ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

# IMPACT OF LAND USE LAND COVER CHANGE ON HYDROLOGY OF BORKENA WATERSHED, ETHIOPIA

A THESIS SUBMITTED TO ADDIS ABEBA UNIVERSITY SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

BY

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ADVISOR

Dr. YENESEW MENGISTE

OCTOBER, 2018

ADDIS ABEBA, ETHIOPIA

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Approval by Board of Examiners

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| ____________________ | ____________ | ____________ |
| Chairman (Department of Graduate Committee) | Signature | Date |

# DECLARATION

I hereby declare that this Master of Science thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ArcSWAT | ArcGIS Integrated with SWAT Hydrological Model |
| DEM | Digital Elevation Model |
| ENS | Nash-Sutcliffe Efficiency |
| GIS | Geographic Information System |
| GWQ | Groundwater flow |
| HBV | Hydrologiska Byroans Vattenavdelning model |
| HEC-HMS | Hydrologic Engineering Center-Hydrologic Modeling System |
| HRU | Hydrologice response unit |
| LULC | Land Use Land Cover |
| m.a.s.l | Meter above sea level |
| MWIE | Ministry of Water, Irrigation and Electricity, Ethiopia |
| NMA | National Meteorological Agency |
| $R^2$ | Coefficient of Determination |
| SCS | Soil Conservation Service |
| SCS-CN | Soil Conservation Service-Curve number method |
| SURQ | Surface Runoff |
| SWAT | Soil and Water Assessment Tool |
| WXGEN | Weather Generator |

# ABSTRACT

Land use and land cover change (LULCC) has been a key research priority throughout the world with multi-directional impacts on both human and natural systems. The objective of this study is to assess the effect of land use land cover change on stream flow of Borkena watershed. The study was examined by Arc GIS10.3. SWAT model used with GIS to assess the impact of land use and land cover change on stream flow. Specifically, the study analyzed the temporal changes of land use land cover change using 1986, 2000 and 2011 land use and land cover maps. The model was set up using readily available temporal data, and calibrated using the measured discharge. Land cover change analysis shown that the cultivated land increased from 8.58% to 14.25%,agricultural land increased from 9.88% to 34.82% as well as urban areas from 1.16% to 9.94% between 1986 and 2011. While shrub land decreased from 11.04% to 8.39%, Forest decreased from 57.33% to 23.77%, grassland decreased from 10.74% to 8.74%, wetland decreased from1.26% to 0.09% between 1986 and 2011.CN2, ALPHA_BF, CH_K2 and SOL_Z were the most sensitive parameters identified for the stream flow of the study area and used for calibration of the model. The model calibration was carried out using observed stream flow data from 01 January 1998 to 31 December 2001 and a validation period from 01 January 2002 to 31 December 2003. Both the calibration and validation results showed a good agreement between measured and simulated stream flow with the coefficient of determination ($R^2$) of 0.93 and Nash-Sutcliffe efficiency (ENS) of 0.89 for the calibration, and $R^2$ of 0.98 and ENS of 0.95 for the validation periods. Within the calibration and validation period the rainfall and surface runoff pattern is the same with percentage of fit 90%. Evaluation of SWAT model showed that, annual surface runoff for land use land cover period of 1986, 2000, and 2011 is 152.37mm, 193.44mm and 198.8mm respectively. Therefore annual surface runoff increased by +46.43mm and ground water flow declined by -31.97mm between 1986 and 2011.Therfore, the model results showed that the stream flow characteristics changed due to the land use/cover changes during the study periods. This study plays a role to build the ability of planners, researchers and other stake holders to formulate and implement sound policies to minimize undesirable land use and land cover impacts on stream flow.

**Key words:** Stream flow, SWAT model, Land Use land cover change, Borkena watershed

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1 Background

Land use land cover change is ubiquitous drivers of global environmental change. The changes in land use land cover have affected the surface and groundwater hydrology and altering the hydrological cycle (Skaggs et al., 2006). Hydrologic modeling and water resources management studies are closely related to the spatial processes of the hydrologic cycle. This cycle is affected by several factors like climate and land use and land cover change. Land use and land cover change has significant impact on the watershed hydrology by affecting the magnitude and pattern of surface runoff, ground water and soil moisture content. Thus, understanding the interaction between land use and land cover and hydrological cycle is imperative.

Currently many studies revealed that hydrologic models provide a framework for examining the effects of land use and land cover changes on soil erosion and stream flow (Legesse et al., 2003; Xu, 2000; Arnold and Fohrer, 2005).

Land cover change, associated with the intensification of agriculture, cattle rising and urbanization, could have a profound impudence on the hydrological processes in Small watersheds and at the regional level (Mendoza et al., 2002). Land use/land cover changes occur in the country, Ethiopia, as a whole and in the study area in particular due to increasing population, which has almost doubled in the country over the past 40 year (CSA, 1999). It is thus essential to analyze the possible impacts of these changes at deferent scales. In this study, different scenarios of land use change will be used in the watershed to assess the impact of this change on the Rain fall-runoff hydrology of the Borkena River and its tributaries. The effect of land use land cover especially in the mountainous part of the catchment will have a significant effect on the rainfall-runoff response of the catchment.

As a key technical challenge, it is reasonable to expect the variation in flood response from the gauged catchment of Borkena watershed in time due to which more robust projections can be made to alleviate the probable impacts of land use and climate change. To provide a road map of how to address the impact this changes on the hydrology of the watershed.

As the Assessment of LULC changes on the stream flow and characterization of the rainfall-runoff relationships of the watershed need both spatial and temporal data to observe the effect, the chosen model should incorporate both temporal and spatial parameters. Therefore, the Physically based, semi-distributed, Computationally efficient and public domain model, SWAT, which uses a GIS interface and readily available input data such as Digital Elevation Model (DEM),climate, soil and land-use etc is used to investigate the hydrologic dynamics of land use land cover changes.

This paper intends to investigate how the land use land cover interaction affects the transformation of rainfall into flood runoff on the study area for different scenarios of land use land cover change.

### 1.2 Statement of problem

In the past few decades drought and flood damages in the world have increased considerably (Munich, 2005). Droughts are the world's costliest natural disasters, causing an average \$6–\$8 billion in global damages annually and collectively affecting more people than any other form of natural disaster (Lampros Vasiliades, 2009). Proper quantification of stream low flow and high flow can greatly reduce the damages aggravated by these extreme flows.

Ethiopia is one of the countries that can be considered to have abundant water resources, available for hydropower and irrigation, at the same time as having significant problems related to water resources, such as flooding, drought and depletion of ecosystem services (Tessema, 2011).Since the land in Ethiopia is less intensive, more land is needed to grow crops with increase population of the country. As a result, deforestation is inevitable and conversion of forest in to agricultural land thereby changing the land use of the country.

Borkena watershed, because of the rapid growth of population the demand for increase of the cultivation area is growing and even steeply sloped areas are being ploughed to be cultivated. More over the use of woods for fuel consumption and as a construction material is influencing the land use land cover pattern of the area. Mainly for these reasons the catchments is getting degraded from time to time.

Urbanization leads to a higher impervious area and conversion of natural forests in to agricultural land would decrease the amount of ground water recharge both of which can lead to increased surface runoff. It is rather clear that the change in „land use" or „land cover" are of major relevance for rainfall runoff processes, in particular if runoff-generation processes are influenced by the land surface conditions of the catchment. (Tamiru, 2014)

Therefore, Borkena watershed is the one which is affected by the effects of land use land cover change. Hence, this study will assess the hydrological impacts of land use land cover dynamics dynamics.

## 1.3 Objective of the study

### General objectives

The general objective of this study is to assess the effect of Land Use land cover change on hydrology of Borkena watershed by using SWAT model.

### Specific objectives

I. To assess the change in different categories of LULC change in the watershed.
II. To estimate and compare the stream flow in relation to different LULC period of the watershed.
III. To observe the rain fall –runoff relationship in the watershed

### Research Questions

- ✓ How will be land use land cover change impacted the stream flow?
- ✓ Is there land use land cover change in Borkena Catchment over the past?
- ✓ What is the trend of land use land cover look like?

### 1.4 Significance of the study

The main significances of this study are:

- ✓ It allows the planners, decision makers and other concerning bodies to integrate their due attentions land use changes.
- ✓ Quantifying land use land cover change impacts on hydrological regimes of the study area.

### 1.5 Scope of the study

This study was investigated the rainfall and runoff relationship in the watershed. And hydrologic modeling was done using SWAT model incorporated with GIS. Moreover, this model is simulating the flow in the watershed and identifies flow sensitive parameters. Also the land use and land cover change has identified using 1986, 2000 and 2011 land use and land cover maps. Using these maps the stream flow components such as surface runoff and ground water flow was estimated and its impact on the watershed was assessed. Although, water resources are affected by many factors like climate change, this study only focus on the impact of land use and land cover change on stream flow component such as surface runoff.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1 Overview of land use and land cover change

Land cover is defined by the attributes of the earth's land surface captured in the distribution of vegetation, water, desert and ice and the immediate subsurface, including biota, soil, topography, surface and groundwater, and it also includes those structures created solely by human activities such as mine exposures and settlement (Lambin et al., 2003). In Ethiopia the rapid increase in human population and strive for growth in the standard of living has put great pressure on natural resources. As human population number have been rising the need for cultivated land, grazing land, fuel wood, settlement areas also increases to meet the ground demand for food & energy and livestock population. As many researchers indicated that, in Ethiopia, several factors have been contributing towards modifying the original form of land cover.

These include human activities such as an expansion of cultivated land at the expense of the grasslands, the decrease of natural vegetation and expansion of agricultural land cover as a result of population pressure Hadgu (2008), reduction of natural vegetation cover, but an expansion of open grassland, cultivated areas and settlements Abebe and Bewket (2013), conversion of natural vegetation cover to cultivated land reduction of natural forest cover and grasslands, but an increase of croplands increase of open areas and settlements as the expense of forests and shrub land decline of natural forests and grazing lands due to conversions to croplands and an increase in agricultural land at the expense of natural vegetation Kassa (2003).

### 2.2 land use land cover change impacts on watershed Hydrology

Land use and land cover (LULC) changes influence hydrological processes by altering interception rates, soil water, evapotranspiration (ET), infiltration, and groundwater, leading to changes in surface runoff and stream flow. Land cover change refers to modification of the existing land cover or complete conversion of land cover to a new cover type (Wu et al., 2013).

Increasing land use conversion (especially for urbanization, deforestation, grassland depletion) can potentially lead to an increase in stream flow and flood frequency (Schilling et al., 2014). During storm events, greater surface runoff can exceed the flow carrying capacity of the stream within the watershed which may increase the risk of potential flooding.

Higher porosity increases infiltration and percolation rates and the water-holding capacity of the soil. Infiltration rates are positively related to litter and grass basal cover, being up to 9 times faster with 100% litter cover than for bare soil. Therefore, deforestation increases surface runoff and reduces recharge by affecting the above condition especially if the area is steeply sloped and recharging zone (Maidment, 1993a). Land use/land cover affects runoff in the form of accelerated or retarded overland flow as a result of slow or fast infiltration rate and initial abstraction due to canopy cover (Jinno *et al*., 2009).

The amount and type of vegetative land cover is one determinant of the water yield of a drainage basin. Forests produce higher rates of evapotranspiration and interception (the storage of water on leaf surfaces) than do grass or shrub lands, all of which influence the amount of water that is available for direct drainage into streams or for aquifer recharge (Farley *et al*., 2005). Trees have lower surface albedo, higher surface aerodynamic roughness, higher leaf surface area, and deeper roots than other types of vegetation, with each characteristic tending towards an increase in evapotranspiration of water and a decrease in stream flow discharge (Costa *et al*., 2003).

The conversion of the land surface from native cover to managed cropland has an effect on the evapotranspiration, infiltration and overland runoff characteristics of a watershed. Crops need less soil moisture than forests; therefore, the rainfall satisfies the shortage of soil moisture in agricultural lands more quickly than in forests there by generating more runoff. The increased removal of native vegetation and soil compaction decreases soil infiltration capacity. Hence, this leads to an increase in stream flow. Depending on the type of product being grown, croplands tend to have a percentage of bare ground even during the peak of the growing season, and may be completely bare prior to being planted. In both instances, most of the precipitation that lands on these denuded areas will be discharged directly into the stream channel rather than infiltrating into the soil or evaporating/transpiring from the plant surfaces. As a result, conversion to cropland tends to increase water yield compared to native vegetation (Fisher & Mustard, 2004).

Besides the above factors, physical changes resulting from urbanization also affects the water budget through reduction of interception of rainfall due to removal of trees; removal of natural vegetation and change in the drainage patterns; loss of natural depressions which temporarily store surface water (i.e. regarding of areas results in a change in topography); loss of rainfall absorbing capacity of humus on the forest floor; creation of impervious surfaces (rooftops, roads, sidewalks, driveways) etc. In urban and suburban areas, much of the land surface is covered by buildings and pavement, which do not allow rain and snowmelt to soak into the ground. Studies have indicated that soil compaction as a result of urban growth is more likely to influence flood responses than the presence of forests. Impervious surfaces prohibit infiltration of water to the soil during precipitation events, thus inhibiting groundwater recharge and increasing overland runoff during precipitation events (Fisher & Mustard, 2004).

### 2.4 General overview of Hydrological models

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The one objective of the watershed hydrologic modeling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena. The other objective is for hydrologic prediction (Tadele, 2007). They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate.

On the basis of process description, the hydrological models can be categorized in to three main parts (Cunderlik, 2003):

**1. Lumped models:** Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Cunderlik, 2003).

**2. Distributed models:** Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often unavailable) data. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy (Cunderlik, 2003).

**3. Semi-distributed models:** Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold, *et al.,* 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), are considered as semi-distributed models. Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. Event driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003).

### 2.4.1 Model Selection

There are ranges of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. Beven (2000) suggested criterions for selecting model structures as below.

- ✓ Consider models which are readily available and whose investment of time and money appeared worthwhile.
- ✓ Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.

Make a list of the inputs required by the model and decide whether all the information required by the model provided within the time and cost constraints of the project the SWAT model is selected rather than the other model for this hydrological component relationship is for the following reasons:

- ✓ Uses readily available inputs for weather, soil, land, and topography.
- ✓ Allows considerable spatial detail for basin scale modeling.
- ✓ It is capable of simulating change in watershed characteristics using different scenarios.
- ✓ Capability for interface with a geographical information system (GIS).

### 2.5 Soil and Water Assessment Tool (SWAT) model

SWAT is a physically based watershed-scale continuous time-scale model, which operates on a daily time step. The SWAT model can simulate runoff, sediment, nutrients, pesticide, and bacteria transport from agricultural watersheds (Arnold et al., 1998). The SWAT model delineates a watershed, and sub-divides that watershed in to sub-basins. In each sub-basin, the model creates several hydrologic response units (HRUs) based on specific land cover, soil, and topographic conditions. Model simulations that are performed at the HRU levels are summarized for the sub-basins. Water is routed from HRUs to associated reaches in the SWAT model. SWAT first deposits estimated pollutants within the stream channel system then transport them to the outlet of the watershed. The HRUs provide opportunity to include processes for possible spatial and temporal variations in model input parameters. The hydrologic module of the model quantifies a soil water balance at each time step during the simulation period based on daily precipitation inputs.

The SWAT model distinguishes the effects of weather, surface runoff, evapotranspiration, crop growth, nutrient loading, water routing, and the long-term effects of varying agricultural management practices (Neitsch et al., 2005). In the hydrologic module of the model, the surface runoff is estimated separately for each sub-basin and routed to quantify the total surface runoff for the watershed. Runoff volume is commonly estimated from daily rainfall using modified SCS-CN method. The model needs several data inputs to represent watershed conditions which include: digital elevation model (DEM), land use and land cover, soils and climate data.

### 2.5.1 Hydrological Component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation (Neitsch et al., 2005).

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-1)$$

Where,

SWt is the final soil water content (mm)
SWo is the initial water content (mm)

t is the time (days)

$R_{day}$ is the amount of precipitation on day i (mm)

$Q_{surf}$ is the amount of surface runoff on day i (mm)

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

$W_{seep}$ is the amount of water entering the vadose zone from the soil profile on day i (mm), and

$Q_{gw}$ is the amount of return flow on day i (mm).

### 2.5.2 Potential Evapotranspiration

Evapotranspiration is the combination of two terms which are transpiration from the plant and evaporation from the water bodies and soil. SWAT provides three options for PET calculation: Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and Hargreaves (Hargreaves *et al.,* 1985) methods. These have different data requirement of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind speed; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only. Hargreaves method is used in this study.

### 2.5.3 Surface Runoff

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating the surface runoff: the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911). The Green and Ampt method requires sub-daily time step rainfall which was difficult to be used for this study due to unavailability of sub-daily rainfall data. As a result, the SCS curve number method was adopted for this study which is computed by using equation 2-2:

$$Qsurf = \frac{(Rday - Ia)\Delta 2}{(Rday - Ia + S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2\text{-}2)$$

Where,

$Q_{surf}$ Is the accumulated runoff or rainfall excess (mm)

$R_{day}$ Is the rainfall depth for the day (mm water),

$I_a$ Is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water),

S is retention parameter (mm water).

The retention parameter computed by equation 2-3:

$$S = \frac{1000}{CN} - 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2 - 3)$$

Where, *CN* is the curve number for the day and its value is the function of land use practice, soil permeability and soil hydrologic group.

The initial abstraction, $I_a$ is commonly approximated as 0.2*S* and equation 2-2 rewritten as follows:

$$Qsurf = \frac{(Rday - 0.2S)\Delta 2}{(Rday + 0.8S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2 - 4)$$

### 2.5.4 Ground Water Flow

To simulate the ground water flow, SWAT separates groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer which contributes return flow to streams outside the watershed (Arnold *et al.,* 1993). In SWAT the water balance for a shallow aquifer is computed by using equation 2-5.

$$\alpha q_{sh,i}=\alpha q_{sh,i-1}+W_{rchrg}-Q_{gw}-W_{revap}-W_{deep}-W_{pump\cdot sh}\ldots\ldots\ldots\ldots(2\text{-}5)$$

Where,

$aq_{sh,i}$ Is the amount of water stored in the shallow aquifer on day i (mm),

$aq_{sh,i-1}$ Is the amount of water stored in the shallow aquifer on day i-1 (mm),

$W_{rchrg}$ Is the amount of recharge entering the aquifer on day i (mm),

$Q_{gw}$ Is the ground water flow, or base flow, or return flow, into the main channel on day i (mm),

$W_{revap}$ Is the amount of water moving in to the soil zone in response to water deficiencies on day i (mm),

$W_{deep}$ Is the amount of water percolating from the shallow aquifer in to the deep aquifer on day i (mm), and

$W_{pump,sh}$ Is the amount of water removed from the shallow aquifer by pumping on day i (mm).

### 2.6 Previous Studies on LULCC in Ethiopia

In Ethiopia, the land is used to grow crops, trees, animals for food, as building sites for houses and roads, or for recreational purposes. Most of the land in the country is being used by smallholders who farm for subsistence. With the rapid population growth and in the absence of agricultural intensification, smallholders require more land to grow crops and earn a living; it results in deforestation and land use conversions from other types of land cover to cropland. The researches that have been conducted in different parts of Ethiopia have shown that there were considerable land use and land cover changes in the country. Most of these studies indicated that croplands have expanded at the expanse of natural vegetation, including forests and shrub lands; (Belay (2002); Bewket (2003); Kidanu (2004); Abebe (2005) in the northern part of Ethiopia, Zeleke and Hurni, (2001) in the northwestern part of Ethiopia, Kassa, (2003) in the northeastern part of Ethiopia; and Denboba, (2005) in the southwestern part of Ethiopia).

White et al (2008) used a Water Balance-Based and Water Assessment Tool (SWAT) for improved Performance in the Ethiopian Highlands of Gumera watershed with an area of 1270 km2. The model uses the CN and water balance based approach. The author compares the efficiency of the model prior to any calibration. They reported SWAT can accurately model saturation-excess process without using the curve Number technique.

Sirak (2008) assessed the application of SWAT model in the Lake Tana basin Ethiopia The model is physically based distributed model. The author aims to test the performance of SWAT model for stream flow prediction in Tana Basin .The model was calibrated and validated on four tributaries of Lake Tana: Gumera, Gilgel-Abbay, Megach, and Ribb Rivers.They reported that SWAT 2005 model was successfully calibrated and validated in the Lake Tana Basin using different algorithm and give good simulation result for daily and monthly time steps.

The researches that have been conducted in different parts of Ethiopia have shown that there were considerable land use and land cover changes in the country. Most of these studies indicated that, cultivated land is expanded in expense of natural vegetation like forest. For instance: Abate, (2011); Habtamu, (2011); Haregeweyn et al (2012); Dorosh and Schmidt (2010); Zeleke and Hurni (2001); Amsalu et al (2007) and Bekalo (2009).

