluation was carried out using SWAT-CUP. Sensitivity analysis, calibration and validation was the major model evaluation criteria which were conducted in daily and monthly levels. The daily model performance evaluation could not achieved with in the objective function due to uncertainty of the model parameters to handle daily levels of the calibration times. The sensitivity of parameters were measured considering the stream flow at the outlet of Chemoga River. The model sensitivity of parameters were expressed in t-stat and p-values of SWAT-CUP tools and soil evaporation compensation factor (ESCO) is the most sensitive parameter in Chemoga watershed. Subsurface parameters are the next sensitive elements. The calibration and validation performance were achieved with the objective functions of statistical measures of  $R^2 > 0.6$ ,  $E_{NS} > 0.5$  and  $D \leq \pm 15$  for both of evaluation criteria's.

Surface and subsurface water flow from the water were clearly identified SWAT model .The simulation result had indicted 68% of the total water yield from the watershed is contributed from ground water flow(base flow).Waterbalnce of the watershed were investigated and shows that the change in soil water content is 24.5mm.

## 5.2. Recommendation

The following are major points that are recommended at the result of the study.

- This study result gives the basic clue to understand surface and subsurface hydrologic process undertaking in the watershed.
- Different hydrological models other than SWAT model could be conducted in the watershed for checking up of certainty fittings of hydrological results with different models in the same watershed.
- The weather stations in Chemoga watershed have no full climatic data records except Debremarkos station (weather generator station of the study).Hence, other stations should also have full records to have well managed temporal data in the catchment.
- Land use/cover change is the determinant factor to study change hydrological processes with time changes, so further studies should be conducted to detect stream flow changes with time.
- The result of this study could be the source to plan water resource management plans and also could be used as hydrologic input to design different hydraulic structures in the river.
- Future studies in the watershed of Chemoga River should handle the case of removal of loam soil as sediment, water quality and best management of hydrological components in the watershed should be considered.
- Appropriate watershed management plan and policy should be drafted to keep the Waterbalnce in watershed in undisturbed system and minimize the runoff from high lands.

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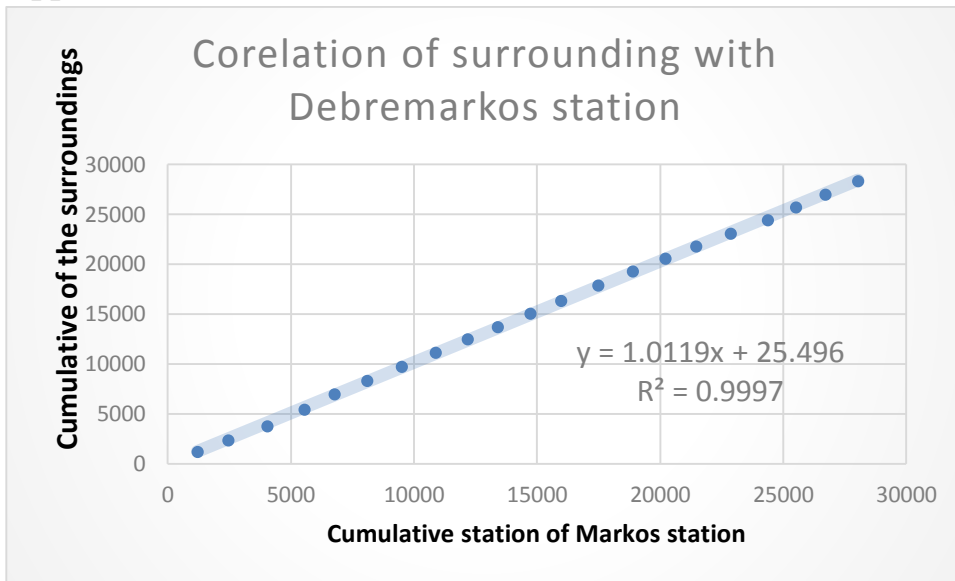
Wisler, j., 1985. *Hydrology*. Rome: .

