Masters Program in **Geospatial Technologies**

ASSESSING THE IMPACTS OF LAND USE AND LAND COVER CHANGE ON HYDROLOGY OF WATERSHED:

A Case study on Gilgel–Abbay Watershed, Lake Tana Basin, Ethiopia

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ABSTRACT

The population growth for the last 16 years caused changes in land cover of the Gilgel Abbay watershed, Lake Tana basin, Ethiopia. The effects of the land cover changes have impacted on the stream flow of the watershed by changing the magnitude of surface runoff and ground water flow. This study is mainly focusing on the assessment of the impacts of the land cover changes on the stream flow by changing SURQ and GWQ for the wet months (June, July, August) and dry months (January, February, March) through satellite Remote Sensing (RS) and Geographic Information System (GIS) integrated with the SWAT model. ArcGIS used to generate land use and cover maps from Landsat TM and ETM+ acquired, respectively, in 1986 and 2001. The land cover maps were generated using the Maximum Likelihood Algorithm of Supervised Classification. The accuracy of the classified maps was assessed using Confusion Metrics. The result of this analysis showed that the cultivated land has expanded during the study period of 1986-2001. Using the two generated land cover maps, two SWAT models set up were run to evaluate the impacts the land use and cover changes on the stream flow of the study watershed. The performance of the SWAT model was evaluated through sensitivity analysis, calibration, and validation. Ten flow parameters were identified to be sensitive for the stream flow of the study area and used for model calibration. The model calibration was carried out using observed stream flow data from 01 January 1987 to 31 December 1994 and a validation period from 01 January 1995 to 31 December 2001. Both the calibration and validation results showed good match between measured and simulated stream flow data with the coefficient of determination (R^2) of 0.93 and Nash-Sutcliffe efficiency (ENS) of 0.95 for the calibration, and R^2 of 0.91 and ENS of 0.90 of the validation period. The result of this analysis indicated that the mean monthly stream flow increased by 16.26m^3/s for the wet months while for the dry months decreased by 5.41 m^3/s. Generally, the analysis indicated that flow during the wet months has increased, while the flow during the dry months decreased. The SURQ increased, while GWQ decreased from 1986 to 2001 due to the increment of cultivated lands. The model results showed that the stream flow characteristics changed due to the land cover changes during the study period.

KEYWORDS

Geographic Information system (GIS)

Gilgel Abbay Watershed

Land use and cover change

Remote sensing

Soil and Water Assessment Tool (SWAT)

Stream flow

ACRONYMS

ANRS – Amhara National Regional State
CSA – Central statistical Agency
DEM – Digital Elevation Model
ENS – Nash-Sutcliffe Efficiency
ETM+ – Enhanced Thematic Mapper Plus
GIS – Geographical Information System
GWQ – Ground Water Flow
HBV – Hydrologisika Bayraans Vattenbalans-avediling
HEC-HMS – Hydraulic Engineering Centre-Hydrologic Modeling System
HRU – Hydrological Response Unit
IGBP-IHDP – International Geosphere-Biosphere Program and the International Human Dimension Program
LULCC – Land Use and Land Cover Change
MoA – Ministry of Agriculture
MoEWR – Ministry of Energy and Water Resources
MRS – Mean Relative Sensitivity
R^2 – Coefficient of Determination
RS – Remote Sensing
SURQ – Surface runoff
SWAT – Soil and Water Assessment Tool
TM – Thematic Mapper
USDA-ARS – United States Department of Agriculture-Agricultural Research Service
WXGEN – Weather Generator
WXPARM – Weather Parameter Calculator

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CHAPTER ONE

INTRODUCTION

1.1. Study Background

Water is the most essential natural resources for living species. Since the available amount of water is limited, scarce, and not spatially distributed in relation to the population needs, proper management of water resources is essential to satisfy the current demands as well as to maintain sustainability. Land use planning and management are closely related to the sustainability of water resources as changes of land use are linked with amount of water through relevant hydrological processes (Guo *et al*, 2008). To maintain water sustainability, effective methods and mechanisms should be used. In nowadays, the hydrological models are good to represent the hydrological characteristics (Surur, 2010).

Hydrologic modeling and water resources management studies are closely related to the spatial processes of the hydrologic cycle. Hydrological cycle is the continuous movement of water on, above and below the surface of the Earth. This cycle is affected by several factors like climate and land use and land cover change. Therefore, the interaction between land use and land cover and hydrological cycle should be well understood. Land use and land cover are highly changes especially in the developing countries which have agriculture based economics and rapidly increasing populations. The land use and land cover changes are caused by a number of natural and human driving forces (Meyer and Turner, 1994). Natural effects are such as climate changes are only over a long period of time, whereas the human effects are immediate and often direct. Out of the human factors, population growth is the most important in Ethiopia (Tekle and Hedlund, 2000), as it is common in developing countries. Ethiopia is one of the most populous countries in Africa with over a population of 70 million people and an annual growth rate of 2.6 million people (CSA, 2008). 85 % of the population of lives in rural areas and directly depends on the land for its livelihood. This means the demands of lands are increasing as population increases. Agriculture, which depends on the availability of seasonal rainfall, is the main economy of the country. People need land for the food production and for housing and it is common practice to clear the forest for the farming and housing activities. Therefore, the result of these activities is the land use and land cover changes due to daily human intervention. Hence, understanding how the land cover changes influence on the hydrology of the watershed will enable planners to formulate policies to minimize the undesirable effects of future land cover changes.

Providing a scientific understanding of the process of land use and land cover change, the impacts of different land use decisions, and the ways that decisions are affected the hydrological cycle and increasing variability are priority areas of research (Abraha, 2007). The main intention of this study is to analyze the effect of land use and land cover changes on the wet month and dry month stream flow and the components (surface and ground water flow) of stream flow of the watershed. Stream flow usually has high seasonal variability, and seasonal local water scarcity is a problem faced by many farmers in watersheds (Jamtsho and Gyamtsho, 2003). Generally, this study can be achieved through the integration of Remote Sensing, Geographic Information System (GIS) and Soil and Water Assessment Tool (SWAT model).

1.2. Statement of the Problem

The Lake Tana basin is densely populated with a total population of about two million (Surur, 2010). Gilgel Abbay watershed which is one of the sub watersheds of Lake Tana basin is densely populated with an annual growth rate of 2.3 % according to CSA (central statistics authority). This causes various effects on resource bases like deforestation, expansion of residential area, and agricultural land. Gilgel Abbay watershed which is one of the sub watersheds of Lake Tana basin is facing these types of effects. Deforestation is a day to day activity of the people living in the watershed. The watershed is also facing high erosion by the effects of intense rainfall of the watershed which aggravates the land cover change of the watershed. This continuous change in land cover has impacted the water balance of the watershed by changing the magnitude and pattern of the components of stream flow which are surface runoff and ground water flow, which results increasing the extent of the water management problem. Therefore, a strong need is identified for the hydrological techniques and tools that can assess the effects of land cover changes on the hydrologic response of a watershed. Such techniques and tools can provide information that can be used for water resources management at a watershed.

1.3. Objective of the Study

The main objective of this study was to assess the impacts of land use and land cover change impact on the stream flow of Gilgel Abbay watershed using Remote Sensing and GIS Techniques, and Soil and Water Assessment (SWAT model) Tool for the past 16 years (1986-2001).

The specific objectives:

- ❖ To produce the land use and land cover maps of the Gilgel Abbay watershed for 1986 and 2001 years.

- ❖ To assess the accuracy of the classified maps using the Error Matrix (Confusion Matrix)
- ❖ To identify the flow sensitive parameters of the watershed
- ❖ To calibrate and validate of the stream flow simulation
- ❖ To evaluate the performance of the hydrological (SWAT) model

1.4. Research Questions

To address the above objectives, the following research questions were designed.

1. How is the trend of land use and land cover changes from 1986 to 2002 in the study watershed?
2. How well can SWAT model simulate stream flow in the watershed?
3. How does land use and land cover change affects the stream flow of the watershed?

1.5. Significance of the Study

The land use and land cover change has significantly impacts on natural resources, socioeconomic and environmental systems. However, to assess the effects of land use and land cover change on stream flow, it is important to have an understanding of the land use and land cover patterns and the hydrological processes of the watershed. Understanding the types and impacts of land use and land cover change is essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable management of natural resources in the country in general and at the study area in particular.

Moreover, the study presents a method to quantify land use and land cover change and their impact on hydrological regime. This has been achieved through a method that combines the hydrological model (SWAT) to simulate the hydrological processes, GIS and remote sensing techniques to analysis the land use and land cover change.

1.6. Softwares and Materials used

To meet the objectives of the study various software and materials are necessary. ArcGIS was used to the preliminary data processing, extracting, mosaicing satellite images and image classification. For the modeling part, SWAT model embedded in ArcGIS 9.3 has been used to simulate stream flow of the watershed.