The impacts of land use and land cover changes on the hydrological flow regime of the watershed have been reported in many studies. The impact is through altering the balance between rainfall and evaporation and the runoff response. It was also reported by Geremew (2013) that land use and land cover changes affected the stream flow of Gilgel Abbay watershed, Ethiopia. According to his study, the mean monthly stream flow for wet months had increased by value 16.26 m3/s while the dry season had decreased by value 5.41 m3/s for years from 1986 to 2001 due to the land use and land cover change. Haile and Assefa (2012) reported that the mean wet monthly stream flow was increased by 39% and dry average monthly flow decreased by 46% for 2011 land cover as compared to 1985 land cover due to land use land cover change on Angereb Watershed. Getahun and Lanen (2015) reported that the stream flow increased by the

2003 land use was 25% in June, 4% in July, 6% in August and 9% in September for the main rainy season as compared to the 1986 land use due to expansion of land under agriculture in expense of other land use of Melka Kuntrie sub basin in the Upper Awash River Basin using the semi-distributed HBV hydrological model.

# CHAPTER THREE

## 3. MATERIALS AND METHODS

### 3.1 Description of the study area

### 3.1.1 Location

The Borkena River is one of the main tributaries of the Awash River. It drains from the mountainous chains and escarpments found in the northern plateau which is adjacent to the Afar rift down to south eastern direction and after joining the Jara River in around the Cheffa swamp, it finally enters the Awash River. And the Berberie River also drains from the mountainous area situated mainly on the north eastern direction of the town of Kombolcha and after passing the meandering path through the town joins the Borkena River a few meters upstream of the bridge on the main high way connecting Addis to Dessie.

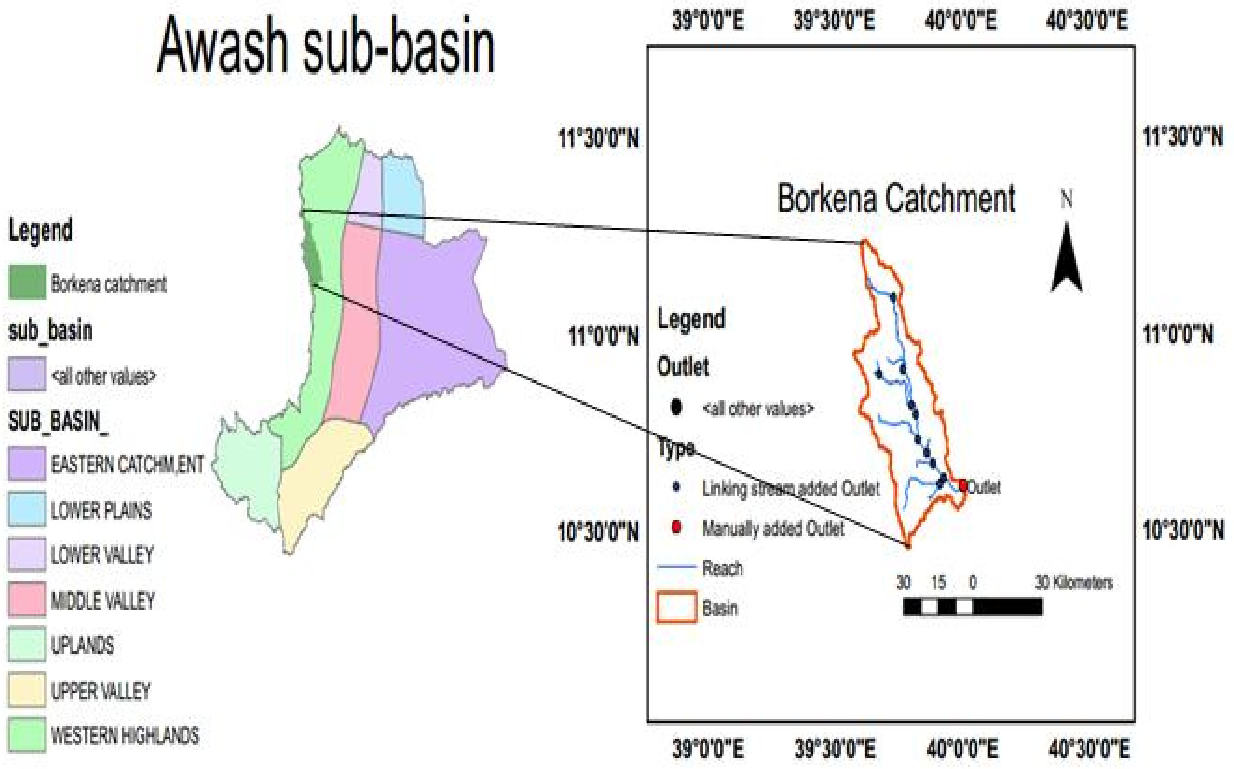


Figure3-1Location of Borkena catchment

Borkena watershed at swamp outlet located roughly at 10$^{o}$ 03’ N and 39$^{o}$56’E latitude and longitude respectively. The catchments upstream of the swamp extend from the town of Kutaber, and the average elevation varies between 1228m to 3480m a.s.l. the total catchment area reaches 1671 square kilometers.

### 3.1.2 Climate

#### 3.1.2.1 Rainfall

The climate of the area upstream of the town of Kombolcha varies between sub humid and sub tropical, and according to the traditional classification of climate which is mainly based on altitude variation, the climate is classified as “Dega and Weyna Dega”. The main annual rain fall over the catchments is 1028mm and most of which is concentrated in the big rainy months that lasts from July to September.this study have four stations namely Kombolcha station, Kabie station,Cheffa station and Majete station. The station Kombolcha and Cheffa is inside the Borkena catchment Kabie and Majete stationis around the cathment.

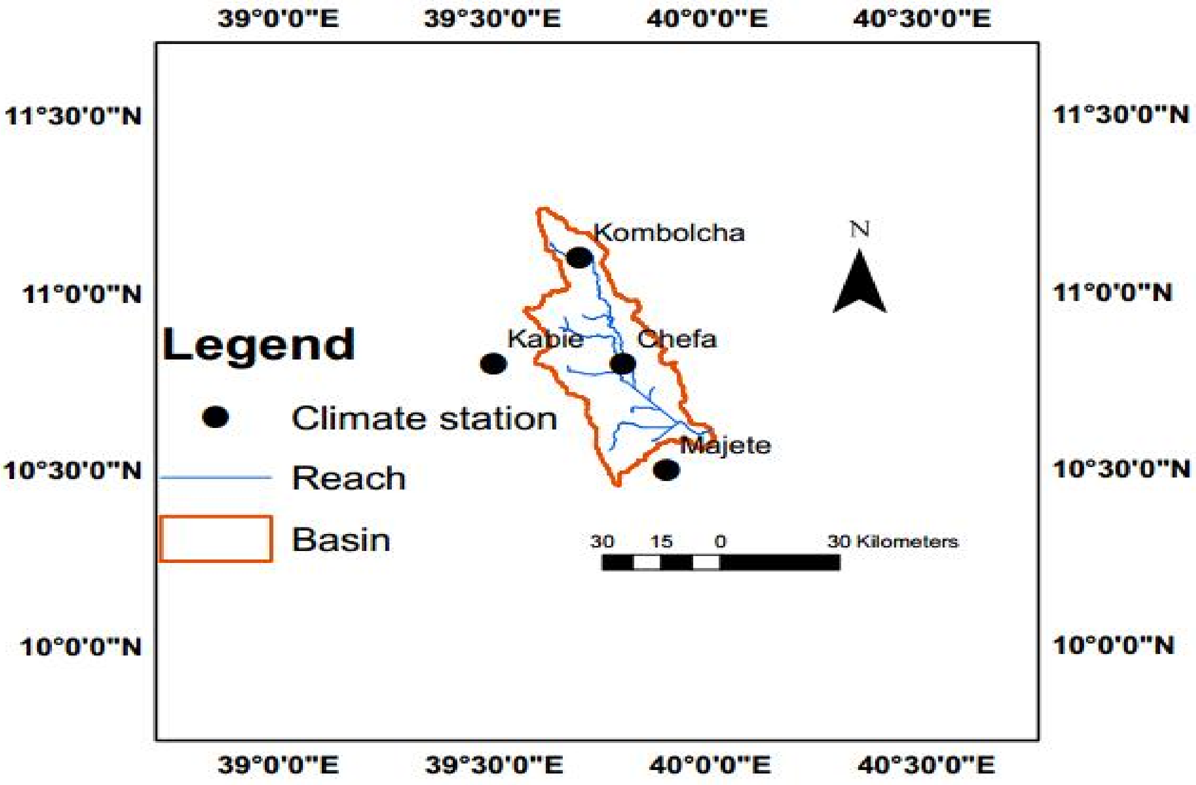


Figure 3-2 Location of climate station in and around Borkena watershed

### 3.1.2.2 Temperature

The mean monthly temperature considering the Kombolcha station varies between 16.1$^{o}$c to 22.1$^{o}$c which corresponds to December and June respectively. Monthly mean sunshine hour and relative humidity varies between 5.0 to 8.5 and 40.1% to 64.3% respectively with rainy seasons being humid and have lower sunshine hour.

## 3.1.3 Catchments Characteristics

### 3.1.3.1Topography

The topographic variation of the area ranges from about 3480 m a.s.l on the top of the ridge in around the north west of the water divide at Kutaber, to 1228 m a.s.l in the floor of the graben at around the swamp outlet. Both the towns of Dessie and Kombolcha are located at an elevation of about 2660m a.s.l and 1800m a.s.l respectively. The fault bounded graben form large plain areas such as the Boru plain, Alaska plain, Marim Weha plain, and large flat lands in Kombolcha and its surroundings. These plains are seasonally flooded by the Borkena River.

The catchments are bounded by very steep fault bounded grabens. To the west it is bounded by the Tossa, Wefkele and Walet ridges, and to the east it is bounded by Dosheny, KundiAmeraro, and Irfo ridge. As one goes from Dessie to Kombolcha the topography gets lowered from the ridge towards the floor of the graben. On topographically high areas the drainage pattern is denser and most of the streams entering in to the Borkena River originate from the surrounding ridge, hills and fault escarp regions.

#### 3.1.3.2 Land use-land cover

Because of the rapid growth of population the demand for increase of the cultivation area is growing and even steeply sloped areas are being ploughed to be cultivated. More over the use of woods for fuel consumption and as a construction material is influencing the land use land cover pattern of the area. Mainly for these reasons the catchments is getting degraded from time to time. The vegetation cover of the area includes Eucalyptus, Acacia and Juniper trees over a small area and bushes and shrubs cover the larger area proportion. (Adopted from Fantaw, 2008)

#### 3.1.3.3 Soil type

The major soil types in the catchment are clay, loam soil, residual clay soil rich in organic material, gravelly sand soil and fractured rock with big boulders and cobbles. These different soils occupy the flat, gentle-moderate, and moderate steep slopes respectively. (Adopted from Fantaw, 2008)

#### 3.1.3.4 Geology

The Borkena, Berberi, Arawle, Worka and Livole river banks constitute alluvial or lacustrine soils. Because such soils are composed of clays (that comprise organic matter and silt), sands and gravels (very rounded), the banks are highly susceptible for bank erosion. Cited in (Kombolcha city service bank protection design document) from hard copy document.

#### 3.1.3.5 Hydrology

Borkena is the main perennial river that flows in the Awash River. Its main tributaries are the Berebire River and other tributaries around kalu town but it is seasonal. The berberie river join Borkena river at upstream of the brige on highway of connecting addis to dessie. Most of the tributaries are seasonal.

### 3.1.4 Materials used

The following spatial (image) data, soil map and historic time series of hydro meteorological data have been collected and used in this study for the assessment of the impact of vegetation cover reduction on hydrology, by using Soil and Water Assessment Tool (SWAT), remote sensing and Geographical Information System (GIS).

- ✓ GIS
- ✓ Hydro meteorological data
- ✓ GPS
- ✓ SWAT
- ✓ SWAT-CUP
- ✓ Soil map
- ✓ Land use land cover map
- ✓ DEW02

## 3.2 Software used

Hydrologic modeling was done using Soil and Water Assessment Tool (SWAT) model. It is semi-distributed model which can be applied to model the impact of land management activities on water, sediment, nutrient etc. at watershed scale. It requires a certain input data which includes; weather, hydrological and spatial data. Geographical Information System was used to process the spatial data and as interface to SWAT model. For this study GIS version 10.3 and SWAT 2012 was used.

## 3.3 SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty 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 requires that 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.

### 3.4 Data collection and analysis

The basic data sets that are required to develop an input database for the model are climatic, stream flow, topographic and land use data. The climatic data such as rainfall, max and min temperature, wind speed… etc. were obtained from the meteorological stations of the area. The daily stream flow data was obtained from the Ministry of Water Irrigation and Energy Resources. The topographic, soil, land use and other data were collected from the concerning bodies.

**Input data's for the model**

**Spatial data**

- ✓ Land use land cover data: The land use/ Land Cover spatial dataset in the model defines the densities and types of land use found within a given area. Thus dates from Ethiopian Mapping Agency (EMA).
- ✓ DEM / Topography data: To delineate a watershed into multiple sub watersheds and also to calculate watershed/sub-watersheds parameters such as average slope, slope length, and the accumulation of flow for the definition of stream networks. Obtained in the form of Digital Elevation Model from Ministry of water, irrigation and electricity (MWIE).
- ✓ Soil map/ Soil Data: Soil characteristics, coupled with other landscape factors, will be used to determine soil moisture properties. The physical and chemical Characteristics are the two soil data's used by SWAT data base.
- ✓ Slope: During the creation of HRU the slope is classified to the reasonable range. Accordingly for this work the slope can be classified with due consideration given to minimizing complexity, manageable data usage, and considering the steepness of the area.

**Weather data**

- ✓ Rainfall, temperature (maximum and minimum air temperature), relative humidity, solar radiation and wind speed for this study, daily precipitation and temperature data can be collected from NMA.
- ✓ Hydrological data-- including stream flow from Ministry of water, irrigation and electricity (MWIE).

### 3.4.1 Digital Elevation Model

The digital elevation model (DEM) is one of the input data required by the SWAT to delineate the watershed in to a number of sub basins. DEM is used to examine the drainage pattern of the watershed, stream length and slope, and width of channels of the watershed. DEM 30*30 was used in this study and it is obtained from the Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia. The raw data was processed and projected using Arc GIS 10.3 the Figure below presents Digital Elevation Model of Borkena watershed.

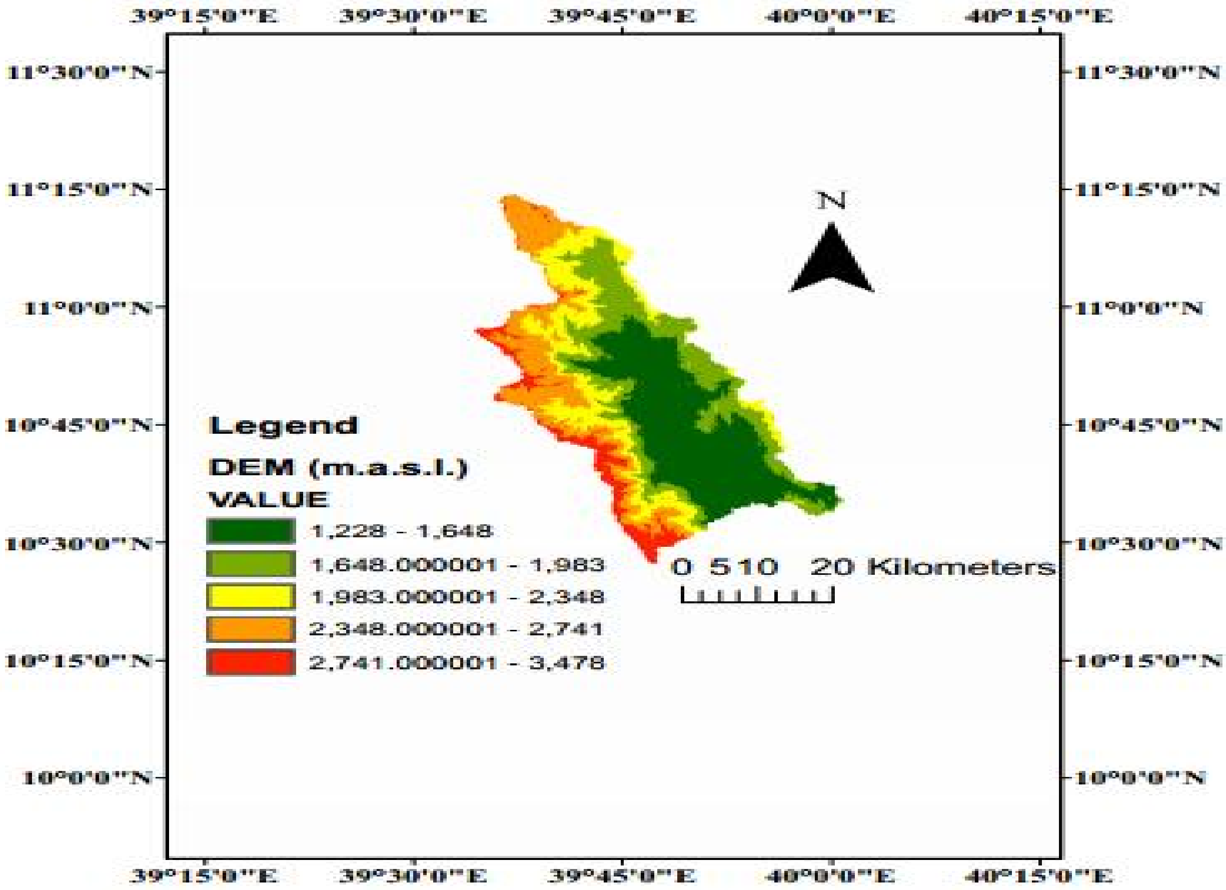


Figure 3-3 Digital Elevation Model of Borkena Watershed

### 3.4.2. Soil Map

Soil properties are one of the major inputs data required by SWAT model of the watershed. The soil data needed can be divided into physical characteristics (required) and chemical characteristics (optional). This consist of properties such as available water content, soil texture, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. They play a great role in determining the movement of water and air within the hydrologic response unit (HRU). These data were obtained from Ministry of Water, Irrigation and Energy (MWIE).

To incorporate the soil map with SWAT model, a user soil database which contains physical and chemical properties of soils was prepared for each soil layers and added to the SWAT user soil databases. Major soil of study area include Haplic nitisols,Chromic luvisols, Eutric Cambisols, Eutric leptosols, Eutric vertisols, Humic nitisols and Lithic Leptosols as shown in the Figure 3-4.

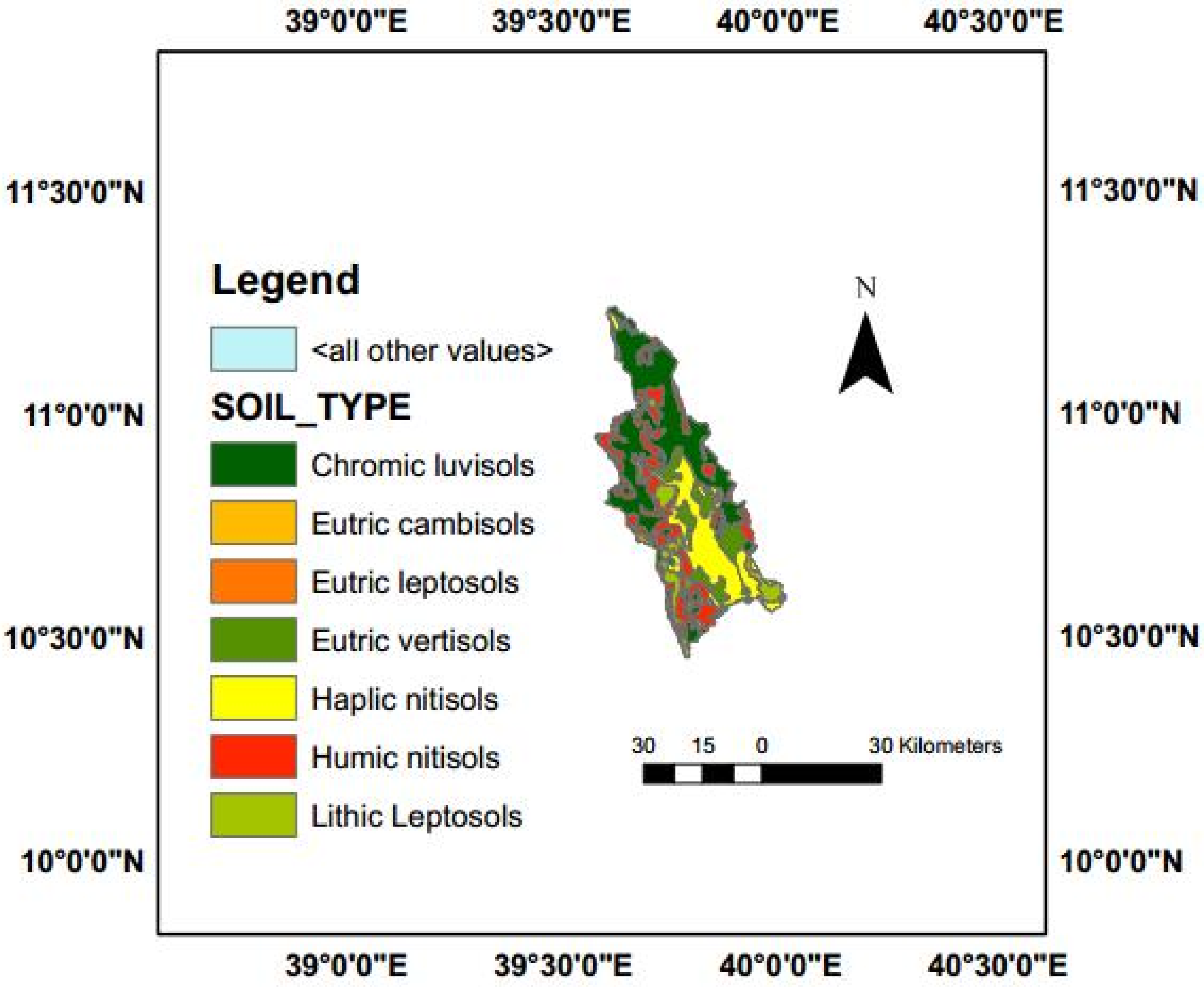


Figure 3-4Soil Map of Borkena Watershed

Table 3-1 Symbols and areal coverage of the soils in Borkena watershed

| Soil Types | Symbole | Area | |
|---|---|---|---|
| | | Km$^2$ | % |
| Chromic luvisols | Lvx | 668.56 | 40.01 |
| Eutric cambisols | CMe | 0.16 | 0.01 |
| Eutric leptosols | Lpe | 2.00 | 0.12 |
| Eutric vertisols | VRe | 157.57 | 9.43 |
| Haplic nitisols | NTh | 327.01 | 19.57 |
| Humic nitisols | NTu | 360.10 | 21.55 |
| Lithic Leptosols | Lpq | 155.73 | 9.32 |

### 3.4.3. Land Use and Land Cover Map

Land use is the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. This data required by SWAT model to describe the Hydrological Response Units (HRUs) of the watershed together with slope and soil map.

