JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

HYDRAULIC ENGINEERING MASTER OF SCIENCE PROGRAM

ASSESSING TRANSFER OF STREAM FLOW DATA USING SWAT MODEL FOR UNGAUGED SUB BASINS IN MEGECH RIVER CATCHMENT, UPPER BLUE NILE BASIN, ETHIOPIA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

By

MAJOR BERHE

DECEMBER, 2016

JIMMA, ETHIOPIA

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MAJOR BERHE

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DECEMBER, 2016

JIMMA, ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis entitled Discharge estimation for ungauged catchment in Megech River sub basin (watershed), upper Blue Nile, Ethiopia is my original work, and it has not been presented for a degree in Jimma University or any other university and that all source of materials used for the thesis have been fully acknowledged.

Name Signature Date

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This thesis has been submitted for examination with my approval as university supervisor

Name Signature Date

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Principal advisor

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ABSTRACT

Water resources have an enormous impact on the economic development and environmental protection. Water resource is available in different forms and can be obtained from different sources. However, mostly water resources assessment and management relies on available stream flow measurements. Megech River is one of the tributary of Lake Tana which is the main source of Blue Nile. The main objective of this study is to assess possibility of transferring stream flow data from gauged catchment to ungauged sub basin (from the main river, Megech, to other tributaries found in the catchment) by using SWAT model based on specified criteria. Data used in this study were collected from NMSA and MoWIE. Before using these data, quality of the data was checked carefully and necessary measures have been taken to improve their quality. Then Megech catchment was modeled using SWAT model and calibrated (R^2 =0.72 and NSE=0.71) and validated (R^2=0.77 and NSE=0.59). Based on soil, land use/cover, and slope criteria, hydrological and physical homogeneity were compared between the main catchment Megech (gauged) and the sub basins (ungauged) in the catchment; and it was found that sub basin 6,8 and 14 are nearly similar to the main catchment (watershed). Then possibility of transferring stream flow from Megech to sub basin 6, 8 and 14 were tested and it were successful. Testing was made by transferring calibrated model parameter values of main river, Megech, to sub basin sub basin 6,8 and 14 and then caring out sensitivity analysis for the sub basin and comparing the results with the original results at the gauging station of Megech and; and it was found that the sensitivity result is the similar. Hence, it is possible to transfer discharge data of the gauging station to the ungauged sub basins 6, 8 and 14.

In sub basin 6, 8 and 14 the comparison results of SWAT flow output, empirical flow and its percentage difference were: 1.74807 cms, 0.91687 cms and 47.5498 %, 4.58654 cms, 2.99436 cms and 34.7142 %, 2.83856 cms, 3.08365 cms and -8.6345 % respectively.

Therefore, transfer of stream flow from gauged river Megech to ungauged sub basin sub basin 6, 8 and 14 were possible and similar studies can be conducted in other Ethiopian river basins so as to solve the problem of stream flow data shortage at ungauged rivers for water resources project development.

Key Words, Megech River Catchment, Assess Transfer of Stream Flow, SWAT Model, Ungauged Sub basins,

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CMS	Cubic Meter per Second
DEM	Digital Elevation Model
DEW02	Dew Point Temperature Calculator
FAO	Food and Agricultural Organization of the United States
GIS	Geographic Information System
HRUs	Hydrologic Response Units
M.A.S.L	Meter above sea level
MoWIE	Ministry of Water Irrigation and Electric
NMSA	National Meteorological Service Agency
NSE	Nash Sutcliff Efficiency
PBIAS	Mean Relative Bias (Percent Bias)
SUFI-2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs

CHAPTER ONE

INTRODUCTION

1.1. Back ground

Water is vital for the life cycle and precious for human and aquatic ecosystems. No life exist without water but availability of water on the earth surface is limited. The problem is in combination of the impact of human induced changes to the land surface and climate, occurring at the local, regional and global (Niehoff *et al.,* 2002). The rapid growing population of the world, increasing frequency, severity of flood, droughts worldwide and human activities impact on the water resource. Previous studies indicated that most rivers, stream reaches and tributaries in the world are ungauged or poorly gauged (Sivapalan *et al.*, 2003; Young, 2006; Mishra and Coulibaly, 2009). While the importance of water availability and management is increasingly recognized but hydrological observation networks are declining (Mishra and Coulibaly 2009). So, discharge estimation for ungauged watersheds under these conditions are highly uncertain and still, it is fore-seeable that estimation of discharge for ungauged watersheds needed. And also many hydrologist need to know the quantity of water to manage and maintain the existing water resources.

Producing stream flow for ungauged watersheds has extracted a lot of interest among hydrologist and hydraulic engineers, but the problem still remains unresolved (Nandakumar and Mein et al., 1997). And also estimation of magnitude and frequency of steam flow are needed to safely and economically design hydraulic structure such as dams, bridges and culverts (Scott et al., 2003) as well as for managing flood plains, identifying flood hazard areas and establishing flood – insurance rates.

Knowing of river flow data are important for a variety of water resources, flood management application and can be obtained in watersheds with networks of flow gauges and records. However, many watersheds remains ungauged or poorly gauged. This is because of lack of budget for installing and maintaining equipment and environmental constraints on location of gauges. Except few amount of river watersheds most of Ethiopian rivers are ungauged (Awulachew *et al.*, 2007) in these ungauged river streams there are no known inflow and out flow of water from the different watersheds. Due to that regionalization is the key tool to solve this problem. Regionalization approaches is used to transfer of information about flow response from a physically similar gauged catchment (pool of watersheds) to the watersheds or sub watersheds of interest. Reliable continuous stream flow forecasting is an important factor in watershed planning and sustainable water resource management. Regionalization is well recognized as a low- cost and popular solution to provide time series of stream flow at ungauged watersheds (Young, 2006; Samuel et al., 2011). Discharge estimation is an important issue in surface hydrology, especially in ungauged watersheds. According to (Sivapalan et al., 2003), ungauged watersheds are ones with inadequate records (in terms of both data quantity and quality) of hydrological observation. Most of the time watersheds, catchments and drainage basins in hydrology have a similar meaning and which is recognized as an area of land where surface water from precipitation drains to the body of water such as stream, river and lake and finally converges to the common outlet which is at the elevation of the required point basins and sub basins.

According to (Redyy,2006) watershed (also sometimes referred to as drainage basins or river basins) is defined as an area of land where surface water from precipitation drained by a stream or stream channel networks such that all the surface runoff originating in this areal leaves the area in a concentrated flow through a single outlet. The objective of this thesis was to assessing transfer of stream data for the ungauged sub watersheds (sub basins) which was nearly similar in physical catchment characteristics and hydrological homogenous with whole gauged watershed (Megech).

1.2 Statement of the Problem

Even though water is vital for the life cycle, precious for human and aquatic ecosystems, proper management of water especially for ungauged river basins have not been done. Because in the ungauged river catchment there is no adequate gauged data obtained.

Most of Ethiopian river basins are poorly gauged or ungauged (Awulachew *et al.,* 2007). Hence, the inflow and outflow of the catchments are not precisely quantified. On the other hand, water resources planning and management require information of inflows from each catchments and total outflow from the rivers. Knowing of stream flow data from ungauged catchment will make easily of management of water resources in that catchment. Hence, ungauged sub basins in Megech catchment are good example for most ungauged basins and sub basins Ethiopia Rivers.

The estimated flow obtained from ungauged basin is required for the frequently encountered in the design, planning of hydraulic and water resources engineering. Most studies in Blue Nile basin indicated that the general estimation of discharge for ungauged river catchments but this study tries to solve and assessing, synthesizing and compare of stream flow data using SWAT model for ungauged sub basins with in the gauged catchment of Megech River, Upper blue Nile basin, Ethiopia.

1.3 Objective

1.3.1. General objective

The general objective of this study is to assess transfer of stream flow data using SWAT model for ungauged sub basins in Megech River catchment, Upper Blue Nile Basin, Ethiopia.

1.3.2. Specific objective

- To carry out hydrological modelling of Megech catchment using SWAT model
- To synthesizing stream flow data using empirical equation
- To compare the stream flow data using SWAT output and empirical equation for ungauged sub basins.

1.4. Research questions

- Is it possible to apply hydrological modelling in Megech catchment using SWAT model?
- How can stream flow be synthesized using empirical equation?
- Does the synthesized stream flow agree with that of SWAT output stream flow?

1.5. Scope of the study

This study is limited to estimate discharge of ungauged catchments in Upper Blue Nile Basin particularly it's found in the Megech River gauged stations. Other effect, like water chemical yield, nutrients content etc., were not considered.

1.6. Significance of the study

The gauged catchments are often used to predict stream flow in space and time domain for operational and scientific investigations whereas regionalization processes enable to transfer model parameter of the gauged simulate response of catchments for which time-series are not available. Since availability of observed data in the ungauged catchment cannot be easily obtained.

The source of estimated stream flow for ungauged catchment is transfer model parameter using regionalization obtained from gauged catchment. Studies on ungauged river basin is the basic importance because of the countries interest in utilization of its water resources , the need to improve and augment development and management activities of these resources and protect from negative impact of climate change in the future. In Ethiopia most river basins and sub basins have less coverage of hydro-meteorological gauging stations. And also in the Megech catchments most sub basins are ungauged. Due to this reason the estimation of full usable water resource potential requires knowledge of the basin as well as the sub basin. Consequently, there is a need to develop a method for predicting flow at the ungauged sites. Thus in this study, it was attempted to estimate stream flow in gauged and ungauged sub basin.

CHAPTER TWO

LITERATURE REVIEW

2.1. Catchment hydrology

Catchment hydrology deals with surface and ground waters on a landscape scale where the unit of interest is the catchment. The catchment refers to the land area that is drained by one river and its tributaries. Catchment (also sometimes referred to as drainage basin or river basin) is defined as an area drained by a stream or stream channel networks such that all the surface runoff originating in this area leaves the area in a concentrated flow through a single outlet (Redyy, 2006). The surface of the hydrologic cycle is where the rainfall and runoff interaction takes place. The input to this system is the rainfall and the output taken as the stream flow at the outlet of the system.

2.2. Rainfall

In the hydrologic cycle, moisture comes from the atmosphere to the surface as precipitation. The rainfall pattern and intensity greatly influences the runoff. If the rainfall intensity is lower than the equilibrium capacity, then all the water reaching the land surface will infiltrate. If the rainfall intensity is greater than the equilibrium infiltration capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water will remain on the ground surface. Therefore, the nature of rainfall pattern is of great importance in dealing rain fall run-off process. A summary of the cycle is given by (Chow *et al.*, 1988) see in figure (2.1)

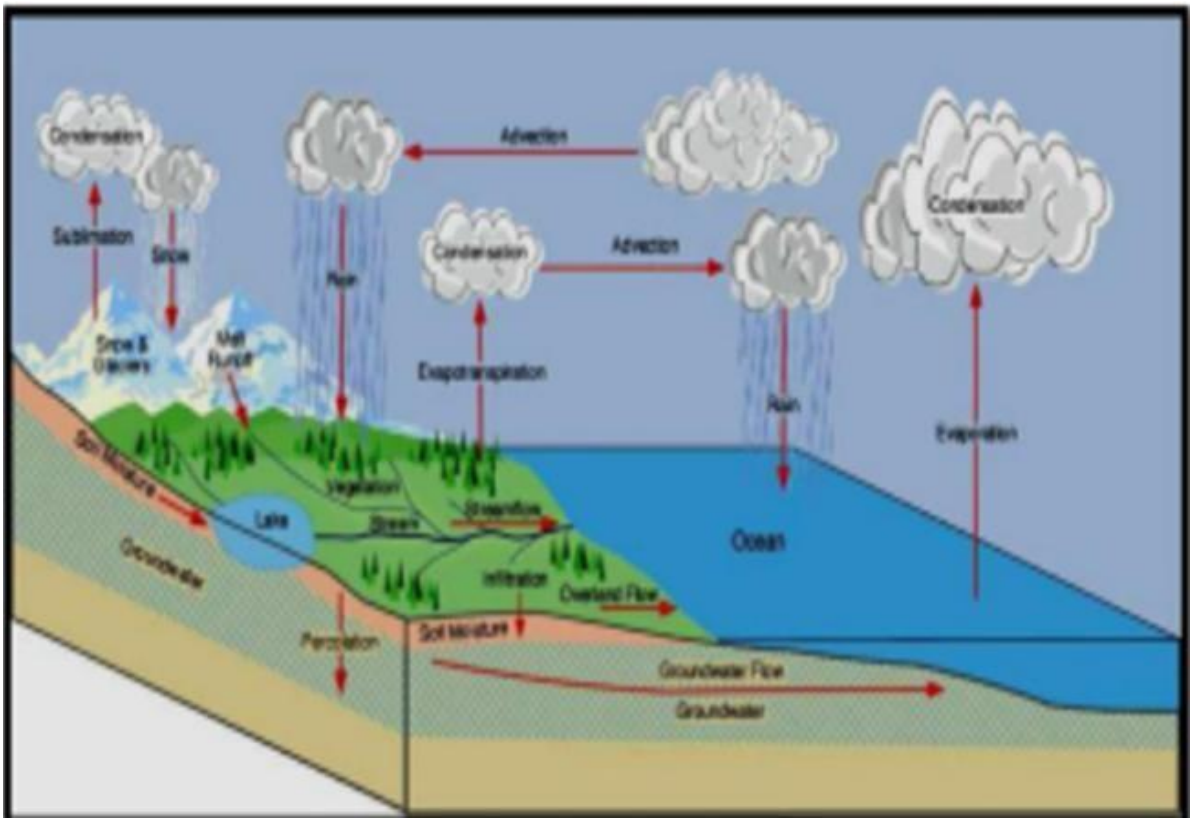

Figure 2. 1 Hydrological cycle (Chow *et al*., 1988)

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 precipitation depth and intensity and for sever conventional storms as is the case in most part of Ethiopia. There is no guarantee that the rainfall will in any way provide a reliable guide to the rainfall of immediate surrounding areas to account the spatial and time variation of rain fall , one can derivate the areal rainfall from a number of point rainfall data.

Flow considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the water that moves over the land in undefined channel is termed as runoff (Chow *et al*., 1988). The derivation of relationships between the rainfall over a catchment area and the resulting flow in a river is a fundamental problem for the hydrologist.

Rainfall-runoff models of different types provide a means of quantitative extrapolation or prediction of discharge and estimation of water balance (Beven, 2001). Two dominant types of these models are physically-based models (PMs) and conceptual models. PMs describe distributed mechanics of hydrological processes. Such models are appropriate for studying the effects of land use changes, soil erosion, and surface groundwater interactions. Beven (1989) made an interesting assertion on current PMs arguing that they are in fact lumped CMs; even if they operate at the grid scale rather than at the catchment scale of more traditional lumped conceptual models. CMs, on the other hand, are well-known for their moderate data requirement. They provide simplified representations of key hydrological processes using a perceived system (Dawson and Wilby, 2001). But they exhibit deficiencies when dealing with ungauged catchments because their model parameters cannot be obtained through calibration. Their conceptual basis also limits their ability to deal with climate/land use change and other dynamic changes taking place in many catchments. This is due to the fact that they only perform reasonably well with calibration based on past data which does not necessarily reflect the future.

2.3. Gauged catchment hydrology

For the purpose of validation of the models used and calibration of parameters, collection of metrological and stream flow data of a gauged catchment is required and for ungauged catchment metrological data is required. In order to apply event based flow estimation for ungauged catchment, the collection of the metrological and stream flow data is the selection of a gauged catchment and metrological data or climatic data of ungauged catchment with daily recording stations required.

2.4. Ungauged catchment hydrology

Stream basin , watershed and catchment or simply basin in hydrology have similar meaning which indicates that an area of land from outer most ridge catchment to the lowest (downstream) point of catchment where surface water from precipitation drains and converges to the common outlet at downstream of river. Outlet in this case the whole delineated watershed surface water passes through it. Ungauged catchment means there has been metrological observation (measurement) but not have hydrological observations (measurements).

According to the definition provided (Sivapalan *et al*., 2003), ungauged catchment is one with inadequate records (in terms of both data quantity and quality) of hydrological observation to enable computation of hydrological variables of interest (both water quantity and /or quality) at the appropriate spatial and temporal scales and to the accuracy acceptable for practical applications. Gauged catchment means it has been estimated daily river discharge (hydrologically) and metrological (climate) measurements. Based on this the gauged catchment classified as the donor of information with respect to simulation results by using SWAT model and total annual rainfall after it has been similar with the ungauged catchments. So, that the gauged catchment is the donor of ungagged catchment with respect to simulation of discharge for both (gauged and ungauged) catchments.

2.5. Regionalization

Spatial proximity and physical similarity are the most used regionalization techniques. Various definitions of regionalization have been used in the literature depending on the contexts and focuses of the studies concerned. The definition of regionalization in different literature was:

He *et al.,* 2011 who stated that Regionalization refers to a process of transferring hydrological information from gauged to ungagged or poorly gauged catchments to estimate the stream flow. The choice of catchment from information to be transferred is usually based on similarity measurements. Similarity measurement is the use of catchment attributes such as land use, soil type and topographic characteristics.

Bloschl and Sivapalan ¨ (1995) conducted that regionalization is transfer of information from one catchment to another.

According to Wagener and Wheater (2006) Regionalization this statistical relationship and theory measurable properties of the ungauged spatial catchment that is used to derive estimates generalization of the local model parameters.

According to (Young, 2006) Regionalization is the relating of hydrological phenomena to physical and climatic characteristics of a catchment/region.

According to (Oudin *et al.,*2010) Regionalization All methods allowing transfer of hydrological information from gauged to ungauged locations regardless of the type of hydrological model used to derive rainfall and runoff relationships, Estimation of model parameters and prediction in ungauged catchments are particularly difficult and are always associated with considerable uncertainties. Estimation of streamflow statistics in ungauged catchments is another issue that is always encountered when engineering design is needed for hydraulic structures. Research focus on prediction in ungauged catchments was formally endorsed and set out by the PUB (Prediction in Ungauged Basins) Science and Implementation Plan within the IAHS (International Association of Hydrological Sciences).

Regionalization techniques have been designed to enable estimates of statistical distribution parameters of stream flow characteristics, e.g. flood frequency distribution, low flow frequency distribution, flow duration curves etc., or rainfall runoff model parameters to simulate continuous stream flow at ungauged catchments. They aim to transfer information from one catchment or a group of catchments to another one or another group. The development of regional analysis for stream flow statistics has a relatively long and rich history and much of its development has benefited the advancement of regional estimation of rainfall runoff model parameters for continuous streamflow simulation (Vogel, 2005). Almost all methods applied to the latter are adapted from the former and hence applicable to the former, with the exception of a number of emerging methods that have only been tested with rainfall runoff models. The most intuitive regionalization method is to identify similar or proxy catchments, be it location wise or behavior-wise. Parameters can be related to catchment descriptors by using regression functions in which rainfall-runoff model parameters and catchment descriptors become explained variables and explanatory variables respectively.

2.6. Previous works on regionalization

Many researchers carried out on discharge estimation for ungauged catchments through regionalization approaches among these researchers some are mentioned below:

Awulachew *et al.*, 2007 reported that that most of Ethiopian rivers are ungauged due to that regionalization is the key tool to solve this problem and Oudin *et al.*, 2008 assessed the relative performance of three classical regionalization schemes over a set of French catchments: spatial proximity, physical similarity and regression.