1.7. Organization of the Thesis

The paper is organized into five sections: Section one is an introduction section where the background, statement of the problem, objectives of the study, research questions and significance of the study are discussed. In section two, review of related literatures where the definition and concepts of land use and land cover changes, land use and land cover changes in Ethiopia, Application of Remote sensing on land use and land cover changes, hydrological models, an Introduction to SWAT model, application of SWAT model worldwide and in Ethiopia are reviewed. Data and methodology section in which Description of the study area, image processing, classification and accuracy assessment, Hydrological model selection criteria, Collection of input data and analysis, model setup, model performance evaluation and evaluation of stream flow due to land use and land cover changes are elaborated in section three. The fourth section describes with the result and discussion which are land use and land cover analysis, stream flow modeling and evaluation of stream flow due to land use and land cover change. The land use and land cover analysis including land covers maps and statistics, and accuracy assessment. The stream flow modeling includes sensitivity analysis, calibration and validation of stream flow simulation, and the performance evaluation of the model. Finally, in section five, conclusions and recommendations of the study are provided.

CHAPTER TWO

LITERATURE REVIEW

Under this section, literatures were cited on relevant topics, such as: definition and concepts of land use and land cover change, land use and land cover change studies in Ethiopia, application of remote sensing on land use and land cover change, Introduction to hydrological models, worldwide perspective of the hydrological (SWAT) model, and SWAT model in Ethiopia. Generally, the reviews were focused on assessing the scientific works that are related to the subject of this study.

2.1. Land Use and Land Cover Change: Definitions and Concepts

According to the International Geosphere-Biospehre Program and The International Human Dimension Program (IGBP-IHDP, 1999), ***land cover*** refers to the physical and biophysical cover over the surface of earth, including distribution of vegetation, water, bare soil and artificial structures. ***Land use*** refers to the intended use or management of the land cover type by human beings such as agriculture, forestry and building construction.

Land use and land cover change (LUCC) is commonly grouped in to two broad categories: conversion and modification (Meyer and Turner, 1994). Conversion refers to a change from one cover or use category to another (e.g. from forest to grassland). Modification, on the other hand, represents a change within one land use or land cover category (e.g. from rainfed cultivated area to irrigated cultivated area) due to changes in its physical or functional attributes. These changes in land use and land cover systems have important environmental consequences through their impacts on soil and water, biodiversity, and microclimate (Lambin *et al*., 2003).

Land cover changes have been influenced by both the increase and decrease of a given population (Lambin et al., 2003). In most developing countries like Ethiopia population growth has been a dominant cause of land use and land cover change than other forces (Sage, 1994). There is a significant statistical correlation between population growth and land cover conversion in most of African, Asian, and Latin American countries (Meyer and Turner, 1994). Due to the increasing demands of food production, agricultural lands are expanding at the expense of natural vegetation and grasslands (Lambin *et al.*, 2003).

Land use and land cover characteristics have many connections with hydrological cycle. The land use and land cover type can affect both the infiltration and runoff amount by following the falling of precipitation (Hougton, 1995). Both surface runoff and ground water flow are significantly affected by types of land cover (Abebe, 2005). Surface runoff and Ground water flow are the two components of the stream flow. Surface runoff is mostly contributed directly from rainfall, whereas ground water flow is contributed from infiltrated water. However, the source of stream flow is mostly from surface runoff during the wet months, whereas during the dry months the stream flows from the ground water.

Increase of crop lands and decrease of forest, results increase of stream flow because of the crop soil moisture demand. 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 when the area under agricultural land is extensive. Hence, this leads to an increases stream flow. In addition, deforestation also has its own impact on hydrological processes, leading to declines in rainfall, and more rapid runoff after precipitation (Legesse *et al*, 2003). Therefore, such changes of land use and land cover may have impacts on the stream flow during the wet and dry months, and on the components of stream flow (surface runoff and ground water flow) and assessing such impacts is the core of this study.

Generally, knowing of the impacts of land use and land cover change on the natural resources like water resources depends on an understanding of the past land use practices, current land use and land cover patterns, and projection of future land use and land cover, as affected by population size and distribution, economic development, technology, and other factors. The land use and land cover change assessment is an important step in planning sustainable land management that can help to minimize agro-biodiversity losses and land degradation, especially in developing countries like Ethiopia (Hadgu, 2008).

2.2. Land Use and Land Cover Change Studies 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 shrublands; for example Belay, (2002); Bewket, (2003); Kidanu, (2004); Abebe, (2005) in northern part of Ethiopia, Zeleke and Hurni, (2001) in north western part of Ethiopia, Kassa, (2003) in north eastern part of Ethiopia; and Denboba, (2005) in south western part of Ethiopia.

Kassa (2003) in his study, in southern Wello, reported the decline of natural forests and grazing lands due to conversions to croplands. Bewket (2003) have reported an increase in wood lots (eucalyptus tree plantations) and cultivated land at the expense of grazing land in both Chemoga watershed in north-western Ethiopia, and Sebat-bet Gurage land in south-central Ethiopian. The changes of land use and land cover that occurred from 1971/72 to 2000 in Yerer Mountain and its surrounding results an expansion of cultivated land at the expense of the grasslands (Gebrehiwet, 2004).

Hadgu (2008) identified that decrease of natural vegetation and expansion of agricultural land over a period of 41 years in Tigray, northern part of Ethiopia. He concluded that population pressure was an important deriver for expansion and intensification of agricultural land in recent periods. Garedew, (2010) in the semi-arid areas of the central Rift Valley of Ethiopia, during the period 1973-2000 cropland coverage has increased and woodland cover lost. Similarly, Feoli, *et al.*, (2002) also reported the expansion of evergreen vegetation with increase of population.

According to many literatures, population growth has a paramount impact on the environment. For instance, population pressure has been found to have negative effect on Riverine vegetation, scrublands and forests in Kalu district (Tekle and Hedlund, 2000), Riverine trees in Chemoga watershed (Bewket, 2003), and natural forest cover in Dembecha Woreda north-western Ethiopia (Zeleke and Hurni, 2001). Similarly, Pender *et al.,* (2001) report that the population growth has significant effect on land degradation, poverty and food insecurity in the northern Ethiopian highlands.

However, most of the empirical evidences indicated that land use and land cover changes and socioeconomic dynamics have a strong relationship; as population increases the need for cultivated land, grazing land, fuel wood; settlement areas also increases to meet the growing demand for food and energy, and livestock population. Thus, population pressure, lack of awareness and weak of management are considered as the major causes for the deforestation and degradation of natural resources in Ethiopia.

2.3. Application of Remote Sensing on LULCC

Remote Sensing (RS) is defined as the science of obtaining information about an object, area, or phenomenon throught the analysis of data acquiring by a device that is not contact with the object, area, or phenomenon under investigation (Bawahidi, 2005). It provides a large amount of data about the earth surface for detailed analysis and change detection with the help of sensors. Most of data inputs to the hydrological (SWAT) model is directly or indirectly extracted from remotely sensed data. Some of the important data used in the hydrological modelling that are obtained from remote sensing include digital elevation model (DEM), land cover maps.

Some of the application of remote sensing technology in mapping and studying of the land use and land cover changes are; map and classify the land use and land cover, assess the spatial arrangement of land use and land cover, allow analysis of time-series images used to analyze landscape history, report and analyze results of inventories including inputs to Geographic Information System (GIS), provide a basis for model building.

Land use and land cover is changing rapidly in most parts of the world. In this situation, accurate, meaningful and availability of data is highly essential for planning and decision making. Remote sensing is particularly attractive for the land cover data among the different sources. Stefanov *et al* (2001) reported that in 1970's satellite remote sensing techniques have started to be used as a modern tool to detect and monitor land cover change at various scales with useful results.

William *et al* (1991) showed that the information of land use and land cover change which is extracted from remotely sensed data is vital for updating land cover maps and the management of natural resources and monitoring phenomena on the surface. The importance of land cover mapping is to show the land cover changes in the watershed area and to divide the land use and land cover in different classes of land use and land cover. For this purpose, remotely sensed imagery play a great role to obtaining information on both temporal trends and spatial distribution of watershed areas and changes over the time dimension for projecting land cover changes but also to support changes impact assessment (Atasoy *et al.*, 2006). To monitor the rapid changes of land cover, to classify the types of land cover, and to obtain timely land cover information, multitemporal remotely sensed images are considered effective data sources.

2.4. 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 modelling 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 classified in to three main categories (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.

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 behaviour. Distributed models generally require large amount of (often unavailable) data. However, the governing physical processes are modelled in detail, and if properly applied, they can provide the highest degree of accuracy.

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).

Generally for this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models. Therefore, three selected semi-distributed models were reviewed (Table 1).