<http://swat.tamu.edu/software/links-to-related-software/> SWAT input preprocessors

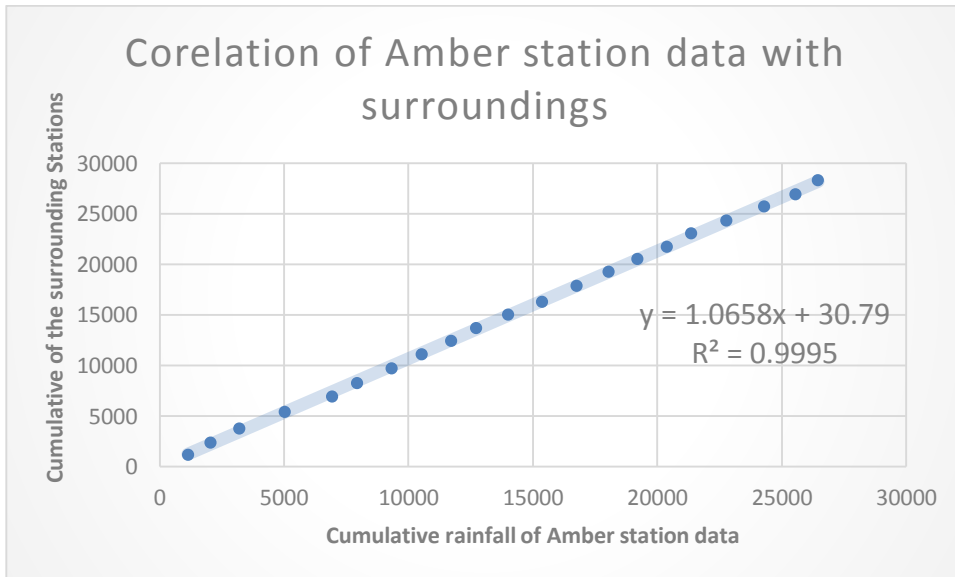
Dewpoint estimation programs: pcpSTAT and dew02. Accessed on 08/21/2015

## APPENDICES

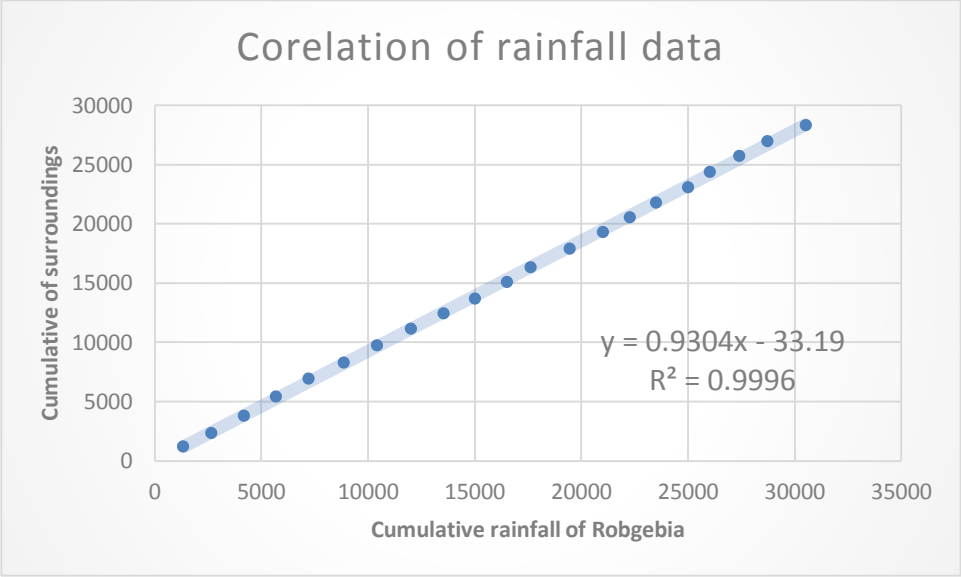
### Appendix-1; Debremarkos rainfall data correlation with cumulative surroundings