The spatial proximity approach used to transferring parameter sets from neighboring to the target ungauged catchment. Proximity (relationship) of the ungauged catchments to the gauged ones is quantified by the distances between catchments. The transfer of catchment information is only based on some sort of similarity between ungauged and gauged catchments. A number of methods have been applied to modelling ungauged basin such as spatial proximity (Merz and Blo”schl, 2004). The spatial proximity method is based on the principle of catchments that are close to each other. The spatial proximity approach is criticized (indicate the faults of in a disapproving) in the literature (WA-Gener and Wheater, 2006), because of geographical closeness of catchments does not hydrologically similar. Therefore, the physical similarity approach that compares the closeness of catchments on the basis characteristics seems to be the most reasonable regionalization approach. Since the purpose of the regionalization is to estimate some characteristics of the flows at an ungauged site rather than estimating the model parameters, the performance of the regionalization should be assessed by comparing the predicted and observed response characteristics for gauged test catchments. Regional homogeneity can be evaluated using one of a number of tests that have been developed for this purpose. A commonly used approach is a homogeneity test developed by (Hosking and Wallis, 1997). Hydrologic similarity is an essential concept in regionalization. Many similarity concepts have been proposed in the literature that attempt to represent various hydrologic process occurring at different locations: those are spatial proximity and similar catchment attributes. Spatial proximity, catchments that are close to each other which is hydrologic ally similar. Similar catchment attribute, such as catchment size, mean annual rainfall and soil characteristics are used as indictor of physiographic similarity. Physiographic catchment characteristics are shape, location, elevation, slope, aspect, stream density, stream frequency, vegetation cover and soil types

a. Shape of the catchment is characterized by its area and perimeter,
b. location of the centroid of each catchment in Eastings and Northings are derived using GIS tools and the catchment boundaries
c. Elevation, the mean, maximum, minimum and range of elevations within the catchment are derived using DEM
d. Slope the mean, maximum, minimum and range of slope within the catchment are derived using DEM
e. Aspect is the catchment presented as the percentage of catchment that faces North, South, East and West. these percentage are derived using DEM
f. Stream density of the catchment is defined as the total length of stream within the catchment divided by the catchment area.
g. Stream frequency of a catchment is defined as the total number of stream junctions within the catchment divided by the catchment area. Junction are

defined as the number of points where two stream line intersect. But, a stream running straight through the catchment have no junction.

h. Vegetation cover has been expressed as the percentage of a catchment covered by woody vegetation
i. Soil type is the selected catchment various soil hydrological characteristics are calculated.

According to (Niehoff *et al.*,2002) Land use/cover refers to natural vegetation cover and the human activities that are directly related to land, making use of its resources and interfering in the ecological process that determine the functioning of land cover.

The impact of land use change on the hydrologic process in the tropics was particularly investigated in terms of rainforest conversion during the 1980s and 1990s (Giertz *et al.,* 2005). In a study conducted by (Hundecha and Bardossy, 2004). It was found that urbanization leads to a 2.9% increase in the peak flow following a summer storm while an increase in the peak flow. In the peak flow due to increased afforestation was also reported by (Hundecha and Bardossy, 2004). According to (Schaetzl and Anderson, 2005), soil means different things to different people. By Engineers view soil as material that be used in construction and as a medium for foundation ; farmers view soil as a medium where it can grow crops ; penologists , then again , view soil simply as something natural , formed on the earth surface. There are four components of soils: Air 25%, water 25%, mineral particles 45%, and organic matter 5%, Adopted from (Pidwirny, 2006). The texture of a particular soil refers to the size distribution of the particles found in a representative sample of that soil (Pidwirny, 2006). Soil texture and coarse fragment content are most important properties for a number of reasons but most importantly the way water moves through and is retained in the soil (Schaertzl and Anderson, 2005). Different soil types affect runoff generation differently.

Topography is represents the contour or arrangement of land surface including its relief and the position of its natural and man-made features (Krause, 2008). Topographic maps are usually used to show areas of different elevations on the area. Elevation of mountains and valleys, steepness of slope and the direction of stream flow can be determine. The larger slopes generate more velocity than the smaller slopes and hence can dispose of runoff faster. Hence, for smaller slopes the balance between rainfall input and the runoff rate gets stored temporally over the area and is able to drain out gradually over time.

(Haggard *et al*., 2005) as well as (Khan *et al*., 2007) reported that an increase in surface in slope showed an increase in surface runoff.

Rientjes *et al* ., 2011 and Wale *et al*., 2009, performed model calibration in Lake Tana Basin to get optimized parameters for gauged catchments and used the advantages of physical catchment characteristics similarity to transfer the optimized characteristics and finally conclude that the physical catchment characteristics outperform than regression method.

According to (Deckers D, 2006) the choice of catchments from which information is transferred is usually based on some sort of similarity. A number of methods have been applied to modeling ungauged basins such as similarity of spatial proximity and similarity of catchment characteristics

2.7. Hydrological modeling

Hydrology models are used extensively for hydrologic predictions and hydrologic system analysis (Chow *et al.*, 1998). A hydrologic model can be defined as a mathematical model representing one or more of the hydrologic process resulting from precipitation and culminating in catchment runoff. Hydrologic models aid answering questions about the effect of land management practices on quantity and quality of runoff (Hundecha and Ba'rdossy, 2004 and Moriasi *et al.*, 2012). Many hydrologic models, which are hydrological transport models, distributed hydrological models, composite models etc., have been used in order to understand hydrological processes in the world. Distributed hydrologic models take spatial dependence of meteorological input, soils, vegetation and land use into account. Since the distributed hydrological models combine spatial variability of these inputs while simulating hydrologic process in the watershed basin, the models are frequently applied to produce water management strategies. Advantages of these models are that they can better streamflow prediction at the basin outlet and predict streamflow at the interior locations where streamflow measurements may not be applicable. Semi-distributed models are based on lumped models, which treat the complete basins as a homogeneous whole. They model hydrological processes at sub-basins or sub-areas of the basin that are considered as homogeneous within themselves. The semi-distributed models can estimate the stream flow at the basin outlet and at the interior points more accurately than distributed models (Khakbaz *et al*., 2012).Since semi-distributed and physical based models are easier to setup and require relatively shorter running times and the physical based SWAT model was chosen for this study.

2.8. Hydrological model selection

Hydrological models are mathematical formulations which determine the runoff signal which leaves a watershed basin from the rainfall signal received by this basin. They provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources. Such hydrological models are also used as means of extrapolating from those available measurements in both space and time into the future to assess the likely impact of future hydrological change. Changes in global climate are believed to have significant impacts on local hydrological regimes, such as in stream flows which support aquatic ecosystem, navigation, hydropower, irrigation system, etc. Many comprehensive spatially distributed hydrologic models have been developed in the past decade due to advances in hydrologic sciences, Geographical Information System (GIS), and remote sensing. Among the many hydrologic models developed in the past decade, the Soil and Water Assessment Tool (SWAT), developed by (Arnold *et al*., 1993), has been used extensively by researchers. This is because SWAT

- ❖ Uses readily available inputs for weather, soil, land, and topography,
- ❖ Allows considerable spatial detail for basin scale modeling, and
- ❖ It is capable of simulating change in catchment characteristics using different scenarios
- ❖ Hence, SWAT will be used in this study to stream flow the gauged and ungauged catchments on river flow.

2.9. SWAT model

SWAT is a public domain model actively supported by the USDA (United States Department of Agriculture) – ARS (Agricultural Research Service) at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. The SWAT2009 model was built with an attempt to simulate the stream flow processes and the effects of land management on water quality and quantity. The model uses readily available inputs as it is coupled with an Arc GIS environment. This enables the users to study long-term impacts of land cover and climate, land management and nutrient supply on the water resource potential. The major components simulated by SWAT are: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch *et al.,* 2005). Evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing are simulated by the hydrologic component of the SWAT model (Arnold and Allan, 1996). The hydrological component divides the simulation into four processes: surface flow, subsurface flow, and interflow, shallow aquifer and deep aquifer, and open channels. Total stream flow is determined by summing the surface flow into lateral flow and base flow which is returned to the stream from the shallow aquifer. The deep recharge to the aquifer is considered as a loss from the hydrologic component. 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. In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation (Setegn *et al*., 2009):

$$\mathrm{SWt} = \mathrm{SWo} + \sum_{i=1}^{t} (\mathrm{Rday} - \mathrm{Qsurf} - \mathrm{Ea} - \mathrm{Wseep} - \mathrm{Qqw}) \qquad (1)$$

Where; SWt is the final soil water content (mm), SWo is the initial soil water content on day i (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), and Qgw is the amount of return flow on day i (mm).

2.9.1. Sensitive analysis

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 and Williams,

1990) 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. Once the total amount of rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green & 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).

2.9.2. Calibration

Calibration is the process whereby model parameter 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 (Grassman *et al*., 2007). (Coffey *et al.*, 2004) presented nearly 20 different statistical tests that can be used for evaluating SWAT stream flow output during a manual calibration process. They recommended using the NashSutcliffe simulation efficiency ENS and regression coefficients R^2 for analyzing monthly output and median objective functions, sign test, autocorrelation and cross-correlation for assessing daily output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by (Spruill *et al.*, 2000). (Eckhart and Arnold 2001) outlined the strategy of imposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT.

Subsequently an automatic calibration of the version 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 (Grassman *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.

2.9.3. Validation

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

2.9.4. Advantage and disadvantage of SWAT model

2.9.4.1. Advantages

One fundamental advantage of SWAT is its ability to model ungauged or poorly gauged watersheds. This makes it attractive for use in developing countries where there is in adequate infrastructure to measure required inputs for hydrologic modeling (Mutenyo et al., 2013). Setegn *et al*, (2008) has tested the performance of SWAT in the northern highlands of Ethiopia for modeling of hydrology and sediment yield. He made modeling of four tributaries of Lake Tana and he found SWAT model gives good agreement with observed and simulated flows. (Ephrem, 2011), the prediction of quantity and stream flow from land surface in particular for ungauged catchments is difficult and time consuming.

According USEPA (2005) key features that make the model applicable for a wide range of studies are:

- Modeling based on physical process associated with soil and water interaction.
- Flexibility to incorporate crop characteristics , cropping stage and practices
- computational efficiency
- Capability of long-term simulation
- Capability of modeling catchment areas varying between few hectares to thousands of sq.k.
- The model is freely available and can be easily downloaded from the internet

2.9.4.2. Disadvantages

Following are some of the limitations using SWAT for hydrological modeling (USEPA, 2005): Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to present the spatial variation in the hydro-meteorological characteristics in the area.

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

CHAPTER THREE

MATERIALS and METHODS

3.1 Description of the study area

Megech watershed is part of the Blue Nile basin and also the tributaries of Tana basin. Dega and weynadega are the most common types of agro ecological zones of the watershed with the rainfall over the study area mono-modal and it receives its main rainfall from June to September. The annual rainfall varies between 1500 to 2000 mm and the annual average rainfall is 1823mm. The maximum and minimum monthly temperature varies between 22.9 – 29.9 ^{0}C and 11.6 – 15.8 ^{0}C respectively. The watershed total area is 431.52 km^2 and which is located in Amhara National Regional State, North Gondar Zone , Ethiopia and the geographical coordinate of the area is 12°31'12"N’ to 12°38'42"N” North in latitude and from 37°25'48"E’ to 37°30'0"E’ East in longitude with an average altitude of 1973-2417 m.a.s.l.

It is accessed by all-weather road of near town through the regional town Bahir Dar to North Gondar. It’s found at 720 km distance from the capital city of Ethiopia, Addis Ababa and found at a distance of 175 km from the regional state of Amhara, Bahrdar in the north part.

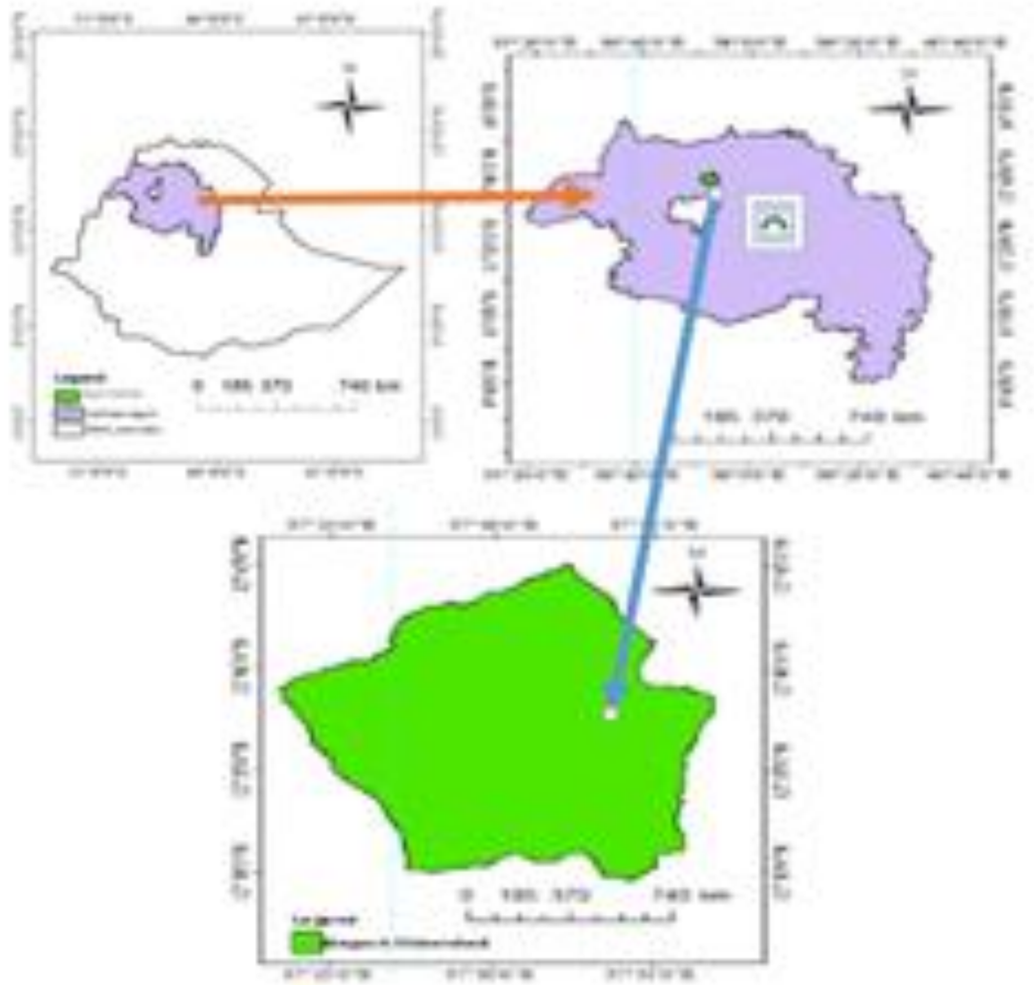

Figure 3. 1 Location of study area

3.2. Land use/cover

The land use map of the study area was obtained (MoWIE, 2010). It helped as categorized the land use land cover of the study area. These are: Agricultural, Urban, Pastoral and Agro pastoral. The watershed area is dominated by Agricultural land use. This indicated that most of agricultural land use in includes: cultivating a large number of crops belonging to cereals, pulses, oilseeds and horticultural groups mainly under rained production system. Coverage area in percentage of each land use land cover of the watershed from large to small see in (Table 3.1) respectively.

Table 3. 1 Description land use/ covers type

Land use	Land use swat	Swat code	Area (Km^2)	%Watershed area
Agriculture	Agriculture Generic	AGRL	321.81	74.58
Agro-pastoral	Agricultural close grown	AGRC	5.88	1.36
Urban	Urban	URLD	94.92	22
Pastoral	Pasture	PAST	4.12	0.95
Teff	Eragrostis	TEFF	4.79	1.11
Total			431.52	100

3.3. Soil

Data that obtained from the (MoWIE, 2008) which are important for identifying major soil types of studying area. The major and dominant soils in the study area are EutricLeptosols, EutricVertisols, Dystric cambisols, Haplic Nitosols and EutricFluvisols. Sea in table (3.2)

Table 3. 2 Description of soil types using SWAT code.

Soil swat	Swat code	Area(Km^2)	%Watershed area
EutricLeptosols	LPe	372.71	86.37
EutricFluvisols	Je	37.3	3.66
EutricVerticsols	VRe	0.88	0.2
Dystric Cambisols	Bd	4.82	1.12
Haplic Nitosols	NTh	15.79	8.65
Total		431.5	100

3.4. Study design (procedure)

The flow chart figure (3.2) below shows that the study design (procedure) of this methodology.

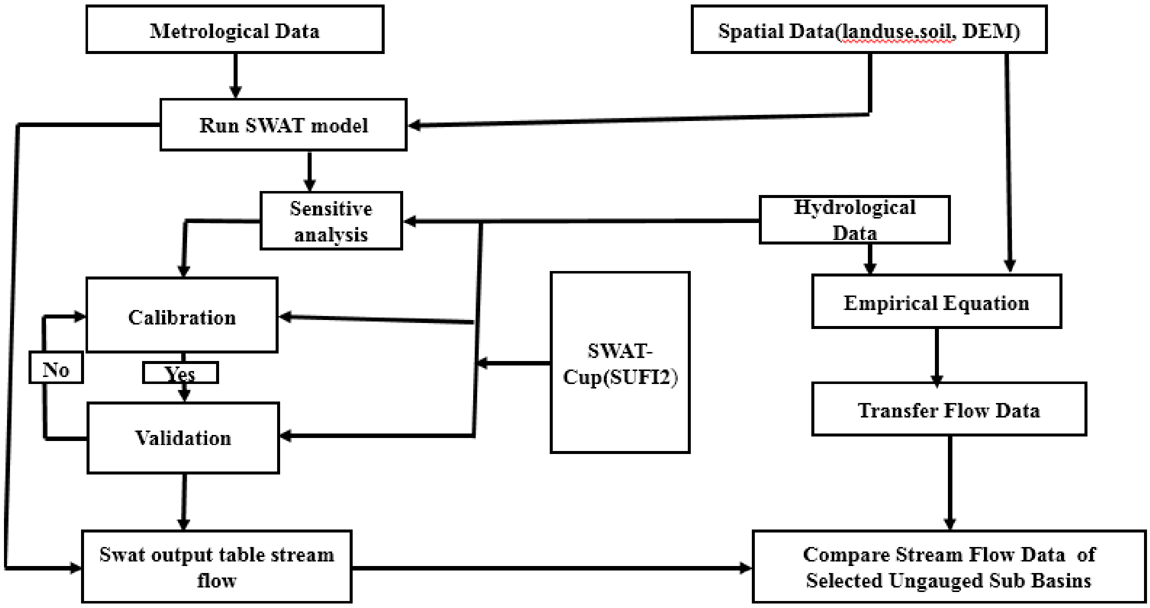

Figure 3. 2 Flow chart of study area

3.5. SWAT input data and software

3.5.1. SWAT input data

The data that used for processing and analysis of this study were relevant such as spatial data (DEM, land use map and soil map) metrological data (rainfall, temperature, sunshine, relative humidity and wind speed) and hydrological stream flow data were gathered and collected from different organizations or sources for more details see table (3.3) below

Table 3. 3 SWAT input data and sources

Data type	Source	Period	Description	Remark
Metrological (weather)	NMSA, Climate Forecast System Reanalysis' (CFSR) Global Weather Data for SWAT)	2000-2013	Daily precipitation, maximum and minimum temperature, wind speed and relative humidity	There is no quality data long period of mean missing (especially in relative , and temperature
Hydrology data	MoWIE	2000-2013	Daily and monthly flow data	No missing data
Soil,	MoWIE			
landuse/cover	MoWIE			
DEM	MoWIE		90m×90m	

Table 3. 4 Location of weather station

Weather Monitoring Station	Coordinates			Remark
	Latitude	Longitude	Altitude (m. a. s. l)	
Megech(Aezozo station)	12°31'16.14"N	37°25'54.84"E	1974	Used as weather generator station
W123	12°38'42"N	37°30'0"E	2417	CFSR's grid
W123	12°19'58.8"N	37°11'16.8"E	1836	CFSR's grid
Enfranz	12°15'30.492"N	37°37'33.35"E	1937	
Maksegnit	12°23'18.24"N	37°33'18.36"E	1912	

Table 3. 5 Location of stream flow gauging station.