Table 1. Description of three selected semi-distributed hydrological models

Description	**SWAT**	**HEC-HMS**	**HBV**
Model type	Semi-distributed Physically-based Long-term	Semi-distributed Physically-based	Semi-distributed Conceptual model
Model objective	Predict the impact of land management practices on water and sediment	Simulate the rainfall-runoff process of watershed	Simulate rainfall-runoff process and floods
Temporal scale	Day $^{+}$	Day $^{-}$	Day $^{-}$
Spatial scale	Medium $^{+}$	Flexible	Flexible
Process modelled	Continuous	Continuous & event	Continuous & event
Cost	Public domain	Public domain	Public domain

2.4.1. Introduction to SWAT Model

The SWAT (Soil and Water Assessment Tool) watershed model is one of the most recent models developed at the USDA-ARS (Arnold *et al.,* 1998) during the early 1970's. SWAT model is semi-distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch, et al, 2005).

The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed. In SWAT model, the impacts of spatial heterogeneity in topography, land use, soil and other watershed characteristics on hydrology are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics.

The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch, et al, 2005). Major hydrologic processes that can be simulated by the this model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998). Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer).

2.4.1.1. SWAT Model Application Worldwide

The SWAT model has good reputation for best use in agricultural watersheds and its uses have been successfully calibrated and validated in many areas of the USA and other continents (Ndomba, 2002; Tripathi *et al.,* 2003). The studies indicated that the SWAT Model is capable in simulating hydrological process and erosion/sediment yield from complex and data poor watersheds with reasonable model performance statistical values. Ndomba (2002) was applied the SWAT model in modeling of Pangari River (Tanzania) to evaluate the applicability of the model in complex and data poor watersheds. Tripathi *et al.,* (2003) applied the SWAT model for Nagwan watershed in India with the objective of identifying and prioritizing of critical sub-watersheds to develop an effective management plan and the model was verified for both surface runoff and sediment yield. Accordingly, the study concluded that the SWAT model can be used in ungauaged watersheds to simulate the hydrological and sediment processes.

SWAT has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences, hundreds of SWAT-related papers presented at numerous other scientific meetings, and large number of articles published in peer-reviewed journals (Gassman, 2007).

However, Cibin *et al.* (2010) indicated that SWAT model parameters show varying sensitivity in different years of simulation suggesting the requirement for dynamic updating of parameters during the simulation. The same study also indicated that sensitivity of parameters during various flow regimes (low, medium and high flow) is also found to be uneven, which suggests the significance of a multi-criteria approach for the calibration of the model.

2.4.1.2. SWAT Model Application in Ethiopia

The SWAT model application was calibrated and validated in some parts of Ethiopia, frequently in Blue Nile basin. Through modeling of Gumara watershed (in Lake Tana basin), Awulachew *et al*. (2008) indicated that stream flow and sediment yield simulated with SWAT were reasonable accurate. The same study reported that similar long term data can be generated from ungauged watersheds using the SWAT model. A study conducted on modeling of the Lake Tana basin with SWAT model also showed that the SWAT model was successfully calibrated and validated (Setegn *et al.,* 2008). This study reported that the model can produce reliable estimates of stream flow and sediment yield from complex watersheds. Gessese (2008) used the SWAT model performed to predict the Legedadi reservoir sedimentation. According to this study, the SWAT model performed well in predicting sediment yield to the Legedadi reservoir. The study further put that the model proved to be worthwhile in capturing the process of stream flow and sediment transport of the watersheds of the Legedadi reservoir.

In addition to the above, the SWAT model was tested for prediction of sediment yield in Anjeni gauged watershed by Setegn *et al.,* (2008). The study found that the observed values showed a good agreement at Nash-Sutcliff efficiency (ENS) of 80 %. In light of this, the study suggested that the SWAT model can be used for further analysis of different management scenarios that could help different stakeholders to plan and implement appropriate soil and water conservation strategies. The SWAT model showed a good match between measured and simulated flow and sediment yield in Gumara watershed both in calibration and validation periods (Asres and Awulachew, 2010). Tekle (2010) through modeling of Bilate watershed also indicated that SWAT Model was able to simulate stream flow at reasonable accuracy.

The literature reviewed and presented above showed that SWAT is capable of simulating hydrological and soil erosion process with reasonable accuracy and can be applied to large and complex watersheds.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Gilgel Abbay is the largest tributary of the Lake Tana basin, Ethiopia. This watershed is located in West Gojjam and Awi Administrative Zones of the Amhara National Regional State (ANRS) of Ethiopia. The watershed area comprises of 10 Woredas' namely: Mecha, South-Achefer, Dangla, Sekela, Fagtalakuma, North-Achefer, Bahir-Dar zuria, Banja, Quarit and Yilmanedensa.

In terms of geographic coordinate system, the watershed lies between 10.95^o and 11.80^o North latitudes and 36.70^o and 37.40^o East longitudes. Gilgel Abbay originates from the Southern side of the watershed and flows in to the North direction and forms part of the Lake Tana basin (Fig 1). The total area of the watershed is estimated to be 3779.16 km^2.