The SWAT model has predefined land use categories in its database. To make compatible with it lookup table was prepared which includes the corresponding land use categories of the model for each land use categories of the watershed. The land use and land cover map data collected from Ethiopian map agency (EMA).

The seven land cover classes were considered namely; Agricultural land, forest land, grass land, cultivated land, settlement (urban), wet land (marsh land) and shrub land.

**Agricultural Land**: is the science and practice of growing crops and rearing animals for human consumption. Raising both crops and animals.

**Forest Land**: Area with high density of trees which include deciduous forest land, ever green forest land mixed forest land and plantation forests.

**Grass land**: Area covered with grass that is used for grazing.

**Cultivated land**: relates to crops. Usually refer more specially to preparing the soil for growing crops.

**Settlement (Urban) land**: Areas where there is a permanent concentration of people building, and other man-made structures and other activities.

**Wet land**: Areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered by herbaceous.

**Shrub land**: Areas which are coved with shrubs.

Table 3-2 Major land use types, their SWAT codes and area cover of Borkena watershed (2011 lulc).

| Land use types | Swat code | Area($Km^2$) | Area (%) |
|---|---|---|---|
| Agricultural Land | AGRC | 581.84 | 34.82 |
| Forest Land | FRST | 397.19 | 23.77 |
| Wet land | RNGE | 1.50 | 0.09 |
| Grass land | DWHT | 146.04 | 8.74 |
| Settlement (Urban) land | URBN | 140.19 | 8.39 |
| Cultivated land | WETN | 238.11 | 14.25 |
| Shrub land | RNGB | 166.09 | 9.94 |

### 3.4.4. Stream Flow data

The measured stream flow data of the Borkena River is needed for the calibration and validation of the model. The daily stream flow data of (1996-2003) at Kombolcha station were collected from Ministry of Water, Irrigation and Energy (MWIE). The long term mean monthly river discharge of Borkena River at swamp outlet station shown in Figure 3-5. As the Figure 3-5 indicates that the wettest months are from July to September while driest months are from December to June.

Table 3-3 Summary of available stream flow data

| Station | River | Data available | Percentage of Missing |
|---|---|---|---|
| Swamp outlet | Borkena | 1996-2003 | 2.46% |

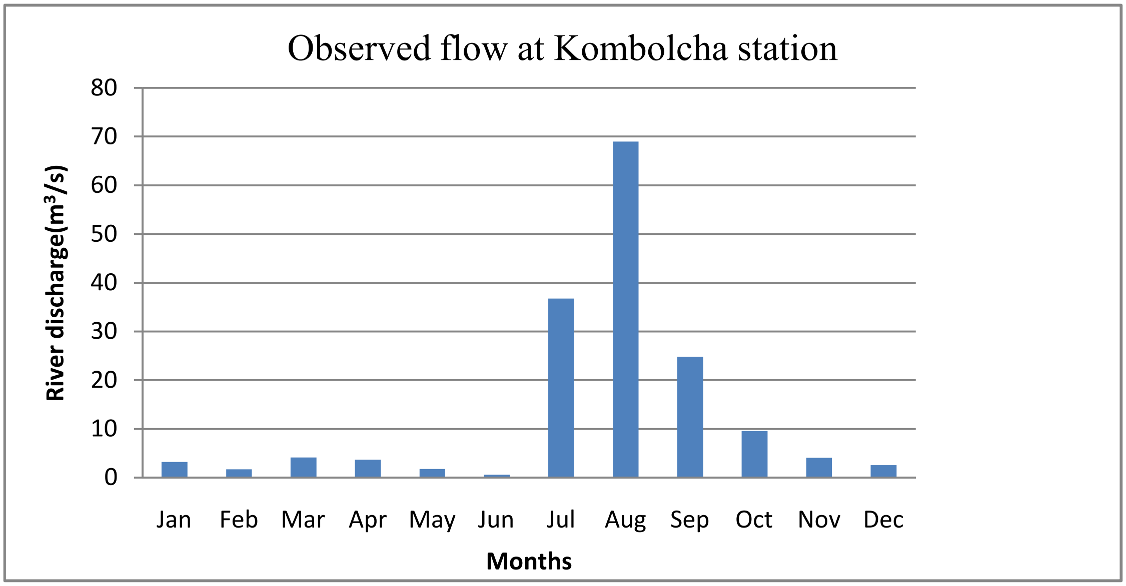


Figure 3-5 Long terms mean yearly river discharge at kombolcha

### 3.4.5. Weather Data

Weather data are among the main required input data for the SWAT model. The weather input data needed for SWAT simulation includes daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. These data were collected from the National Meteorological Services Agency. The weather data used were represented from four meteorological stations in and around Borkena catchment, which includes Kombolcha, Cheffa, Kabie and Majete as shown above in the Figure 3-2.

The number of meteorological variables collected varies from station to station based on the class of the stations. In the Borkena catchment the stations classified in to three group; first and second class stations. Kombolcha is the first class station which contains all meteorological variables (1995-2016) required for SWAT. The other weather stations Cheffa and Majete contains all meteorological variables but the period of recording time is from (2000-2016) and (2003-2016) respectively. The Kombolcha station was used as weather generator station so as to generate weather variables for missing records assigned with no data code value (-99) in SWAT database. The other selected station Kabie were containing only rainfall and temperature data. The climatic data used for this study cover 21 years from January 1996 to December 2016.

Table 3-4 Details of hydro-meteorological dataset used for analysis

| Station Name | data available | Percentage of missing (%) | | | | | | Discharge(m3/s) | Sources |
|---|---|---|---|---|---|---|---|---|---|
| | | Pcp | $T_{max}$ | $T_{min}$ | Rh | Shr | Wd | | |
| Kombolcha | 1996-2016 | 3.6 | 4.5 | 3.3 | 5.6 | 8.9 | 11.2 | | NMA |
| Kabie | 1996-2016 | 4.6 | 5.1 | 5.6 | | | | | |
| Cheffa | 1996-2016 | 11.2 | 9.2 | 6.0 | | | | | |
| Majete | 1996-2016 | 6.5 | 3.8 | 3.2 | | | | | |
| Kombolcha station | 1996-2003 | | | | | | | 2.46 | MWIE |

Where: Pcp=precipitation; $T_{max}$= maximum temperature; $T_{min}$= minimum temperature; Shr= sunshine duration; Rh= relative humidity; Wd= wind speed.

### 3.5 Data analysis

The land use land cover and soil map layers provided spatial information of the study area for the watershed-modeling program. Both maps were provided by extracting large dataset land use land cover and soil map collected from Ethiopian map agency (EMA) and Ministry of Water Irrigation and Electricity (MWIE) respectively. To agreement all the layers be geometrically aligned and fit to the study area, they were georeferenced to the corresponding coordinate projection of the study area which is North African spatial reference called Adindam_UTM_Zone_37N. As far as weather data is concerned, even though it was a long time-series data, it had several gaps of missing data values.

### 3.5.1 Filling Missing Rainfall Data

Measured precipitation data are important to many problems in hydrologic analysis and design. However, due to failure of the observer to make the necessary visit to the gage, Vandalism of recording gages or instrument failure (by mechanical or electrical malfunctioning) may result in missing data. There are methods to estimate these missing values in the given stations. For this study missing values was estimated from neighboring stations around the missed record station.

A number of methods have for estimating missing rainfall data. There are station average method, normal ratio method, quadrant method, and inverse-distance weighting method and regression methods. From five methods normal ratio is use for this study. In the normal ratio method, the rainfall PA at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and those of the neighboring stations for the period of missing data at the station under question.

$$Pm = \frac{1}{n} + \sum_{i=1}^{n}(\left(\frac{Nm}{Ni}\right)Pi) \quad \text{.......................................................(3-1)}$$

**Where,**

pi = is the rainfall at surrounding stations,
$N_m$=is the normal monthly or seasonal meant at station A,
Ni= is the normal monthly or seasonal rainfall at station i, and
n=is the number of surrounding stations whose data are used for estimation.

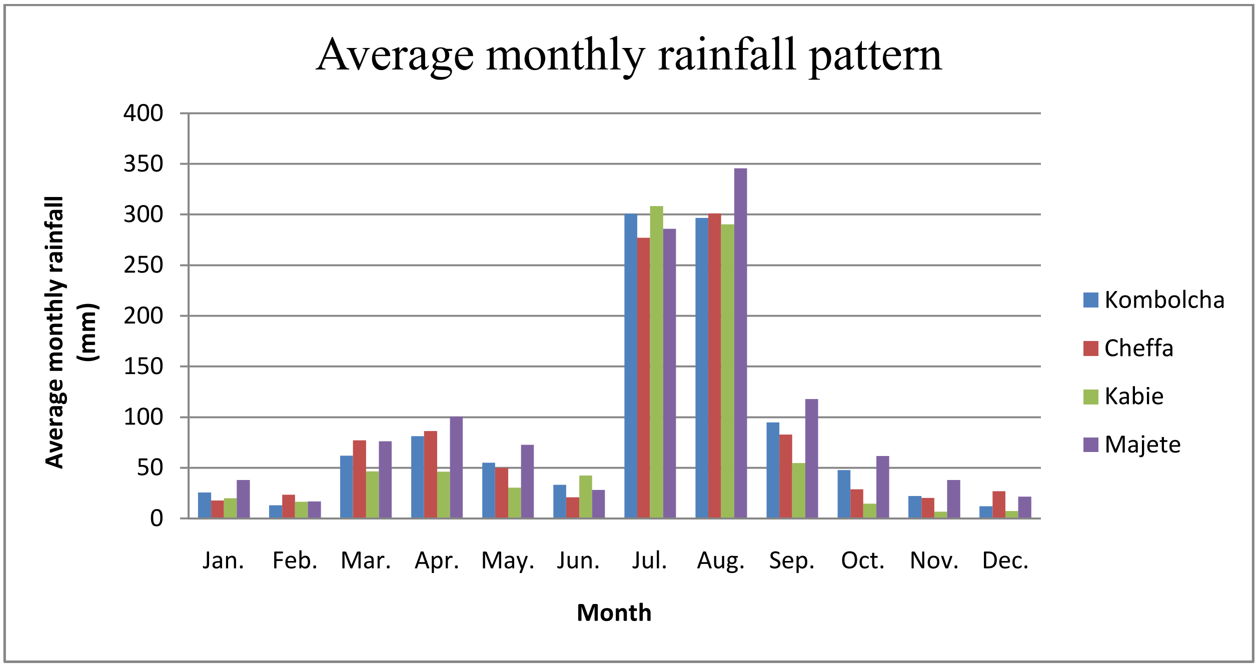


Figure 3-6 Average monthly rainfall pattern of station

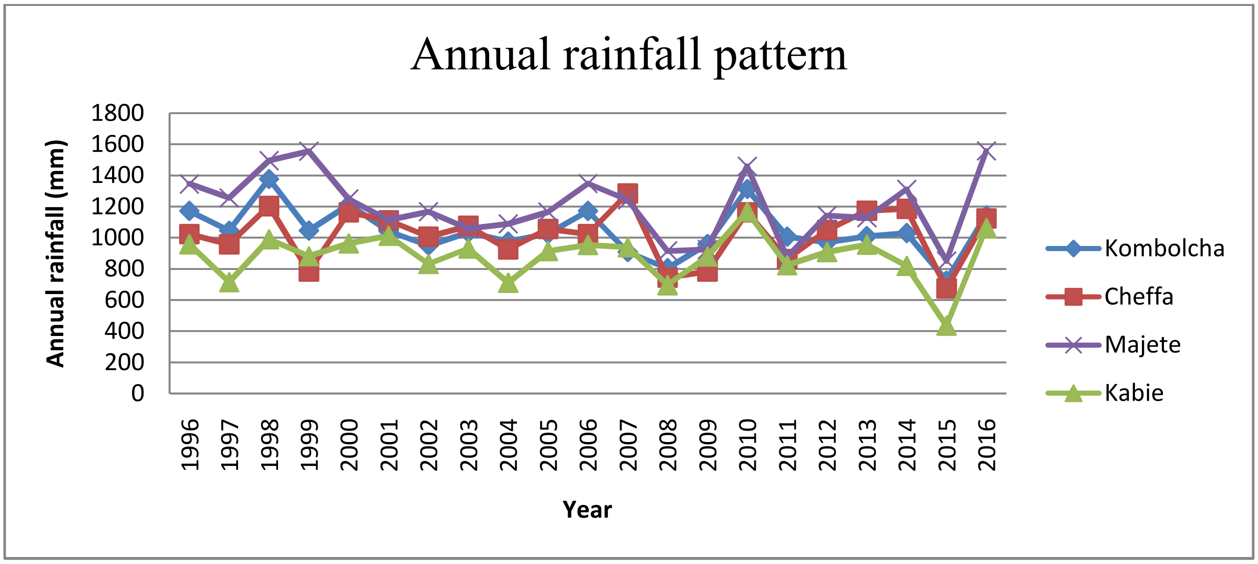


Figure 3-7 Annual rainfall pattern of stations

### 3.5.2 Filling Missing Temperature Data

The same method (Normal ratio method) is adopted to fill missing air temperature data which is use for filling data. Thus after filling both rainfall and air temperature daily 21 year data and their consistence checked by double mass curve.

### 3.5.3 Checking Homogeneity of stations

Homogeneity analysis is used to identify a change in the statistical properties of the time series. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation station. Therefore, to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations monthly rainfall records were computed by equation 3-1:

$$Pi = \frac{Pi,av}{Pav} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}2)$$

Where,

Pi=Non dimensional Value of precipitation for the month in station i

Pi,av =Over years averaged monthly precipitation for the station i

Pav= the over years averaged yearly precipitation of the station i

In the Borkena watershed there are two rainy seasons; heavy rainfall from Jul-August and small rainfall from October-February. The data recorded in the selected stations of the study area shows that a bi-modal rainfall pattern which has two peaks for two rainy seasons. The selected stations are also plotted for comparison with each other. Figures 3-8 show the result of homogeneity analysis. As it is shown in the Figure 3-8 same-modes and pattern of the stations are observed and hence group stations selected are homogenous.

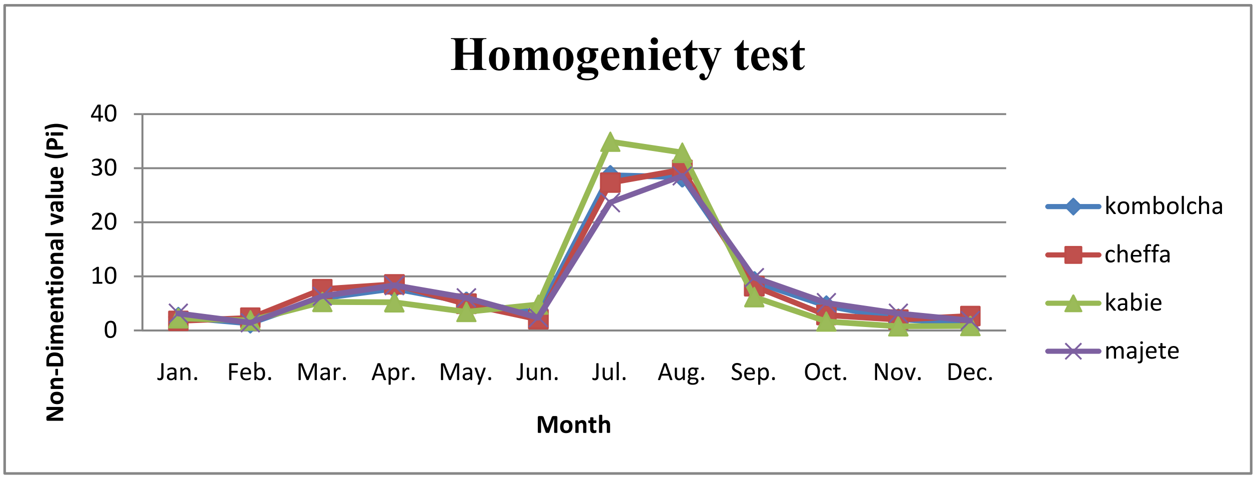


Figure 3-8 Homogeneity test of selected stations with in and around the Borkena Watershed

### 3.5.4 Checking Consistency and Adjustment of rainfall stations

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. Checking for inconsistency of the record is done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique is used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge. If significant change in the regime of the curve is observed, it should be corrected by using equation 3-3:

$$P'x = Px * \frac{M'}{M} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}3)$$

Where:

Px'= corrected precipitation at station x

Px =original recorded precipitation at station x

M' =corrected slope of the double mass curve

M= original slope of the double mass curve

According to the double mass curves, all the stations were consistent. The double mass curves for selected stations are presented in the figure 3-9.

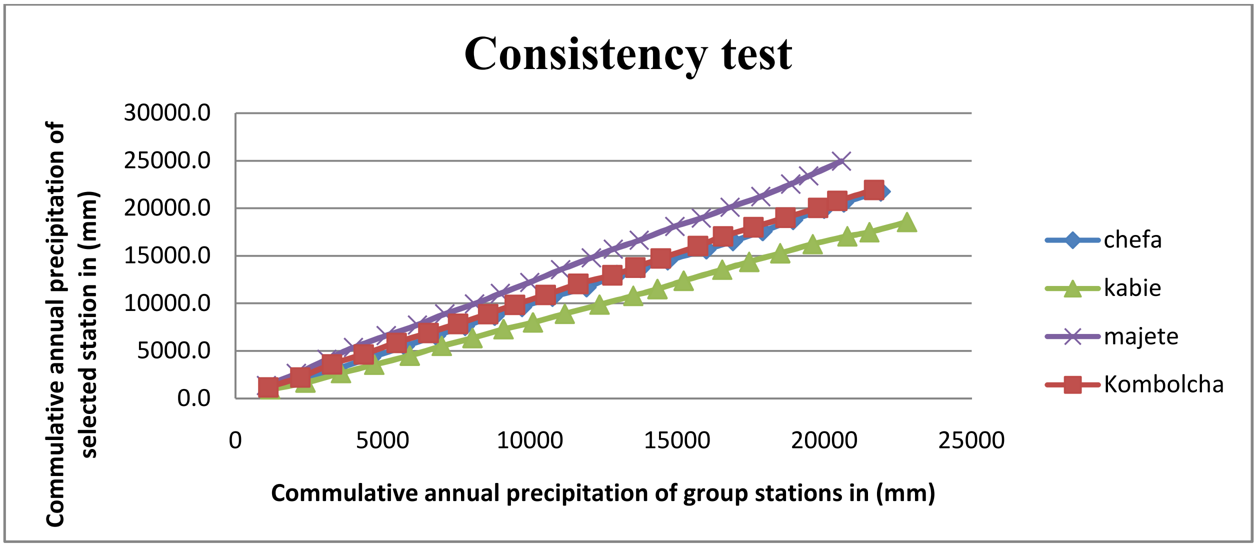


Figure 3-9 Double mass curve for selected stations

### 3.5.5 Estimation of Areal Rainfall

Rain gauges represent point sampling of the areal distribution of a storm. In practice, hydrological analysis requires knowledge of the rainfall over an area. Station average method, Thiessen polygon, Isohyetal methods are some of the methods used to convert point (gauged) rainfall values at various stations into an average value over a watershed. Among those methods Theissen polygon method is used for this study even though the method is depend on a good network of representative rain gauge.

### 3.5.6 Thiessen Polygons

Thiessen polygon method is one way of calculating areal precipitation. The method gives weight to satiation data in proportion to space between stations. Lines are drawn between adjacent stations on map. The area of each polygon inside the sub basin area is calculated. This factor is then used as weight of station studies within that the polygon according the proportion of the total watershed area that are geographically closed to each of the rain gages.