Flow Monitoring Station	Coordinates		Catchment Area (km2)
	Latitude	Longitude	
Megech river near azezo station	12°17'24"N	37°16'12"E	462

Source: Ministry of Water, Irrigation and Electric

3.5.2. Software

Different software were used to effectively execute the research. These were including for organize and configure the projection system of digital elevation model (DEM), Arc SWAT 2009 used for Watershed delineation and discharge simulation of gauged catchments with Arc GIS 9.3 in interface and which was used for processing and analyzing the data base , developing and executing map from the database. SWAT CUP 2012 for the hydrological model calibration and validation and Global Weather Generator for SWAT data used for additional or for those have a scarce of data , Stationeries , Computer, PcpSTAT , Dew point 02 and Microsoft Excel were used for writing and preparation of the research .

3.6. Estimating of missing data

3.6.1. Data quality and consistency analysis

The collected data from different sources were contained errors and missed due to the failures of measuring device or the recorder. So, the raw data before using for the target area, the data were filled missing data and check consistency.

3.6.2. Filling-in missing data

Stations having missed data of records were identified and filled using appropriate method. There are different methods for filling the missing data. Like, average arithmetic and normal ratio method etc. The normal ratio method is used if any surrounding gauges the normal annual precipitation exceeding 10% the considered gauges (Singh, 1994; as quoted in Samuel, 2014). So, the missed data were estimated and reconstructed by normal ratio method because the normal annual precipitation of the meteorological station of the study area is exceeding by 10%. The method is given as:

$$Px = \frac{Nx}{N}\left(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pn}{Nn}\right) \quad (2)$$

Where: P_x = Missing value of precipitation to be computed, N_x=Average annual value of rainfall for the station, N1, N_2, N_n = Average Annual value of rainfall for the neighboring station. P_1, P_2, P_n= Rainfall of neighboring station during missing period N = Number of stations used in the computation.

3.6.3. Consistency analysis

The consistency of the meteorological data set of the given station was cheeked by the double mass curve method with in reference to their neighborhood station. The double mass curve was plotted by using the annual cumulative total rainfall of the station under study as ordinate and the average annual cumulative total rainfall of neighboring station (base station) as abscissa, and checking whether they align in a single straight line or not and correlation between the variables (ADF, 2003). For this study the double mass curve which was used for the plot of the annual cumulative total rainfall data of the base station with the average annual cumulative total rainfall data of neighborhood station. The graph of the double mass curve plot was found almost linear this implies that the rainfall data was consistent over the considered period. A consistent record is one where the characteristics of the record have not changed with time. Double-mass-curve analysis is the method that is used to check for an inconsistency in a gauge record.

The method for checking consistency of a hydrological or meteorological record is considered to be an essential tool for taking it for analysis purposes. It is determined by plotting the cumulative values of observed time series of station for which consistency need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x- coordinate. The station affected by trend or a break in slope of the curve would indicate that conditions have changed that location. The data series, which is inconsistency, will be adjusted to consistent values by proportionality. Therefore, the station to be adjusted for consistency by using the equation:-

$$Si = \frac{\Delta Yi}{\Delta Xi} \quad (3)$$

Where, S_i = the slope of section i, ΔY_i = the change in the cumulative catchment for gauge Y between the end point of the section i and ΔX_i = the change in the cumulative catchment for the sum of the regional gauges between the endpoints of sections i.

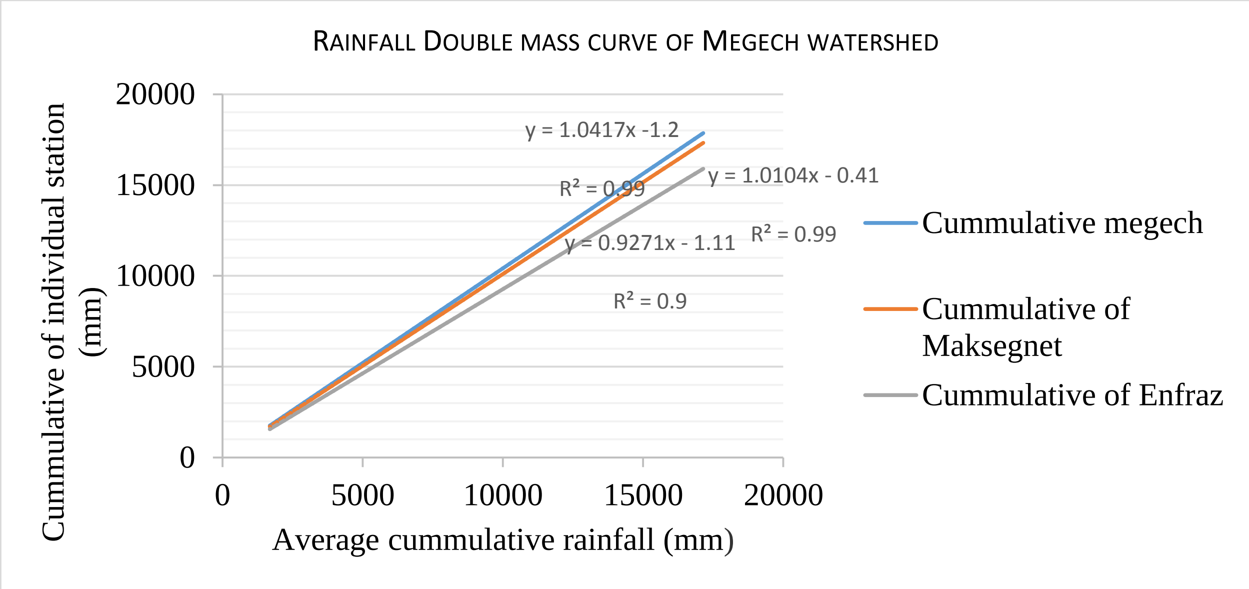

Figure 3. 3 Double mass curve of all the stations

3.7. Hydrological model selection

Hydrological models are mathematical formulations which determine the runoff signal which leaves a watershed basin from the rainfall signal received by this basin. They provide a means of quantitative prediction of catchment runoff that may be required for efficient Management of water resources. Such hydrological models are also used as means of extrapolating from those available measurements in both space and time into the future to assess the likely impact of future hydrological change. Changes in global climate are believed to have significant impacts on local hydrological regimes, such as in stream flows which support aquatic ecosystem, navigation, hydropower, irrigation system, etc. In addition to the possible changes in total volume of flow, there may also be significant changes in frequency decade due to advances in hydrologic sciences, Geographical Information System (GIS), and remote sensing. Among the many hydrologic models developed in the past decade, the Soil and Water Assessment Tool (SWAT), developed by (Arnold *et al.*, 1993), has been used extensively by researchers. This is because SWAT

- ❖ Uses readily available inputs for weather, soil, land, and topography,

- ❖ Allows considerable spatial detail for basin scale modeling, and
- ❖ It is capable of simulating change in catchment characteristics using different scenarios

3.8. Description of SWAT model

SWAT is a public domain model actively supported by the USDA (United States Department of Agriculture) – ARS (Agricultural Research Service) at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. The SWAT2009 model was built with an attempt to simulate the stream flow processes and the effects of land management on water quality and quantity. The model uses readily available inputs as it is coupled with an ArcGIS environment. This enables the users to study long-term impacts of land cover and climate, land management and nutrient supply on the water resource potential.

The major components simulated by SWAT are: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch *et al.*, 2005). Evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing are simulated by the hydrologic component of the SWAT model (Arnold and Allan, 1996). The hydrological component divides the simulation into four processes: surface flow, subsurface flow, and interflow, shallow aquifer and deep aquifer, and open channels. Total stream flow is determined by summing the surface flow into lateral flow and base flow which is returned to the stream from the shallow aquifer. The deep recharge to the aquifer is considered as a loss from the hydrologic components (Arnold and Allan, 1996).

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.

In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation (Setegn *et al*., 2009): as shown in equation (1)

$$\mathrm{SWt} = \mathrm{SWo} + \sum_{\mathrm{i}=1}^{\mathrm{t}} (\mathrm{Rday} - \mathrm{Qsurf} - \mathrm{Ea} - \mathrm{Wseep} - \mathrm{Qqw}) \qquad (1)$$

Where; SWt is the final soil water content (mm), SWo is the initial soil water content on day i (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea 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 Qgw is the amount of return flow on day i (mm). Arc SWAT component have four main steps: Watershed Delineation, Hydrologic Response Unit (HRU) Analysis, Weather Data Definition and SWAT simulation including sensitivity analysis and calibration. In order to understand how each section works within the modeling process, it is important to understand the conceptual framework of each step,

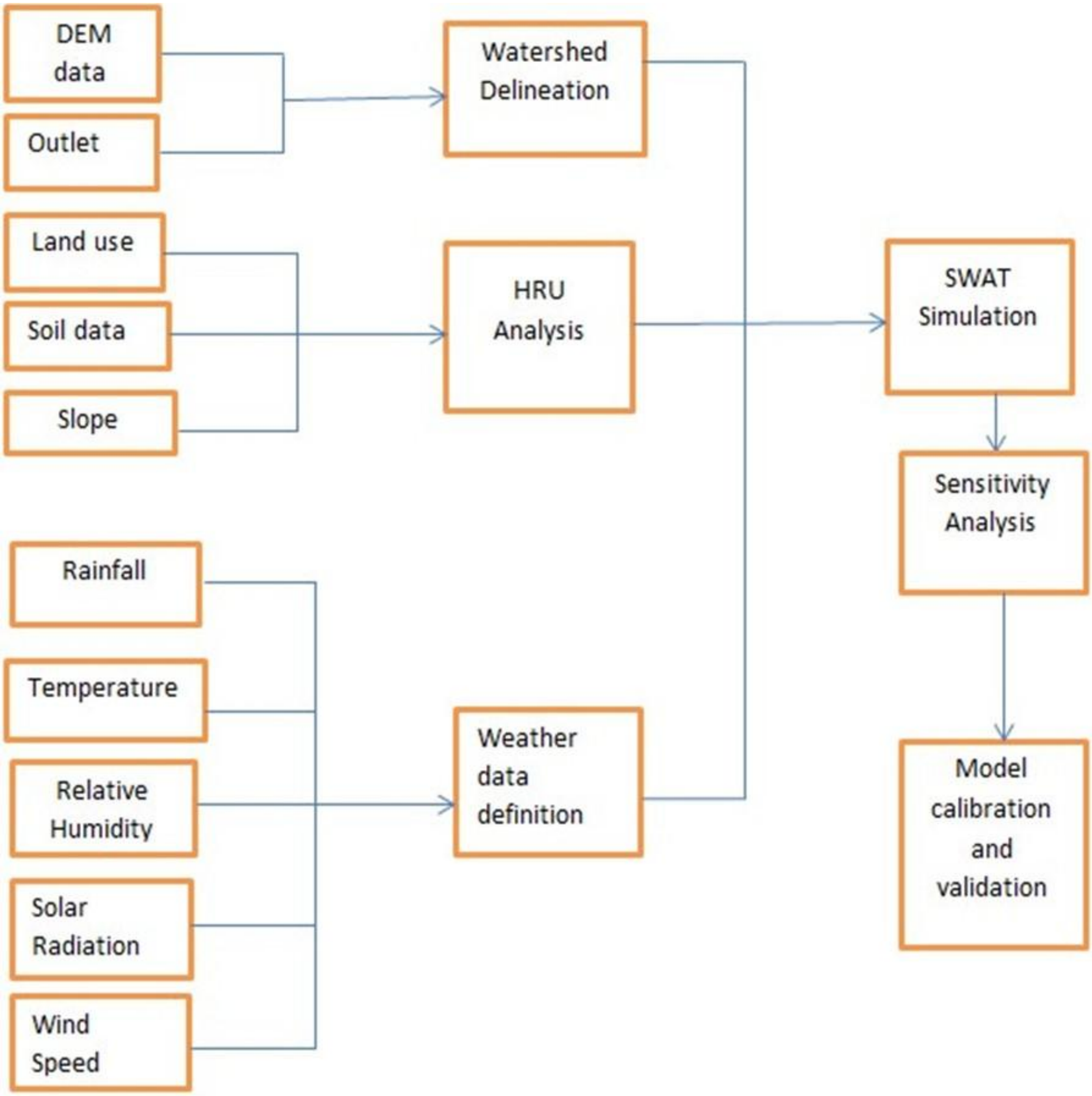

Figure 3. 4 Component of Arc SWAT (Arnold and Allan, 1996)

3.9. SWAT-CUP

SWAT CUP is an interface that was developed for SWAT. Using this generic interface, any calibration or sensitivity program can easily be linked to SWAT. This is demonstrated by the program links GLUE, Parasol, SUFI2, and MCMC procedures to SWAT. In this particular study, it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration that requires the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model.

3.10. Model Set Up

Component of Arc SWAT model mentioned as follow:

3.10.1. Watershed delineation

Automated watershed delineation embedded in Arc SWAT interface was used to delineate the watershed. The Megech watershed delineation was done using DEM 90m x 90m. DEM was imported into the SWAT model and projected to UTM zone 37N, projection area of Ethiopia.

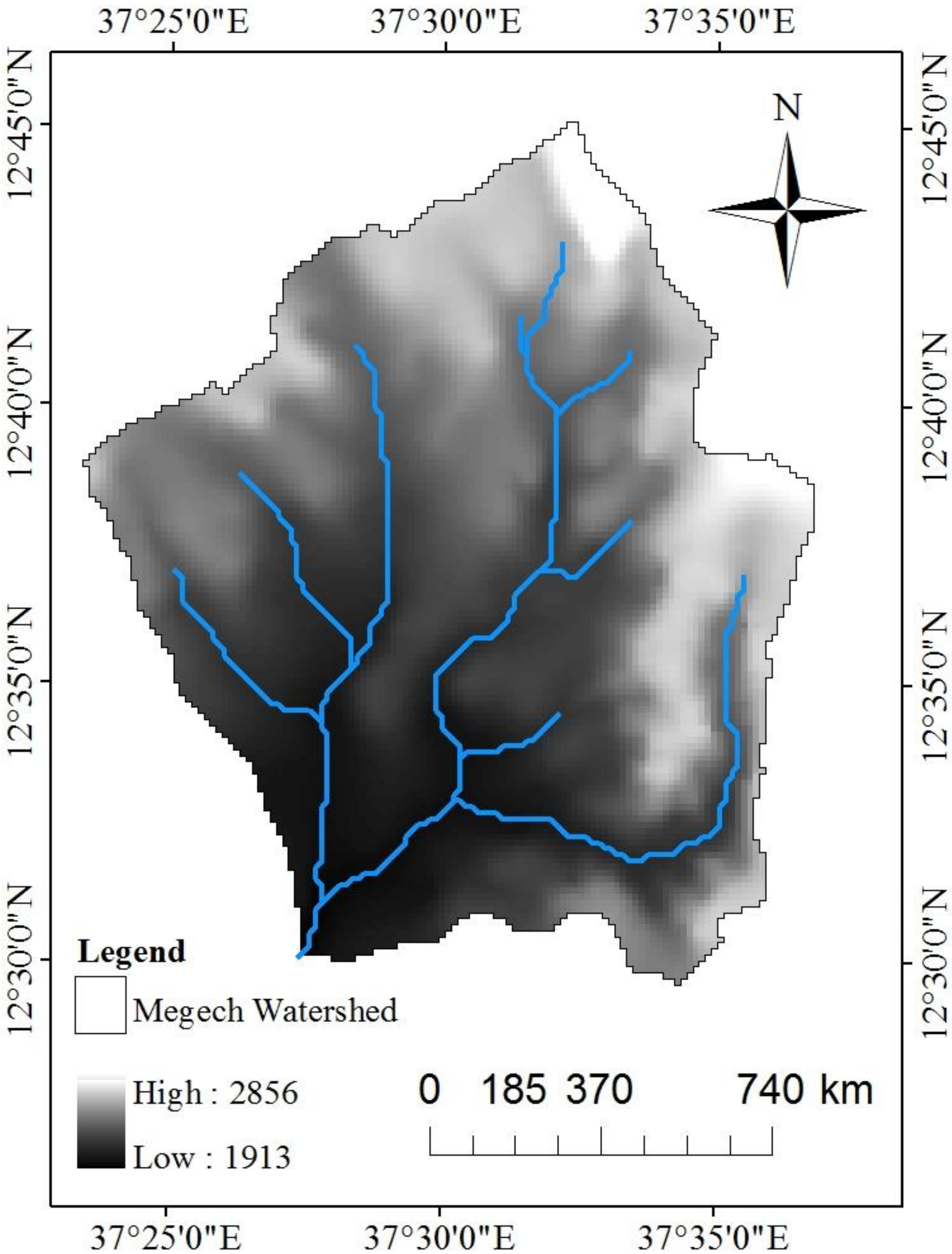

Figure 3. 5 DEM of the study area

In this study, the minimum threshold area of 1000 ha was used to define the stream network and detail delineation of the watershed. This threshold area was used to define the minimum drainage area required to form the origin of a stream and to decide the number of sub-watersheds (sub basin) with in the watershed. The stream network and the sub basin outlets were defined. Using of the gauge station coordinate, outlet the catchment was manually defined and there were 17 sub basin created.