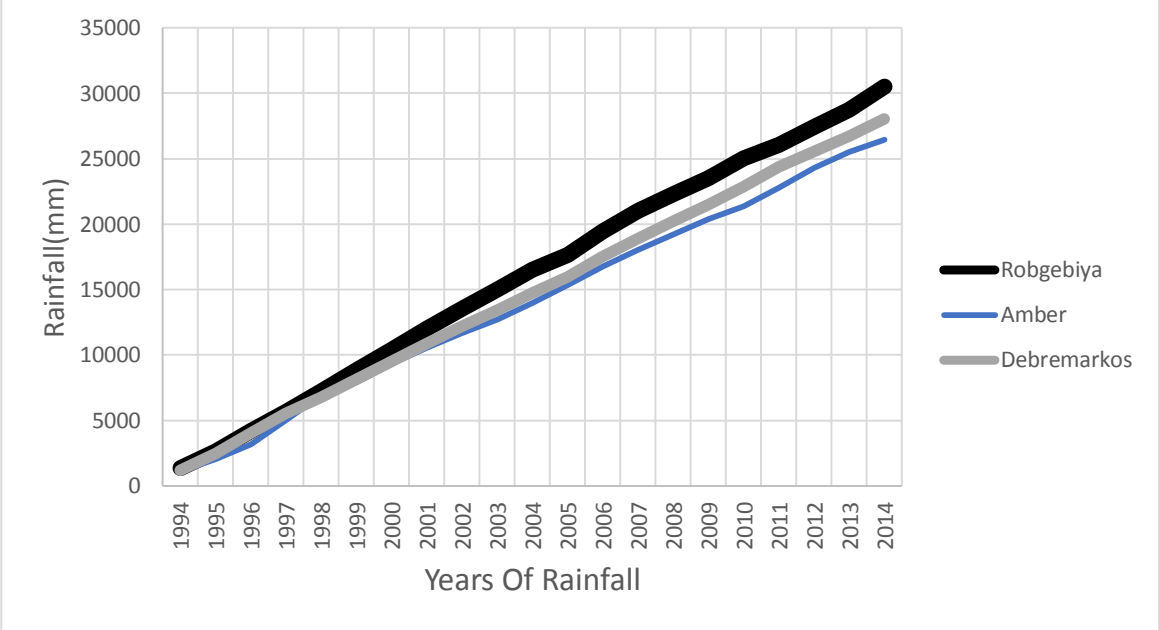
### Appendix-2; Correlation of Amber rainfall with surrounding cumulative



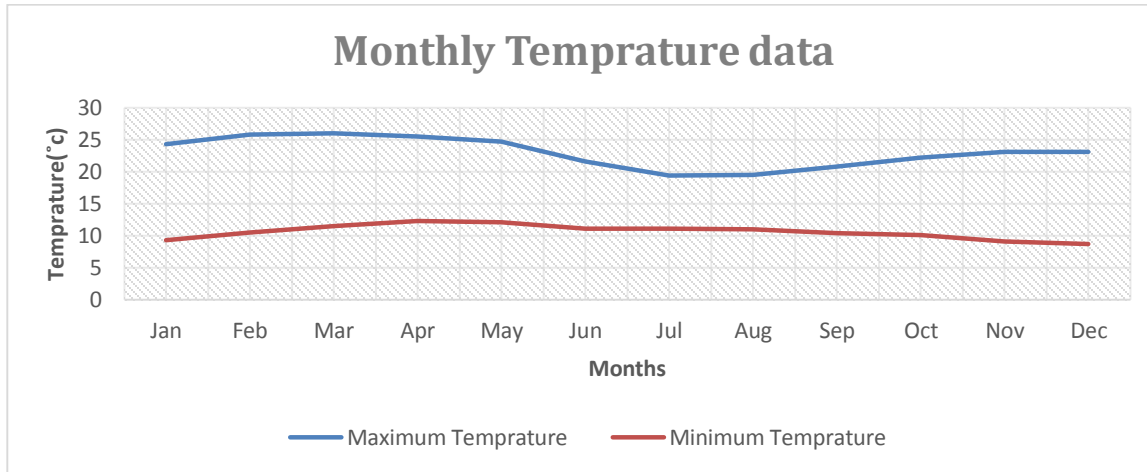
### Appendix-3; the correlation of Robgebia rainfall with surroundings



**Appendix-4; The annual cumulative of all Rainfall Stations**



**Appendix 5: Mean monthly maximum and minimum temperature of Debremarkos Station**



**Appendix 6: Definition of the weather generator statistical and probability parameters (Winchell et al.2007)**

Parameter Nomenclature	Nomenclature definition
TMPMX	Average daily maximum air temperature in a month (oC)
TMPMN	Average daily minimum air temperature in a month (oC)
TMPSTDMX	Standard deviation for daily maximum air temperature in a month (oC)
TMPSTDMN	Standard deviation for daily minimum air temperature in a month (oC)
PCPMM	Average daily precipitation in a month (mm/day)
PCPSTD	Standard deviation for daily precipitation in a month (mm/day)