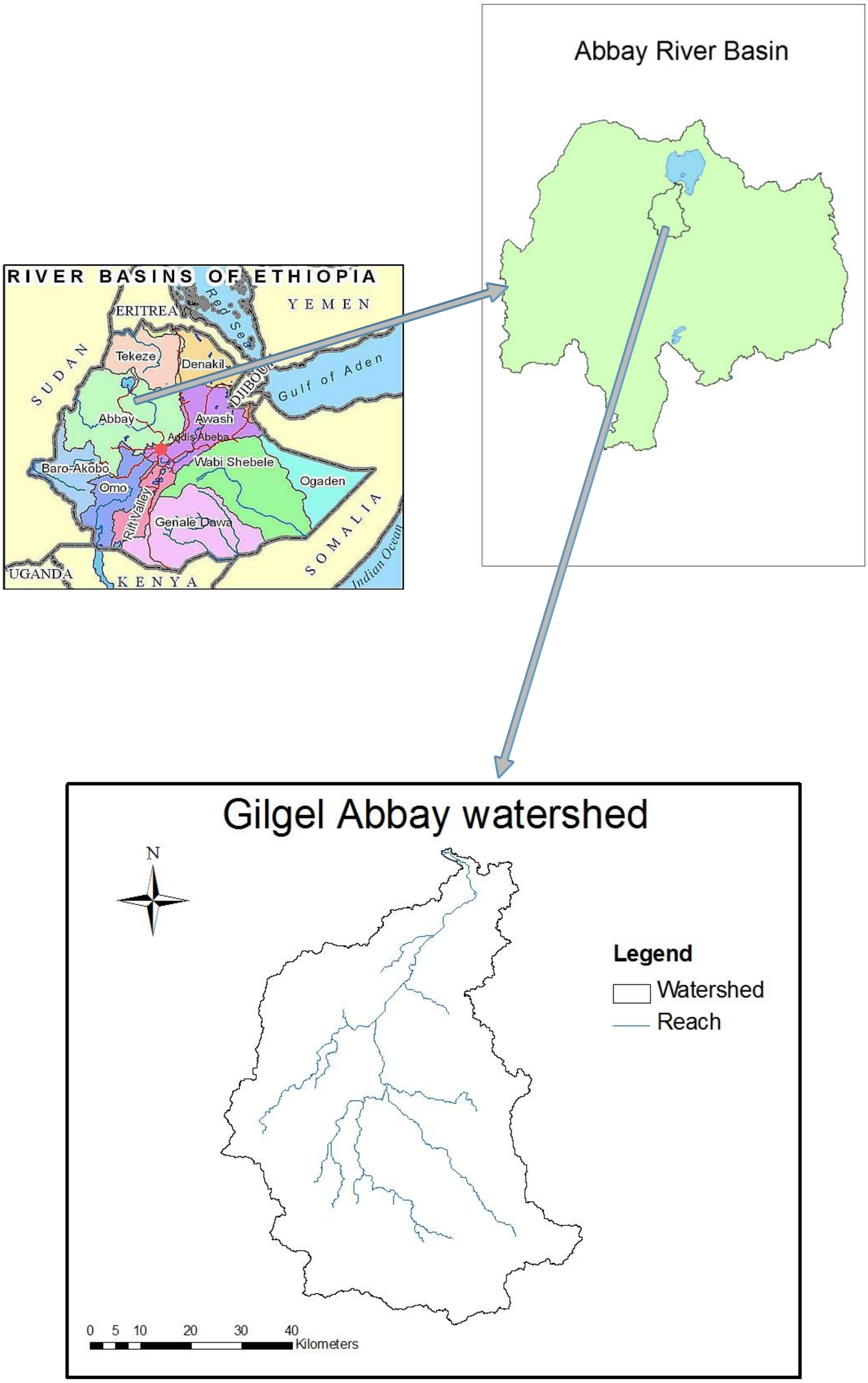


Figure 1. Major River Basins in Ethiopia and Location Map of the study area

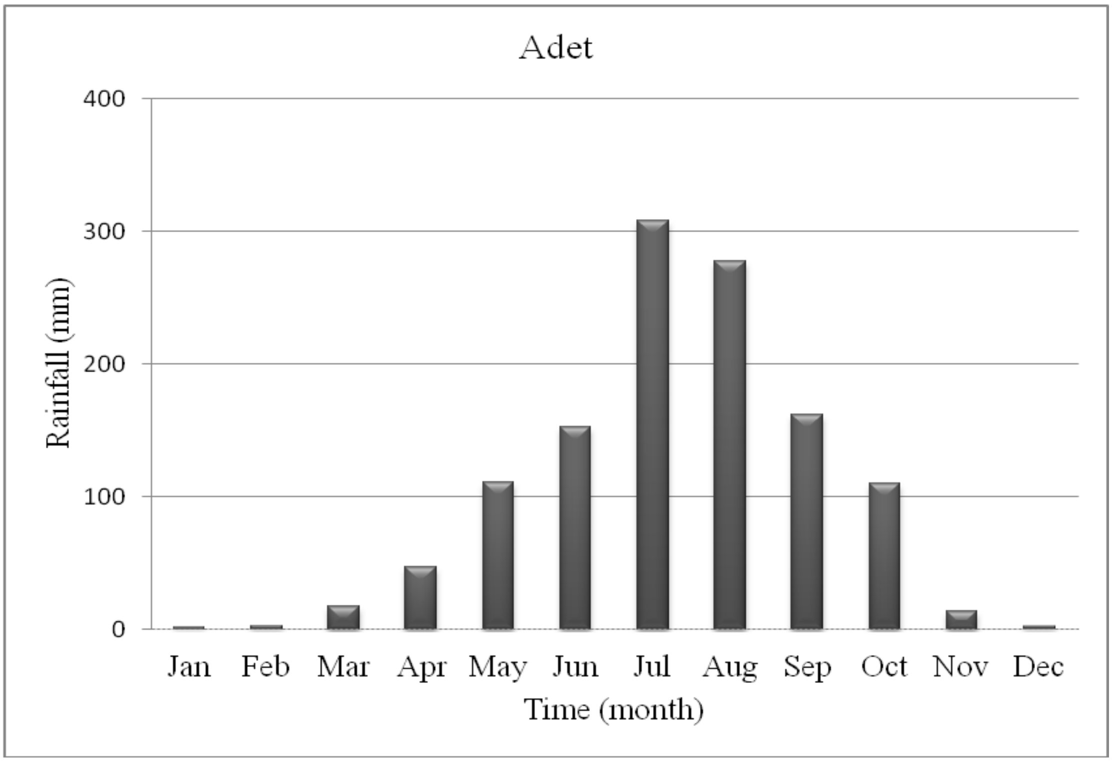
3.1.2. Climate

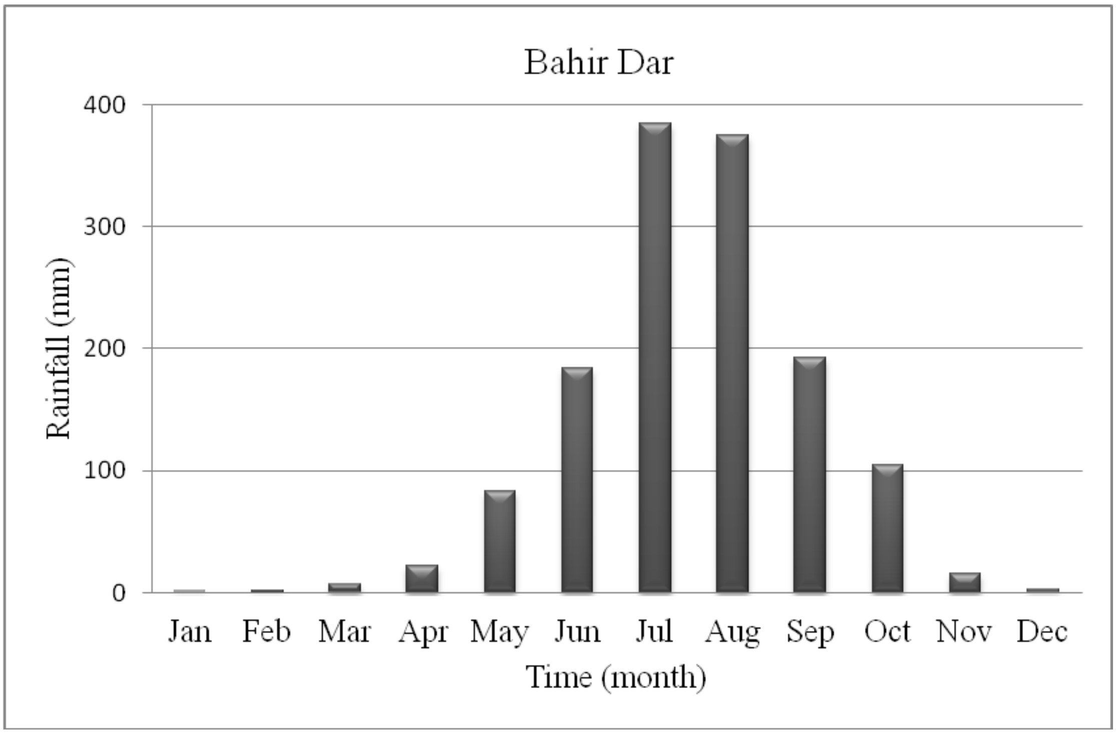
The climate of Ethiopia can be classified in different ways including the Traditional, Koppen's, Throthwaite's, Rainfall regimes, and Agro-climatic zone classification systems. The most common used classification systems are the traditional and the agro-ecological zones. According to the traditional classification system, this mainly relies on altitude and temperature; there are five climatic zones namely: Wurch (cold climate at more than 3000 Mts. altitude), Dega (temperate like climate-highlands with 2500-3000 Mts.altitude), Woina Dega (warm at 1500-2500 Mts. altitude), Kola (hot and arid type, less than 1500m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001).

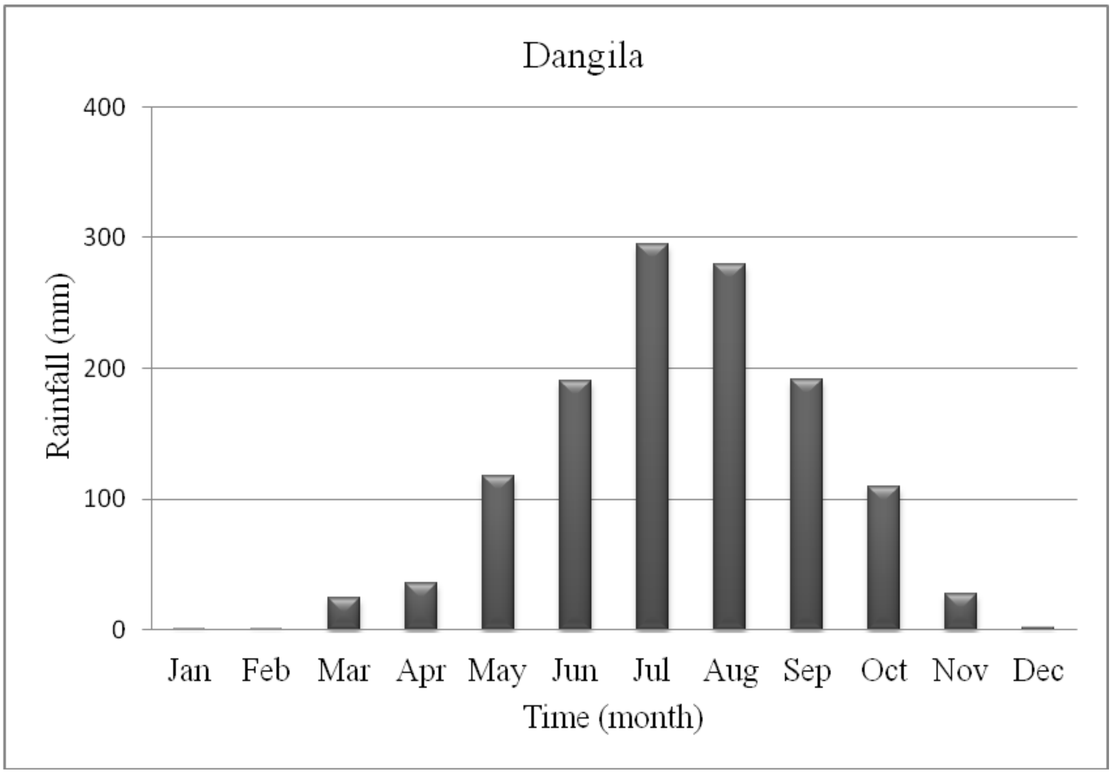
There is high spatial and temporal variation of rainfall in the study area. The main rainfall season which accounts around 70-90% of the annual rainfall occurs from June to September, while small rains also occur occurs during December to March.