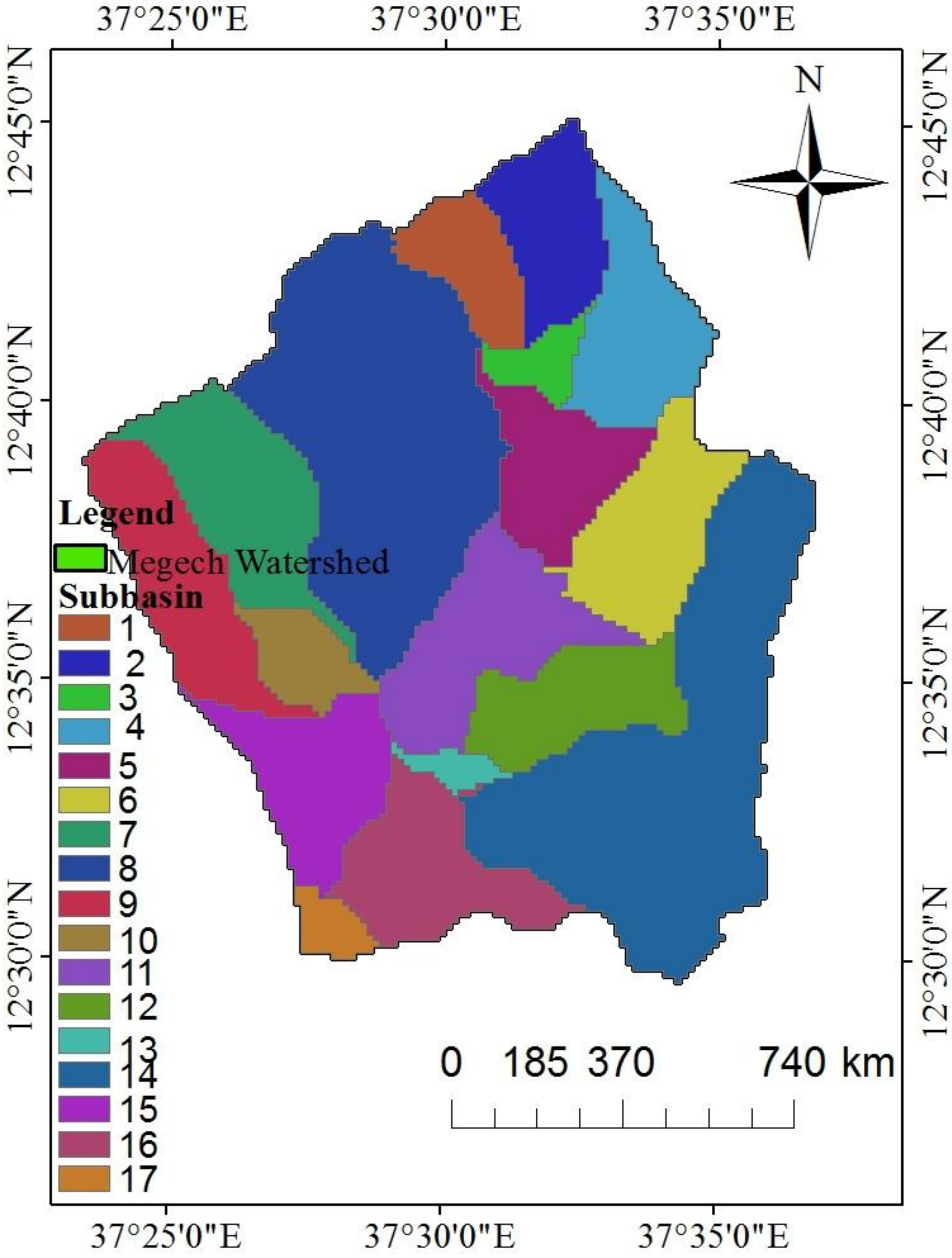

Figure 3. 6 Sub basin of watershed

SWAT model require land use/land cover and soil data in order to determine the area and the hydrologic parameters of each land use and soil category simulated in each sub watershed. The land use/land cover, slope and soil map were imported into the interface and reclassified. Classes which belonged to the same category and had close hydrological properties were combined into five land use/land cover major classes. The very small classes which are far less than 5% percent of the total area were ignored. This was done using Arc Map interface Arc SWAT. Land use, slope and soil were reclassified again in Arc SWAT interface. Current SWAT database has only values of hydrological property parameters of the most common type of land use/land cover classes. Some of the land use land cover classes and their parametric values did not exist in SWAT default data base. It was necessary to replace these classes with land use/land cover classes of the SWAT database which have similar hydrological properties.

Therefore, during reclassification, land use/land cover classes which were not exist in SWAT database substituted by classes which exist in SWAT database and have similar hydrological properties. The soil map of the study area was reclassified according to Arc SWAT requirements. It was reclassified into the most representative classes of the study area. During the reclassifying process there was a problem of obtaining the values of soil parameters that represent physical and chemical properties of each soil class which were used as SWAT input data. Food and Agriculture Organization of the United Nations (FAO) soil classification system which was supported by other additional method was used to determine soil types and properties of each soil class. Partly the values of the parameters of hydrological properties have been determined by studying typical textural characteristics of an existing soil material and estimating their values by referring other similar previous works.

Slope classification was carried out based on the height range of the DEM used during watershed delineation. The slope values were reclassified in percent. It was reclassified in to three classes. In the next step, all the reclassified three maps were overlaid. This procedure helped to determine land use/cover /soil /slope class combination and distribution for the delineated watersheds and each respective sub-watershed. Then, the sub basins were divided into Hydrologic Response Units (HRUs) by assigning the threshold values of land use/cover and soil percentage. While assigning multiple HRUs to each sub basin the thresh hold level should be defined in which the user can specify sensitivities for land use/cover, soil and slope data that will be used to determine the number and kind of HRUs in each watershed. In general the thresh hold level used to eliminate minor land use/land cover in sub basin, minor soil with in a land use/land cover area and minor slope classes with in a soil on specific land use/land cover area. Following minor land use/land cover, soil areas and minor slope classes elimination, the area of remaining land use/covers, soils and slope classes are reapportioned so that 100% of their respective areas are modeled. SWAT2009 threshold value was chosen for soil and land use/land cover for defining the number of HRUs.

3.10.2. Hydrologic Response Unit (HRU) definition

Sub watersheds were subdivided after watershed delineation, into areas having unique land use, soil and slope so called hydrologic response unit (HRUs). Even if the individual fields with specific land use, soil and slope were scattered over the sub watersheds, when lumped together they form HRUs. The land use, soil and slope data sets were projected in to the same projection as DEM. Then land use, soil and slope grids were overlaid and linked with the SWAT databases and ready for HRU definition. To define the distributions of HRUs multiple HRU definition options were selected. The threshold level set for land use, soil and slope was used to define the number of HRUs within the sub watersheds. During the delineation of watershed, the area and sub watershed results obtained were 431.5 km^2 and 17 respectively. The HRUs of the watershed was derived from the combination of DEM, soil, slope and LULC data provided to the software. Most of the time the default of SWAT recommends that 10% soil, 20% LULC, and 20% slope thresholds have been used (Neitsch *et al.*, 2005); however, the selection is based on the user’s purpose. Similarly, for this thesis work for more precise of HRU creation, 10% soil class over land use area , 5% land use percentage over sub basin area and 10% slope class over soil area combinations in the multiple HRU option was used. Based on this, 82 HRUs were created.

The SWAT model requires the creation of Hydrologic Response Units (HRUs), which are the unique combinations of land use, soil and slop type within each sub basin. The land use, soil and slop classifications for the model are slightly different than those used in many readily available datasets and therefore the land use, soil and slop data were reclassified into SWAT land use and soil classes. See figure (3.7,3.8 and 3.9).

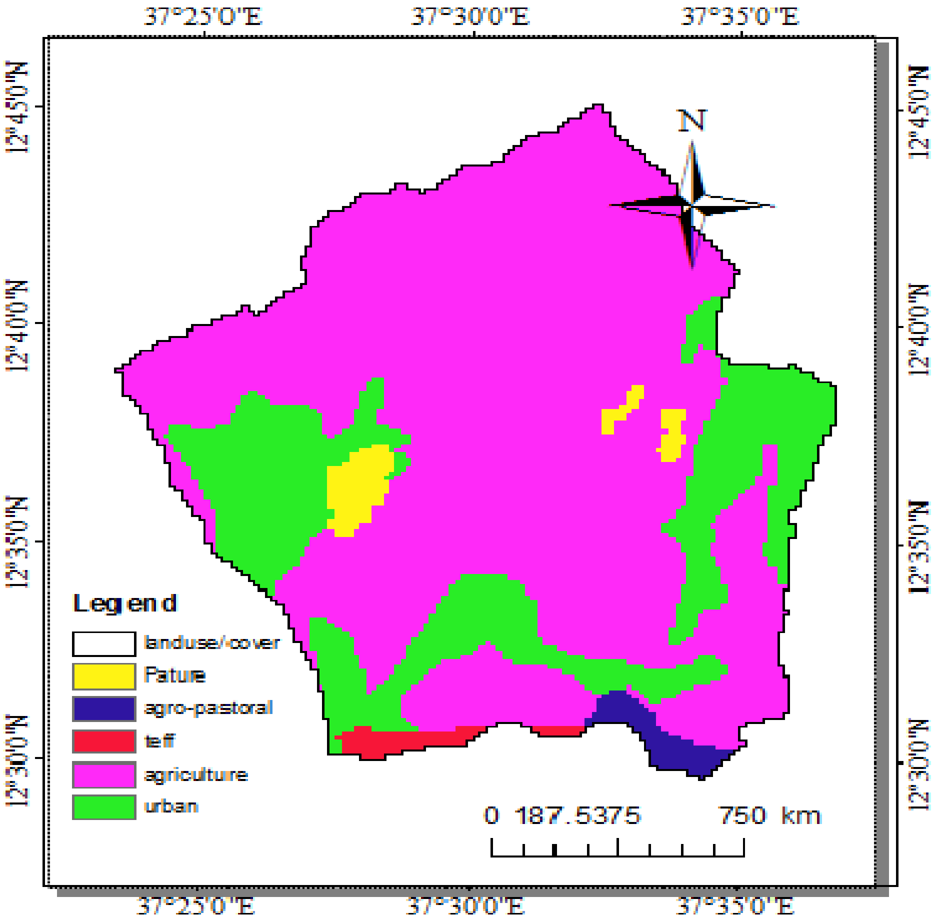

Figure 3. 7 Land use classification.

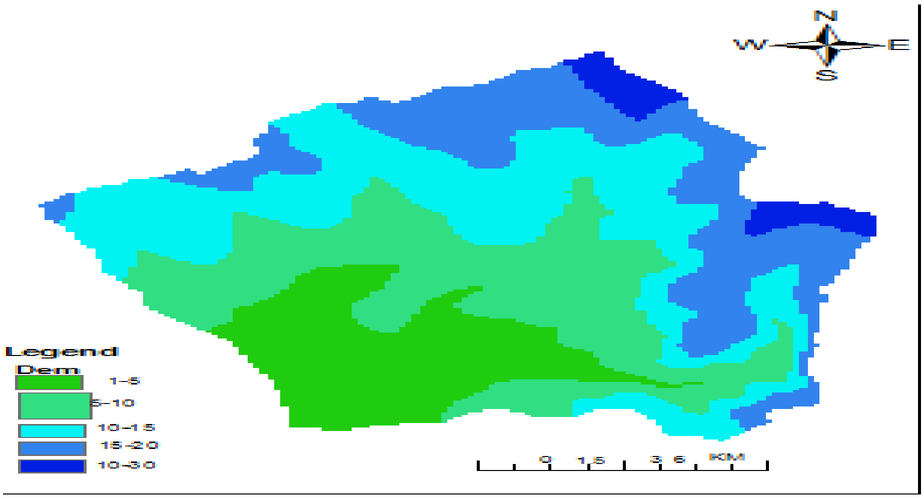

Figure 3. 8 Slope clasification

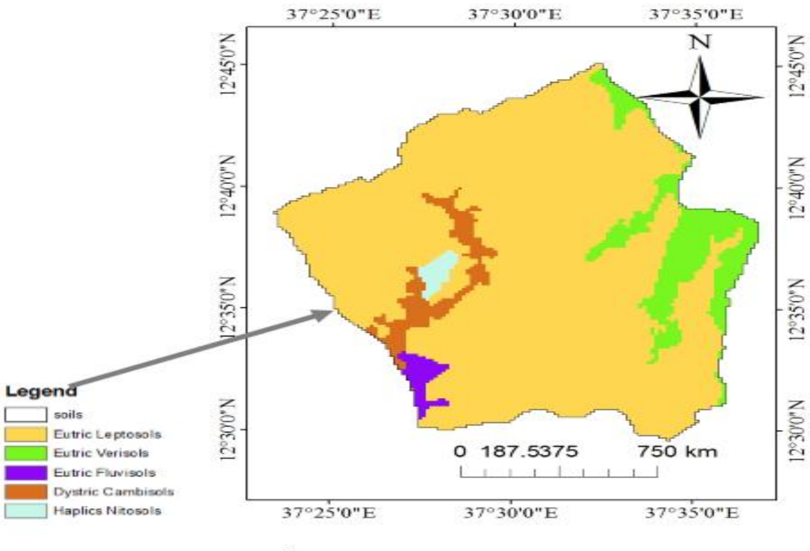

Figure 3. 9 Soil classification

3.10.3. Weather input data

Daily time-series of weather data, which includes precipitation and maximum and minimum air temperature etc., is required for the SWAT modeling. The climatic stations which were used in the study are called Enfranz, Makisignit and Azezo station. The periods of the measured weather data, which was obtained from National Meteorology Service Agency of Ethiopia (NMSA), was differ from station to station. From January 1st 2000 to December 31th 2013 including 2 year warm up period was used for SWAT simulation. To deal with the weather data, it should be stored in a specific tabular and supportive file format of Arc SWAT. In this case, they were stored in TEXT format which is read by Arc SWAT interface. The geographical coordinate names of the weather stations of the study area were introduced into Arc SWAT database. The data has provided the most representative precipitation and temperature data available. However, some metrological data such as: wind speed, daily sunshine hour and relative humidity data available only at Azezo station. Even though they were less significant compare to the data which were obtained, they were generated by the model and including data obtained from Global weather for SWAT data. The elevation of precipitation and temperature gauges were entered. The elevation information help to correctly estimate the amount of rainfall and temperature for a given elevation band in the sub basin.

3.10.4. Simulation

The database files containing the information needed to generate default input for SWAT model were built. In SWAT, once the default input database files are built, the necessary parameter values can be entered and edited manually. The HRU distribution was also modified whenever it was needed. The soil parameters values of each type of soil were entered. The land use land cover parameters were edited where it was necessary. SWAT simulation run was carried out on the 2000 - 2013 climate data. Two year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm-up period differ from catchment to catchment. It is mainly depend on the objective of the study. The run output data imported to database and the simulation results were saved in different files of SWAT output. It is used for SWAT model calibration since most of the observations of the watersheds behavior are obtained by measuring these parameters.

3.10.5. Sensitivity analysis

Sensitivity analysis is a method of identifying the most sensitive parameters that significantly effect on model calibration or on model prediction. Sensitivity analysis describes how model output varies over a range of a given input variable (Dilnesaw, 2006). According to Lijalem (2006), sensitivity analysis is a method of reducing the number of parameters to be used in calibration step and using the most sensitive parameter largely controlling the behavior of the simulation processes which finally eases calibration and validation processes as well as the time required for it.

Sensitivity analysis is an instrument for the assessment of the input parameters with respect to their impact on model output which is useful for model development, model validation and reduction of uncertainty, which can be classified in to four orders after Len hart *et al*. 2002. See table (3.6) below after a complete preprocessing of the required input for SWAT - CUP (SUFI-2) model, flow simulation was performed for 14 years of recording period of 2000 - 20113. The first two years which was used as a warm up period and the remaining records was used for flow simulation, which then used for sensitivity analysis of hydrologic parameters.

Table 3. 6 Sensitivity classes

Class	index	Sensitivity
1	0≤index<0.05	Small to negligible
2	0.05≤index<0.2	Medium
3	0.2 ≤index<1	High
4	Index>1	Very high

Source (Len hart, 2002)

Based on this classification, sensitive parameters with Index value of medium to very high were selected for calibration. The higher the value of Index, the higher will be the influence on the flow generation. Following the sensitivity analysis, the SWAT Calibration and Uncertainty Procedures (SWAT- CUP) version 5.1.6 was applied to calibrate, validate, and assess model uncertainty (Abbaspour *et al*,. 2007). The calibration and validation was performed using the SUFI-2 (sequential uncertainty fitting version 2) algorithm, which is a semi-automated inverse modeling procedure for a combined calibration-uncertainty analysis (Abbaspour *et al*. 2004; 2007).

3.10.6. Model calibration

Calibration is the process whereby model parameter are adjusted to make the model output match with observed data. There are five calibration approaches widely used by the scientific community. These are the Sequential uncertainty Fitting (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), Markov Chain Monte Carlo (MCMC) and Particle Swarm Optimization (Pso). Sequential uncertainty fitting (SUFI-2) is the most widely used in Tana Sub Basin approach. In this study SUFI-2 was employed to get the best model parameters. The final model parameters values that were SUFI-2 calibrated and reached to acceptable value as per the R^2 and NSE were used as initial values for the auto calibration procedure. The maximum and minimum limits of parameter value were used to keep the output values within a reasonable range. After calibration, checking the R^2 , NSE and RSR values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 and $0.6 \leq RSR \leq 0.7\%$, (Moriasi et al.2007).

3.10.7. Model validation

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation period stream flows confirm that the model performs satisfactorily. In this study, data for a period of 5 years (2009-2013) was used at Megech watershed to validate and evaluate the model accuracy. The statistical criteria used during the calibration procedure were also followed for model validation. The statistical criteria (R^2 ,NSE and RSR) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits. $R^2 > 0.6$, NSE > 0.5 and $0.6 \leq RSR \leq 0.7$ (Moriasi *et al*., 2007).

Based on the available model input data parameters the time periods of modeling are:

- Flow Calibration period (2002- 2008)
- Flow Validation period (2009- 2013)

The first two year of each period used (2000, 2001) is used as a model warm up period but not for model evaluation

3.10.8. Model evaluation

The performance of SWAT-CUP (SUFI2) was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE) were used as measure of the goodness of fit to evaluate model prediction.

The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (NSE) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, NSE is 1. If the NSE is between 0 and 1, it indicates deviations between measured and predicted values. If NSE is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). The R^2 and NSE values are calculated as follows in equations 4 and 5 respectively.

$$R^2 = \frac{[\sum_{i=1}^{n}(Qm - Qm^-)\ \ (Qs - Qs^-)]^2}{\sum_i(Qm - Qm^-)\ \sum_i(Qm - Q^-\ \ )^2} \qquad (4)$$

$$NSE = 1 - \frac{\sum_i^n(Qs - Qs^-)^2}{\sum_i^n(Qm - Qs^-)^2} \qquad (5)$$

Percent bias (PBIAS): PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta *et al*., 1999). The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999) and calculated as follows in equation 6.

$$PIAS = \left[\frac{\sum_i^n(Qm - Qs)^2}{\sum_i^n(Qm)} * 1000\right] \qquad (6)$$

Root mean Square Error Standard Deviation Ratio (RSR): RSR is calculated as the ratio of the Root mean square error (RMSE) and standard deviation of measured data, as follows in equation

$$RSR = \frac{RMSE}{SYDEVobs} = \left[\frac{\sqrt{\sum_i^n(Qm - Qs)^2}}{\sqrt{\sum_{i=1}^{n}(Qm - Qm^-)^2}}\right] \qquad (7)$$

Where: R^2 is the Coefficient of determination, NSE is the Nash Sutcliffe Efficiency Qm is the measured discharge, Q_s is the average simulated discharge, Q_m^- is the average measured discharge, n is the number of observations during the simulation period, PBIAS is mean relative bias, RSR is Root mean Square Error Standard Deviation Ratio, RMSE is Root mean square error, STDEVobs is Standard deviation of measured data

Uncertainty measure: P – Factor and R - Factor .The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU).