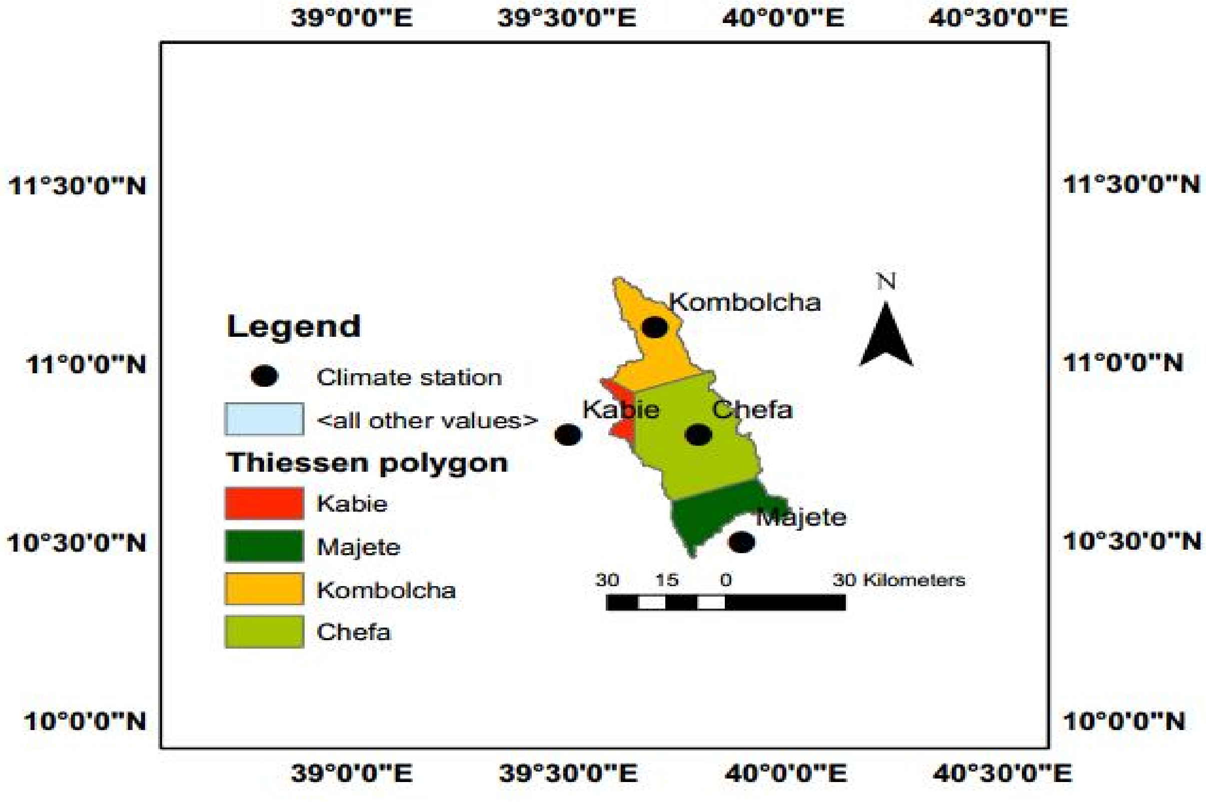


Figure 3-10 Thiessen polygon of Borkena catchment

Thiessen polygon is drawn by using Arc view GIS software. After drawing the polygon it is necessary to find percentage of area that each rainfall station represents. To determine mean areal rain fall amount of each station multiplied by area of its polygon and the sum of those products is divided by total area of the catchment. Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P1, P2, P3 ... pn are the rainfalls at the individual stations, and A1, A2, A3 ... An are the areas of the polygon surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$Pav = \frac{P1A1+P2A2+\cdots\ldots\ldots+PnAn}{A1+A2+\cdots\ldots\ldots+An}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}4)$$

Where,

$P_{av}$…………….. Average areal rainfall (mm),

P1, P2, P3……..Pn are the precipitation of stations 1, 2, 3…n, respectively

A1, A2, A3……An are the area coverage of stations 1, 2, 3…n respectively in the Thiessen polygon.

The advantage with the method is that is easy to understand and disadvantage is that it does not take in to account the geographic nature of rainfall and those change in station net that works it necessary to redo the procedure .(Table 3-5) below is result obtained from Thiessen polygon showing area covered by each percentage of area.

Table 3-5 Thiessen polygon result for meteorological station

| Station Name | Area by each polygone(Km$^2$) | Area ratio | Mean Annual Rainfall(mm) | Percentage of area covered (%) |
|---|---|---|---|---|
| Kombolcha | 410 | 0.2453 | 1044.24 | 24.53 |
| Cheffa | 861 | 0.5152 | 1017.92 | 51.52 |
| Kabie | 74 | 0.0442 | 883.47 | 4.42 |
| Majete | 326 | 0.1950 | 1202.61 | 19.50 |
| Sum | 1671 | 1 | | 100 |

## 3.6 Model Setup

### 3.6.1 Watershed Delineation

The watershed and sub watershed delineation was performed using 30 m resolution DEM data using Arc SWAT model watershed delineator tools. First, the SWAT project set up was create necessary folders and databases to store all the data.The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. Once, the DEM setup was completed and the location of outlet was specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tools.

The size of sub-basin in the watershed will affect the assumption of homogeneity. Hence, definition of watershed, sub-basin boundaries and streams is decided by selecting a threshold area or the minimum drainage area to define streams. Configuration of a lot of sub-basin requires a long time simulation period and even difficult to run. On the other hand, too small number of sub watershed could affect the simulation results by ignoring spatial variability and lumps watershed condition together.

Using a threshold value suggested by the Arc SWAT interface, the Borkena watershed was delineated in to 21 sub watersheds having an estimated total area of 1671 $km^2$ as shown in the Figure 3-11.

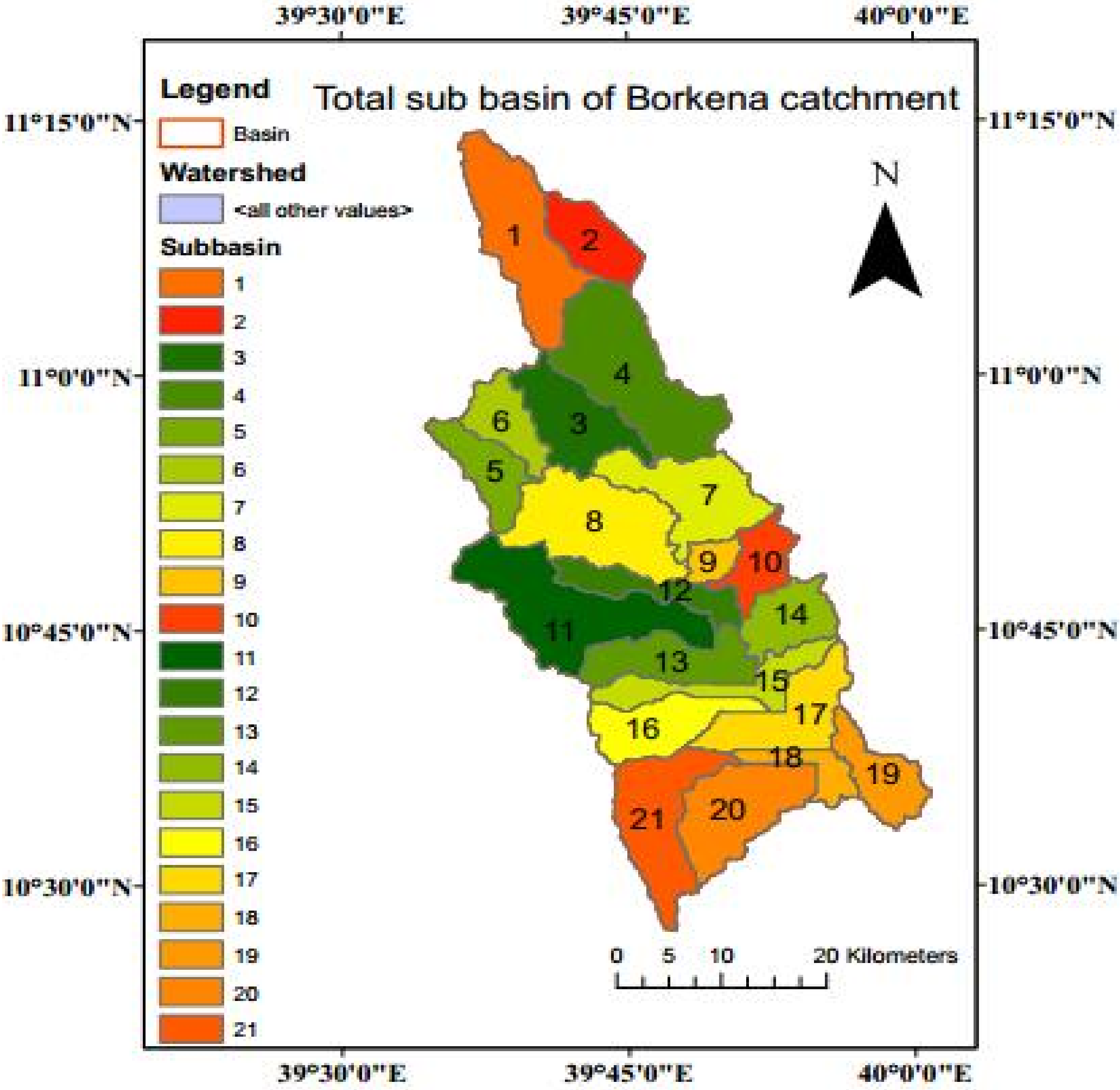


Figure 3-11 Sub basin map of the Borkena watershed

### 3.6.2 HRU Definition

SWAT a watershed is subdivided into sub basins based on the number of tributaries. The sizes of watersheds and number sub basins in the watershed vary from place to place. The sizes of sub basins also vary based on the nature of the topographic and the stream network system of an area. The sub basins of the watershed are divided into multiple Hydrologic Response Units (HRUs). The HRUs represent areas with homogeneous land use/cover, management, and soil characteristics. However they have no separate spatial representation in SWAT simulation. The HRU in SWAT are spatially implicit, their exact position on the surface cannot be identified, and the same HRU may cover different locations in a sub basin (Neitsch et al., 2002) and (Di Luzio et al., 2005).

The main part of SWAT analysis can be performed in ArcSWAT2012 interface. Geographical Information System (GIS) is used as an auxiliary and a preprocessor to the SWAT modeling process. Arc Map interface of Arc GIS 10.3 can be used for managing and processing spatial data which were used as SWAT input data in a project. Spatial data including digital elevation model (DEM), thematic map layers of land use/cover and soil data are necessary data to perform hydrological water balance analysis of a basin in SWAT. The DEM is used to gain the topographical characteristics of an area which are required by SWAT modeling and has direct impact on hydrological cycle. The land use/cover map is used to categorize vegetation types that have impact on the hydrological process of the area. The soil map is used to identify physical and chemical characteristics of various soils that have major role in the hydrological process of an area. Whereas weather data can be entered in SWAT interface following the reclassification of land use/cover and soil data. It is important for calculating the water balance components in each HRU in the watershed.

Slope classification was carried out based on the elevation range of the DEM used during watershed delineation. The slope values of the watershed were reclassified in percent. It reclassified in to four classes as shown in the Table 3-6.

Table 3-6 slope classes and their area covers in Borkena watershed.

| Slope Classes | Slope range (%) | Area | |
|---|---|---|---|
| | | Km$^2$ | % |
| Class 1 | 0-2 | 264 | 15.79 |
| Class 2 | 2-5 | 311 | 18.61 |
| Class 3 | 5-10 | 278 | 16.63 |
| Class 4 | >10 | 816 | 48.83 |

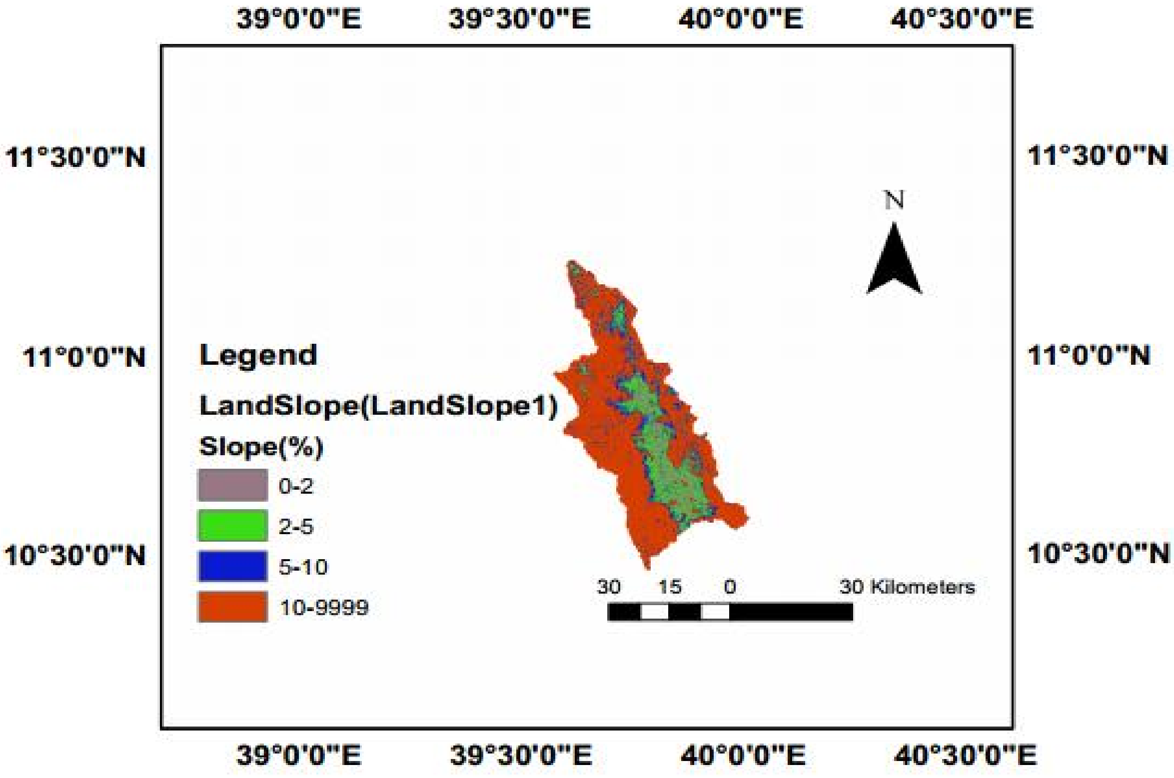
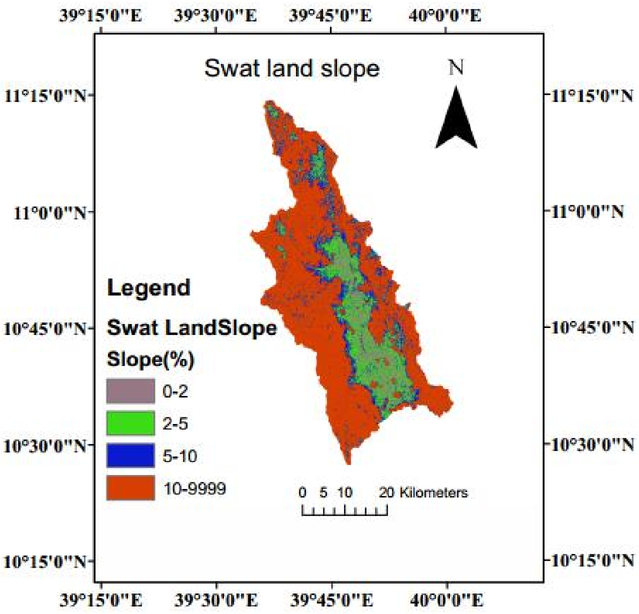
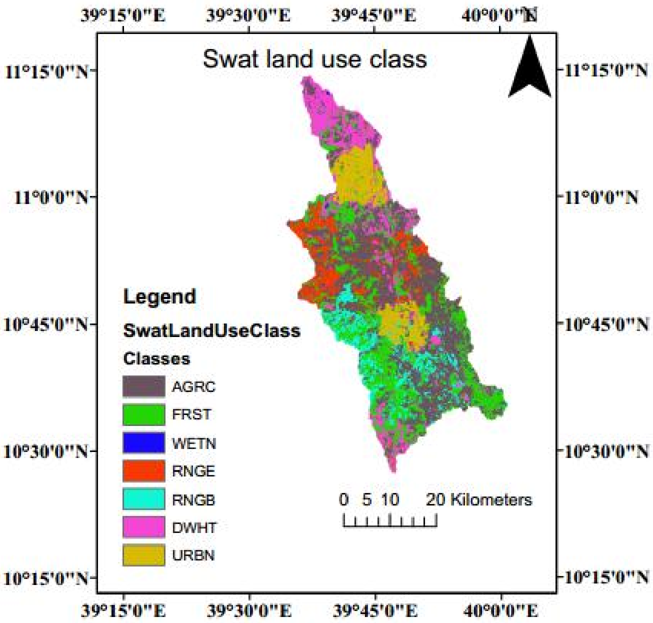


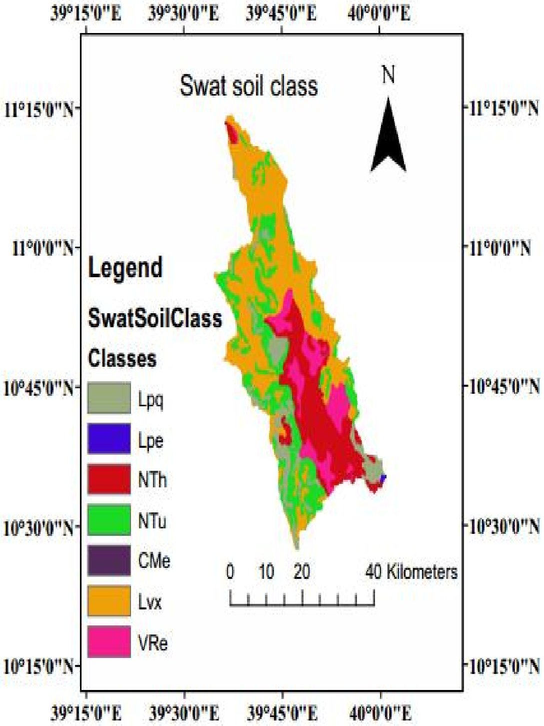
Figure 3-12 Reclassified slope map of Borkena watershed

In the model, there are two options in defining HRU distribution: assign a single HRU to each sub watershed or assign multiple HRUs to each sub watershed depending on a certain threshold values. The SWAT user’s manual suggests that a 20 % land use threshold, 10 % soil threshold and 20 % slope threshold are adequate for most modeling application. All three maps (land use, soil and topography) were overlaid to create a total number of 119,158 and 185 HRUs with unique land cover/soil and slope class for 1986, 2000 and 2011 land use, respectively.

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 (Figure.3-13).







| LULC | | SOIL | |
|---|---|---|---|
| Swat code | lulc | Swat code | soil |
| AGRC | Agricultural land | Lvx | Chromic luvisols |
| RNGE | Grass land | CMe | Eutric cambisols |
| FRST | Forest land | Lpe | Eutric leptosols |
| WETN | Wetland | VRe | Eutric vertisols |
| DWHT | Cultivated land | NTh | Haplic nitisols |
| RNGB | Shrub land | NTu | Humic nitisols |
| URBN | Urban area | Lpq | Lithic Leptosols |

Figure 3-13 the reclassified classes land use, slope and soil of Awassa catchment

### 3.6.3 Weather Data Definition

SWAT requires long year's daily record of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. These data records and geographic locations were prepared according to the model table format and saved in DBF format so as to import in to the database by using weather data input wizard. Once database setup is completed in Arc SWAT, the designated weather station locations are added to the Monitoring Point layer created during Watershed Delineation. The last step before a SWAT simulation can be run is to write all of the input files required by SWAT and produced from the preprocessed data from Arc SWAT. Once they are written, individual files can be edited through Arc SWAT, or externally. Because it is cumbersome to edit information for each sub basin, reservoir, etc. individually in ArcSWAT, tables were linked to an Access database and automatically updated based on predetermined queries. Values for all these variables may be read from records of observed data or they may be generated by using weather generator station. The weather generator input file contains the statistical data needed to generate representative daily climate data for the sub basins. The SWAT Model contains weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data.

### 3.6.4 Sensitivity Analysis

After the model setup has been finished, the next step is to run the model and analyze the simulation result. Sensitivity analysis is used to estimate the rate of change of model outputs with respect to change of model inputs. It is also useful to recognize how the model depends on the information fed into it (Willems, 2000). Sensitivity analysis provides for better understanding of the behavior of the system being modeled, such as model parameters and applicability, thus it increases the confidence level of the model and its predictions. SWAT model have large number of parameters and a number of outputs, thus, an initial parameter selection makes the calibration process easier and reduces the uncertainties related to diverse parameters.

In the sensitivity process, by using SWAT-CUP, first create the new folders and copy the SWAT simulation results to perform the sensitivity analysis and then, chosen parameters were entered for the sensitivity analysis with the default lower and upper parameter bounds. The calibration process is running with 12 flow parameters. Choosing of flow parameters is based on available information on literature. And compare the observed flow data to simulated output. Therefore, for this study, sensitivity analysis was done prior to the calibration process in order to identify important parameters for model calibration. The average monthly stream flow data of 6 years from 1996 to 2001 of the watershed gauging station were used to compute the sensitivity of the stream flow parameters and out of these 2 years from 1996 to 1997 was set for the model warm up period.