The monthly rainfall distributions of the study area indicate that July and August are the wettest months of the year in all the selected stations. The mean monthly rainfall of the Adet, Bahir Dar, Dangila and Enjibara stations for the period of 1986-2001 is shown in Figure 2.

The mean annual rainfall (1986-2001) of the study area as shown in Figure 3 varies from around 1266 mm (Dangila) up to 2072 mm for Enjibara.




Bahir Dar
400
300
200
100
0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)


Dangila
400
300
200
100
0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)

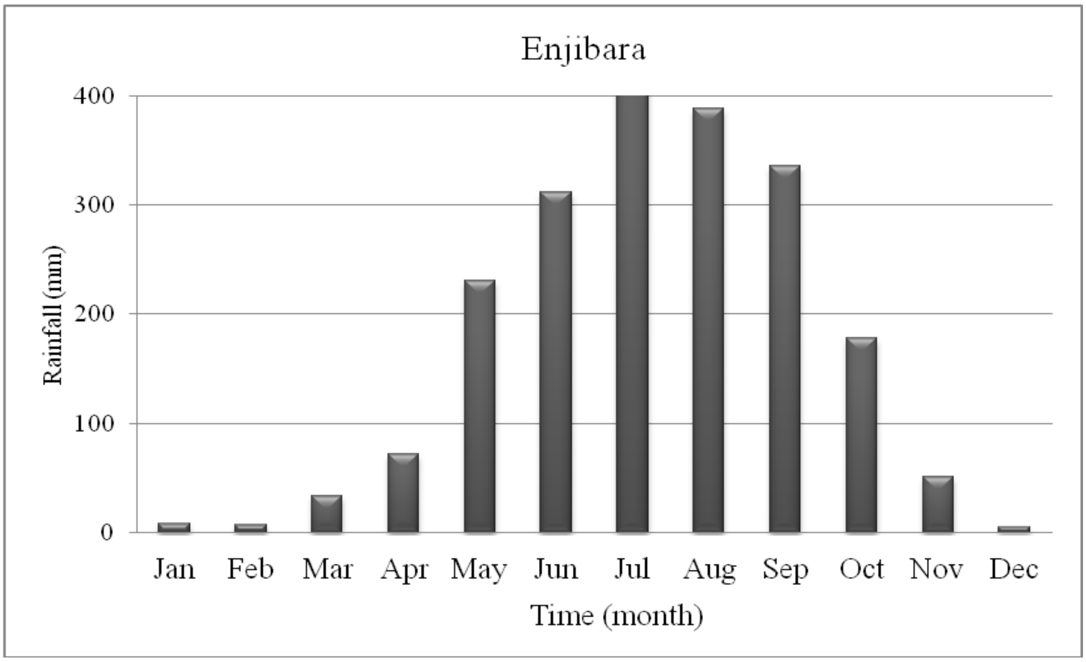


Figure 2. Mean monthly rainfall distribution of selected meteorological stations for the period of 1986-2001

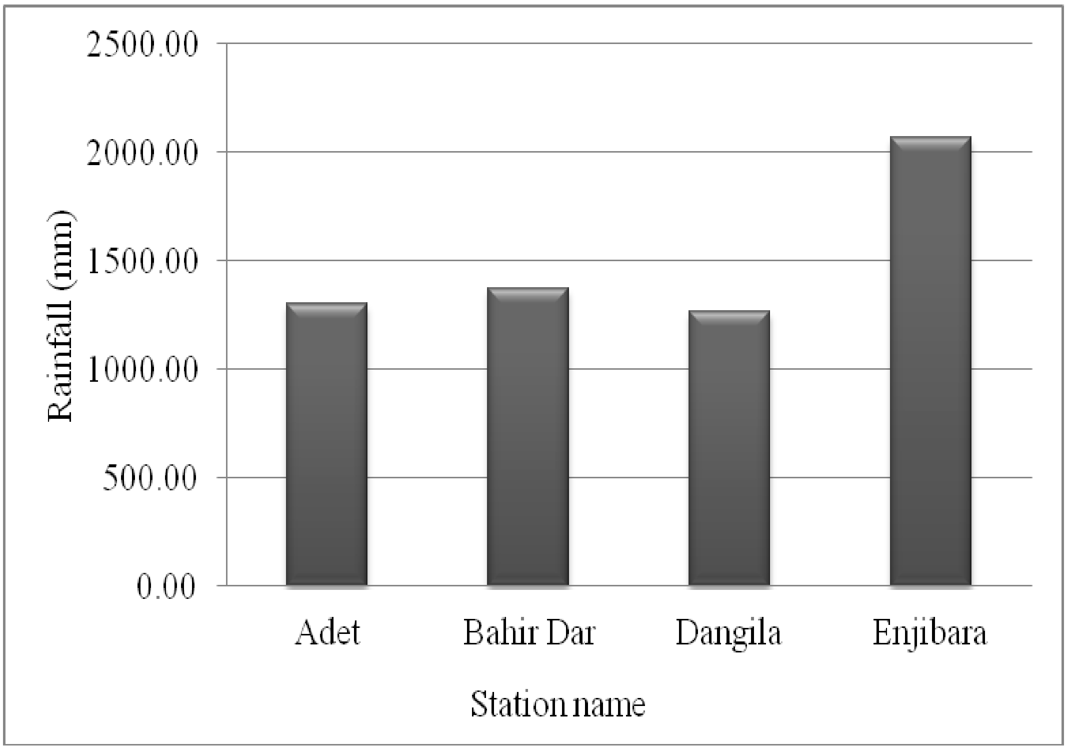


Figure 3. Mean annual rainfall from 1986-2001

3.1.3. Soil types, Geology and Land Cover

The regional geology of the Gilgel Abbay watershed is dominated by the Tertiary volcanic rock and Quaternary Basalts. In this watershed seven main soil types are found which include, Luvisols, Fluvsisols, Alisols, Nitisols, Vertisols, Leptosols and Regosols. Generally, the soils types of this watershed area are characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay texture types. The erodibility of these soils also varies from medium to very erodible characteristics.

Vertisols are deep to very deep, moderately well to poorly drained, very dark grey to dark yellowish brown in the topsoil, and clay textured throughout. The soils have large surface cracks in the dry season. Run-off formation from Vertisols is high and hence it is susceptible to erosion. The recent soils which are not developed are classified as Fluvisols and found in small extent in the watershed area. The shallow and very shallow soils are classified as Leptosols. Leptosols are found in relatively small areas in the watershed area. These are stony and rocky. The texture of Leptosols varies from sandy clay loam to clay and has excessive drainage characteristics.

Nitisols occupied about 2% of the watershed area. They are reddish brown to red clay soils. These soils are deep and have very good potential agriculture. The Nitisols of the area are intensely cultivated for annual crops.

Luvisols exist in bigger extent in the watershed area. These soils show textural differentiation with moderate to high clay content. These soils are almost intensively cultivated. The major red clay soils (Alisols) occur mainly on flat to rolling upland plain and flat to undulating land features. These are deep, well drained, permeable and medium textured soils. Regosols are found in very small extent in the watershed area. They are very deep and are imperfectly drained soils. The soils have very organic matter content and good inherent fertility status.

The land covers of the watershed are mainly cultivated land, grass land, water and marshy land, forest and shrub land.

3.1.4. Population

According to the 2007 Census, each successive Population and Housing Census showed that the total population size of the country, Ethiopia, increased. For instance, the results of the 2007 census shows that the population of the country increased by more than 20.8 million people from 1994 to 2007. Similarly, from 1984 to 1994, the population of the country increased by 13.2 million people (Table 2).

Table 2. Population Size of Ethiopia (in millions) 1984-2007

Census Year	Population (In Millions)
1984	39.9
1994	53.1
2007	73.9

Source: CSA (2008).

The total population living around the Lake Tana basin and the surrounding of the watershed is estimated about two million (Surur, 2010). According to CSA (central statistics authority), Gilgel Abbay is densely populated with an annual growth rate of 2.31 %. The economic activity of the population is depends on agriculture and cattle breeding activities.

3.1.5. Agriculture

The agriculture production system in the area is a subsistence type of crop and livestock production system. In this production system, the crop production is entirely dependent on livestock where the contribution of livestock include, drat power, transportation, manure, and income generating purposes. Due to high population pressure, the land is moderately to intensively cultivate.