Another measure quantifying the strength of a calibration/uncertainty analysis is the factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. Theoretically, the value for p-factor ranges between 0 and 100%, while that of r factor ranges between 0 and infinity. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to measured data. A larger p-factor can be achieved at the expense of a larger r- factor. Hence, often a balance must be reached between the two. When acceptable values of r-factor and p-factor are reached, then the parameter uncertainties are the desired parameter ranges (SWAT - CUP (SUFI 2). General performance ratings for recommended statistics for a monthly time step (Moriasi *et al.,* 2007)

Table 3. 7 Performance ratings for recommended statistics

Performance Rating	RSR	NSE	PBIAS (%)
			Stream flow
Very good	0.00≤RSR≤0.50	0.75≤NSE≤1.0	PBIAS≤±10
Good	0.05≤RSR≤0.60	0.65≤NSE≤0.75	±10≤PBIAS≤±15
Satisfactory	0.6≤RSR≤0.70	0.50≤NSE≤0.65	±15≤PBIAS≤±25
Unsatisfactory	≥RSR	NSE≤0.50	PBIAS≥25

In this study Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE) statistical measures were only considered.

3.11. Selection of ungauged sub watershed from gauged watershed

The gauged watershed helped to assess the potential hydrologically homogenous sub basins. Hydrologically homogenous in this definition all sub-basins found in one watershed which means it has been uniform climate (annual average rainfall in mm) distribution but have different catchment characteristics like : land use/cover , soil, slope and area size . The dominant percentage of each sub basin catchment characteristics were used to similar and compared with dominant percentage watershed characteristics of the whole watershed.

The SWAT model is used to delineate and assess the hydrologically homogenous sub watersheds within the gauged watershed (Megech) and there are 17 sub watershed obtained from whole catchment, among these 16 are ungauged.

Second, the relationships were carried out between the SWAT output, empirical equation and physical catchment characteristics (PCCs) to develop transferring of stream flow. Identify and compare each individual of 16 ungauged sub watersheds with the whole gauged watershed based on the similar physical characteristics criteria like: Percentage of land use/cove, soil, area in size, slope. In the whole watershed the most dominated physical catchment characteristics were: agriculture (cultivated area), Eutric Leptosols and slope which is the percentage of watershed area 74, 86 and 55% respectively. Whereas based on their dominated PCCs in the 16 ungauged sub watersheds the most similar with whole catchment obtained were sub basins 6, 8 and 14 and also selected. Because the three sub basins were have been relatively similar physical characteristics with the whole gauged watershed as compared each 16 sub basins. The dominated physical characteristics of sub watershed 6, 8 and 14 were see in figure () below: uniform climate (annual average rainfall in mm), area size in (km^2), Agriculture (AGL), Eutric Leptosols (LPe) and slope. The total area coverage and percentage of agriculture, Eutric Leptosols of sub basins 6, 8 and 14 were mentioned in table () below.

Based on this the Megech watershed have seventeen (17) hydrologically homogenous sub watersheds. Out of the 17 sub watershed 16 are ungauged and only one sub watershed (sub basin) gauged which is sub watershed 17. The stream flow of each ungauged sub watershed contributed to the gauged watershed and has a common outlet. And the whole catchment is the tributaries of Tana basin. See figure (3.11) below.

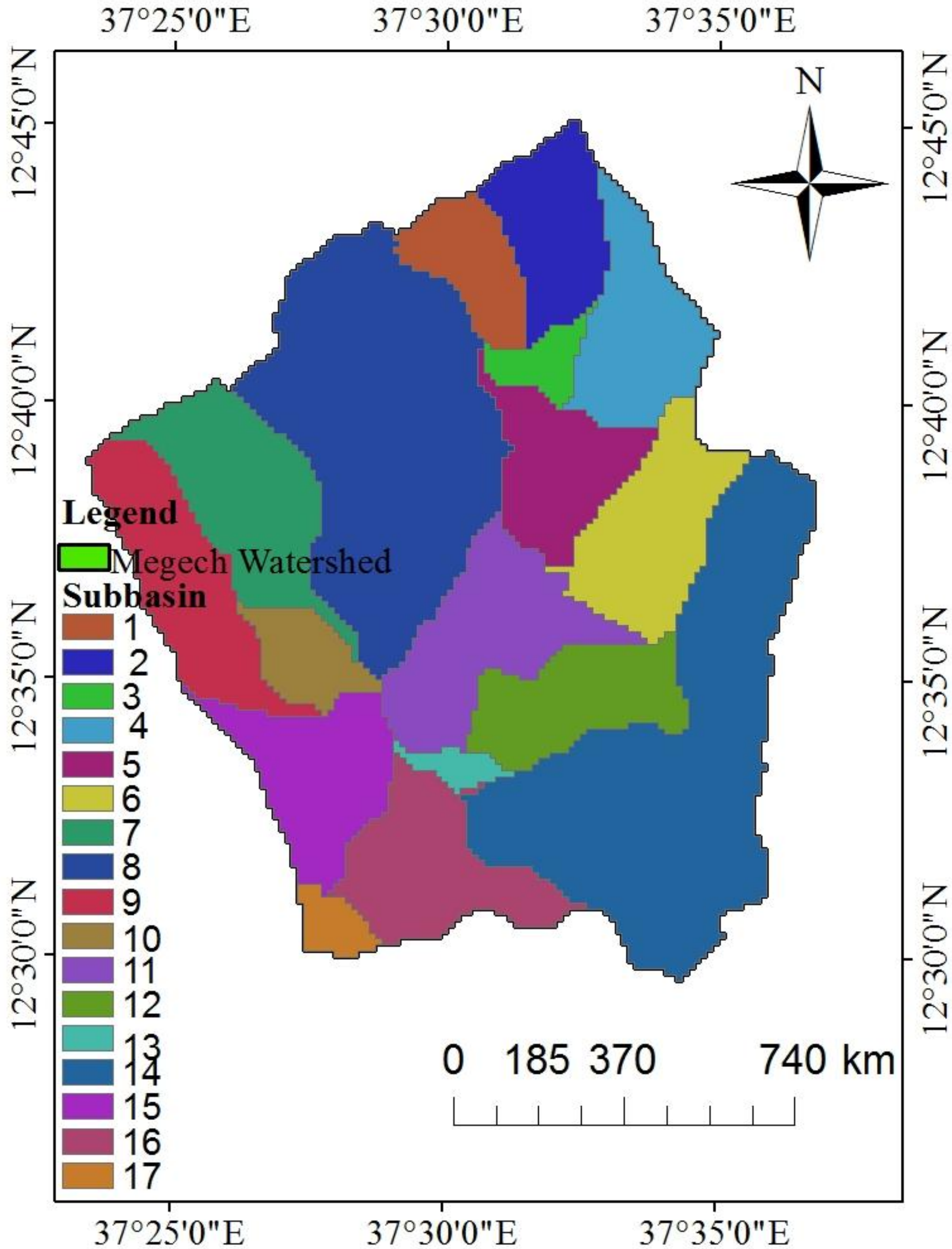

Figure 3. 10 The total seventeen sub-basins where inside to the Megech watershed

Table 3. 8 Total area of Seventeen sub basins in Megech catchment

Sub basin	AGL (%)	Soil (%)	Total area of AGL (Km^2)	Soil in (Km^2)	Remark
1	2.98	2.06	12.84	12.84	
2	4.4	3.92	19	16.92	

3	1.27	1.27	5.48	5.48	
4	5.03	4.33	21.72	18.68	
5	4.38	0.32	18.92	1.4	
6	20.07	22.1	29	32.21	Selected
7	6.75	4.75	9.88	7.24	
8	16.5	15.83	71.88	68.32	Selected
9	2.7	5.75	24.8	5.75	
10	0.85	1.3	3.37	2.7	
11	3.56	2.67	12.37	5.65	
12	7.89	0.68	14.25	6.03	
13	10.1	8.95	15.99	6.89	
14	10.33	14.83	44.56	64	selected
15	3.68	3.61	15.88	15.66	
16	3.25	5.65	14.15	24.12	
17	0.45	0.75	1.96	3.2	

3.11.1. Synthesizing of discharge for ungauged sub watershed 6, 8 and 14

Using the above criteria in section (3.11) mentioned and transfer of stream flow from the whole watershed to the selected sub basins (watersheds) by the empirical equation that adopted from GebeyehuAdmasu (1989). This equation was applied for ungauged catchments with in the same river basin and hydrological characteristics.

$$\frac{Qu}{Qg} = \left(\frac{Au}{Ag}\right)^{0.7} \quad (8)$$

Where: Qu - Discharge ungauged of sub-basin 8 (m^3/s)

Qg - Discharge of gauged whole catchment (m^3/s)

Au - Area of ungauged sub-basin 8 (km^2)

Ag - Area of gauged the whole catchment (km^2)

3.11.2. Comparison of stream flow from SWAT output and empirical equation for ungauged sub basins

After the SWAT modelling was successfully applicable in the Megech watershed. And then it is possible to compare the stream flow SWAT output and the synthesized stream flow obtained from the empirical equation of (GebeyehuAdmasu (1989)) at the selected ungauged sub basins. The result of flow obtained from SWAT output and empirical equation helped for different water resources management, planning and design infrastructures. The total amount of stream flow in each selected sub basins (sub basin 6, 8 and 14) mentioned in Appendix (**E**) on page (66).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Watershed characteristics

The watershed delineation and HRU definition in the Megech watershed resulted the total area of 431.52 km^2 and included 17 sub watershed with 82 HRUs. The physical watershed characteristics were land use/cover, soil and slope. From the land use/cover there were carried out agriculture, agro-pastoral, urban, pastoral and teff and the model parameters were included: AGRL, AGRC, URLD, PAST and TEFF. Among the model parameters and physical watershed characteristics the most dominated were AGRL, URLD and agriculture, urban respectively. For this study agriculture was selected. Because as it shown in table (4.1) below 74.58 % of watershed area covered and also found in the all sub watershed either in the high percentage or low percentage. Therefore, it was taken as the dominated and prepared for the similarity and comparison of sub watershed that included. Agriculture in this case indicated that cultivated area. The farmers in the study area are cultivating a large number of crops belonging to cereals, pulses, oilseeds and horticultural groups mainly under rain fed production system and also small scale irrigations during dry season. The areal percentage of the land use land cover type which were listed in table (4.1) below,

Table 4. 1 Description major land covers type using SWAT code

Land use	Land use swat	Swat code	Area (Km^2)	%Watershed area
Agriculture	Agriculture Generic	AGRL	321.81	74.58
Agro-pastoral	Agricultural close grown	AGRC	5.88	1.36
Urban	Urban	URLD	94.92	22
Pastoral	Pasture	PAST	4.12	0.95
Teff	Eragrostis	TEFF	4.79	1.11
Total			431.52	100

From the soil, the major and dominant soils in the study area were carried out that EutricLeptosols, EutricVertisols, Dystric Cambisols, Haplic Nitosols and EutricFluvisols and the model parameters were: LPe, Je, VRe, Bd and NTh. Among the model parameters and physical watershed characteristics the most dominated were LPe, NTh and Eutric

Leptosols, Haplic Nitosols respectively. Among the areal percentage of the watershed, EutricLeptosols the most dominated soil which was found in the whole watershed and in all sub watershed either in large or small portion and was selected for further similarity and comparison. See table (4.2)

Table 4. 2 Result of soil properties whole catchment

Soil swat	Swat code	Area(Km^2)	%Watershed area
EutricLeptosols	LPe	372.71	86.37
EutricFluvisols	Je	37.3	3.66
EutricVerticsols	VRe	0.88	0.2
Dystric Cambisols	Bd	4.82	1.12
Haplic Nitosols	NTh	15.79	8.65
Total		431.5	100

The slope were categorized as from 0-7 and 7-9999. From this the most dominated from 7-9999 covers 55.71 % of the whole watershed area and also found in all sub watershed (basin).

4.4. Hydrological model performance assessment

The flow simulation was performed for Megech watershed catchment at near Gondar hydrometric station. The result of sensitive parameters, calibrated, validation and performance evaluation result on this watershed and its ungauged sub-basin 8 were discussed below

4.4.1. Flow sensitivity analysis

It's known that recently Arc SWAT was the main software to model watershed and selected in this research. Sensitivity analysis investigates how model output varies when the model input parameters are changing. In a particular area it can identify those model parameters that result the highest influence in model calibration and validation process (James and Burges, 1982). Model sensitivity can be defined as the ratio of the change in model output to a change in parameter. Performing model calibration is usually difficult with a large number of parameters. Thus one important aim of parameter sensitivity analysis is to provide opportunities to reduce the number of input parameters thereby reducing the computation time for model calibration. For SWAT model calibration of this study, out of 27 potential parameters which have any sort of impact on watershed stream flow on daily time steps and only 5 parameters table (4.3) were found sensitive in controlling the stream flow. The remaining parameters were not to have an effect on the simulated stream flow of the catchment and they were not considered for model calibration.

Table 4. 3 Result of sensitive parameters

Parameter	Parameter Description	Category	Rank
R_Cn2.mgt	Initial SCS CN2 value	High	1
V_Esco.hru	Soil evaporation compensation factor	High	2
R_Sol_Awc (...)sol	Available water capacity (mm water/mm soil)	High	3
R_Sol_Z (...).sol	Soil depth (mm)	High	4
V_Alpha_BF.gw	Base flow factor (days)	High	5

4.4.2. Flow calibration

The higher value result of sensitive parameters required for calibration and validation. Due to that calibration and validation was executed for the significant of parameters respectively. The process of sensitivity analysis was done before the calibration process was carried out and 5 important parameters were selected for calibration of the model and then simulated flow was modified until it was strongly fit with the corresponding observed flow by changing the values of those parameters. After sensitive parameters have been selected. The calibration of the model was executed to adjustment of the observed and simulated model simulation using SWAT CUP model. Initially it was carried out using the most sensitive parameters and the best parameter value which were resulted from sensitivity analysis. Among the 27 parameters which resulted from sensitivity analysis method Initial SCS Curve number (Cn2), soil evaporation compensation factor (Esco), available water capacity of the soil layer (Sol _ Awhc), depth from soil surface to bottom of the layer (Sol _ Z) and Base flow factor (days) (Alpha_BF) were found the most influential parameters and were used for further calibration table (4.3). These were the considerable parameters to fit the data while changing. Most models are provided with default values of the parameters. However, in this case initial values of the model parameters were defined. The minimum and maximum acceptable values were provided based on related pervious works and literatures.

On (figure 4.2) below showed the average monthly observed and simulated flows from 01 January, 2002 to 31 December 2008 and two year for warm up period (2000-2001) for the calibration phase. The calibration period has shown a good agreement between monthly measured and simulated flows. The calibration result showed that the coefficient of determinations (R^2) and the Nash Sutcliffe Efficiency (NSE) are 0.72 and 0.71 respectively. The scatter plot of the values of the measured and the simulated monthly stream flow data have also shown a fair linear correlation between the two data sets. The trend and the magnitude of the two data set values are shown in (Figure 4.1).

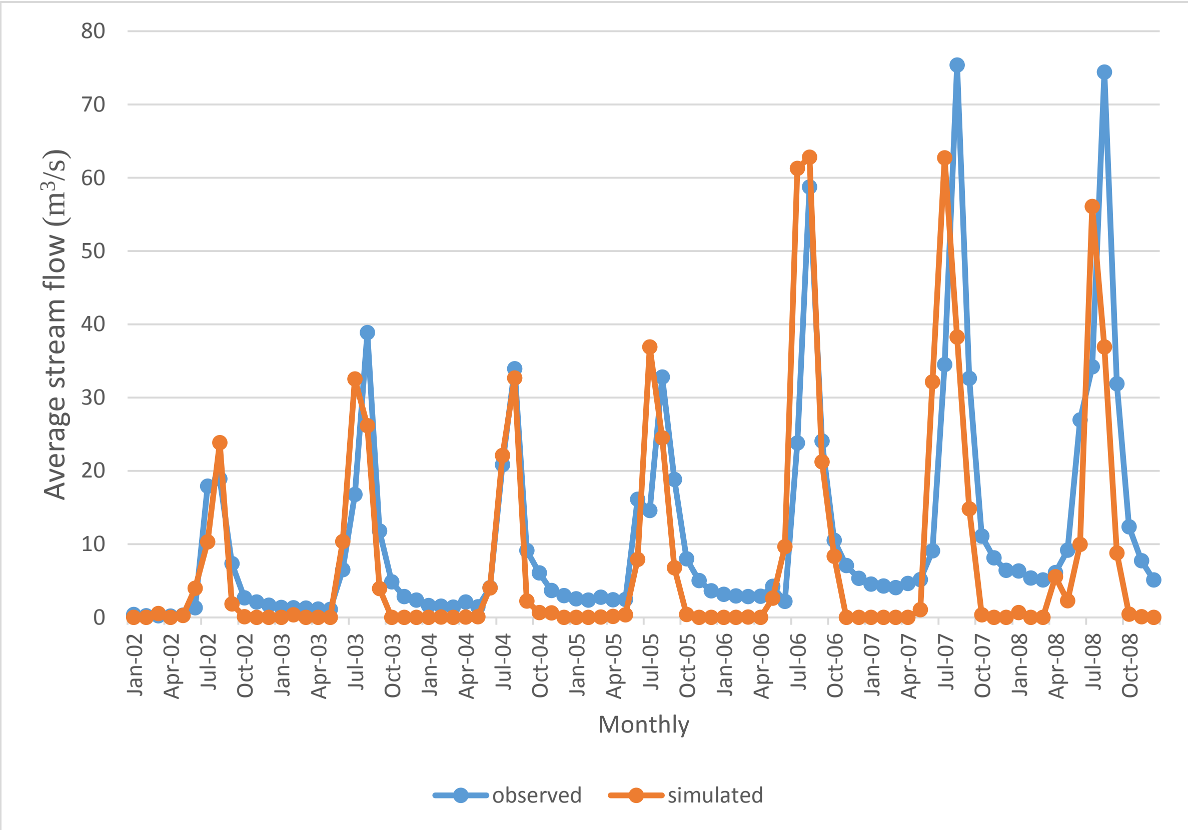

Figure 4. 4 Average monthly observed and simulated stream flow calibration (2002-2008)