## 3.7 Model Calibration and Validation

### 3.7.1Model Calibration

The time series of discharge at the outlet of the catchment was used as data for calibration and validation for SWAT model, the model was calibrated using the measured stream flow data from January 1996 to December 2000 with 2 years warm up periods. For this study automatic calibration is used. The auto calibration was done using the SWAT-calibration and uncertainty programs (SWAT-CUP) package using the sequential uncertainty fitting (SUFI-2) algorithm which is developed by Abbaspour *et al*. (2007). In the automatic calibration the model enables to calibrate by changing the parameters itself iteratively. The initial parameters range is set to by default and read the available literatures. The calibration was done by adjusting parameters until the simulated and observed value showed good agreement.

The model was run using the best parameter output values and the simulations were compared with observed stream flow data using Percent BIAS (PBIAS), Nash and Sutcliffe coefficient of efficiency (ENS) and coefficient of determination (R2). Both graphical methods and statistical tests (R2, PBAIS and ENS) are used in model calibration and validation. It was calibrated until monthly $R^2 > 0.6$ and ENS > 0.5 (Santhi *et al*., 2001).

### 3.7.2 Model Validation

Model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2002) at different spatial and temporal scales. In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation. For this research work the measured stream flow data of Borkena River at swamp outlet from 01 January 2002 to 31 December, 2003 were used.

## 3.8 Model performance Evaluation

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R2), Nash-Sutcliffe simulation efficiency (ENS) and Percent bias (PBIAS) were the goodness of fit measures used to evaluate model prediction.

The R2 value is an indicator of strength of relationship between the observed and simulated values it is the magnitude linear relationship between the observed and the simulated values. Determination coefficient ranges from 0 (which indicates the model is poor) to 1 (which indicates the model is good), with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Santhi et al., 2001). The $R^2$ is calculated using equation 3-5:

$$R^2 = \frac{\sum[Xi - Xav] * [Yi - Yav]}{\left[\sqrt{\sum[Xi - Xav]^2}\right] * \left[\sqrt{\sum[Yi - Yav]^2}\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}5)$$

Where,

Xi – measured value (m3/s)

Xav – average measured value (m3/s)

Yi – simulated value (m3/s) and

Yav – average simulated value (m3/s)

The Nash – Sutcliffe simulation efficiency (ENS) indicates that how well the plots of observed versus simulated data fits the 1:1 line. The value of ENS ranges from negative infinity to 1 (best). ENS value ≤0 indicates the mean observed value is better predictor than the simulated value, which indicates unacceptable performance. While ENS values greater than 0.5, the simulated value is better predictor than mean observed value and generally viewed as acceptable performance (Santhi *et al*., 2001). ENS is computed using equation 3-6:

$$\text{ENS}=1-\frac{\sum[Xi-Yi]^\wedge 2}{\sum[Xi-Xav]^\wedge 2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}6)$$

Where,

Xi – measured value

Yi – simulated value and

Xav – average observed value

Percent bias (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 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. For stream flow PBIAS Values up to ±25 are considered acceptable (Gupta et al., 1999). PBIAS is computed using equation 3-7.

$$\text{PBIAS}=\frac{\sum_{i=1}^{n}(Xi-Yi)}{\sum_{i=1}^{n}Xi}*100\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}7)$$

Where,

Xi – measured value

Yi – simulated value

Table 3-7 Performance ratings of recommended statistics for monthly stream flow (Moriasi et al., 2007)

| Performance rating | NSE | PBIAS (%) | RSR |
|---|---|---|---|
| Very good | $0.75 < NSE \leq 1$ | $PBIAS < 10$ | 0.0<=RSR<=0.5 |
| Good | $0.65 < NSE \leq 0.75$ | $10 \leq PBIAS < 15$ | 0.5<RSR<=0.6 |
| Satisfactory | $0.5 < NSE \leq 0.65$ | $15 \leq PBIAS < 25$ | 0.6<RSR<=0.7 |
| Un satisfactory | $NSE \leq 0.5$ | $PBIAS \geq 25$ | RSR>=0.7 |

### 3.10 Evaluation of Stream Flow due to LULCC

The three (1986,2000 and 2011) land use and land cover maps, soil, climatic and stream flow data values were used to evaluate the impacts of land use and land cover change on stream flow.

To evaluate the variability of stream flow due to land use and land cover changes from 1986 to 2011, three independent simulation runs were conducted on a monthly basis using land use and land cover maps for the period of 1986-2011 keeping other input parameters unchanged. Seasonal stream flow variability of 1986,2000 and 2011 due to the land use and land cover change was assessed and comparison were made on surface runoff and ground water flow contributions to stream flow based on the three simulation outputs.

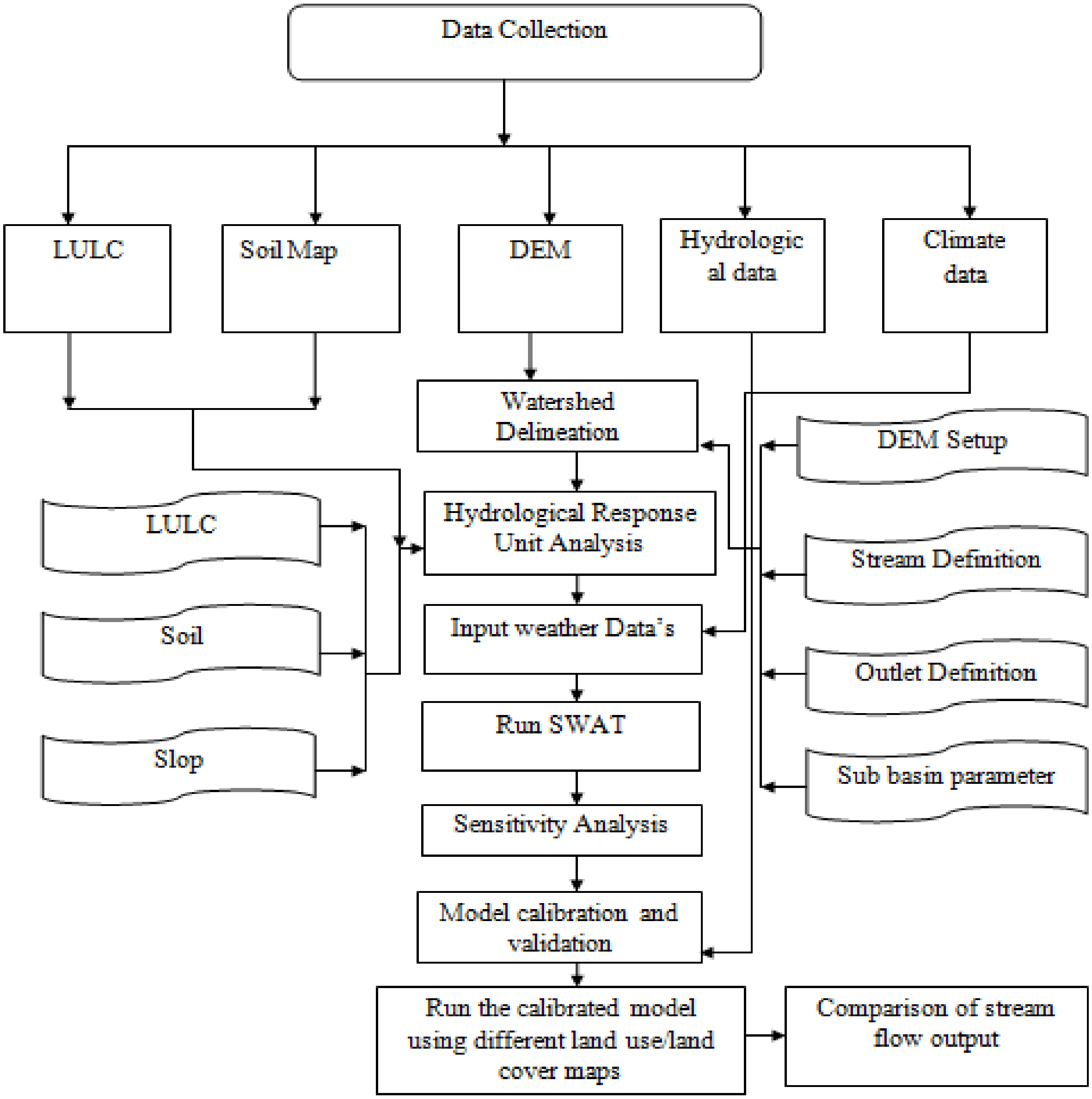


Figure 3-14 Simplified Flow Chart of the Adopted Methodology and framework of the study

# CHAPTER FOUR

## 4. RESULTS AND DISCUSSION

### 4.1 Land use land Cover Map

The data obtained from the Ethiopia map Agency (EMA) for Borkena catchment. The catchment has undergone numerous land use land cover changes in recent decades. Forest cover decreased markedly between 1986's and 2011 by 33.56%. The decrease could be attributed to the cutting of trees in the forests for various uses such as firewood and clearing for cultivation and agricultural purposes. The agricultural land and cultivated land increase between 1986 and 2011 by 24.94% and 5.67% respectively at most part of the catchment. This increase could be linked with high increase population growth. The built up area also changed significantly between 1986 and 2011 by 8.78% due to rapid development of urban centers such as the expansion of the town Cheffa, Kemissie,Kombolcha and Dessie around. The growth of these urban centers can be attributed to high rate of rural urban migration. The land use land cover of grass land, shrub land, forest and wetland (swamp) decrease between 1986 and 2011 by 2%, 2.65%, 33.56 and 1.17% respectively. Grass land, Shrub land, forest and wetland (swamp) most of catchment area was transformed in to agricultural land and cultivated land.

#### 4.1.1 Land use land Cover Map of 1986

The land cover map of 1986 shows that about 9.88% of the Borkena catchment was covered by agricultural land, 10.74% by Grass Land, 57.33% by forest land, 1.26% by wet land, 8.58% by cultivated land, 11.04% by shrub land and 1.16% by settlement (Urban) area. The distribution of land cover class as it is shown below in tabular and graphical form. Forest found in most parts of the watershed.

Table 4-1 Comparison of LULC classes of 1986

| lulc_1986 Class name | Area(Km$^2$) | Percentage Area % |
|---|---|---|
| Agricultural land | 165.0948 | 9.88 |
| Grassland | 179.4654 | 10.74 |
| Forest | 957.9843 | 57.33 |
| Wetland | 21.0546 | 1.26 |
| Cultivated land | 143.3718 | 8.58 |
| Shrub land | 184.4784 | 11.04 |
| Urban area | 19.3836 | 1.16 |
| Total | 1671 | 100 |

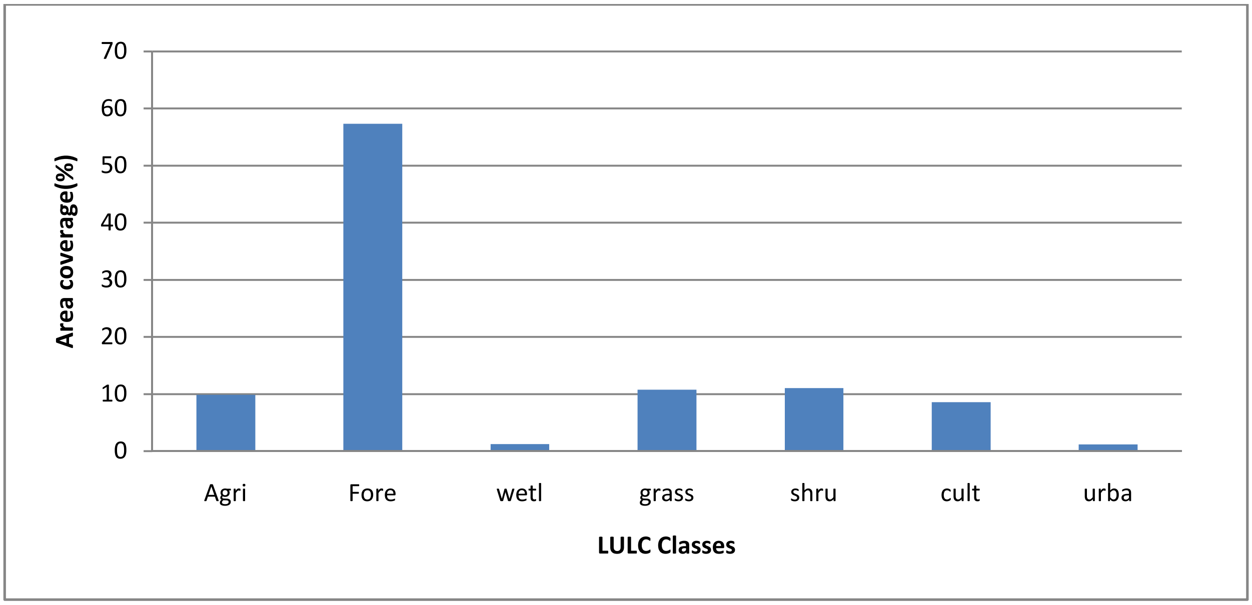


Figure 4-1 Comparison of LULC classes of 1986

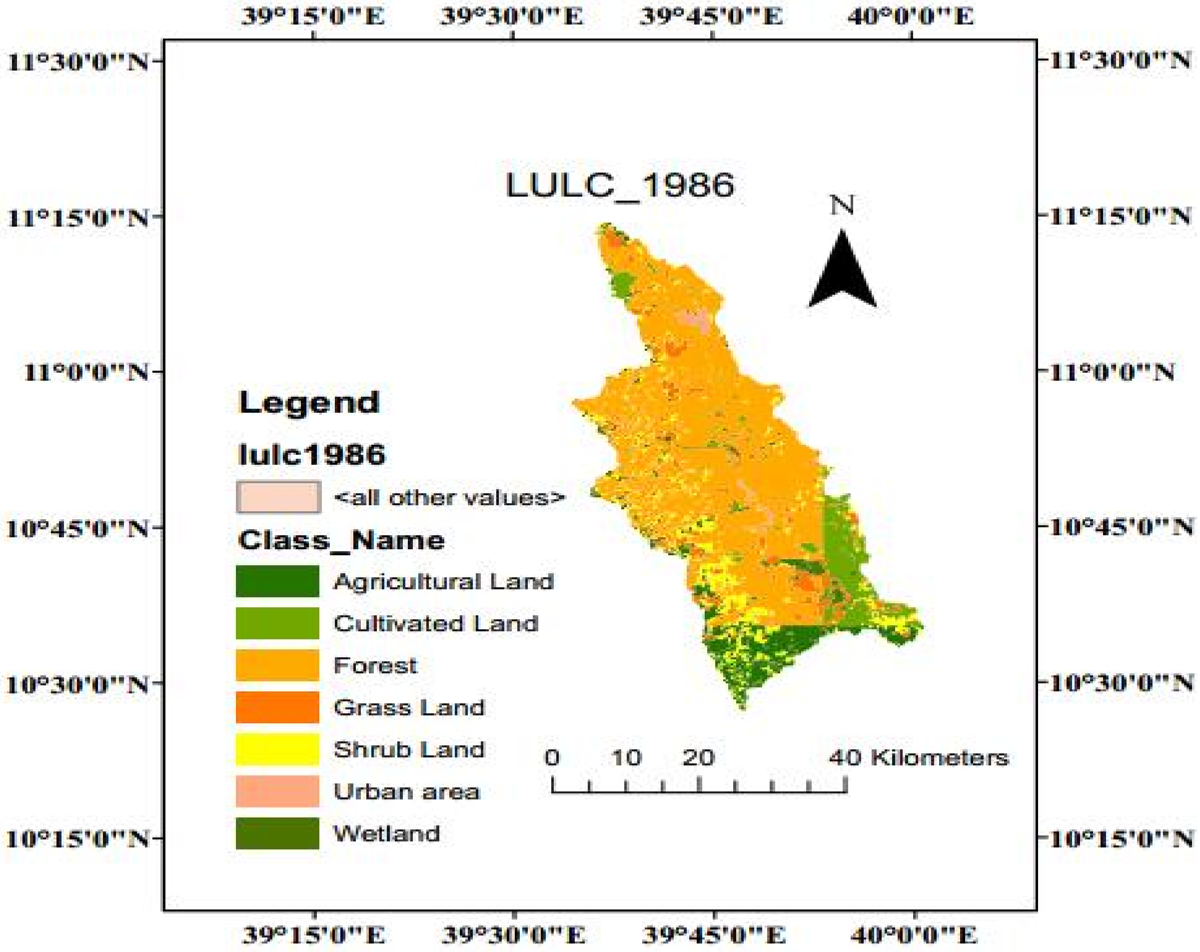


Figure 4-2 Land use land cover map of Borkena catchment in the year 1986

### 4.1.2 Land use land Cover Map of 2000

The land cover map of 2000 shows that about 30.92% of the Borkena catchment was covered by agricultural land, 11.07% by grass land, 30.40% by forest land, 0.57% by wet land, 11.68% by cultivated land, 12.61% by shrub land, 2.75% by settlement (urban) area. The distribution of land cover class as it is shown below in tabular and graphical form. During this period, mainly the forest land was completely changed in to agricultural land and cultivated land. The forest and agricultural land were found in most parts of the watershed.

Table 4-2Comparison of LULC classes of 2000

| lulc_2000<br>Class name | Area(Km$^2$) | Percentage<br>Area % |
|---|---|---|
| Agricultural land | 516.6732 | 30.92 |
| Grassland | 184.9797 | 11.07 |
| Forest | 504.984 | 30.40 |
| Wetland | 9.5247 | 0.57 |
| Cultivated land | 195.1728 | 11.68 |
| Shrub land | 210.7131 | 12.61 |
| Urban area | 45.9525 | 2.75 |
| Total | 1671 | 100 |

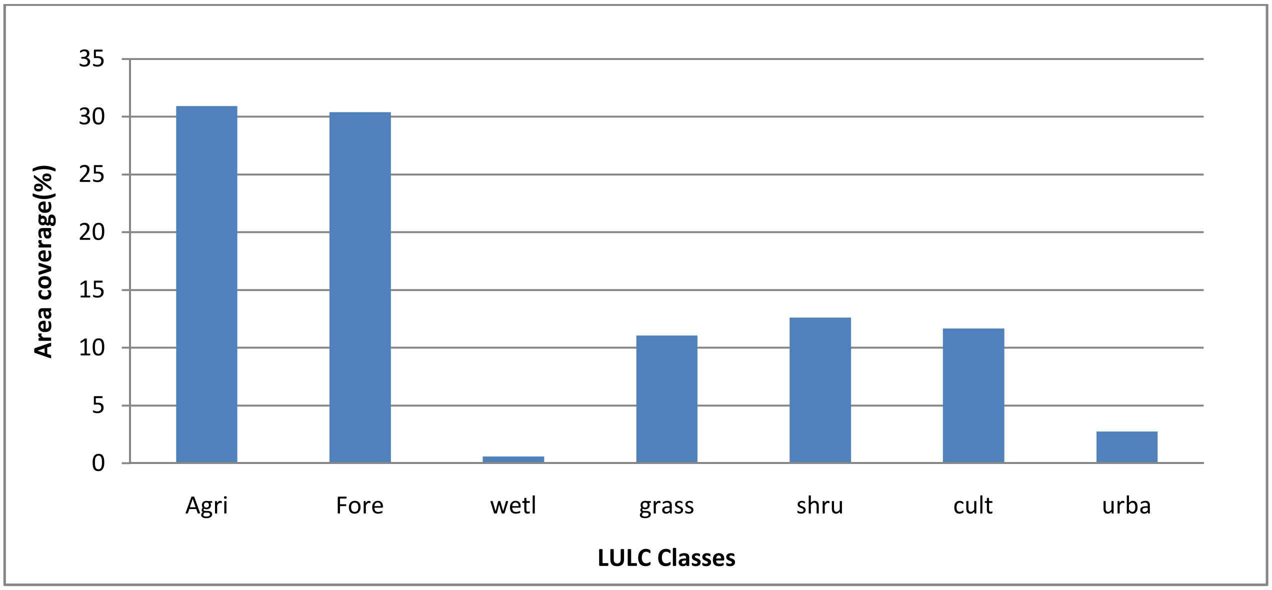


Figure 4-3Comparison of LULC classes of 2000

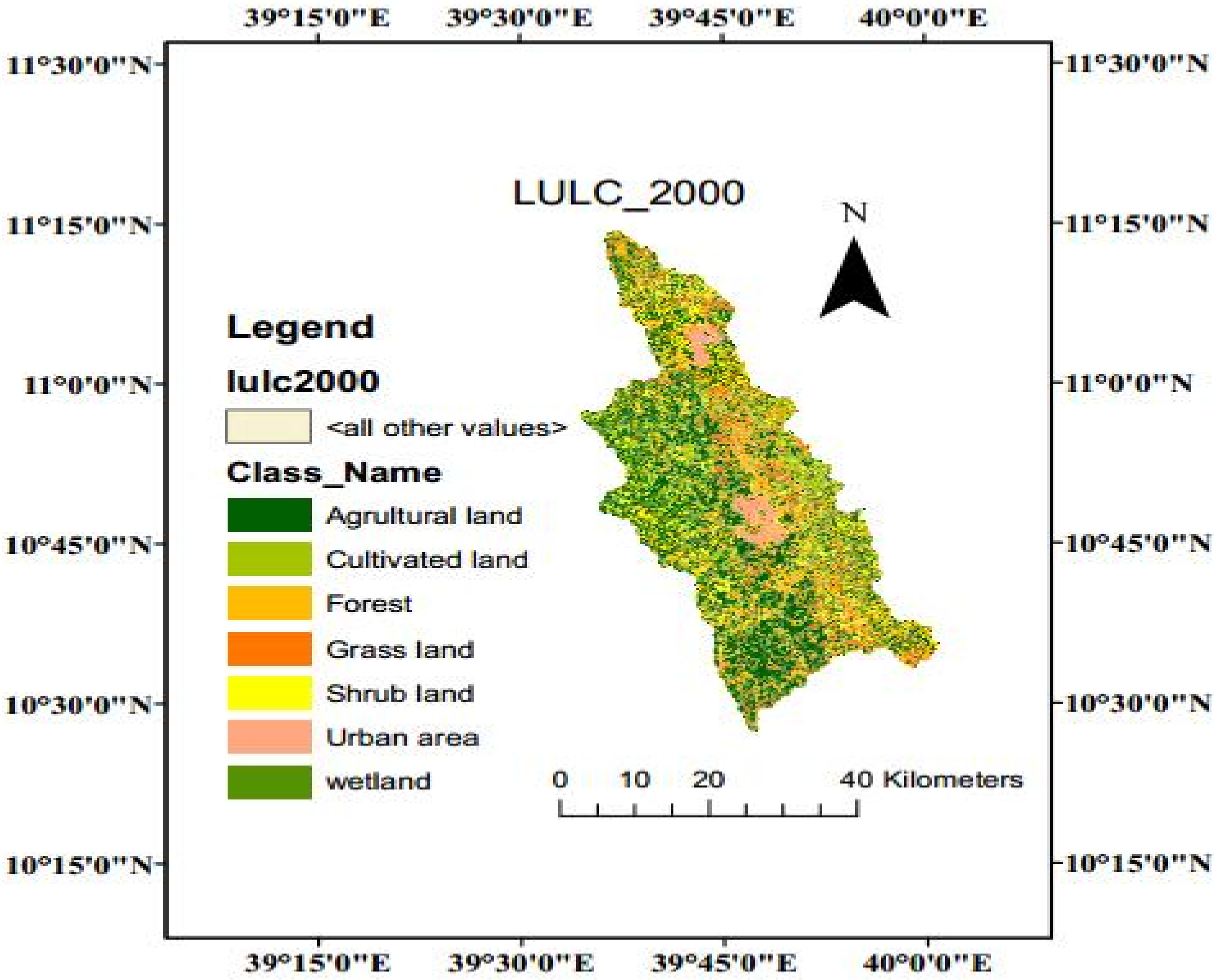


Figure 4-4 Land use land cover map of Borkena catchment in the year 2000

### 4.1.3 Land use land Cover Map of 2011

The land cover map of 2011 shows that about 34.82% of the Borkena catchment was covered by agricultural land, 8.74% by grass land, 23.77% by forest land, 0.09% by wet land, 14.25% by cultivated land, 8.39% by Shrub land, 9.94% by settlement (urban) area. The distribution of land cover class is shown below in tabular and graphical form. During this period due to high increase of population density, most of the catchment area was transformed into cultivated land, agricultural land and Settlement (urban).