Generally, the watershed is well known by rain fed cereal crops production. Major types of crops grown in the area includes barely, wheat, maize, teff, sorghum, finger millet and small extent pulses and oil crops. In this watershed, some farmers also practices traditional irrigation development activities from perennial rivers and springs. Moreover, recently Koga large irrigation development project with a command area of 7000 ha is under operation in the watershed. In this command area, farmers produce vegetables such as onion, potatoes, cabbage, switchyard, green pepper, etc. In addition, farmers grow field crops like maize and wheat by irrigation.

Livestock production is an important and integral component of the agricultural sector in the Gilgel Abbay watershed. Communities keep livestock for multi-purpose i.e. for draft power, transportation, for production of milk and meat, and earning income.

3.2. Hydrological Model Selection Criteria

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always project dependant, since every project has its own specific requirements and needs. Further, some criteria are also user-depended (and therefore subjective). Among the various project-dependant selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 2003):

- Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as long-term sequence of flow?),

- Hydrologic processes that need to be modelled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?),

- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),

- Price (Does the investment appear to be worthwhile for the objectives of the project?).

Reasons for selecting SWAT model

The reasons behind for selecting SWAT model for this study are;

- The model was applied for land use and land cover change impact assessment in different parts of the world.
- The model simulates the major hydrological process in the watersheds
- It is less demanding on input data, and
- It is readily and freely available.

A major limitation to large area hydrologic modeling of SWAT is the spatial detail required to correctly simulate environmental processes. For example, it is difficult to capture the spatial variability associated with precipitation within a watershed. Another limitation is data files can be difficult to manipulate and can contain several missing records. The model simulations can only be as accurate as the input data. The third limitation is that, the SWAT model does not simulate detailed event-based flood and sediment routing.

3.2.1. Description of SWAT Model

Soil and Water Assessment Tool (SWAT) was applied in the Gilgel Abbay watershed to assess the impacts of land use and land cover changes on hydrological components. The criterion used to select this model is based on benefits it provides to meet the objectives of the study area. The SWAT model is embodied in ArcGIS that can integrate various readily available geospatial data to accurately represent the characteristics of the watershed.

The SWAT watershed model is one of the most recent models developed by the USDA-ARS to predict the impacts of land management practices on water, sediment and agricultural chemicals yields in watersheds with varying soils, land use and management practices over long periods of time (Neitsch, *et al*, 2005).

The model is a physical based, semi-distributed, continuous time, and operating on daily time step (Neitsch, *et al*, 2005). As a physical based model, SWAT uses Hydrological Response Units (HRUs) to describe spatial heterogeneity in terms of land use, soil types and slope with in a watershed.

In order to simulate hydrological processes in a watershed, SWAT divides the watershed in to sub watersheds based upon drainage areas of the tributaries. The sub watersheds are further divided in to smaller spatial modelling units known as HRUs, depending on land use and land cover, soil and slope characteristics.

One of the main advantages of SWAT is that it can be used to model watersheds with less monitoring data. For simulation, SWAT needs digital elevation model, land use and land cover map, soil data and climate data of the study area. These data are used as an input for the analysis of hydrological simulation of surface runoff and groundwater recharge.

SWAT splits hydrological simulations of a watershed in to two major phases: the land phase and the routing phase. The land phase of the hydrological cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub watershed. While the routing phase considers the movement of water, sediment and agricultural chemicals through the channel network to the watershed outlet.

The land phase of the hydrologic cycle is modelled in SWAT based on the water balance equation (Neitsch, *et al*, 2005):

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

Where, SW_t is the final soil water content (mm)

SW_o 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).

The model has eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch, *et al*, 2005). However, brief description of some of the SWAT computation procedures which are considered in this study are presented under the following subsections. For complete model description, one may refer to SWAT Theoretical Documentation (Neitsch, *et al*, 2005).

3.2.1.1. Surface Runoff

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration (Solomon, 2005). 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 needs sub-daily time step rainfall which made it difficult to be used for this study due to unavailability of sub-daily rainfall data. Therefore, the SCS curve number method was adopted for this study.

The general equation for the SCS curve number method is expressed by equation 2:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (2)$$

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 varies spatially due to changes with land surface features such as soils, land use, slope and management practices. This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as:

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \quad (3)$$

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 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (4)$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified in to four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively.

3.2.1.2. Potential Evapotranspiration

Potential Evapotranspiration is a collective term that includes evaporation from the plant (transpiration) and evaporation from the water bodies and soil. Evaporation is the primary mechanism by which water is removed from a watershed. An accurate estimation of evapotranspiration is critical in the assessment of water resources and the impact of land use change on these resources.

There are many methods that are developed to estimate potential evapotranspiration (PET). SWAT provides three options for PET calculation: Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and Hargreaves (Hargreaves *et al.,* 1985) methods. The methods have various data needs of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind sped; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only.

For this study, the Penman-Monteith method was selected as the method is widely used and all climatic variables required by the model are available for the three stations in and around the study watershed area.

3.2.1.3. Ground Water Flow

To simulate the ground water, SWAT partitions 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 calculated with equation 5.

$$aq_{sh,i} = aq_{sh,i-1} + W_{rchrg} - Q_{gw} - W_{revap} - W_{deep} - W_{pump,sh} \quad (5)$$

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).

3.2.1.4. Flow Routing Phase

The second component of the simulation of the hydrology of a watershed is the routing phase of the hydrologic cycle. It consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network.

Two options are available to route the flow in the channel network: the variable storage and Muskingum methods. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In the latter method, when a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave recedes or retreat, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length.

The variable storage method was used for this study. The method was developed by (Williams, 1969). The equation of the variable storage routing is given by:

$$\Delta V_{stored} = V_{in} - V_{out} \qquad (6)$$

Where, ΔV_{stored} is the change in volume of storage during the time step (m^3 water)
V_{in} is the volume of inflow during the time step (m3 water), and
V_{out} is the volume of outflow during the time step (m^3 water).

3.3. Methodology

The following framework illustrates the general workflow of the study can be described by Figure 4.