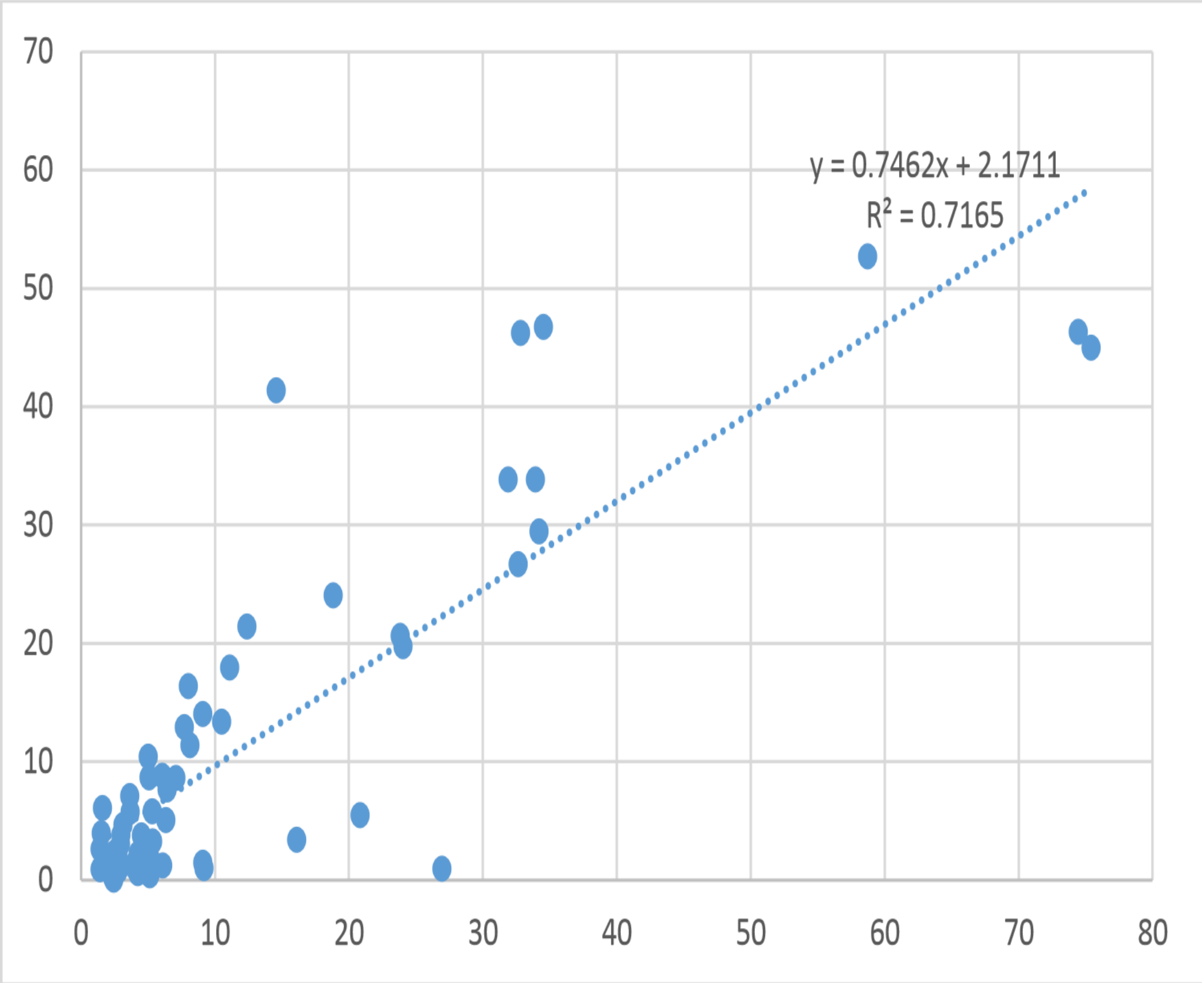

Figure 4. 5 Scatter plot comparison of observed and simulated stream flow calibration (2002-2008)

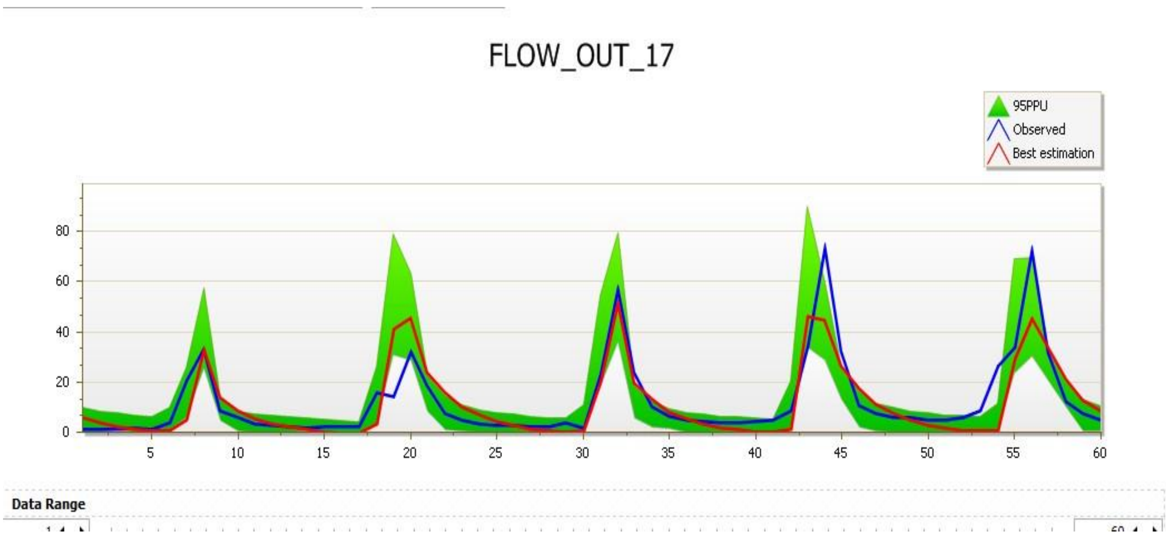

Figure 4. 6 The 95PPU observed versus simulated.

4.4.3. Flow validation

Using an independent set of observed data the validation process tested the certainty of model prediction. Calibration used for SWAT model can be certainly checked through validation process. If the model performance in calibration and validation values in the included in the standard interval the model was successful applied but now a day most of recent studies revealed that there a number of difficulties climate model validation. This is because of complexity of the nature of climate and time dependent uncertainties of modeling dataset and hydrologic condition during calibration and validation period not gave the same result. The comparison between the observed and calibrated flow discharge value for fourteen years of simulations indicated that there is a good agreement of the observed simulated flows using SUFI-2 algorithms with higher value of coefficient of determination and Nash Sutcliffe efficiency (NSE) for R^2 (0.77) suggested that model simulation can be judged as satisfactory and if R^2 is greater than 0.6 and NSE 0.59 is greater than 0.5. Hence the result agree with reasonably well with these values. Without change of the parameter that can be used in calibration it was carried out also for validation. In this case the validation process started from 2009 to 2013 were used. The validation has also shown a good agreement between the observed and simulated flows figure (4.4).

In general, the model performance assessment indicated a good correlation and agreement between the monthly measured and simulated flows. The scatters plot of the values of the measured and the simulated monthly stream flows data has also shown a fair linear correlation datasets. The trend and the magnitude of the two data set values are shown in figure (4.5).

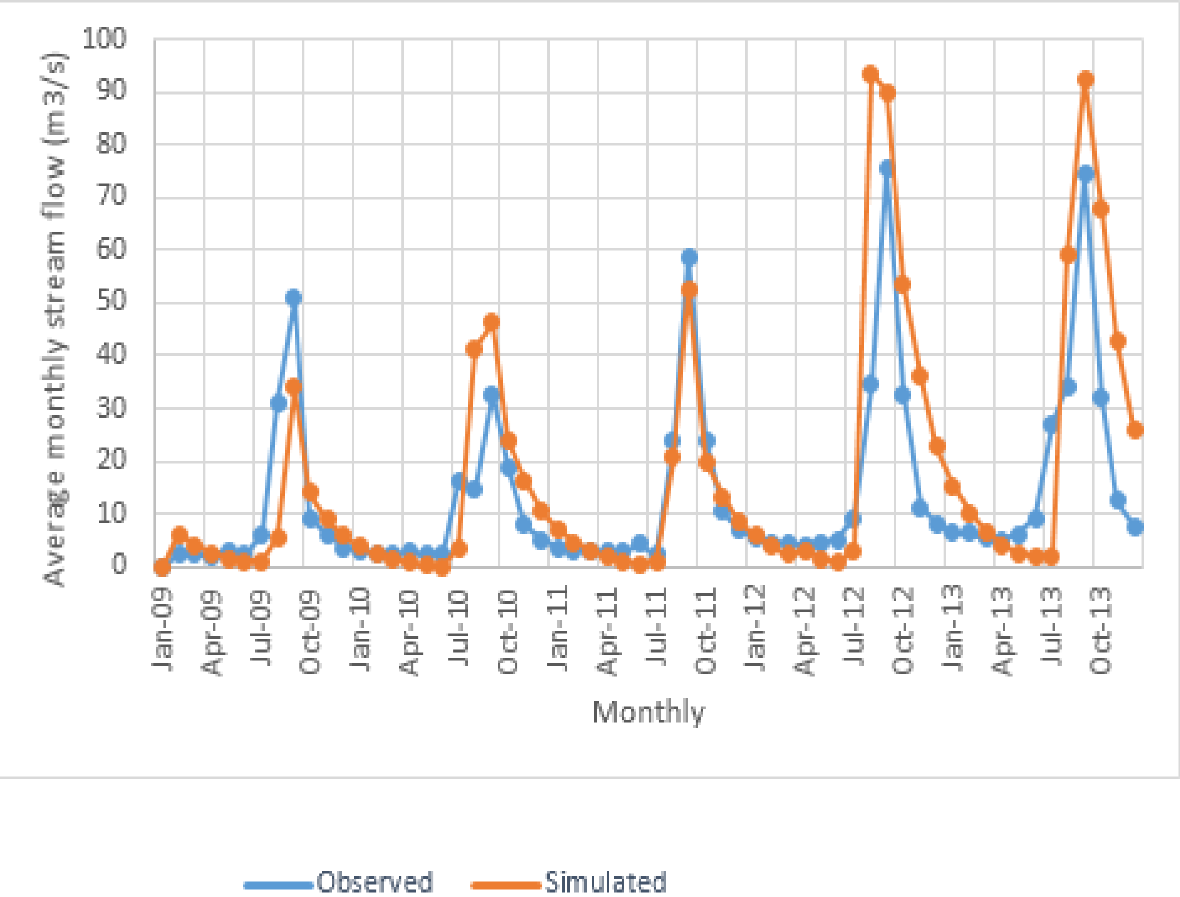

Figure 4. 7 Average monthly observed and simulated stream flow validation (2009-2013)

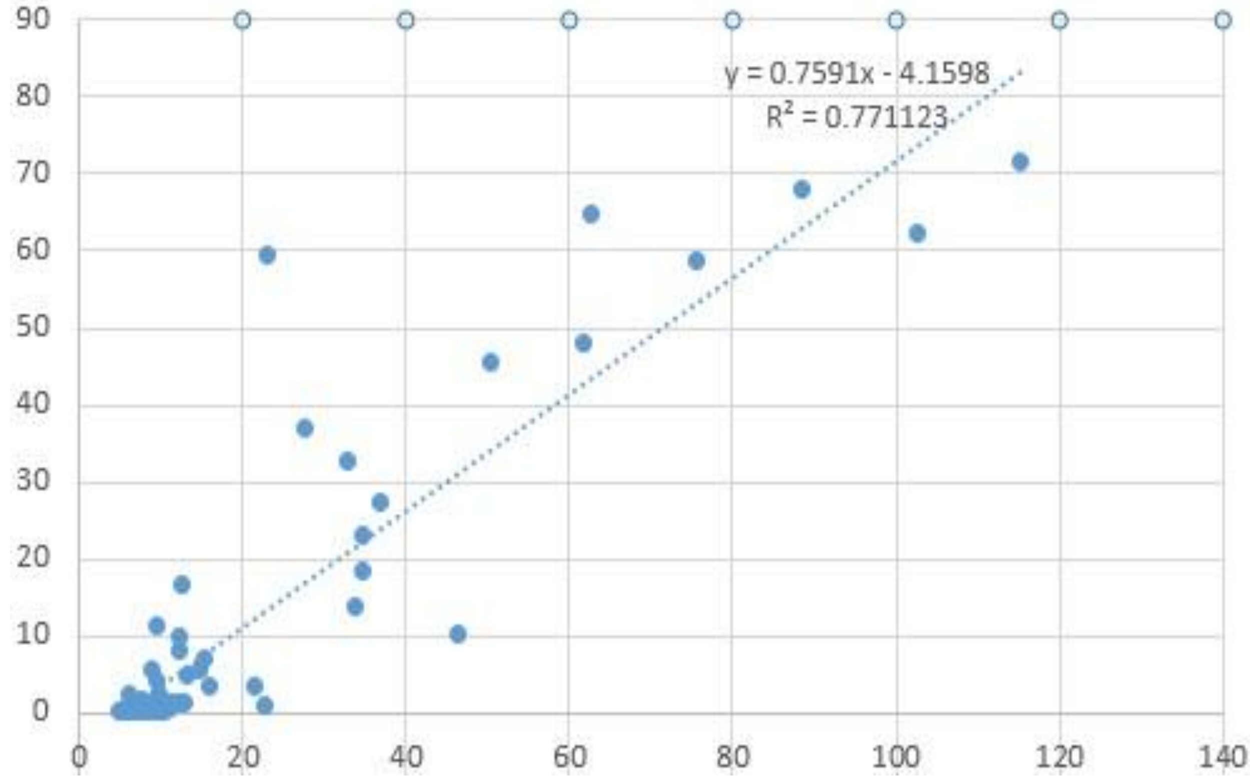

Figure 4. 8 Scatter plot observed and simulated stream flow validation (2009-2013)

4.5. Synthesizing stream flow data using empirical equation for ungauged sub watersheds

Based on the empirical equation of GebeyehuAdmasu (1989) the synthesized stream flow of sub basin 6, 8 and 14 are shown in figure (4.6) below. In this figure amount of stream flow in sub basin 8 was greater than from the two sub basins next to observed flow in sub basin -17(gauged) and transferring of stream flow successfully achieved.

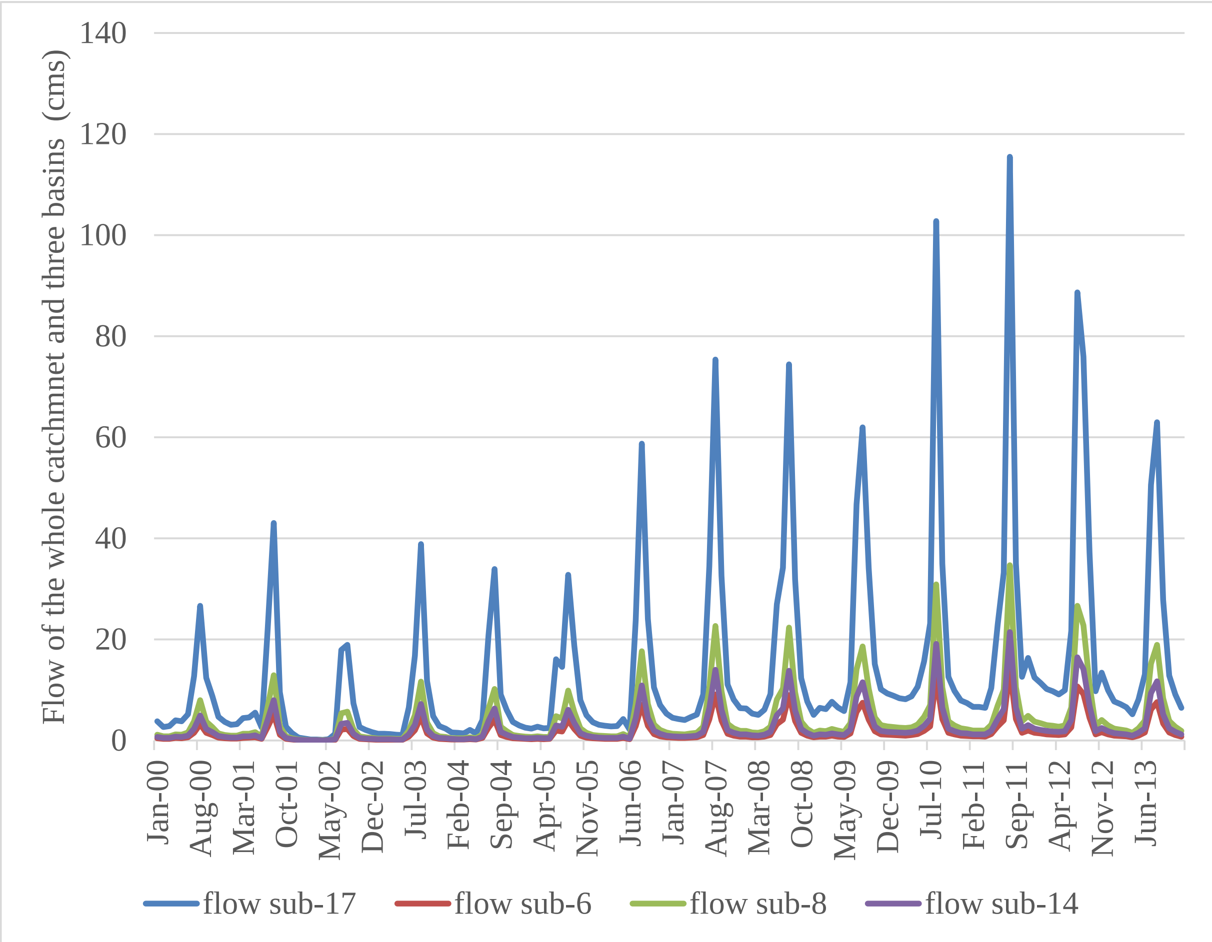

Figure 4. 9 Flow of the whole catchment and the empirical equation of three sub basins

4.5.1.1. Comparison of stream flow from SWAT output and empirical equation for ungauged sub basins

The average monthly stream flow obtained from SWAT output, empirical equation (GebeyehuAdmasu (1989)) and its percentage difference were mentioned in table (4.4) below.