PCPSKW	Skewness coefficient for daily precipitation in a month
PR_W1	Probability of wet day following dry day in a month
PR_W2	Probability of wet day following wet day in a month
PCPD	Average number of days of precipitation in a month
SOLARAV	Average daily solar radiation in a month (MJm-2day-1)
DEWPT	Average dew point temperature in a month (oC)
WNDVAV	Average wind speed in a month (m/s)
RAINHHMX	Maximum half hour rainfall in a month

#### Appendix-7: Monthly precipitation data of Weather generator Station

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1994	9.3	5	35.2	42.7	139.6	147.6	281.2	301	218.1	7.4	13.2	0.5	1200.8
1995	0	1	20.3	90.4	146.6	126.4	246.1	344.6	151.2	14.4	12.4	95.5	1248.9
1996	27.6	4.6	74.1	108	228	291.7	252.3	360.5	152.1	33.1	35.2	23.2	1590.4
1997	14.3	0	29.6	97.5	118.7	151	286.8	338.8	205.8	183.5	85	6.7	1517.7
1998	2.9	2.2	21	4.4	152.4	89.4	203.2	252.6	270.7	200.8	6.9	0	1206.5
1999	72.6	0	2.8	43.2	46.8	180.7	252.1	340.3	164.3	210.5	2.5	28.3	1344.1
2000	0	0	2.9	110.5	29.5	174.9	293.1	211.1	271	265.9	32.7	12.3	1403.9
2001	0	3.7	58.1	101.2	129.6	154.7	365.2	322.3	170.3	66.9	0	2.2	1374.2
2002	57	0	92.2	75.2	11.2	155.9	276.3	335.5	234.6	3.9	2.2	61.5	1305.5
2003	3.6	57.4	69.6	19.2	5.3	212	205.5	351.6	256.8	10.7	0.3	18.8	1210.8
2004	4.1	7.6	13.8	120.1	19.8	195	286.6	317.7	205.2	87.5	37.7	23.2	1318.3
2005	2.3	0.6	110.6	42.9	43.7	150.4	314	223.06	235.3	90.2	41.5	0	1254.56
2006	3.5	20.7	87.8	67.4	104.5	190.9	364.1	281.1	301.5	37.1	30.7	32.3	1521.6
2007	1.7	15.6	77.5	71	166.56	188	250.6	325.9	269	37.9	0.4	0	1404.16

2008	0	0	0	15.7	169.9	290.3	250.5	273.9	195.1	71.2	39.1	9.5	1315.2
2009	11.7	21.1	56.5	22.7	16.8	159.3	276.7	452.3	98.5	110	10.9	21.8	1258.3
2010	18.7	22.8	35.4	84.7	153.4	151	240.5	339.6	307	17.5	16.7	5	1392.3
2011	2	3.7	110.4	68.9	237.8	143	231.1	288.3	282.9	37.9	97.3	11.5	1514.8
2012	13.9	0	33.1	33.1	23.4	124.2	240.5	250.9	362.4	21.3	30.9	5.2	1138.9
2013	3.6	4.7	4.2	109	79	146.1	274.6	256.7	194.6	100.5	9.2	9.2	1191.4
3	9.1	8.6	42.9	138.4	130.1	101.9	274.6	257.1	255.5	100.5	9.2	4.1	1332

**Appendix-8:PCPstat result for the input of weather generator**

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	12.28	2.3694	9.3978	0.0589	0.386	2.71
Feb.	8.54	1.6119	7.7216	0.042	0.4783	2.19
Mar.	46.57	3.8186	3.5934	0.1642	0.5495	8.67
Apr.	69.82	5.451	4.2399	0.2696	0.5766	11.81
May.	102.51	6.5124	3.4429	0.2791	0.658	14.62
Jun.	167.83	6.9662	2.3607	0.6429	0.8359	24.67
Jul.	269.79	8.5001	2.1657	0.9655	0.9228	29.62
Aug.	305.95	10.5979	2.4315	0.7907	0.9112	28.95
Sep.	228.66	8.8587	1.6407	0.5682	0.8092	23.71
Oct.	81.37	6.5741	3.74	0.119	0.6455	9
Nov.	24.48	3.161	5.7755	0.0889	0.4	4.29
Dec.	17.66	2.7274	7.2734	0.0599	0.4328	3.19