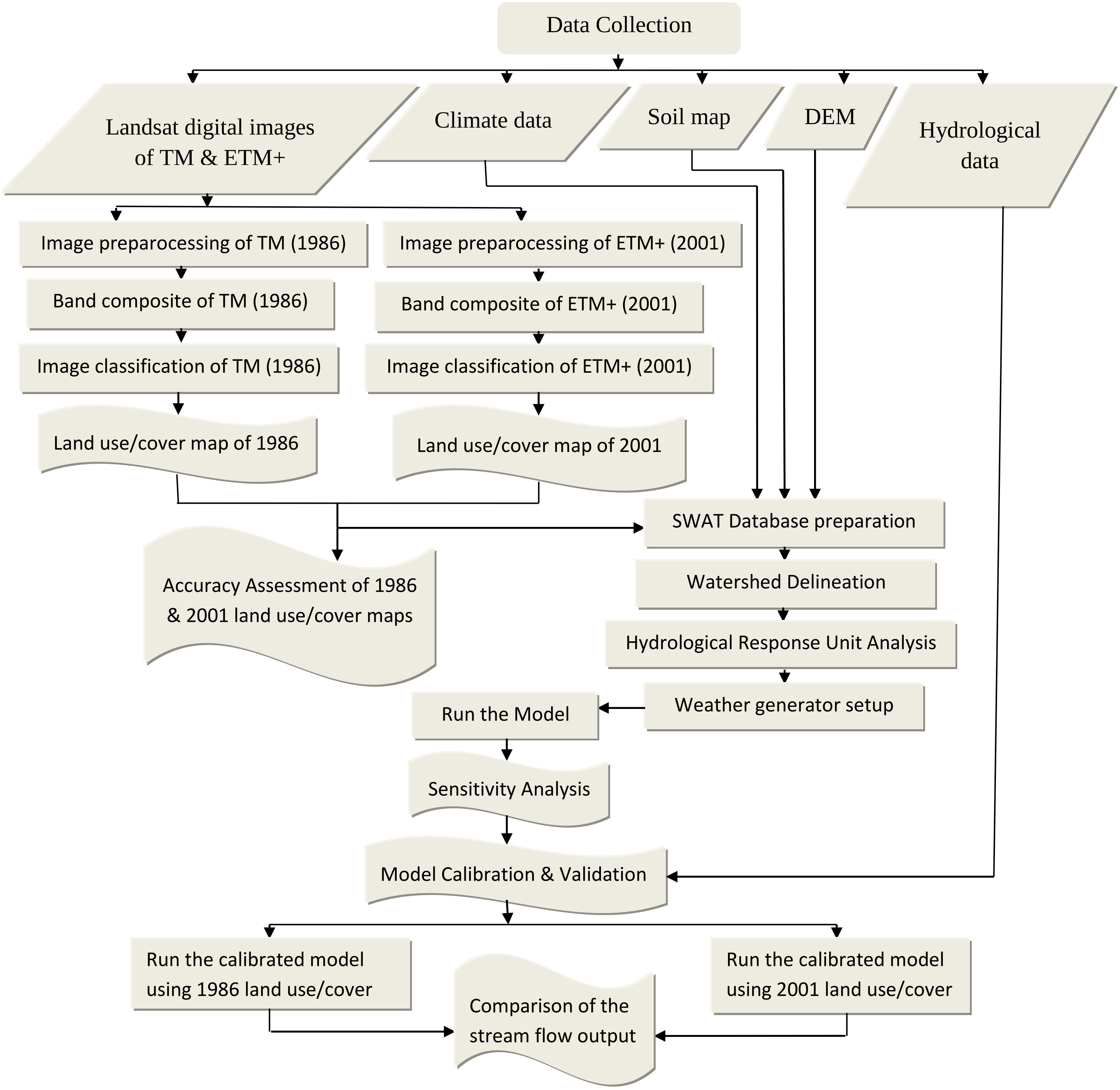


Figure 4. Frame work of the study

3.3.1. Data Acquisition

For this study, various data are required that includes topographic data (DEM), Land use and land cover data, soil data, daily data of climatic variables (daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation). The DEM and land cover satellite data were obtained from the NASA website. Soil and hydrological data were collected from the Ministry of Energy and Water Resources of Ethiopia. The climatic data were obtained from the National Meteorological Agency of Ethiopia.

3.3.2. Image Processing

This study was done using Landsat imageries of six bands to identify changes in land use and land cover distribution in the Gilgel Abbay watershed over 16 years period from 1986 to 2001. Landsat TM and ETM+ were selected for the period of 1986 and 2001 respectively. To avoid a seasonal variation in vegetation pattern and distribution throughout a year, the selection of dates of the acquired data were made as much as possible in the same annual season of the acquired years. The images used in this study area were orthorectified to a Universal Transverse Mercator projection using datum WGS (World Geodetic System) 84 zone 37N. In order to view and discriminate the surface features clearly, all the input satellite images were composed using the RGB color composition (Figure 5). The images provide complete coverage of Gilgel Abbay watershed.

The image data files were downloaded in zipped files from the United State Geological Survey (USGS) website and extracted to Tiff format files. The acquisition dates, sensor, path/row, resolution and the producer's of the satellite images used in this study are summarized in the Table below.

Table 3. The acquisition dates, sensor, path/row, resolution and the producer's of the images

Path/Row	**Acquisition date**	**Sensor**	**Resolution (m)**	**Producer**
170/052	Jan 01, 1986	TM	30	USGS
170/052	Feb 02, 2001	ETM+	30	USGS

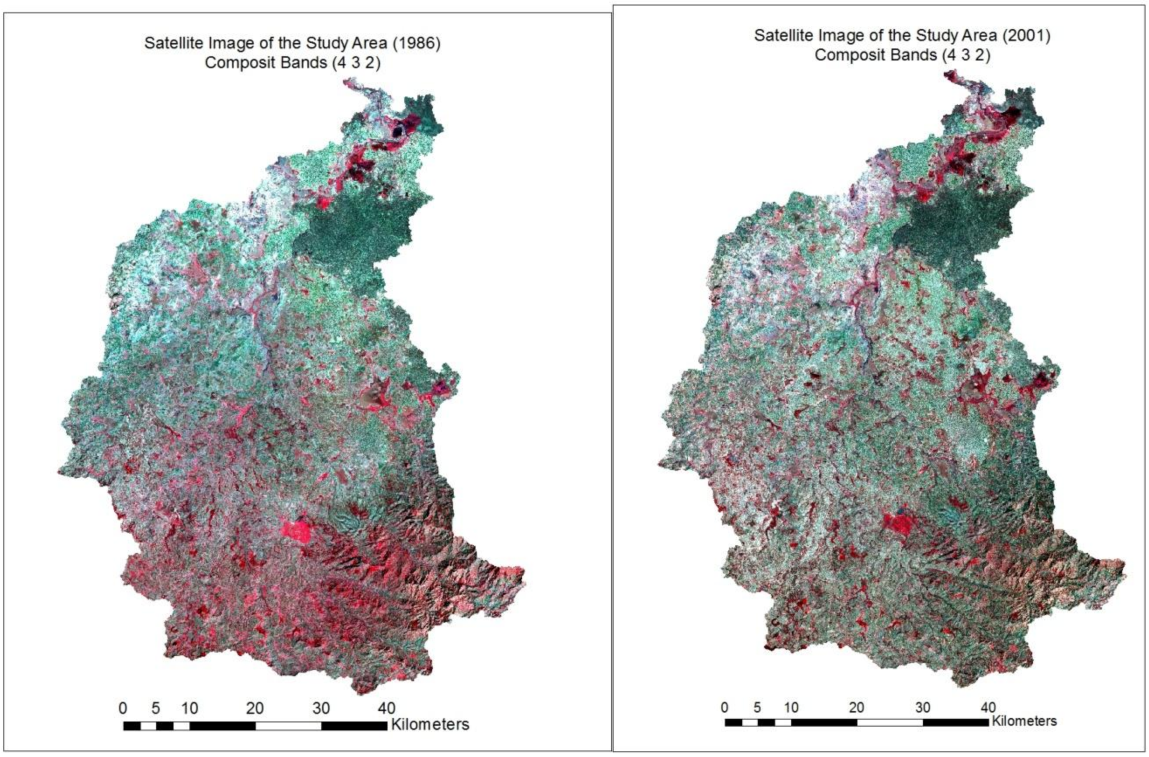


Figure 5. The Standard "False Color" composite satellite image of the study area of the year 1986 and 2001

3.3.3. Land Use and Land Cover Mapping

3.3.3.1. Land Use and Land Cover Classes

The Land use and land cover change studies usually need the development and the definition of homogeneous land use and land cover units before the analysis is started. These have to be differentiated using the available data source such as remote sensing, any other relevant information and the previous local knowledge. Hence, based on the priori knowledge of the study area and additional information from previous research in the study area (Taddele *et al*, 2009; Abebe *et al*, 2005), five different types of land use and land cover have been identified for the Gilgel Abbay catchment. The descriptions of these land use and land covers are given as follows:

Cultivated land: Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlement that are closely associated with the cultivated fields. Due to the difficulty encountered to identifying the dispersed rural settlements this kind of land cover was combined with the cultivated land during classification.

Forest land: Land covered with dense trees which includes ever green forest land, mixed forest and plantation forests.

Shrub land: Areas with shrubs, bushes and small trees, with little wood, mixed with some grasses.

Grass land: Areas covered with grass used for grazing, as well as bare lands that have little grass or no grass cover. It also includes other small seized plant species.

Water and marshy land: Areas which are water logged and swampy throughout the year, the rivers and its main tributaries.

3.3.3.2. Image Classification

Image classification is the process of assigning of pixels of continuous raster image to the predefined land cover classes. It is always a difficult and time consuming task. Different issues to keep in mind to avoid overlapping features and finish with effective classification leis parallel with the ground truth. The result of the classification is mostly affected by various factors such as classification methods, algorithms, collecting of training sites etc.

In remote sensing, there are various image classification methods. Their appropriateness depends on the purpose of land cover maps produced for and the analyst's knowledge of the algorithms is using. However, in most cases the researchers categorized them in to three major categories: Supervised, unsupervised and hybrid. For this study, the supervised classification type was applied. It is the most common type of classification technique in which all pixels with similar spectral value are automatically categorized in to land cover classes or themes. Supervised classification which relies on the prior knowledge of pattern recognition of the study area was used. It requires the manual identification of point of interest areas as reference or Ground Truth within the images, to determine the spectral signature of identified features.

For this study, the land cover map was produced based on the pixel based supervised classification throught the steps such as: First, selecting of the training sites which are typically representative for the land cover classes. The training sites were collected based on the analyst's personal experience and knowledge of the physiographical knowledge of the area. In addition, image enhancement and composition were applied for better discriminating the land cover classes. Using these approaches around 130 training sites were collected as from each image (1986 and 2001). Second, perform the classification using the Maximum Likelihood Classifier and finally the accuracy assessment of the classified images were assessed by using of the original mosaic and the Google Earth images as references, randomly samples of 81 and 83 points were selected for the 1986 and 2001 maps, respectively and analysis of the confusion matrix was done.

3.3.3.3. Accuracy Assessment

Accuracy assessment is an important step in the image classification process. The objective of this process is to quantitatively determine how effectively pixels were grouped in to the correct features classes in the area under investigation. It is a process used to estimate the accuracy of image classification by comparing the classified map with a reference map (Caetano *et al,* 2005). The most widely used classification accuracy is in the form of error matrix which can be used to derive a series of descriptive and analytical statistics (Manandhar *et al*, 2009). The columns of the matrix depict the number of pixels per class for the reference data, and the rows show the number of pixels per class for the classified image. From this error matrix, a number of accuracy measures such as overall accuracy, user's and producer's accuracy determined. The overall accuracy is used to indicate the accuracy of the whole classification (i.e. number of correctly classified pixels divided by the total number of pixels in the error matrix), whereas the other two measures indicate the accuracy of individual classes. User's accuracy is regarded as the probability that a pixel classified on the map actually represents that class on the ground or reference data, whereas product's accuracy represents the probability that a pixel on reference data has been correctly classified.