Table 4. 4 Comparison of stream flow from SWAT output, empirical and its percentage difference

Month	Emper-6	SWAT flow Output-6	Difference In %	Emp-8	SWAT flow Output-8	Difference In %	Em-14	SWAT flow Output-14	Difference In %
Jan	0.62	0.04	94.05	1.54	0.11	92.99	0.95	0.10	89.68
Feb	0.57	0.01	98.14	1.42	0.03	98.05	0.88	0.02	97.92
Mar	0.57	0.00	99.28	1.41	0.01	99.52	0.87	0.01	99.28
Apr	0.56	0.01	98.99	1.39	0.01	99.28	0.86	0.02	97.81
May	0.69	0.03	95.76	1.72	0.08	95.55	1.06	0.09	91.22
Jun	1.52	0.49	68.00	3.78	1.87	50.54	2.34	1.78	24.06
Jul	4.08	3.09	24.32	10.14	10.74	-5.98	6.27	10.66	-70.00
Aug	7.58	3.55	53.15	18.83	11.64	38.21	11.65	12.09	-3.71
Sep	3.07	1.98	35.45	7.63	6.02	21.08	4.72	6.53	-38.39
Oct	1.19	1.08	9.74	2.96	3.24	-9.41	1.83	3.45	-87.78
Nov	0.96	0.53	44.60	2.39	1.62	32.06	1.48	1.68	-13.84
Dec	0.74	0.19	74.04	1.84	0.57	68.94	1.14	0.58	48.93
Mean annual	**1.75**	**0.92**	**47.55**	**4.59**	**2.99**	**34.71**	**2.84**	**3.08**	**-8.63**

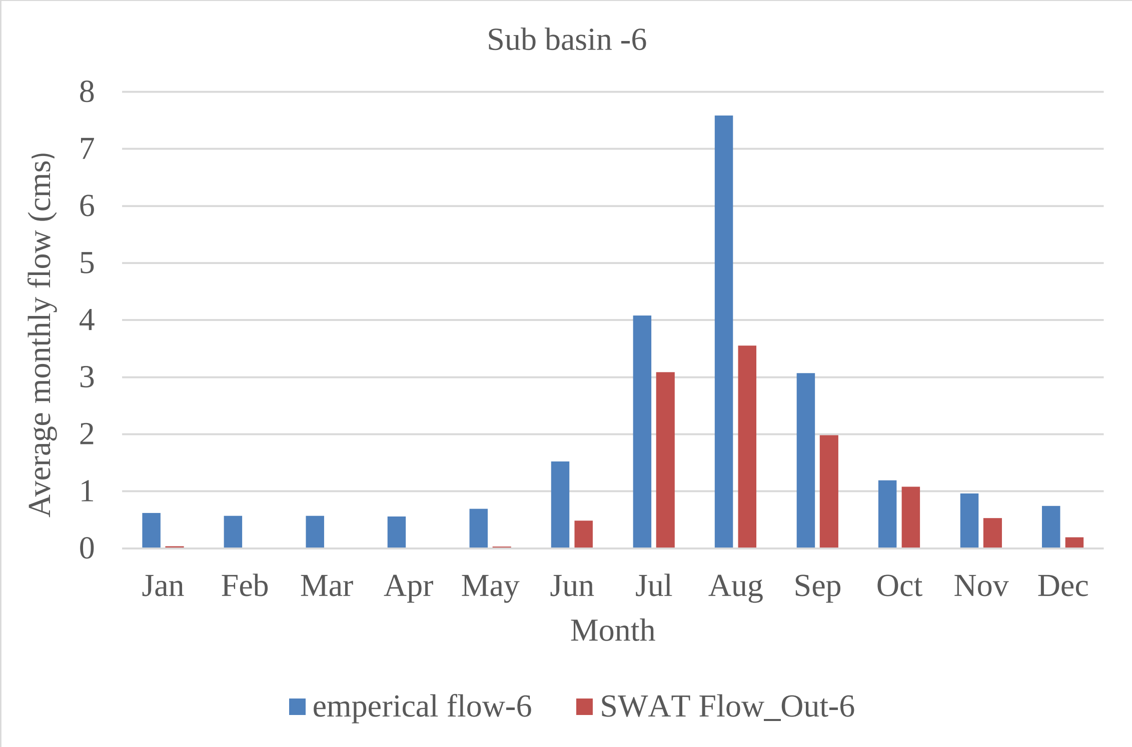

Figure 4. 10 Comparison of empirical flow and SWAT flow output of sub basin 6

In this figure (4.11) above mentioned the mean annual stream flow obtained from empirical, SWAT output and its percentage difference were 1.74807 cms, 0.91687 cms and 47.5498 % respectively. The empirical flow was greater than SWAT output and the percentage difference indicated that a little be agreed.

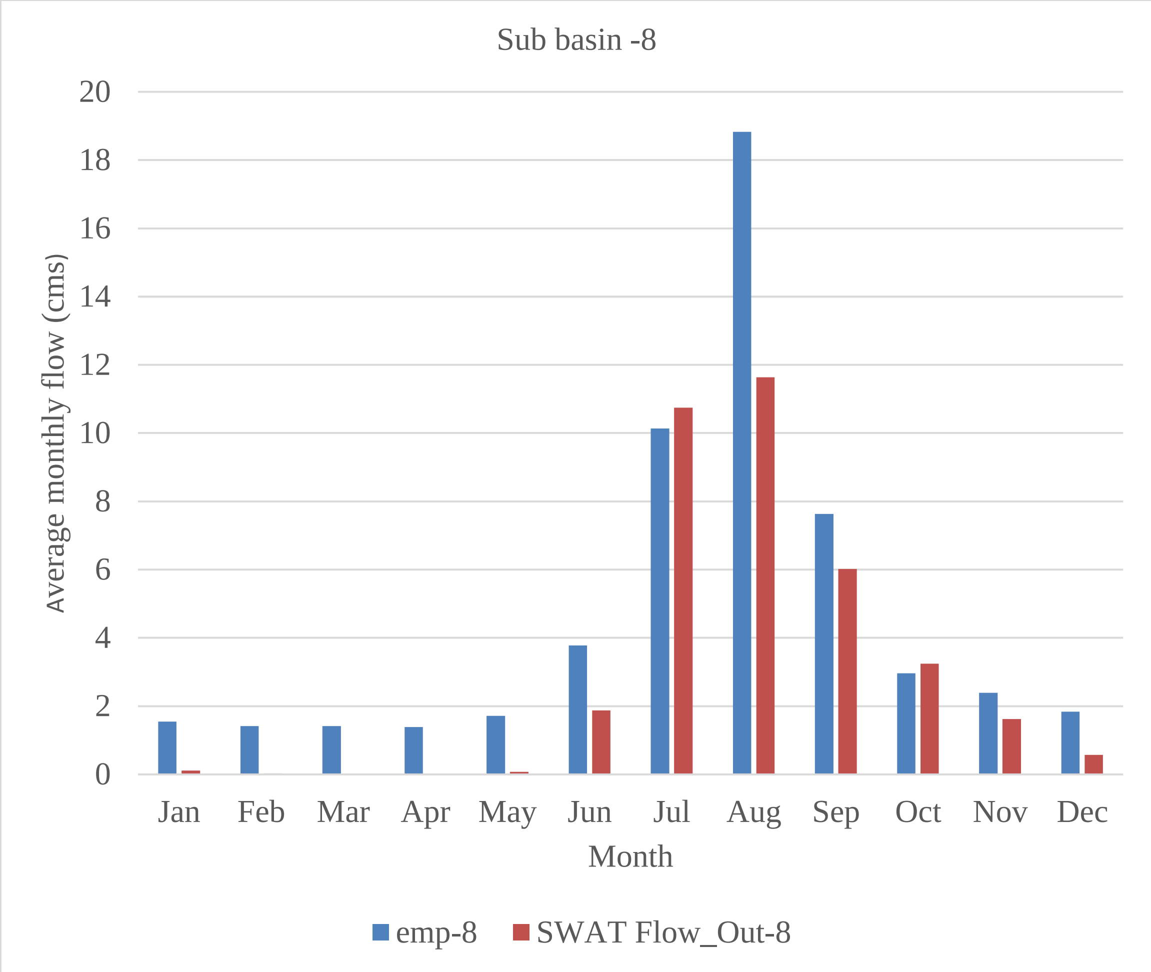

Figure 4. 11 Comparison of empirical flow and SWAT flow output of sub basin 8

.In this figure (4.8) above mentioned the mean annual stream flow obtained from empirical, SWAT output and its difference were 4.586544 cms, 2.99436 cms and 34.7142 % respectively. The empirical flow was greater than SWAT output and the percentage difference indicated that it was nearly agreed.

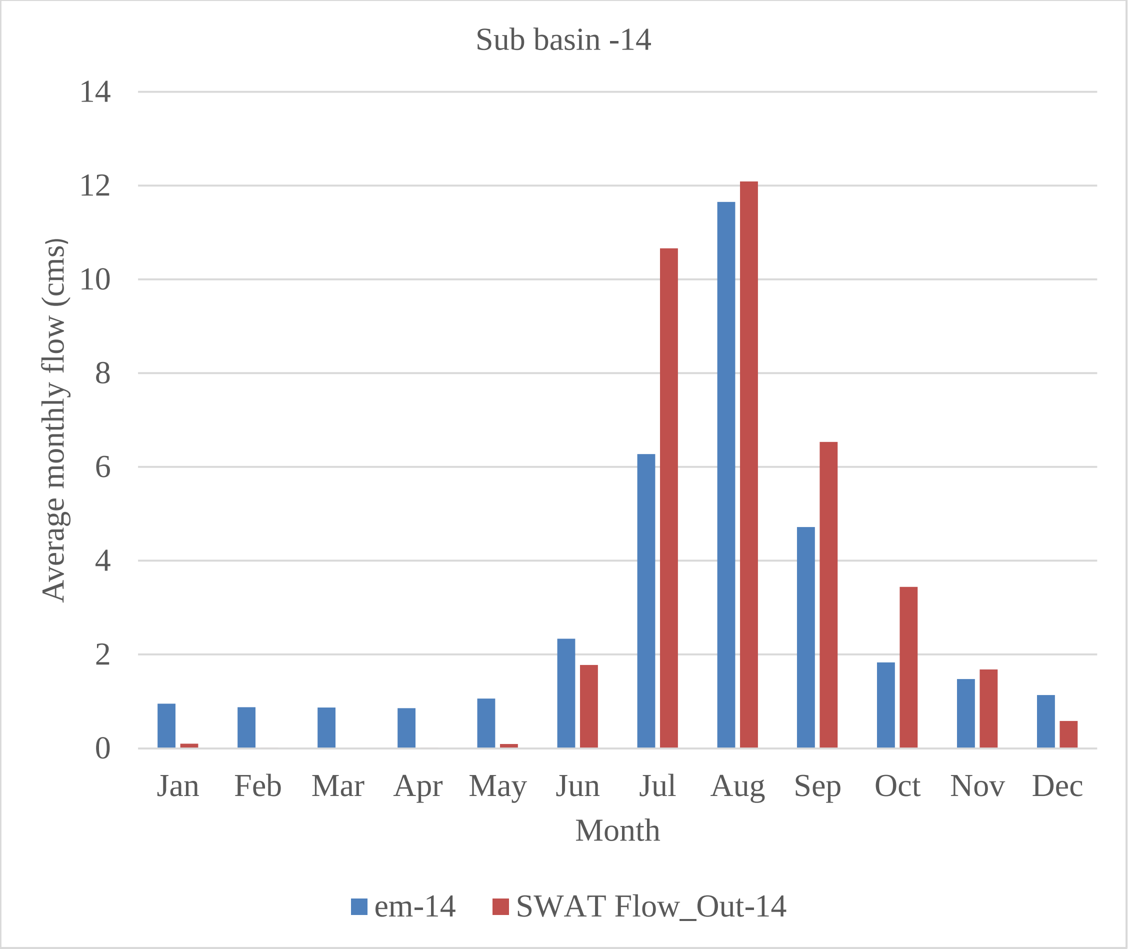

Figure 4. 12 Comparison of empirical flow and SWAT flow output of sub basin 14

In this figure (4.9) above mentioned the mean annual stream flow obtained from empirical, SWAT output and its difference were 2.83856 cms, 3.08365 cms and -8.6345% respectively. In this case the percentage difference of the stream flow is negative. This implies that the SWAT output is greater than the empirical stream flow and had been closely agreed.

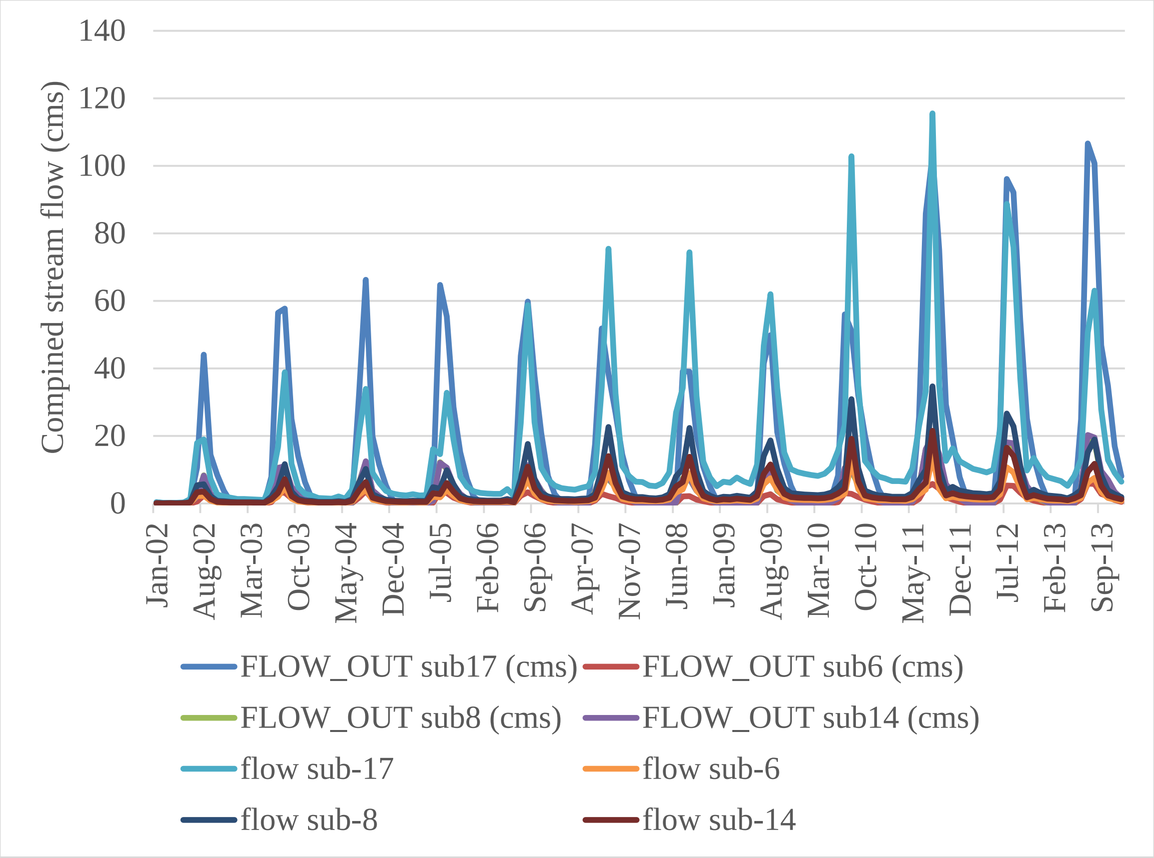

Figure 4. 13 Over all companied comparison of stream flow SWAT output and empirical equation.

CHAPTER FIVE

CONCLUSIONS and RECOMMENDATIONS

5.1. Conclusions

According to the result the comparison of physical catchment characteristics between gauged catchment and ungauged sub basin was done using percentage of land use/cover, soil, mean elevation and area. Based on this the following conclusion were carried out:

The predicted discharge obtained from the SWAT - CUP (SUFI-2) was to detect the performance evaluation using R^2 and NSE statistics. The statistical results of the model performance for both calibration and validation period on monthly time (R^2 = 0.72), Nash-Sutcliffe Efficiency (NSE=0.71) for calibration period of 2002-2008 and (R^2 = 0.77) Nash-Sutcliffe Efficiency (NSE=0.59) for validation of period 2009-2013 for whole gauged catchment.

The performance and applicability of SWAT model was successfully evaluated through sensitivity analysis, model calibration and validation. From the result of sensitive analysis Initial SCS Curve number (Cn2), soil evaporation compensation factor (Esco), available water capacity of the soil layer (Sol _ Awc), depth from soil surface to bottom of the layer (Sol _ Z) and Base flow factor (days) (Alpha_BF). Initial SCS Curve number (Cn2) is the most sensitive to the streamflow of the whole catchment and sub basin 8. SWAT model was found to produce a reliable estimated flow for Megech watershed and its sub basin. Therefore, the calibrated parameter values can be considered for further hydrologic simulation of the watershed. The model can also be taken as a potential tool for simulation of the hydrology of ungauged watershed in similar areas, which behave hydro-meteorologically similar with Megech watershed.

In this research, it was attempted to determined model Parameters required for estimating flow for ungauged sub basin. The SWAT 2009 model was successfully calibrated and validated in the Megech River watershed for modeling of stream flow. In this case the synthesized of streamflow for ungauged sub basin well performed and transfer of stream flow involving SWAT model was achieved. Because the sub basin 6, 8 and 14 and the whole catchment (Megech catchment) are physically and hydrologically homogenous. Transfer of stream flow from gauged catchment (Megech) to ungauged sub basin (three sub basins) was done using the concept of empirical equation and SWAT output and it was possible estimating discharge for ungauged sub basins from gauged catchment.

The average monthly stream flow obtained from SWAT output, synthesized empirical equation and its percentage difference of the three sub basins were:

1. In sub basin -6 the stream flows were 1.74807 cms, 0.91687 cms and 47.5498 % respectively.
2. In sub basin -8 the stream flows were 4.58654 cms, 2.99436 cms and 34.7142 % respectively.
3. In sub basin -14 the stream flows were 2.83856 cms, 3.08365 cms and -8.6345 % respectively.

The comparison results, sub basin-6 and sub basin -8 were carried out that the empirical flow gained from the empirical equation of (Gebeyehu Admasu (1989)) more than the SWAT output but in sub basin -14 the SWAT flow output was more than the empirical flow and have close agreed between the two.

Even though due to the uncertainties the comparison of synthesized stream flow of each sub basins were not completely similar or agreed but in general the SWAT flow output and empirical steam flow were have been close agreement between each three sub basins.

5.2. Recommendations

According to the results and conclusions

- It is advisable to extend this transferring of stream flow using SWAT model for other parts of Ethiopian river basins and sub basin to compare the hydrologically homogeneous basins of the country so that to solve problems related to absence of sufficiently gauged discharge data for water resources project planning and design.
- For a more accurate estimation of discharge for ungauged basins and sub basins a large effort will be required to improve the quality of available input data from gauged stations.
- For assessing of transfer stream flow in ungauged basins and sub basin , it is better understand that the catchment characteristics have nearly similar and also performance

evaluation of SWAT model can be useful to compare stream flow at ungauged site whenever the following is satisfied :-

1. At the gauged site: Calibration and validation (R^2 > 0.6 and NSE > 0.5)
2. Similar physical catchment characteristics (or hydrological homogeneity) between selected ungauged and gauged basin and sub basins respectively.

❖ The comparison of the transfer of stream flow using SWAT output and the empirical equation (GebeyehuAdmasu (1989)) successfully applied in Megech watershed but its better further studies to other parts of basin and sub basins of Tana basin as well as Blue Nile Rivers, using other recently developed empirical equations.

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Websites used for additional information and software downloads

- SWAT website: http://global weather.tamu.edu/home/view/48161

APPENDIX

Appendix A: Total annual rainfall surrounding selected stations for the site study area and gauged and ungauged catchments.