Table 4-3Comparison of LULC classes of 2011

| lulc_2011 Class name | Area($Km^2$) | Percentage Area % |
|---|---|---|
| Agricultural land | 581.8422 | 34.82 |
| Grassland | 146.0454 | 8.74 |
| Forest | 397.1967 | 23.77 |
| Wetland | 1.5039 | 0.09 |
| Cultivated land | 238.1175 | 14.25 |
| Shrub land | 140.1969 | 8.39 |
| Urban area | 166.0974 | 9.94 |
| Total | 1671 | 100 |

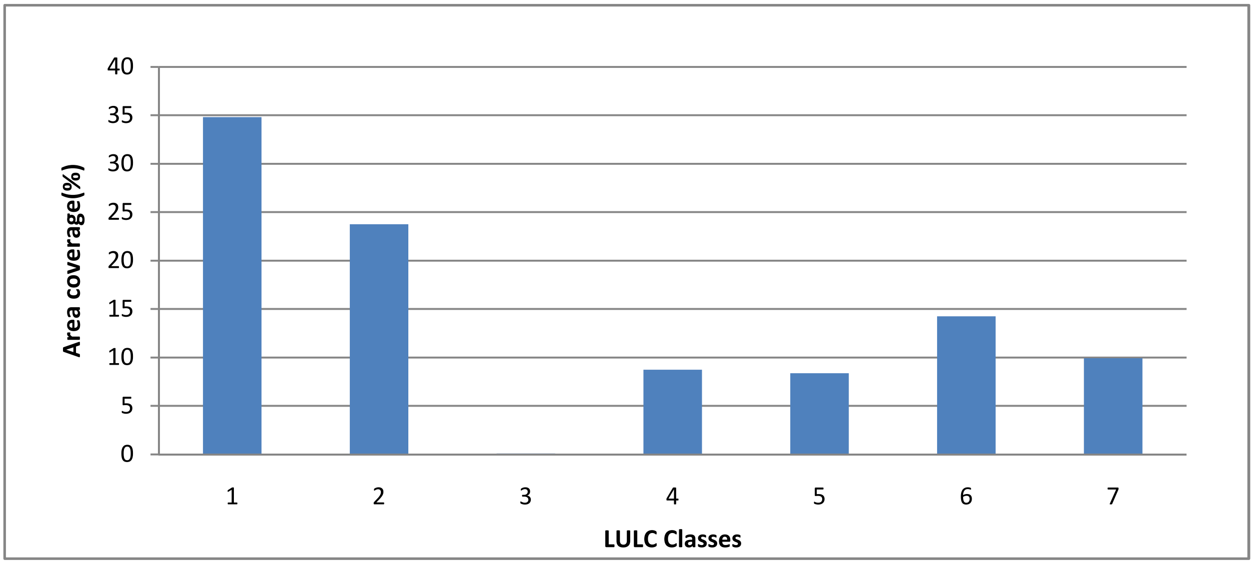


Figure 4-5 Comparison of LULC classes of 2011

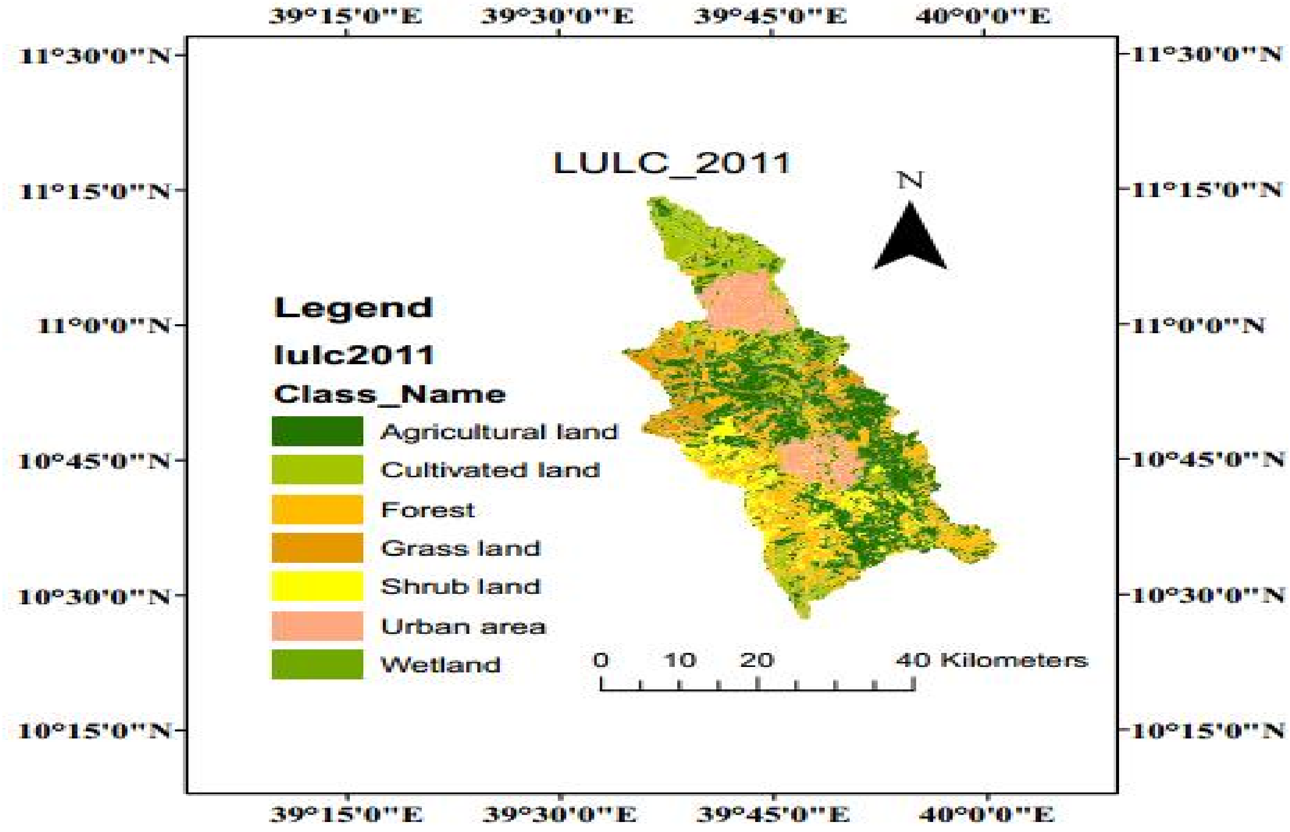


Figure 4-6 Land use land cover map of Borkena catchment in the year 2011

Table 4-4 Land use and Land cover types and changes from1986-2011

| Land use/Cover type | Land use/Cover Area(Km2) | | | Area Change (Km2) | Percentage Area Change |
|---|---|---|---|---|---|
| | Year 1986 | Year 2000 | Year 2011 | 1986-2011 | 1986-2011 |
| Agricultural land | 165.0948 | 516.6732 | 581.8422 | 416.7474 | 24.9400 |
| Grassland | 179.4654 | 184.9797 | 146.0454 | -33.4200 | -2.0000 |
| Forest | 957.9843 | 504.984 | 397.1967 | -560.7870 | -33.5600 |
| Wetland | 21.0546 | 9.5247 | 1.5039 | -19.5507 | -1.1700 |
| Cultivated land | 143.3718 | 195.1728 | 238.1175 | 94.7457 | 5.8500 |
| Shrub land | 184.4784 | 210.7131 | 140.1969 | -44.2815 | -2.6500 |
| Urban area | 19.3836 | 45.9525 | 166.0974 | 146.7138 | 8.7800 |
| Total | 1671 | 1671 | 1671 | | |

## 4.2 Stream Flow Modeling

### 4.2.1 Sensitivity Analysis

The aim of the sensitivity analysis is to estimate the rate of change in the output of a model with respect to changes in watersheds that result in a clear difference in hydrologic sensitivity (Reungsang et.al, 2005). Sensitivity analysis were conducted for the Borkena watershed hydrology to determine the parameters needed to improve simulation results and thus to better understand the behavior of the hydrologic system and to evaluate the applicability of the model.

Sensitivity analysis from SUFI-2 provided partial information about the sensitivity of the objective function to model parameters. Different water-related parameters (global parameters), with absolute minimum and maximum ranges in the SWAT model documents were selected to do sensitivity analysis. The sensitivity ranking and T- stat provides a measure of sensitivity (larger absolute values are more sensitive), and p values determine the significance of the sensitivity (a value close to zero has more significance).

Table 4-5 List of Parameters, descriptions and their ranking values for average monthly flow

| Parameters Name | Descriptions | Rank |
|---|---|---|
| CN2 | SCS runoff curve number (%) | 1 |
| GWQMN | Threshold depth of water in the shallow aquifer required for return flow (mm) | 2 |
| ALPHA_BF | Base flow alpha factor (days) | 3 |
| CH_K2 | Effective hydraulic conductivity of the main channel (mm/hr) | 4 |
| CANMAX | Maximum canopy storage (mm) | 5 |
| SOL_Z | Total soil depth (mm) | 6 |
| GW_REVAP | Groundwater “revap” coefficient | 7 |
| EPCO | Soil evaporation compensation factor | 8 |
| REVAPMN | Threshold depth of water in shallow aquifer for revap or percolation to the deep aquifer(mm) | 9 |
| SOL_K | Saturated hydraulic conductivity | 10 |
| SOL_AWC | Soil available water capacity (water/mm soil) | 11 |
| ESCO | Soil evaporation compensation factor | 12 |

### 4.2.2 Calibration and Validation

Calibration involves testing the model with known input and output data in order to adjust some parameters, while validation involves comparison of the model results with an independent dataset during calibration without any further adjustment of the calibration parameters. For this study SWAT Calibration and Uncertainty Procedures (SWAT-CUP) free software was selected to do sensitivity analysis, calibration and validation.

Table 4-6 List of parameters, descriptions and calibrated values for average monthly flow

| Parameters Name | Descriptions | Minimum range | Maximum range | Calibrated value |
|---|---|---|---|---|
| CN2 | SCS runoff curve number (%) | -25% | +25% | -0.0241 |
| GWQMN | Threshold depth of water in the shallow aquifer required for return flow (mm) | 0 | 5000 | 2908 |
| ALPHA_BF | Base flow alpha factor (days) | 0 | 1 | 0.0001 |
| CH_K2 | Effective hydraulic conductivity of the main channel (mm/hr) | 0 | 150 | 87.2500 |
| CANMAX | Maximum canopy storage (mm) | 0 | 10 | 8.6833 |
| SOL_Z | Total soil depth (mm) | -25% | +25% | -0.1241 |
| GW_REVAP | Groundwater “revap” coefficient | 0.02 | 0.2 | 0.1745 |
| EPCO | Soil evaporation compensation factor | 0 | 1 | 0.4283 |
| REVAPMN | Threshold depth of water in shallow aquifer for revap or percolation to the deep aquifer(mm) | 0 | 500 | 495 |
| SOL_K | Saturated hydraulic conductivity | -25% | +25% | -0.1841 |
| SOL_AWC | Soil available water capacity (water/mm soil) | -25% | +25% | -0.1775 |
| ESCO | Soil evaporation compensation factor | 0 | 1 | 0.9550 |

For calibration and validation use 2011 land use land cover map. During this step, the model was run for period of 6 years from 1996 to 2001. However, as the first two years were considered for model warm up period. Calibration was performed for 4 years from the year 1998 to 2001.And for validation use stream flow from the year 2002 to 2003. The calibration result for monthly flow is shown in the figure 4-7.

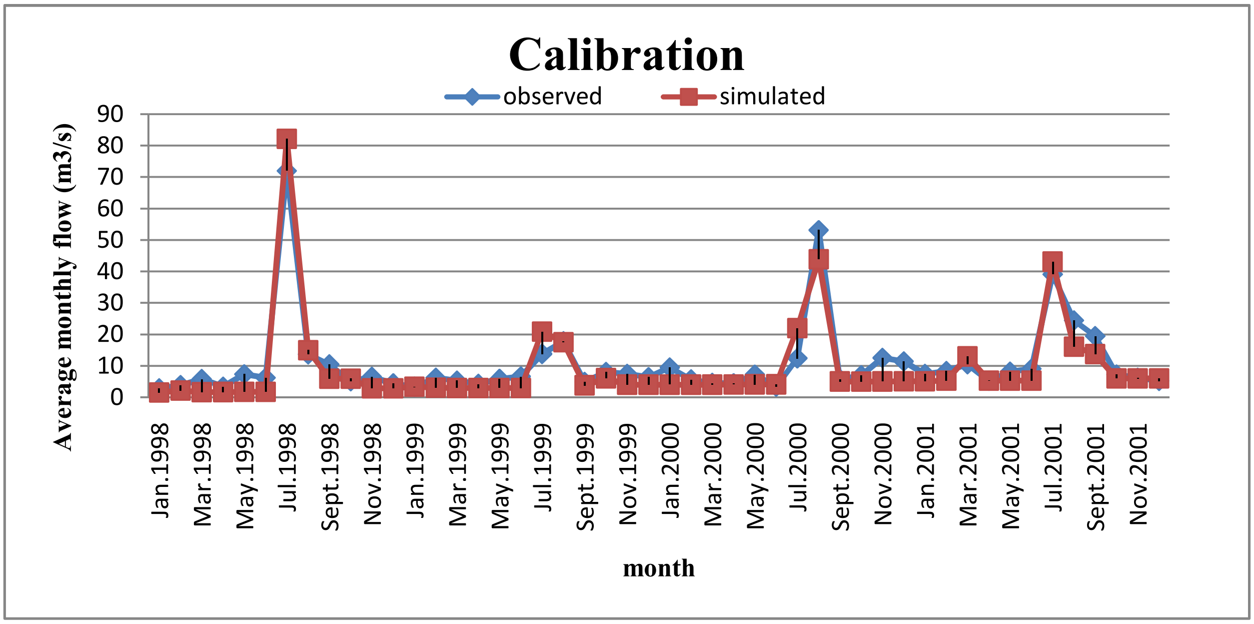


Figure 4-7 Calibration result for average monthly stream flow (1998-2001)

Similar results were reported by different studies that conducted in the country. For example, Haile and Assefa (2012) reported that the SWAT model showed a good agreement between observed and simulated stream flow in Angereb watershed with ENS and $R^2$ of 0.76 and 0.85 for calibration, and 0.72 and 0.79 for validation respectively. Yacob (2010) reported that SWAT model showed a good match between observed and simulated stream flow in Tikur Wuha watershed with ENS and $R^2$ of 0.6 and 0.75 for calibration, and 0.74 and 0.85 for validation respectively.

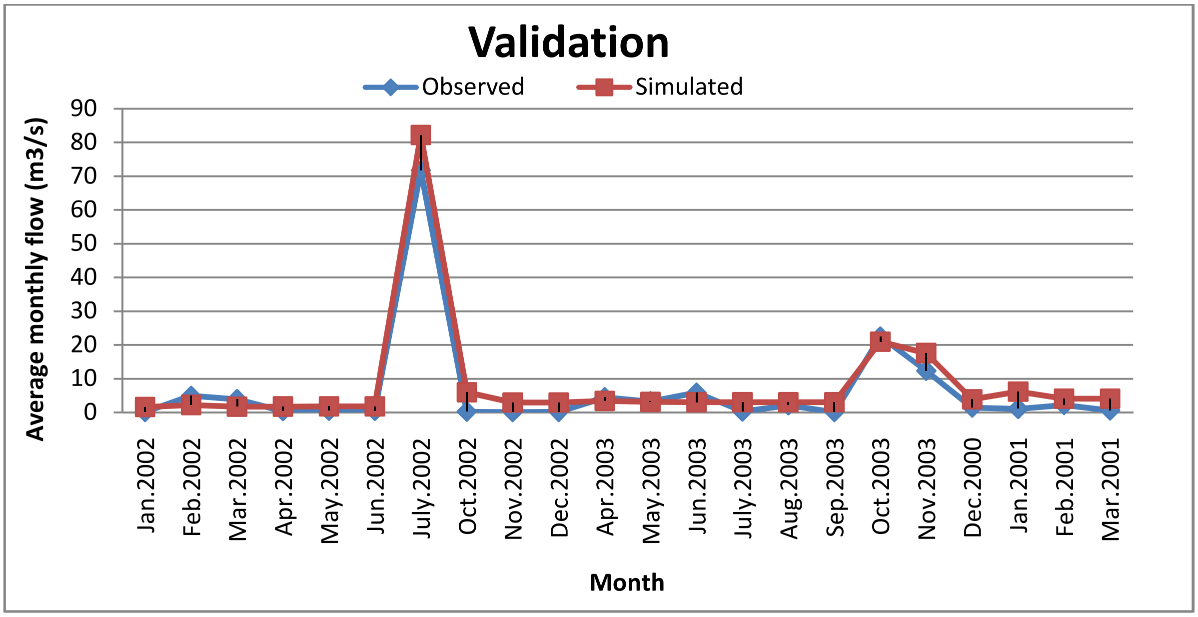


Figure 4-8 Validation result for average monthly stream flow (2002-2003)

The observed and simulated average monthly stream flow was computed. During calibration the stream flow was found to be 10.78m$^3$/s and 9.19m$^3$/s for observed and simulated respectively. On the other hand, during validation the observed and simulated stream flow was 6.30m$^3$/s and 8.14m$^3$/s respectively. Similar results were reported by Samuel Kassa (2016), during calibration 43.16m$^3$/s and 47.11m$^3$/s for observed and simulated respectively and during validation 40.93m$^3$/s and 43.45m$^3$/s for observed and simulated respectively in Upper awash basin. So this studies indicates that reasonable agreement between observed and simulated values in both calibration and validation periods.

Table 4-7 Comparison of observed and simulated average monthly flow for calibration and validation period

| Period | Average monthly flow (m3/s) | | ENS | R2 | PBIAS |
|---|---|---|---|---|---|
| | Observed | Simulated | | | |
| Calibration (1998-2001) | 10.78 | 9.19 | 0.87 | 0.88 | -18.9 |
| Validation (2002-2003) | 6.30 | 8.14 | 0.90 | 0.92 | -3.8 |

Figure 4-9 and 4-10 shows the scatter plot of observed and simulated monthly stream flow data for calibration and validation periods. The Figures presents there are a very good linear correlation between observed and simulated flows with a percentage fit greater than 80%.