**Appendix-9:Dew02 result for the input of weather generator**

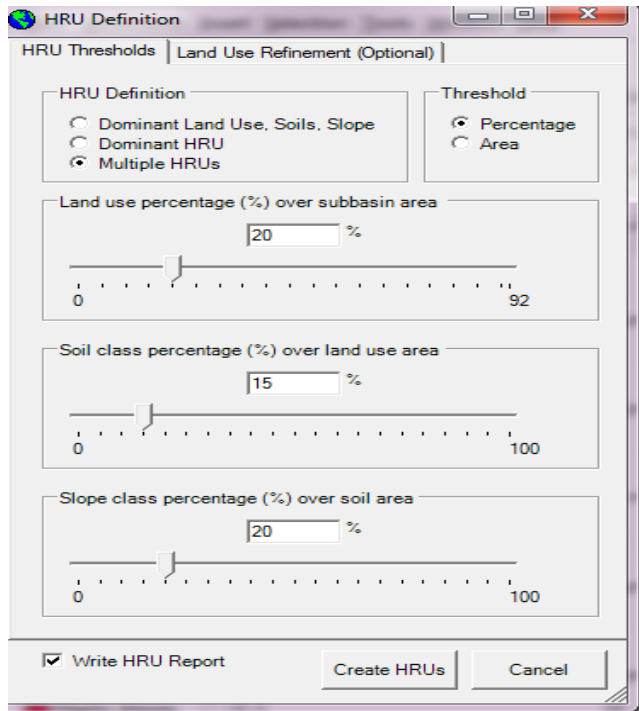
Month	tmp_max	tmp_min	hmd	dewpt
Jan	24.27	9.31	48.21	6.85
Feb	25.83	10.48	41.84	5.98
Mar	25.98	11.52	47.75	8.15
Apr	25.54	12.35	53.23	9.88
May	24.72	12.09	60.16	11
Jun	21.64	11.09	79.22	13.38
Jul	19.37	11.15	86.76	13.49
Aug	19.52	11.03	87.6	13.69
Sep	20.79	10.42	80.48	12.87
Oct	22.26	10.07	63.8	10
Nov	23.09	9.12	58.14	8.86
Dec	23.16	8.71	52.09	7.17

**Appendix-10: Soil parameters of SWAT and properties**

Soil name	No of layers	Hydro l. group	Sol_Z mx (mm)	Textur e	Sol_Z (mm)	Sol_B D (g/cm <sup>3</sup> )	Sol_AW C (mm/mm)	Sol_K (mm/hr)	Clay (%)	Silt (%)	Sand (%)	Sol_ ALB	USLE_ K
Eutric Leptosols	3	C	2422	C	363	1.27	0.11	4.54	61	19	20	0.09	0.2
					847	1.28	0.1	5.16	63	17	21	0.13	0.2
					210	1.45	0.22	38.4	11	67	22	0.13	0.3
Eutric Cambisols	3	B	1100	L	600	1.50	0.20	33.6	21	33	46	0	0.31
					900	1.46	0.18	40	13	46	41	0	0.34
					1100	1.25	0.14	66.4	14	42	44	0	0.24
Haplic Alisols	3	B	900	L-C-L	200	1.45	0.19	30	25	31	44	0.13	0.3
					600	1.32	0.09	5.52	44	23	33	0.13	0.11
					900	1.47	0.15	10.6	35	35	30	0.13	0.18

Haplic luvisols	1	A	500	S-C-L	500	1.44	0.19	28.7	35	38	27	0.13	0.21
Euric vertisols	3	C	1800	C-C-C	300	1.1	0.08	0.5	68	25	7	0.13	0.2
					800	1.36	0.08	0.3	74	19	7	0.11	0.08
					1800	1.36	0.08	0.3	74	17	9	0.11	0.08
Urban	1	A	300	C	300	1.1	0.08	0.5	57	28		15	0.23