YEAR	TAF MEGE	TAFMAKI	TAFENF	TAFW123378	TAFW123381	TAF w 123384
2000	1760.70	1332.10	788.40	296.18	784.42	100.29
2001	1834.70	1687.80	655.80	321.28	843.18	94.71
2002	993.40	777.40	344.20	92.21	391.35	10.44
2003	1075.90	922.00	998.00	265.04	698.01	86.70
2004	1167.90	952.30	1006.40	226.51	618.49	61.44
2005	1040.50	922.00	524.60	261.65	746.85	43.40
2006	1238.50	1172.10	950.60	300.02	738.90	111.66
2007	1164.20	1007.90	1300.30	262.35	701.56	78.57
2008	1243.20	1191.60	1160.40	208.92	611.77	56.28
2009	972.40	746.90	833.10	298.45	614.96	77.08
2010	1069.40	901.70	1068.00	361.32	827.74	133.20
2011	1024.20	749.30	983.80	214.92	777.22	103.87
2012	1144.40	920.80	1247.50	194.49	761.14	75.26
2013	960.70	900.40	962.10	305.71	947.52	139.11
2014	1169.10	941.90	1423.90	98.37	409.05	17.18

Appendix B: Statistical value of weather generator in azido (Megech) station

	Jan.	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
TMPMX	16.43	16.11	16.36	16.21	17.74	25.43	22.82	21.97	22.60	22.93	24.14	27.13
TMPMN	7.15	6.75	7.94	9.61	8.51	12.90	13.06	12.92	11.98	12.09	11.01	11.52
DEWPT	1.36	-0.65	0.02	0.76	3.35	13.84	14.10	13.59	12.64	10.57	8.88	9.16
TMPSTDMX	15.83	15.13	15.11	15.32	14.58	3.82	6.52	6.06	8.04	12.30	9.53	4.14
TMPSTDMN	6.03	7.07	7.58	8.08	8.23	4.85	3.60	3.55	8.23	3.48	8.36	2.65
PCP_MM	3.36	10.17	16.35	35.79	76.86	191.47	330.99	325.09	120.06	67.19	20.39	12.57
PCPSTD	0.92	1.31	3.35	3.54	6.50	11.13	12.09	11.53	6.98	6.26	3.24	1.74

PCPSKW	11.04	5.11	10.97	6.63	4.24	3.24	2.20	2.07	2.84	4.85	7.27	8.38
PR_W1	0.02	0.03	0.08	0.13	0.22	0.56	0.86	0.86	0.42	0.23	0.08	0.02
PR_W2	0.15	0.69	0.25	0.63	0.54	0.70	0.88	0.88	0.59	0.46	0.34	0.80
PCPD	0.87	2.80	3.20	8.20	10.67	19.87	28.07	28.20	16.40	9.67	3.33	2.93
RAINHHMX	0.27	0.26	0.94	0.88	1.18	1.84	1.93	1.78	0.99	1.17	0.84	0.51
WNDAV	0.89	0.99	1.01	1.02	1.10	1.09	0.70	0.67	0.69	0.58	0.68	0.68
SOLRAV	7.99	8.11	7.37	7.21	7.40	4.60	3.80	3.94	6.16	6.69	8.05	8.51

Appendix C: Definition of statistical weather generator and probability value

Symbol	Symbol Description
TMPMX	Average or mean daily maximum air temperature for month (oc) This value is calculated by summing the maximum air temperature for every day in the month for all years of record and dividing by the number of days summed:
TMPMIN	Average or mean daily minimum air temperature for month (oc). This value is calculated by summing the minimum air temperature for every day in the month for all years of record and dividing by the number of days summed:
TMPSTDMX	Standard deviation for daily maximum air temperature in month (oc). This parameter quantifies the variability in maximum temperature for each month.
TMPSTDMN	Standard deviation for daily minimum air temperature in month (oc). This parameter quantifies the variability in minimum temperature for each month.
PCP_MM	Average monthly precipitation [mm]
PCPSTD	Standard deviation Standard deviation for daily precipitation in month (mm H2O/day). This parameter quantifies the variability in precipitation for each month.
PCPSKW	Skew coefficient for daily precipitation in month.
PR_W1	Probability of a wet day following a dry day in the month
PR_W2	Probability of a wet day following a wet day in the month
RAINHHMX	Maximum 0.5 hour rainfall in the entire period of record for the month(mmH2O)
DEWPT	Average daily dew point temperature in month [°C] or Average daily dew point temperature for each month (Oc) or relative humidity (Fraction) can be input.
WNDAV	Average daily wind speed in month (m/s).

Appendix D: Sensitive analysis of sub basin 8

Parameter	Parameter Description	Category	Rank
R_Cn2.mgt	Initial SCS CN2 value	High	1
V_Esco.hru	Soil evaporation compensation factor	High	2
R_Sol_Awc(..)sol	Available water capacity (mm water/mm soil)	High	3
R_Sol_Z (...).sol	Soil depth (mm)	High	4
V_Alpha_BF.gw	Base flow factor (days)	High	5

Appendix E: Comparison of SWAT output and synthesized empirical equations

Date	FLOW_OUT sub17 (cms)	FLOW_OUT sub6 (cms)	FLOW_OUT sub8 (cms)	FLOW_OUT sub14 (cms)	flow sub-17	flow sub-6	flow sub-8	flow sub-14
Jan-02	0.4004	0.02753	0.07842	0.07357	0.37155	0.04495	0.11159	0.06906
Feb-02	0.07594	0.00911	0.02118	0.01282	0.21768	0.02633	0.06538	0.04046
Mar-02	0.02269	0.00505	0.00392	0.00942	0.22177	0.02683	0.06661	0.04122
Apr-02	0	0.00142	8.3E-05	0.00054	0.14163	0.01713	0.04254	0.02633
May-02	0.02657	0.0605	0.0023	0.00963	0.28355	0.0343	0.08516	0.0527
Jun-02	1.189	0	0.2441	0.236	1.30747	0.15816	0.39268	0.24302
Jul-02	10.64	0.5257	2.124	1.889	17.9075	2.16623	5.37822	3.32852
Aug-02	44.08	2.402	8.314	8.242	18.9237	2.28916	5.68344	3.51742
Sep-02	14.41	0.8423	2.648	2.732	7.31853	0.88531	2.198	1.36032
Oct-02	8.437	0.4888	1.571	1.538	2.65945	0.32171	0.79872	0.49432
Nov-02	3.689	0.2145	0.6955	0.6505	2.08877	0.25267	0.62733	0.38825
Dec-02	0.5954	0.03857	0.1159	0.106	1.65977	0.20078	0.49849	0.30851
Jan-03	0.1446	0.01206	0.03402	0.02413	1.32123	0.15983	0.39681	0.24558
Feb-03	0.01678	0.0049	0.00621	0.00567	1.30654	0.15805	0.3924	0.24285
Mar-03	0.00029	0.0014	0.00041	0.00073	1.25045	0.15126	0.37555	0.23243
Apr-03	0	0	0	0	1.12303	0.13585	0.33728	0.20874
May-03	0	2.5E-06	0	0	1.07813	0.13042	0.3238	0.2004
Jun-03	7.863	0.3708	1.594	1.362	6.49487	0.78567	1.95063	1.20722
Jul-03	56.48	3.056	10.65	10.52	16.7632	2.02781	5.03456	3.11583
Aug-03	57.69	3.256	10.64	11.06	38.8809	4.70334	11.6773	7.22692
Sep-03	24.99	1.509	4.45	4.907	11.7819	1.42523	3.53849	2.18993
Oct-03	13.93	0.8339	2.512	2.642	4.84277	0.58582	1.45445	0.90014
Nov-03	6.382	0.3815	1.16	1.196	2.84243	0.34384	0.85368	0.52833
Dec-03	1.531	0.09771	0.2791	0.2782	2.35345	0.28469	0.70682	0.43744
Jan-04	0.2997	0.02153	0.06117	0.05382	1.59158	0.19253	0.47801	0.29583
Feb-04	0.04678	0.00689	0.0153	0.00739	1.51886	0.18373	0.45617	0.28232

Mar-04	0	0.00114	9.1E-05	0	1.40558	0.17003	0.42214	0.26126
Apr-04	0.00086	0.00031	2.9E-05	0.00042	2.09353	0.25325	0.62876	0.38913
May-04	0.01004	0.0018	0.00037	0.00465	1.42197	0.17201	0.42706	0.26431
Jun-04	0.638	0.04092	0.1138	0.1715	4.02757	0.48721	1.20961	0.74862
Jul-04	32.39	1.685	6.245	5.87	20.814	2.51783	6.25116	3.86877
Aug-04	66.2	3.673	12.33	12.54	33.9239	4.1037	10.1885	6.30554
Sep-04	19.85	1.2	3.556	3.868	9.0988	1.10066	2.73268	1.69122
Oct-04	11.49	0.687	2.088	2.165	6.04919	0.73176	1.81678	1.12438
Nov-04	5.297	0.3157	0.9723	0.9791	3.6572	0.4424	1.09838	0.67978
Dec-04	1.039	0.07019	0.188	0.1989	2.96255	0.35837	0.88975	0.55066
Jan-05	0.2346	0.01757	0.04925	0.04197	2.53932	0.30718	0.76264	0.47199
Feb-05	0.01844	0.00504	0.00883	0.00249	2.34404	0.28355	0.70399	0.43569
Mar-05	0	0.00106	0.00018	0	2.75697	0.3335	0.82801	0.51245
Apr-05	0.01187	0.00125	0.00041	0.00442	2.38557	0.28858	0.71647	0.44341
May-05	0.03728	0.00601	0.00144	0.0173	2.4441	0.29566	0.73404	0.45429
Jun-05	3.873	0.1828	0.7945	0.7066	16.0997	1.94754	4.83528	2.9925
Jul-05	64.74	3.486	12.22	12.03	14.5724	1.76279	4.37659	2.70862
Aug-05	55.35	3.128	10.21	10.59	32.8061	3.96848	9.85278	6.09777
Sep-05	28.48	1.684	5.167	5.497	18.8299	2.27781	5.65524	3.49997
Oct-05	15.18	0.9018	2.777	2.836	7.99477	0.96711	2.4011	1.48601
Nov-05	7.185	0.4246	1.329	1.317	5.00673	0.60565	1.50369	0.93062
Dec-05	2.022	0.1247	0.3823	0.3533	3.62606	0.43864	1.08903	0.67399
Jan-06	0.3577	0.02487	0.0738	0.0623	3.12342	0.37783	0.93807	0.58056
Feb-06	0.0617	0.0081	0.01937	0.00937	2.92975	0.35441	0.8799	0.54456
Mar-06	0.00043	0.00186	0.0016	4.2E-05	2.80671	0.33952	0.84295	0.52169
Apr-06	0	3.1E-05	0	0	2.8581	0.34574	0.85838	0.53124
May-06	0.1669	0.01753	0.01646	0.06865	4.24116	0.51304	1.27376	0.78832
Jun-06	1.512	0.07582	0.3149	0.3039	2.1768	0.26332	0.65377	0.40461
Jul-06	43.65	2.303	8.317	8.034	23.8082	2.88002	7.15039	4.4253
Aug-06	59.76	3.333	11.1	11.37	58.7289	7.1043	17.6383	10.9161
Sep-06	37.85	2.214	6.891	7.279	24.0442	2.90858	7.22129	4.46918
Oct-06	20.87	1.205	3.885	3.831	10.5068	1.27098	3.15554	1.95293
Nov-06	8.124	0.481	1.512	1.485	7.06397	0.85451	2.12155	1.313
Dec-06	2.772	0.1654	0.5382	0.4682	5.31087	0.64244	1.59503	0.98715
Jan-07	0.4654	0.02971	0.09514	0.07796	4.50884	0.54542	1.35416	0.83807
Feb-07	0.114	0.0102	0.02917	0.01716	4.26807	0.5163	1.28185	0.79332
Mar-07	0.00055	0.00245	0.00302	0	4.05148	0.4901	1.2168	0.75306
Apr-07	0	0.00027	2.9E-05	0	4.62197	0.55911	1.38813	0.8591
May-07	0.0497	0.00526	0.00485	0.01841	5.13416	0.62107	1.54196	0.9543
Jun-07	17.5	0.8697	3.423	3.114	9.0924	1.09989	2.73075	1.69003
Jul-07	51.81	2.861	9.651	9.85	34.5115	4.17478	10.365	6.41477
Aug-07	38.42	2.181	7.065	7.392	75.4003	9.121	22.6452	14.0149
Sep-07	26.84	1.571	4.901	5.153	32.6314	3.94735	9.80031	6.0653
Oct-07	14.5	0.8512	2.685	2.671	11.0846	1.34088	3.32907	2.06033

Nov-07	6.881	0.4015	1.29	1.241	8.11937	0.98218	2.43852	1.50917
Dec-07	1.873	0.1122	0.366	0.3129	6.40639	0.77497	1.92405	1.19078
Jan-08	0.3834	0.02564	0.07619	0.06976	6.3391	0.76683	1.90384	1.17827
Feb-08	0.06802	0.00827	0.02023	0.01144	5.34331	0.64637	1.60478	0.99318
Mar-08	0	0.00133	0.00057	0	5.09971	0.6169	1.53161	0.9479
Apr-08	0.5274	0.03459	0.09836	0.1349	6.1014	0.73807	1.83246	1.13409
May-08	0.1957	0.02071	0.02106	0.08042	9.16174	1.10828	2.75158	1.70292
Jun-08	1.037	0.06418	0.1872	0.2716	26.9423	3.25915	8.09169	5.00786
Jul-08	39.11	2.04	7.51	7.121	34.1732	4.13386	10.2634	6.35189
Aug-08	39.05	2.202	7.22	7.497	74.4372	9.0045	22.356	13.8359
Sep-08	20.17	1.164	3.758	3.755	31.8796	3.8564	9.57452	5.92556
Oct-08	10.89	0.6248	2.066	1.938	12.3688	1.49623	3.71478	2.29904
Nov-08	5.022	0.2871	0.9653	0.8734	7.7012	0.9316	2.31293	1.43145
Dec-08	0.9792	0.05871	0.2027	0.1497	5.0833	0.61492	1.52669	0.94485
Jan-09	0.2172	0.01592	0.04947	0.03473	6.474	0.78315	1.94436	1.20334
Feb-09	0.03075	0.00532	0.01214	0.00409	6.19529	0.74943	1.86065	1.15154
Mar-09	6E-05	0.00102	0.00085	1.4E-05	7.64726	0.92507	2.29673	1.42142
Apr-09	0.00548	0.00155	0.00024	0.0025	6.55263	0.79266	1.96798	1.21796
May-09	4.6E-05	0.00089	0	0.00069	5.80635	0.70238	1.74384	1.07925
Jun-09	0.7966	0.04501	0.1548	0.1846	11.5023	1.3914	3.45452	2.13796
Jul-09	41.53	2.186	7.949	7.629	46.7416	5.65422	14.0381	8.68801
Aug-09	49.8	2.781	9.257	9.446	61.9977	7.49973	18.62	11.5237
Sep-09	21.1	1.252	3.824	4.066	34.1461	4.13058	10.2552	6.34685
Oct-09	11.86	0.702	2.164	2.223	15.1061	1.82735	4.53688	2.80782
Nov-09	5.222	0.3099	0.9599	0.9612	10.1645	1.22958	3.05275	1.88931
Dec-09	1.056	0.06977	0.1914	0.2012	9.299	1.12488	2.7928	1.72843
Jan-10	0.2429	0.01772	0.05028	0.04357	8.8431	1.06973	2.65588	1.64369
Feb-10	0.02038	0.00522	0.00983	0.00308	8.38571	1.0144	2.51851	1.55868
Mar-10	0.1084	0.00925	0.01682	0.03072	8.16413	0.9876	2.45196	1.51749
Apr-10	0.06147	0.01012	0.0041	0.03241	8.7647	1.06025	2.63233	1.62912
May-10	1.699	0.09304	0.342	0.3624	10.6435	1.28751	3.19659	1.97833
Jun-10	8.275	0.401	1.598	1.55	15.6529	1.8935	4.70109	2.90945
Jul-10	56.02	3.03	10.53	10.48	23.176	2.80355	6.96054	4.3078
Aug-10	51.04	2.878	9.375	9.838	102.81	12.4367	30.8774	19.1097
Sep-10	32.08	1.891	5.81	6.22	35.0347	4.23806	10.5221	6.51201
Oct-10	20.21	1.171	3.786	3.682	12.6073	1.52507	3.78638	2.34335
Nov-10	10.1	0.5749	1.946	1.756	9.84717	1.19119	2.95744	1.83032
Dec-10	4.034	0.2291	0.8059	0.6559	7.93461	0.95983	2.38303	1.47483
Jan-11	0.6174	0.03731	0.1278	0.1004	7.423	0.89794	2.22938	1.37974
Feb-11	0.1496	0.01259	0.03915	0.02089	6.62621	0.80156	1.99008	1.23164
Mar-11	0.01656	0.00426	0.00882	0.00138	6.63929	0.80314	1.994	1.23407
Apr-11	0.07283	0.00756	0.00851	0.02665	6.4561	0.78098	1.93898	1.20002
May-11	2.41	0.1167	0.5009	0.4497	10.3605	1.25328	3.11159	1.92573
Jun-11	25.5	1.313	4.911	4.616	22.9242	2.77309	6.88492	4.261

Jul-11	85.87	4.71	16.03	16.15	33.2487	4.02202	9.98571	6.18004
Aug-11	103.2	5.817	18.98	19.73	115.534	13.9759	34.6989	21.4748
Sep-11	75.07	4.362	13.6	14.56	34.9781	4.23122	10.5051	6.50149
Oct-11	29.3	1.798	5.184	5.712	12.5835	1.52219	3.77923	2.33893
Nov-11	18.97	1.108	3.539	3.497	16.3209	1.97431	4.90173	3.03362
Dec-11	7.811	0.4564	1.487	1.382	12.4827	1.51	3.74897	2.3202
Jan-12	1.917	0.1152	0.3971	0.2905	11.375	1.376	3.41629	2.1143
Feb-12	0.4076	0.02744	0.09024	0.06369	10.1825	1.23176	3.05815	1.89266
Mar-12	0.08726	0.00928	0.02666	0.01084	9.72284	1.17615	2.9201	1.80722
Apr-12	0	0.0019	0.00166	0	9.1527	1.10718	2.74886	1.70124
May-12	0.1294	0.01447	0.015	0.053	9.92313	1.20038	2.98025	1.84444
Jun-12	22.75	1.169	4.391	4.122	21.715	2.62681	6.52174	4.03623
Jul-12	96.14	5.289	17.92	18.14	88.701	10.73	26.6399	16.4871
Aug-12	92.15	5.252	16.8	17.82	75.9425	9.18659	22.8081	14.1157
Sep-12	54.42	3.245	9.608	10.83	37.2031	4.50037	11.1733	6.91505
Oct-12	25.12	1.566	4.279	5.097	9.78442	1.1836	2.93859	1.81866
Nov-12	13.68	0.8496	2.332	2.777	13.4166	1.62298	4.02946	2.49379
Dec-12	6.174	0.3859	1.053	1.231	9.92429	1.20052	2.9806	1.84466
Jan-13	1.36	0.09875	0.2056	0.31	7.723	0.93423	2.31948	1.4355
Feb-13	0.3099	0.02395	0.05939	0.061	7.24111	0.87594	2.17475	1.34593
Mar-13	0.08538	0.0109	0.01753	0.02274	6.61045	0.79965	1.98534	1.22871
Apr-13	0.05573	0.00851	0.00653	0.02349	5.16743	0.62509	1.55195	0.96049
May-13	0.132	0.01495	0.01197	0.05473	8.13352	0.98389	2.44277	1.5118
Jun-13	24.93	1.315	4.711	4.681	13.1087	1.58573	3.93698	2.43656
Jul-13	106.6	5.905	19.76	20.26	50.5851	6.11916	15.1924	9.40241
Aug-13	100.7	5.732	18.33	19.51	62.9741	7.61784	18.9133	11.7052
Sep-13	46.78	2.864	8.03	9.53	27.8318	3.36675	8.35883	5.17319
Oct-13	34.86	2.105	5.929	7.014	12.8768	1.55767	3.86733	2.39345
Nov-13	16.95	1.042	2.754	3.443	9.1214	1.1034	2.73946	1.69542
Dec-13	8.017	0.4988	1.244	1.637	6.43258	0.77813	1.93192	1.19564