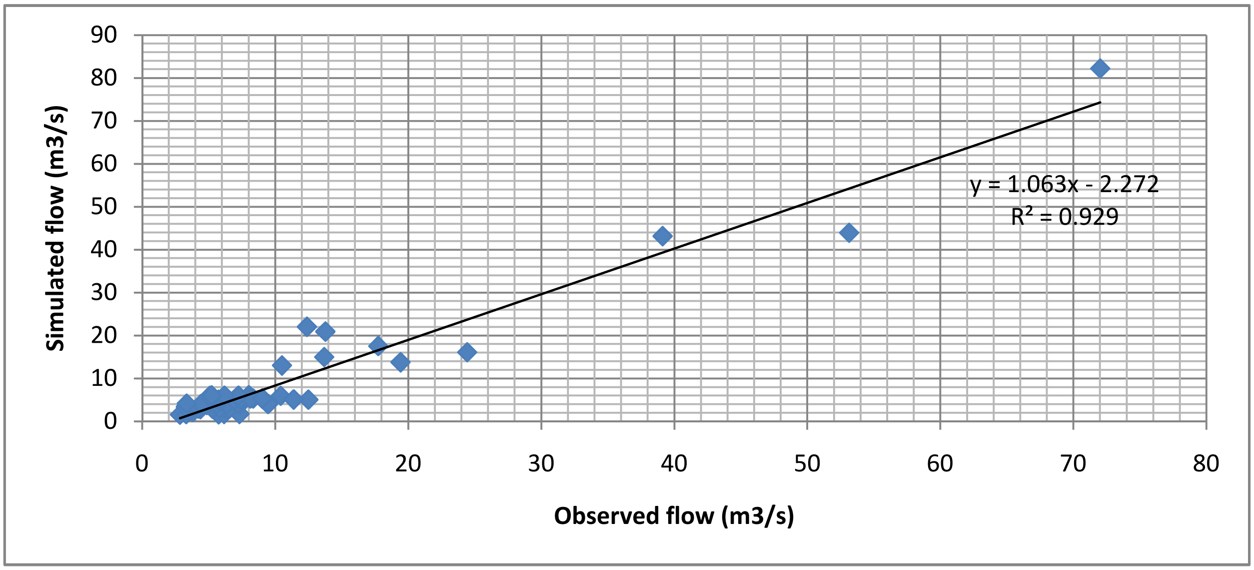


Figure 4-9 scatter plot of observed and simulated discharge for the period of calibration

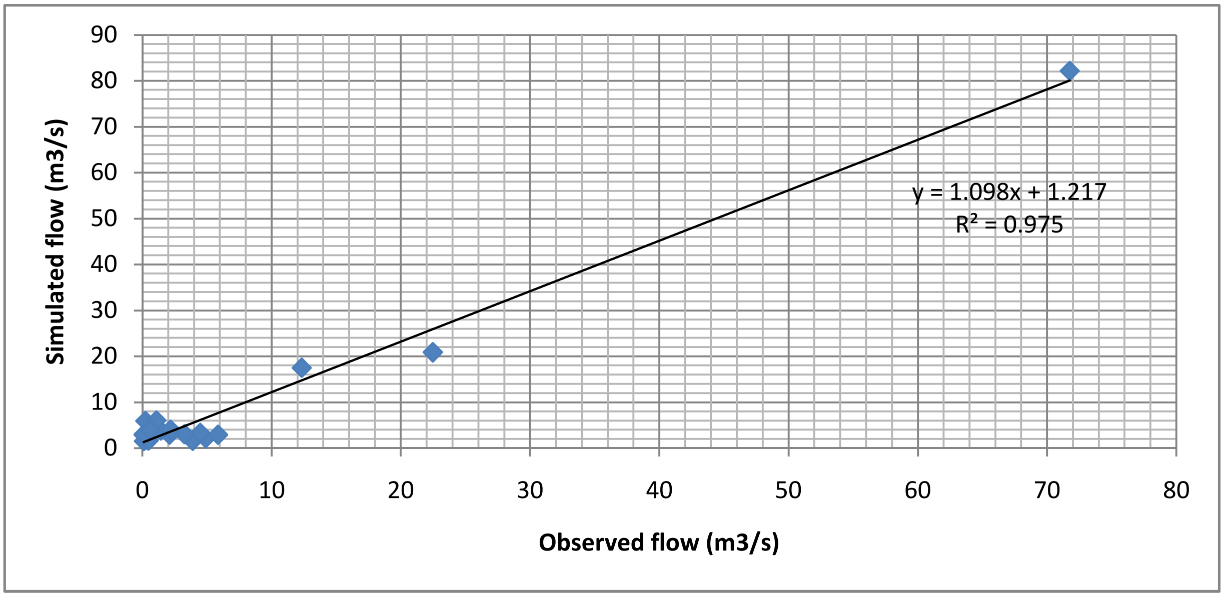


Figure 4-10 scatter plot of observed and simulated discharge for the period of validation

The result of calibration for monthly flow showed that there is a good agreement between the measured and simulated average monthly flows with Nash-Sutcliffe simulation efficiency (ENS) of 0.89 and coefficient of determination ($R^2$) of 0.93 as shown in the above. The model validation was also performed for 2 years from 2002 to 2003 without further adjustment of the calibrated parameters. The validation result for monthly flow is shown in the figure 4-8. The validation simulation also showed good agreement between the simulated and measured monthly flow with the ENS value of 0.95 and $R^2$ of 0.98 as shown in Table 4-7.

### 4.2.3. Rainfall runoff relationship

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. For this study the soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) was adopted. After calibration and validation of the SWAT model for Borkena watershed, model simulation was performed from 1998-2003 on monthly bases to observe the relationship between rainfall and runoff in the watershed. As it presented in the Figure 4-11, the surface runoff has the same pattern with rainfall of the watershed. For instance, if high rainfall recorded in the watershed the peak runoff was inevitable. Similar results were reported by Samuel Kassa (2016), he gets percentage of fit greater than 80% in Upper awash basin. The scatter plot in the Figure 4-12 also shows there is a good linear correlation between rainfall and runoff in the watershed with percentage fit greater than 90%.

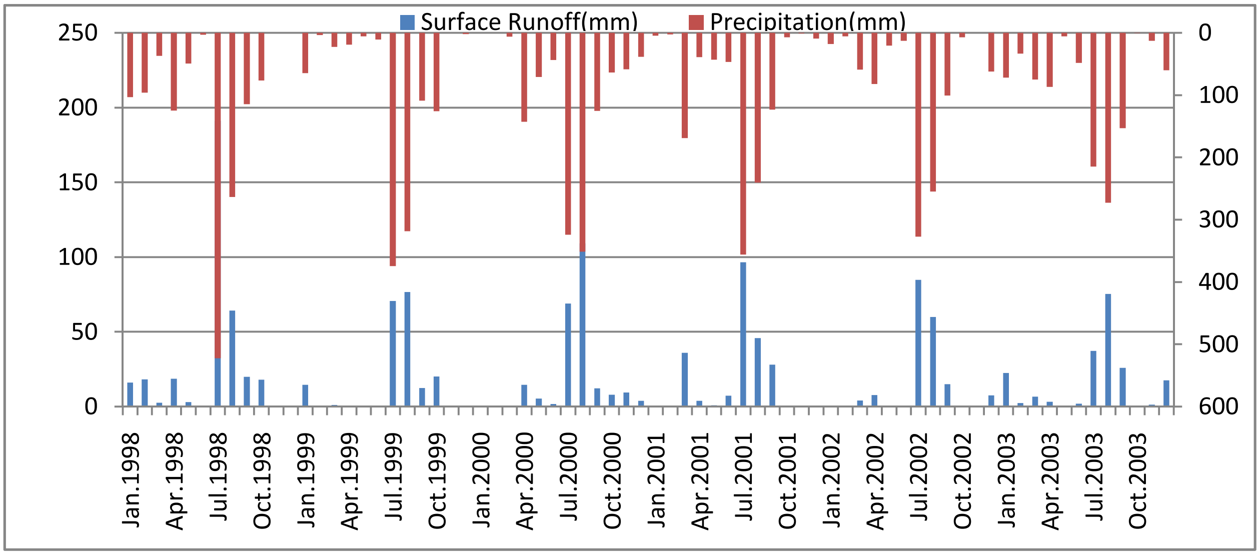


Figure 4-11 Rainfall runoff relationship in Borkena catchment

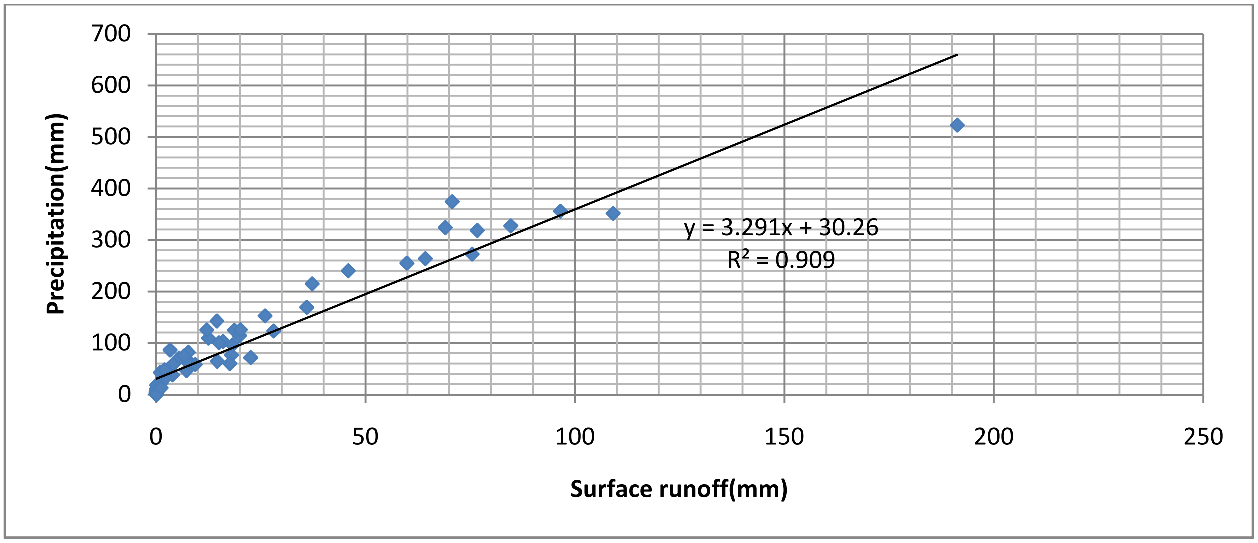


Figure 4-12 Scatter plot of rainfall versus runoff in Borkena catchment

### 4.3 The effect of land use land cover change on stream flow

The hydrological impacts of land use have received a considerable amount of interest in hydrology. LULCC is an important characteristic in the runoff process that affects infiltration, erosion, and evapotranspiration. Understanding of the effects historic land use changes have had on river flow is required to understand the future effects of land use and land cover on hydrological regimes at a watershed level. Along with these changes, considerable consequences are expected in the hydrological cycles and subsequent effects on water resources (Githu, 2007). The SWAT model simulated for the three time periods corresponding to the land cover of 1986, 2000 and 2011. Simulation runs were conducted on monthly basis to compare the modeling outputs using the 1986, 2000 and 2011 land covers. A comparison of surface runoff and ground water flow generated using 1986, 2000 and 2011 land covers respectively is presented in Table 4-8.

The result indicated that the mean annual surface flow for 2000 land cover was increased by 40.15mm than 1986 land cover. Similarly the 2011 land cover mean annual surface flow was higher by 44mm than 1986 land cover.

Table 4-8 surface runoff and ground water flow of the stream simulated using 1986, 2000 and 2011 land use land cover maps

Note: - SURQ=surface water runoff, GWQ =groundwater flow

| Items | LULC 1986 | LULC 2000 | LULC 2011 | Change b/n LULC 1986 and 2000 |
|---|---|---|---|---|
| Mean annual SURQ(mm) | 132.37 | 183.44 | 197.8 | +65.43 |
| Mean annual GWQ(mm) | 73.42 | 52.31 | 41.45 | -31.97 |

As the above table showed as the SURQ and GWQ components of the stream simulated using the 1986 land use and land cover map for the period of 1986 to 2011 were 132.37 mm and 73.42 mm respectively while using 2000 land use and land cover map were 183.44 mm and 52.31 mm and by Using 2011 land use and land cover map were 198.8 mm and 51.45 mm respectively. The contribution of surface runoff has increased from 132.37 mm to 197.8 mm whereas the ground water flow has decreased from 73.42 mm to 41.45 mm due to the land use and land cover change occurred between the periods of 1986 to 2011. This is because of the expansion of agricultural land and urban areas over vegetation that results in the increase of surface runoff following rainfall events (Costa *et al*., 2003). We can explain this in terms of the crop soil moisture demands. Crops need less soil moisture than forests; therefore the rainfall satisfies the soil moisture deficit in agricultural lands more quickly than in forests there by generating more surface runoff where the area under agricultural land is extensive (Jinno *et al*., 2009). And this causes variation in soil moisture and groundwater storage. This expansion also results in the reduction of water infiltrating in to the ground. Therefore, discharge during dry months (which mostly comes from base flow) decreases, whereas the discharge during the wet months increases. These results demonstrate that the land use and land cover change have a significant effects on infiltration rates, on the runoff production, and on the water retention capacity of the soil.

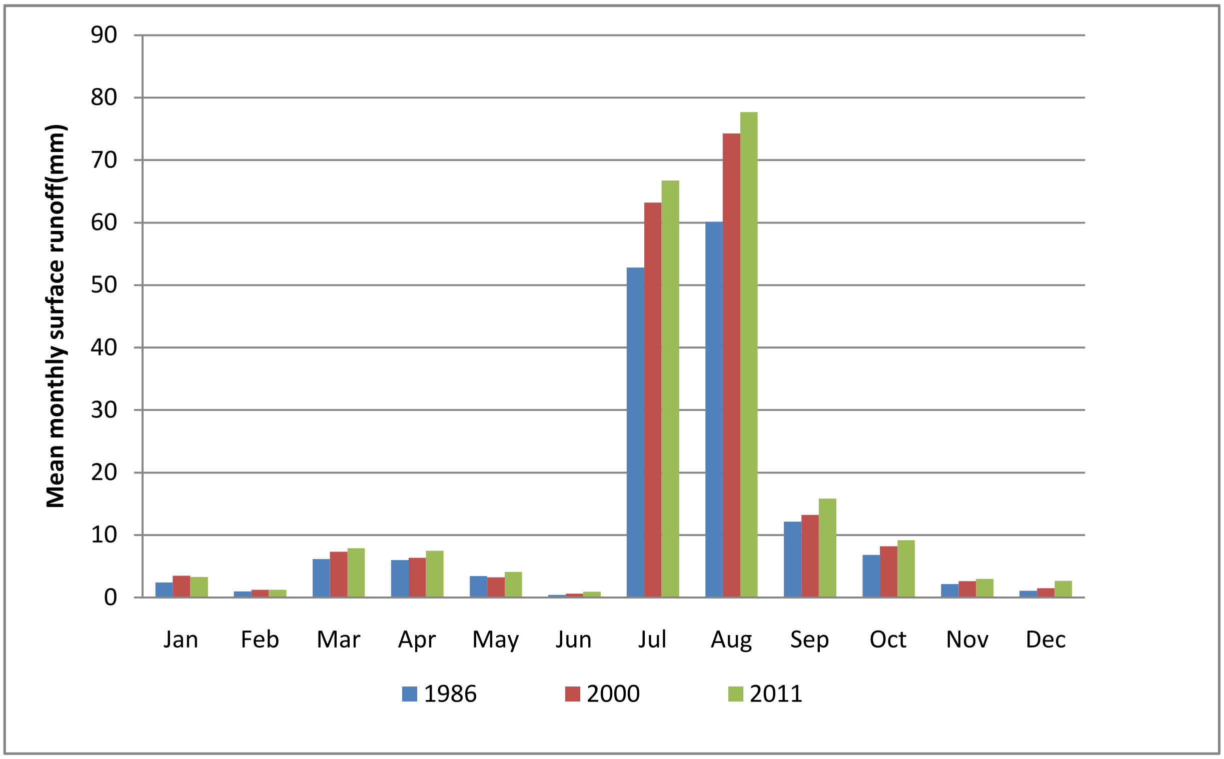


Figure 4-13 Comparison of mean monthly surface runoff for years 1986, 2000 and 2011 land use land cover map

In general, there is a significant change occurred on stream flow components due to land use land cover changes between 1986 and 2011.Accordingly,surface runoff increased by 44 mm and ground water flow declined by -31.61mm.

# CHAPTER FIVE

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1. Conclusions

This study was aimed at assessing the effects of the land use land covers changes on stream flow of Borkena watershed between the years 1996 and 2003 using distributed hydrological model (SWAT). In this study, spatial data and GIS were integrated with a hydrological model to evaluate the impacts of land use and land cover changes on the stream flow of the Borkena watershed. The impacts of the land cover change on stream flow were analyzed statistically using the hydrological model, SWAT. To do this analysis, firstly, land use and land cover change during the past 25 years (1986 – 2011) was analyzed; then SWAT model were tested for its performance at the Borkena watershed in order to examining the hydrological response of the watershed to changes in land use and land cover. Finally, the effect of land use and land cover on stream flow was assessed.

On the other hand, data preparation, sensitivity analysis, calibration, validation and evaluation of model performance were performed using the semi-distributed model, SWAT. These analyses were done before the evaluation of the impacts of the land use and land cover changes on the stream flow of the watershed. The GIS environment uses for the processing of DEM, land use and land cover, soil data layers and displaying model results.

From land cover analysis it can be concluded that there were a significant land use and land cover change in the study watershed during the periods from 1986 to 2011. Land area under agriculture increased by 24.94% of total area in expenses of other land cover classes while land area under forest decreased by 33.56% of total area during the years from 1986 to 2011. Moreover land area under cultivation and Urban increased by 5.67 and 8.78 respectively during period from 1986 to 2011.The other land use land cover grass, wetland and shrub land decreases by 2, 1.17 and 2.65 respectively during period from 1986 to 2011. The expansion of agricultural land was lead to deforestation of forest cover in the Borkena watershed during period from 1986 to 2011. This might be due to the population demand for cultivated lands were increased.

The sensitivity analysis of SWAT model was identified. Twelve more important stream flow parameters were identified significant influence in the Borkena watershed. SWAT model calibration and validation showed that model simulated observed stream flow satisfactorily. The performance evaluation of the model were good with Percent bias (PBIAS) values of 14.7 and –19.2, Nash-Sutcliffe coefficients (ENS) values of 0.89 and 0.95, and coefficient of determination ($R^2$) values of 0.93 and 0.98 for the calibration and validation respectively.

Simulation result of SWAT model for years from 1996 to 2003 showed that there was a good linear correlation between rainfall and runoff in the watershed with percentage fit greater than 90%.

Land use and land cover changes recognized to have major impacts on hydrological processes, such as runoff and groundwater flow. Surface runoff was increased from 132.37mm to 197.8mm while GWQ was decreased from 73.42mm to 41.45mm by using 1986 and 2011 land use land cover maps respectively.

### 5.2 Recommendations

Generally based on this specific study the following major recommendations are made:

- Availability of inadequate data with good quantity and quality were a great challenge in the study area. Most of the meteorological and hydrological stations within and surrounding the watershed were not functional. Hence, it is highly recommended to establish good gauging networks of both hydrological and meteorological stations.
- Change of the land use and land cover in the study area is mainly caused by increasing population. Nowadays, household family size and its annual crop production are not proportional. Moreover, the farmers are unable to improve the amount of the production by the existing farming practices. For this reason, improve of household knowledge with the impact of population growth on their living status has paramount importance. Therefore, family planning should be given widely and continuously through formal and informal education in school and some other social gathering area.

- In this study the model simulation considered only land use land cover change effects by assuming all other variables constant. But change in climate, slope and soil management activities will also contribute great impact on rainfall runoff process of the watershed. Therefore, there is a need for further research to ascertain the hydrological impacts of climate change, slope and soil in the watershed.

# REFERENCES

Abebe, S. (2005). Land-Use and Land-Cover change in headstream of Abbay watershed, Blue Nile Basin, Ethiopia. Addis Ababa University.

Abbaspour, (2007) SWAT-CUP2: SWAT Calibration and Uncertainty Programs - A User Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf,Switzerland, 95pp.

Abate, S. (2011). Evaluating the Land Use Land Cover Dynamics in Borena Woreda. Journal of Sustainable Development in Africa; Vol.13 (1), 87-107.

Amsalu, A., Stroosnijder, L and Graaff, J. de. (2007). Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. Journal of Environmental Management, Vol. 83(4), 448–459.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large-area hydrologic modeling and assessment: Part I, Model development. Water Resource, 34(1), 73–89).

Arnold, J. G., Allen. P. M. and Bernhardt. G. (1993). A comprehensive surface- groundwater flow model. Journal of Hydrology, Vol. 142: 47-69.

Atasoy, M., Biyik, C., Ayaz, H., Karsli, F., Demir, O., Baskent, E. Z. (2006). Monitoring land use changes and determinating the suitability of land for different uses with digital Photogrammetry. Remote Sensing and Photogrammetry, Cairo, Egypt.