### Appendix-11:HRU definations used in SWAT model



## Appendix-12: SWAT edit parameters (Penman Monteith method was used) for PET

Edit General Watershed Parameters

Water Balance, Surface Runoff, and Reaches | **Nutrients and Water Quality** | Basin-Wide Management | Atmospheric Deposition

**Water Balance**

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

**Surface Runoff**

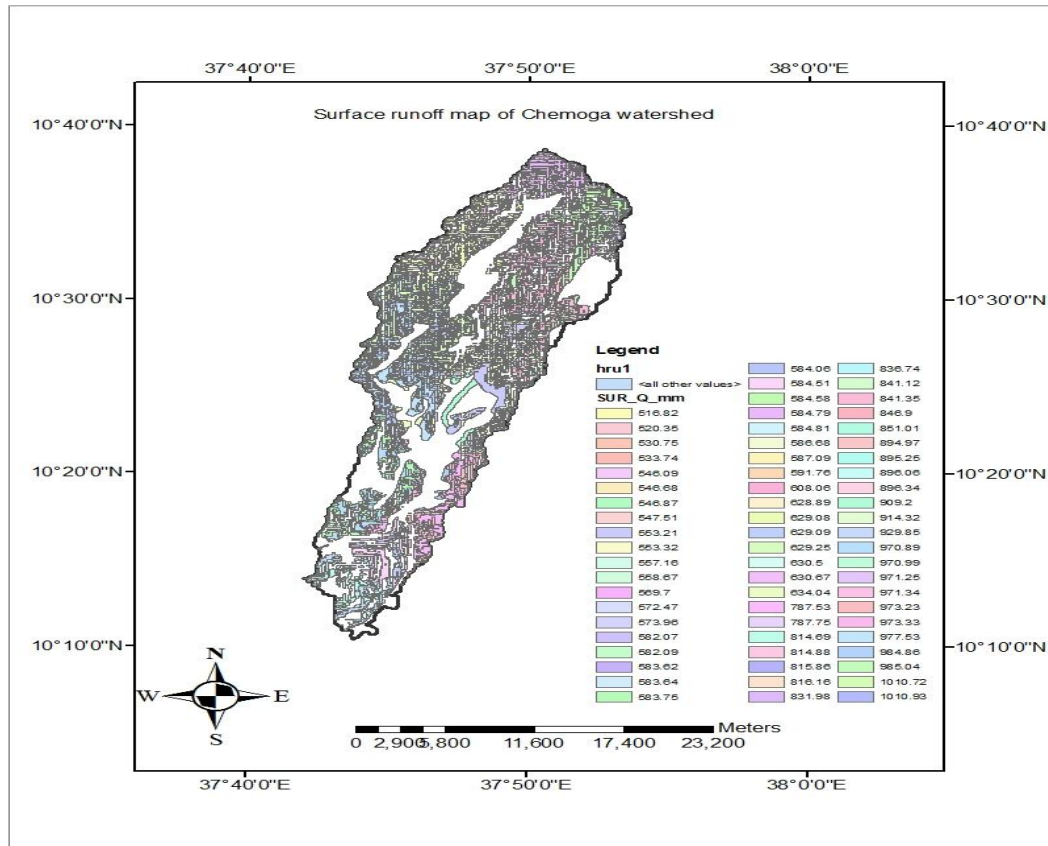
Rainfall-Runoff Method	ICN	CNCOEF	CN_FROZ	
"Daily Rain/CN/Daily Route"	Soil Moisture Meth	1	Inactive	
Crack Flow	SURLAG	ISED_DET	ADJ_PKR	TB_ADJ
Inactive	4	Triangular Dist.	0	0
PRF	SPCON	SPEXP		
1	0.0001	1		