Bekalo, M. T. (2009). Spatial metrics and Landsat data for urban land use change detection in Ababa, Ethiopia. MSc Thesis. Universitat Jaume I,Castellon, Spain.

Belay, T. (2002). Land cover/use changes in the Derekolli catchment of the South Welo Zone of Amhara Region, Ethiopia. Eastern Africa Social Science Research Review 18 (1):pp. 1 - 20.

Belayneh. (2008). Erosion and Sediment Yield Modelling-Application of Soil and Water Assessment Tool, A case study of Bilate Watershed,SNNPR.

Bewket, W. (2002). Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia. Mountain research and development, 22, 263–269.

Conway, D.; Hulme, M. 1993. Recent Fluctuations in Precipitation and Runoff over the Nile Sub-basins and Their Impact on Main Nile Discharge. Climatic Change 25: Pp 127-151.

Cunderlik, (2003) Hyderological model selection for the CFCAS project Assessment of water Resources Risk and Vulnerability change climatic condition, Water Resources research report NO.046.

Degefu, W. 1987. Some Aspects of Meteorological Drought in Ethiopia. In Drought and Hunger in Africa: Denying Famine a Future. Edited by Glantz, M.H., Cambridge University Press, New York.

Denboba, M. A. (2005). Forest conversion - soil degradation - farmers' perception effects: Implications for sustainable land use in the southwest of Ethiopia. Ecology and Development Series No. 26, 2005.

Dorosh, P and Schmidt, E. (2010). The Rural-Urban Transformation in Ethiopia. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia.

Getahun Yitea Sinishaw, Van Lanen HAJ (2015) Assessing the Impacts of Land Use-Cover Change on Hydrology of Melka Kuntrie Sub basin in Ethiopia, Using a Conceptual Hydrological Model. Hydrology Current Research Vol. 6: 210.

Gleick, P. H. (1999) Introduction: Studies from the water sector of the national assessment. American Water Resources Assessment 35, Pp 1297-1300.

Green, W.H. and Ampt, G.A. (1911) Studies in Soil Physics The Flow of Air and WaterThrough Soils. Journal of Agricultural Sciences 4:1-12.

Hadgu, K. M. (2008). Temporal and spatial changes in land use patterns and biodiversity in relation to farm productivity at multiple scales in Tigray, Ethiopia. PhD thesis Wageningen University, Netherland.

Haile, E. and Assefa, M. (2012). The impact of land use change on the hydrology of Angereb Watershed. International Journal of Water Sciences. Vol. 1: 1-7.

Haregeweyn, N., Fikadu, G., Tsunekawa, A., Tsubo, M and Meshesha, D. T. (2012). The dynamics of urban expansion and its impacts on land use/land cover change and small-scale farmers living near the urban fringe: A case study of Bahir Dar, Ethiopia. Landscape and Urban Planning, Vol. 106(2), 149–157.

Hargreaves, G.H., Allen, R.G. (2003) History and evaluation of Hargreaves evapotranspiration equation. J. Irrig. Drain. Eng. ASCE 129 (1), 53–63.

Kassa, G. (2003). GIS based analysis of land use/ cover, land degradation and population changes: A study of Boru Metero area of south Wello, Amhara region, M.Sc. thesis, Addis Ababa University, Ethiopia.

Kidanu, S (2004). Using Eucalyptus for soil and water conservation on the highland Vertisols of Ethiopia, PhD Thesis, Wageningen University, and the Netherlands.

Lampros Vasiliades, A. L. (2009). Hydrological Response to Meteorological Drought Using the Palmer Drought in Thessaly, Greece. Desalination 237, 3-21.

Legesse, D., Vallet-Coulomb, C., and Gasse, F. (2003). Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. Journal of Hydrology Vol. 275: 67-85.

Mendoza, M., Bocco, G., and Bravo, B.: Spatial prediction in hydrology: status and implication in the estimation of hydrological processes for applied research,Prog. Phys. Geog., 26(3),319–338, 2002.

Moriasi, (2007) Model evaluation guidelines for systematic quantification of accuracy in Watershed simulations. Vol. 50(3), 850-900pp. American society of Agr icultural and Biological Engineers ISSN 0001-235.

Munich, R. (2005). Natural Catastrophes. *SeasonalReview.* Munich, Germany.

Neitsch S. L., Arnold J. G., Kiniry J. R., and Williams J. R. (2005). Soil and water assessment tool (SWAT), theoretical documentation, Blackland research center, grassland, soil and water research laboratory, agricultural research service: Temple, Texas.

Priestley, C. H. B. and Taylor. R. J. (1972). On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters. Division of Atmospheric Physics, Commonwealth Scientific and Industrial Research Organization, Aspendale, Victoria, Australia.

Samuel, K. (2016) The impact of land use land cover change on watershed hydrology: the case study of Upper awash basin. Arba Minch university.

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R. and Hauck, L.M., (2001). Validation of the SWAT model on a large river basin with point and nonpoint sources, Journal of the American Water Resources Association, Vol. 37, No. 5.

Sirak T. 2008. Watershed Modelling of Lake Tana Basin Using SWAT. Msc thesis in Arba Minch University.

Stefanov, W. L., Ramsey, M. S., Christensen, P. R. (2001). Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers. Remote sensing of Environment Vol. 77 (2001) 173 – 185.

Tadele, K. (2007). Impact of Land use/cover change on stream flow: the case of Hare River Watershed, Ethiopia. Arba Minch Water Technology Institute, Arba Minch University.

Tessema, SM (2011). Hydrological modeling as a tool for sustainable water resources management: a case study of the Awash River basin. TRITA LWR.LIC 2056.

Williams, J.R. (1975). Sediment routing for agricultural watersheds. Water Resources Bulletin., Vol. 11(5):965-974.

Whittington, D.; Wu, X.; Sadoff, C. 2005, Water Resources Management in the Nile Basin: The Economic Value of Cooperation. *Water Policy* 7: Pp 227-252. 12.

Yacob, E. (2010). Evaluating the impact of land use land cover change on soil erosion. Master thesis. Addis Ababa University, Ethiopia.

Xu, C. 2000. Climate change and hydrological models: A review of existing gaps and recent research developments. Water Resource management 13, 369-382.

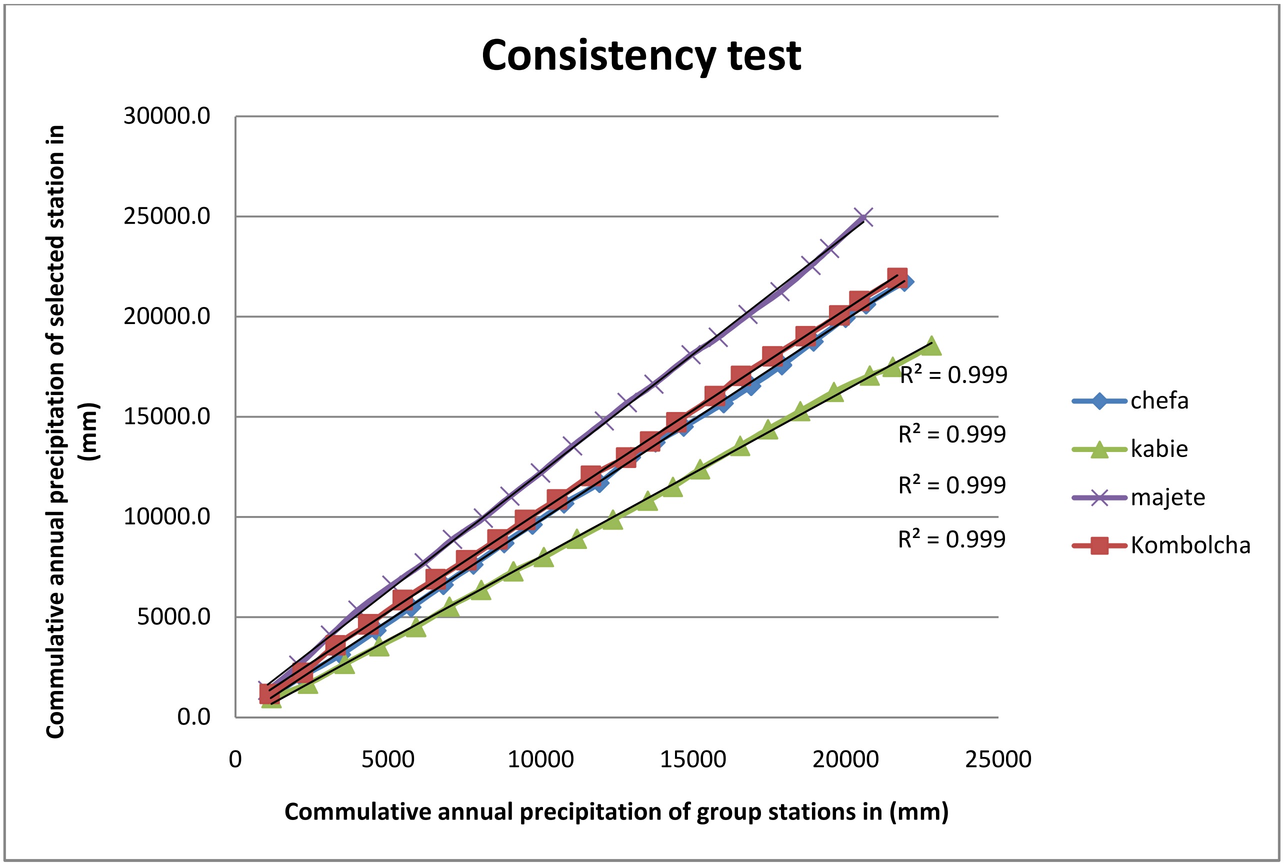
Zeleke, G and Hurni, H. (2001). Implications of land use and land cover dynamics for mountain resource degradation in the Northwestern Ethiopian highlands. Mountain Research and Development, Vol. 21(2), 184–191.

# APPENDICES

Appendix A: Location of meteorological stations in Borkena watershed.

| S.NO | Station name | XPR | YPR | Elevation |
|---|---|---|---|---|
| 1 | Cheffa | 395400 | 104948 | 1512 |
| 2 | Majete | 395100 | 103000 | 2000 |
| 3 | Kombolcha | 344303 | 110502 | 1857 |
| 4 | Kabie | 392754 | 104941 | 2879 |

Appendix B: Double mass curve for selected gauging stations



## Appendix C: Weather generator (WGEN) parameters used by the SWAT for Kombolcha station.

PCP_MM = average monthly precipitation [mm]

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

PCPSKW = Skew coefficient for daily precipitation in month

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

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

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

TMPSTDMX= Standard deviation for daily maximum air temperature in month (oc)

TMPSTDMN =Standard deviation for daily minimum air temperature in month (oc)

SOLARAV= Average daily solar radiation for month (MJ/m2/day)

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

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TMPMX | 24.86 | 26.73 | 27.5 | 27.94 | 29.16 | 30.66 | 23.34 | 22.07 | 26.86 | 26.16 | 25.49 | 24.81 |
| TMPMN | 10.55 | 10.65 | 12.65 | 13.91 | 14.42 | 15.26 | 15.71 | 15.03 | 14.02 | 10.88 | 9.17 | 8.9 |
| TMPSTDMX | 2.17 | 1.94 | 2.15 | 1.91 | 1.89 | 1.52 | 2.14 | 1.64 | 1.26 | 1.36 | 1.50 | 1.5397 |
| TMPSTDMN | 4.73 | 3.08 | 2.64 | 1.96 | 1.59 | 1.58 | 1.29 | 0.98 | 4.79 | 2.42 | 2.78 | 3.216 |
| PCPMM | 25.69 | 13.89 | 61.94 | 88.26 | 56.45 | 33.2 | 300.8 | 294.87 | 93.83 | 46.92 | 21.09 | 13.48 |
| PCPSTD | 3.47 | 2.13 | 5.51 | 6.27 | 5.08 | 3.38 | 13.17 | 11.34 | 5.79 | 5.31 | 3.76 | 2.3672 |
| PCPSKW | 7.74 | 6.77 | 4.31 | 2.76 | 4.60 | 4.79 | 2.08 | 1.59 | 3.20 | 6.16 | 8.00 | 8.8871 |
| PR_W1 | 0.08 | 0.05 | 0.15 | 0.21 | 0.16 | 0.14 | 0.55 | 0.64 | 0.41 | 0.09 | 0.04 | 0.063 |
| PR_W2 | 0.57 | 0.54 | 0.60 | 0.64 | 0.54 | 0.53 | 0.83 | 0.81 | 0.61 | 0.58 | 0.55 | 0.5063 |
| PCPD | 5.5 | 3.5 | 9.18 | 11.91 | 8.64 | 7.27 | 24.45 | 25.23 | 16.68 | 6.64 | 2.64 | 3.59 |
| SOLARAV | 18.73 | 21.54 | 21.61 | 22.29 | 22.62 | 20.68 | 18.78 | 19.08 | 19.74 | 20.55 | 20.42 | 19.35 |
| DEWPT | 10.96 | 9.71 | 11.09 | 11.75 | 10.09 | 8.12 | 13.19 | 14.45 | 13.41 | 10.74 | 9.58 | 9.44 |
| WNDAV | 0.82 | 0.9 | 0.88 | 0.85 | 0.87 | 1.01 | 0.96 | 0.89 | 0.58 | 0.51 | 0.59 | 0.7 |

## Appendix D: Monthly total Rainfall for different stations.

Monthly total rainfall of Kombolcha station (mm)

Monthly total rainfall of Kabie station (mm)

Monthly total rainfall of Majete station (mm)

| year | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **20004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jan** | 41.2 | 41.0 | 108.0 | 94.9 | 0.0 | 7.6 | 106.4 | 63.2 | 58.3 | 53.3 | 56.3 | 20.9 | 50.1 | 28.7 | 12.4 | 10.5 | 0.0 | 0.0 | 1.2 | 28.2 | 14.0 |
| **Feb** | 0.0 | 0.0 | 91.8 | 0.3 | 0.0 | 2.1 | 6.8 | 31.0 | 69.9 | 0.0 | 10.7 | 20.1 | 0.0 | 4.0 | 55.3 | 0.0 | 0.0 | 6.3 | 53.6 | 2.0 | 0.0 |
| **Mar** | 163.3 | 129.7 | 59.7 | 35.6 | 0.3 | 164.2 | 60.4 | 82.7 | 103.5 | 144.4 | 55.4 | 72.9 | 0.0 | 57.4 | 116.4 | 106.6 | 51.0 | 45.1 | 63.8 | 61.6 | 24.1 |
| **Apr** | 120.8 | 69.4 | 121.6 | 91.3 | 85.4 | 14.4 | 104.9 | 98.8 | 97.8 | 98.0 | 152.3 | 86.6 | 59.6 | 25.6 | 152.1 | 36.1 | 162.3 | 65.1 | 128.7 | 0.0 | 336.4 |
| **May** | 120.4 | 7.9 | 74.3 | 22.9 | 78.1 | 96.6 | 31.4 | 3.1 | 5.9 | 113.9 | 9.0 | 79.4 | 28.1 | 50.5 | 133.3 | 68.9 | 83.6 | 95.8 | 113.3 | 150.1 | 158.1 |
| **Jun** | 57.0 | 53.6 | 9.0 | 10.0 | 7.1 | 11.0 | 26.8 | 20.8 | 45.9 | 40.3 | 36.4 | 31.4 | 28.1 | 39.6 | 30.6 | 13.7 | 27.8 | 27.5 | 16.0 | 7.7 | 52.1 |
| **Jul** | 298.9 | 222.4 | 464.8 | 438.6 | 322.0 | 450.8 | 247.5 | 254.1 | 201.5 | 208.6 | 340.0 | 302.9 | 225.6 | 264.0 | 279.0 | 150.9 | 322.6 | 300.7 | 272.9 | 36.9 | 399.7 |
| **Aug** | 374.0 | 261.0 | 373.8 | 504.9 | 413.8 | 240.3 | 311.2 | 250.2 | 259.4 | 228.4 | 508.3 | 438.1 | 254.4 | 251.0 | 527.0 | 323.2 | 343.2 | 363.8 | 428.6 | 243.0 | 361.3 |
| **Sep** | 107.3 | 56.9 | 127.2 | 148.5 | 130.4 | 105.9 | 99.4 | 186.1 | 118.9 | 191.9 | 107.3 | 156.9 | 91.3 | 73.5 | 117.2 | 90.0 | 44.5 | 62.0 | 97.9 | 193.8 | 170.2 |
| **Oct** | 8.9 | 270.3 | 62.7 | 202.3 | 54.4 | 11.2 | 7.4 | 3.0 | 40.4 | 9.5 | 34.9 | 22.6 | 61.7 | 63.2 | 12.7 | 20.5 | 104.8 | 154.2 | 127.5 | 5.9 | 13.7 |
| **Nov** | 53.1 | 143.9 | 2.3 | 5.6 | 103.3 | 8.0 | 2.6 | 3.9 | 59.1 | 62.4 | 0.0 | 12.0 | 117.1 | 11.4 | 22.1 | 56.0 | 0.0 | 8.5 | 6.7 | 90.8 | 27.5 |
| **Dec** | 0.0 | 0.0 | 0.0 | 0.3 | 53.5 | 1.8 | 163.1 | 61.1 | 29.2 | 14.6 | 38.0 | 0.0 | 0.0 | 55.7 | 1.3 | 0.2 | 3.3 | 0.0 | 0.1 | 31.8 | 0.0 |

Monthly total rainfall of Cheffa station (mm)

| year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 20004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jan** | 18.5 | 21.1 | 32.1 | 30.1 | 0.0 | 2.2 | 66.4 | 12.7 | 23.8 | 31.5 | 18.5 | 21.1 | 32.1 | 30.1 | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 4.9 | 25.9 |
| **Feb** | 4.2 | 71.9 | 0.0 | 7.1 | 64.8 | 49.5 | 22.6 | 59.3 | 4.3 | 2.8 | 4.2 | 71.9 | 0.0 | 7.1 | 64.8 | 0.0 | 0.0 | 30.2 | 21.1 | 0.0 | 4.4 |
| **Mar** | 166.6 | 71.1 | 0.0 | 41.1 | 131.6 | 162.2 | 38.3 | 64.1 | 80.9 | 87.9 | 166.6 | 71.1 | 0.0 | 41.1 | 131.6 | 58.0 | 94.3 | 72.6 | 36.1 | 27.4 | 74.7 |
| **Apr** | 73.3 | 134.8 | 58.5 | 35.2 | 70.8 | 23.6 | 87.7 | 117.5 | 156.8 | 90.2 | 73.3 | 134.8 | 58.5 | 35.2 | 70.8 | 34.4 | 173.5 | 62.1 | 125.2 | 0.0 | 194.2 |
| **May** | 19.2 | 57.2 | 12.8 | 12.1 | 40.4 | 77.9 | 9.2 | 0.0 | 11.3 | 156.2 | 19.2 | 57.2 | 12.8 | 12.1 | 40.4 | 192.4 | 39.7 | 68.7 | 88.9 | 76.6 | 41.9 |
| **Jun** | 5.9 | 23.8 | 37.8 | 30.6 | 14.9 | 16.3 | 4.5 | 25.5 | 21.6 | 26.7 | 5.9 | 23.8 | 37.8 | 30.6 | 14.9 | 9.0 | 51.1 | 2.1 | 1.5 | 14.5 | 36.0 |
| **Jul** | 329.4 | 466.0 | 245.0 | 202.3 | 249.5 | 348.2 | 295.8 | 246.0 | 175.3 | 285.5 | 329.4 | 466.0 | 245.0 | 202.3 | 249.5 | 150.1 | 337.8 | 389.3 | 301.9 | 55.7 | 249.3 |
| **Aug** | 299.3 | 309.7 | 186.9 | 158.7 | 515.8 | 345.5 | 237.8 | 313.0 | 271.8 | 239.6 | 299.3 | 309.7 | 186.9 | 158.7 | 515.8 | 257.4 | 302.5 | 385.8 | 393.9 | 303.0 | 332.5 |
| **Sep** | 60.9 | 105.6 | 88.2 | 49.4 | 54.1 | 59.4 | 87.9 | 187.8 | 72.8 | 43.7 | 60.9 | 105.6 | 88.2 | 49.4 | 54.1 | 96.3 | 50.1 | 68.3 | 98.7 | 122.9 | 134.2 |
| **Oct** | 23.5 | 23.2 | 25.0 | 70.0 | 4.9 | 9.6 | 13.1 | 0.0 | 59.3 | 10.7 | 23.5 | 23.2 | 25.0 | 70.0 | 4.9 | 8.0 | 0.0 | 89.7 | 112.8 | 4.3 | 3.0 |
| **Nov** | 2.9 | 0.0 | 57.7 | 11.7 | 10.7 | 0.6 | 0.0 | 0.0 | 44.4 | 81.6 | 2.9 | 0.0 | 57.7 | 11.7 | 10.7 | 56.9 | 0.0 | 3.5 | 3.1 | 39.2 | 28.2 |
| **Dec** | 19.7 | 0.0 | 0.0 | 135.0 | 5.4 | 17.4 | 143.8 | 50.0 | 3.9 | 0.0 | 19.7 | 0.0 | 0.0 | 135.0 | 5.4 | 0.0 | 0.0 | 0.0 | 2.6 | 25.6 | 0.0 |