**Reaches**

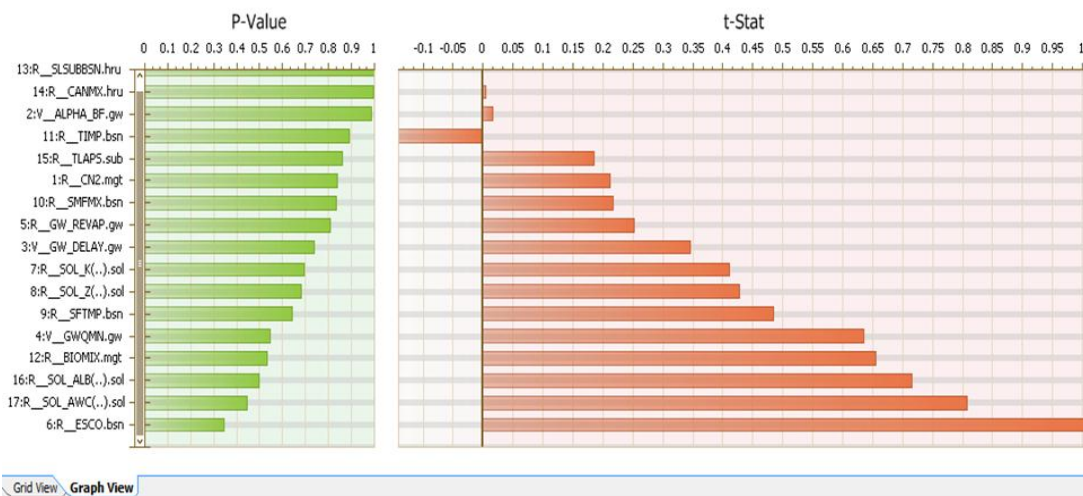
Channel Routing	MSK_CO1	MSK_CO2	MSK_X	Channel Degredation
Variable Storage	0	3.5	0.2	Inactive
Stream Water Quality	TRNSRCH	EVRCH	Routing Pesticide	
Active	0	1		

Edit Values | Cancel Edits | Save Edits | Exit

### Appendix- 13: Surface runoff result of simulation period at HRU level (mm)

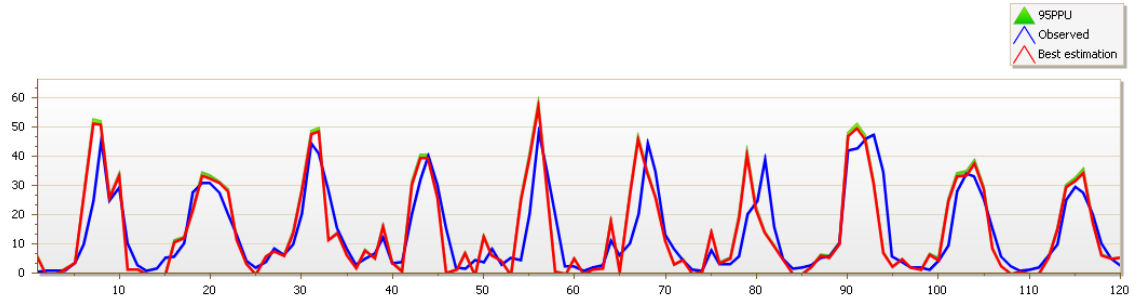


### Appendix-14: sensitivity result of parameters used SWAT- CU SUFI method of Global sensitivity



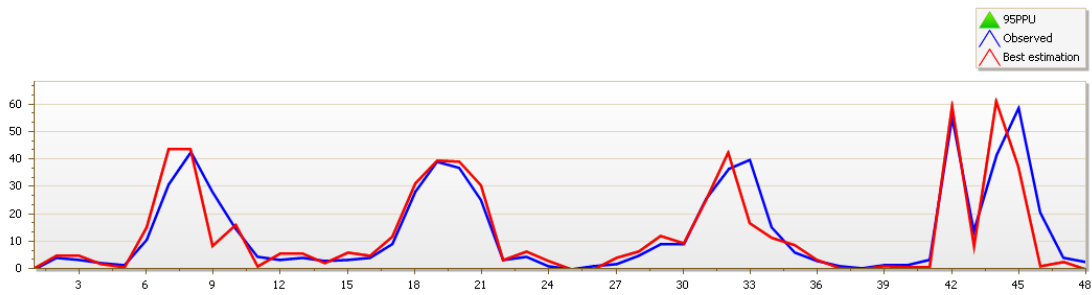
## Appendix-14: Monthly Calibration Result Using SWAT-CUP-SUFI

FLOW\_OUT\_5



## Appendix-15; Validation result of Chemoga flow using SWAT-CUP

FLOW\_OUT\_5



## Appendix-16: The daily calibration result using SWAT-CUP SUFI simulation