The accuracy assessment of the classified map is the comparison of the classified image and the sampling points from the orthophotos, Google Earth Imageries and existing land cover maps (Yesserie, 2009). In this study, the assessment was carried out using the original image for 1986 maps and the Google Earth Image for 2001 together with previous knowledge of the area was used as reference data to generate testing data set. A total of 81 and 83 testing sample points were selected randomly for the year 1986 and 2001 respectively.

3.4. Model Input Data Collection and Analysis

SWAT is highly data intensive model that requires specific information about the watershed such as topography, land use and land cover, soil properties, weather data, and other land management practices. These data were collected from different sources and databases. The data are analyzed as presented in the next sub-sections.

3.4.1. Digital Elevation Model

Digital Elevation Model (DEM) data is required to calculate the flow accumulation, stream networks, and watershed delineation using SWAT watershed delineator tools. A 30 m by 30m resolution ASTER Global Digital Elevation Model was obtained from the NASA website. This data was projected to Transverse Mercator (UTM) on spheroid of WGS84 and it was in raster format to fit in to the model requirement (Figure 6).

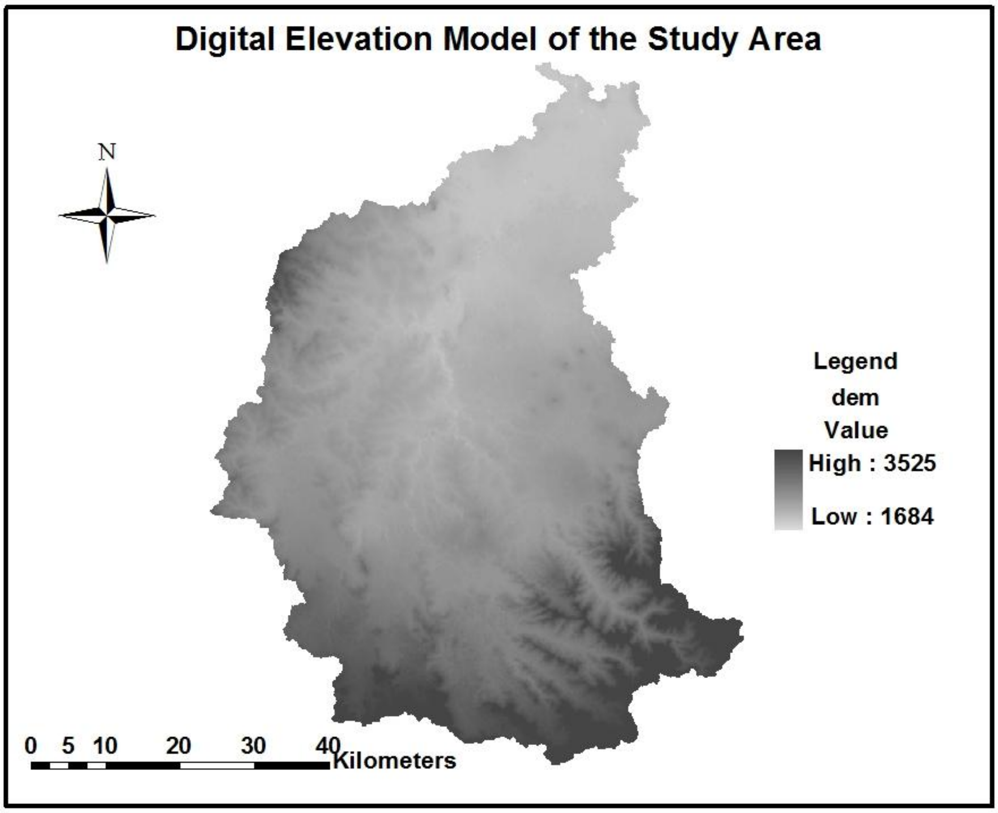


Figure 6. Digital Elevation Model of Gilgel Abbay watershed

3.4.2. Weather Data

Weather data are among the main demanding input data for the SWAT simulation. The weather input data required for SWAT simulation includes daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. These were obtained from the Ethiopian National Meteorological Agency. The weather data used were represented from four stations in and around Gilgel – Abbay watershed, such as Adet, Bahirdar, Dangla and Enjibara stations as shown in figure 7. The first three stations are the first classes that have records on all climatic variables, whereas the last one is the third class stations (Table 4). The climatic data used for this study covers 16 years from January 1986 to December 2001.

Based on the class of the stations, the number of weather variables collected varies from stations to stations that are grouped into two. The first group contains only rainfall data. The second group contains variables like maximum – minimum temperature, humidity, sunshine hours, and wind speed in addition to rainfall.

However, missing values were identified in some of the climatic variables. These values were assigned with no data code (-99) which then filled by the weather generator embodied in the SWAT model from monthly weather generator parameters values. The monthly generator parameters values were estimated from the three weather stations (Adet, Bahir Dar and Dangla).

Finally, the weather data were prepared in DBF format with lookup tables as required by the model.

Table 4. Meteorological station names, locations and variables

No	Station name	Latitude (deg)	Longitude(deg)	Rain fall	Max Temp	Min Tem	Relative humidity	Wind speed	Sunshine hours
1	Adet	11.27	37.49	√	√	√	√	√	√
2	BahirDar	11.61	37.39	√	√	√	√	√	√
3	Dangila	11.26	36.84	√	√	√	√	√	√
4	Enjibara	10.98	36.92	√					

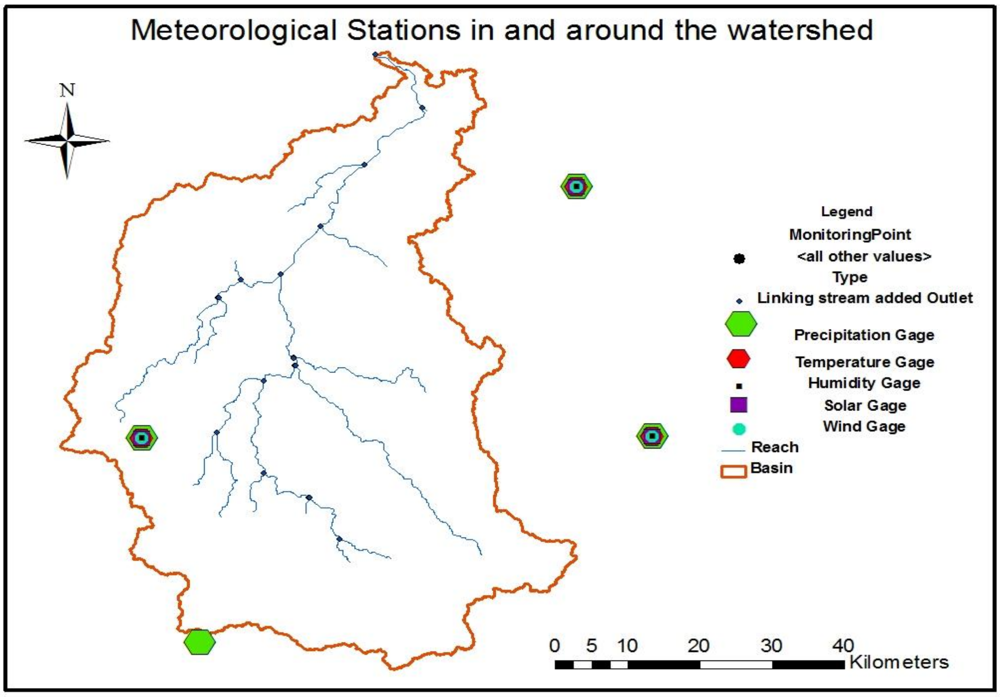


Figure 7. Location of meteorological stations in and around the watershed

3.4.3. Soil Data

Soil data is one of the major input data for the SWAT model with inclusive and chemical properties. The soil map of the study area was also obtained from Ministry of Energy and Water Resources of Ethiopia. According to FAO/UNESCO – ISRIC classification, nine major soil groups were identified in the watershed of Gilgel – Abbay (Figure 8).

SWAT model requires soil physical and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained from Minister of Ethiopian Energy and Water Resources as presented.

To integrate the soil map with SWAT model, a user soil database which contains textural and chemical properties of soils was prepared for each soil layers and added to the SWAT user soil databases using the data management append tool in ArcGIS. The symbol and areal coverage of the soil types are presented in Table 5.

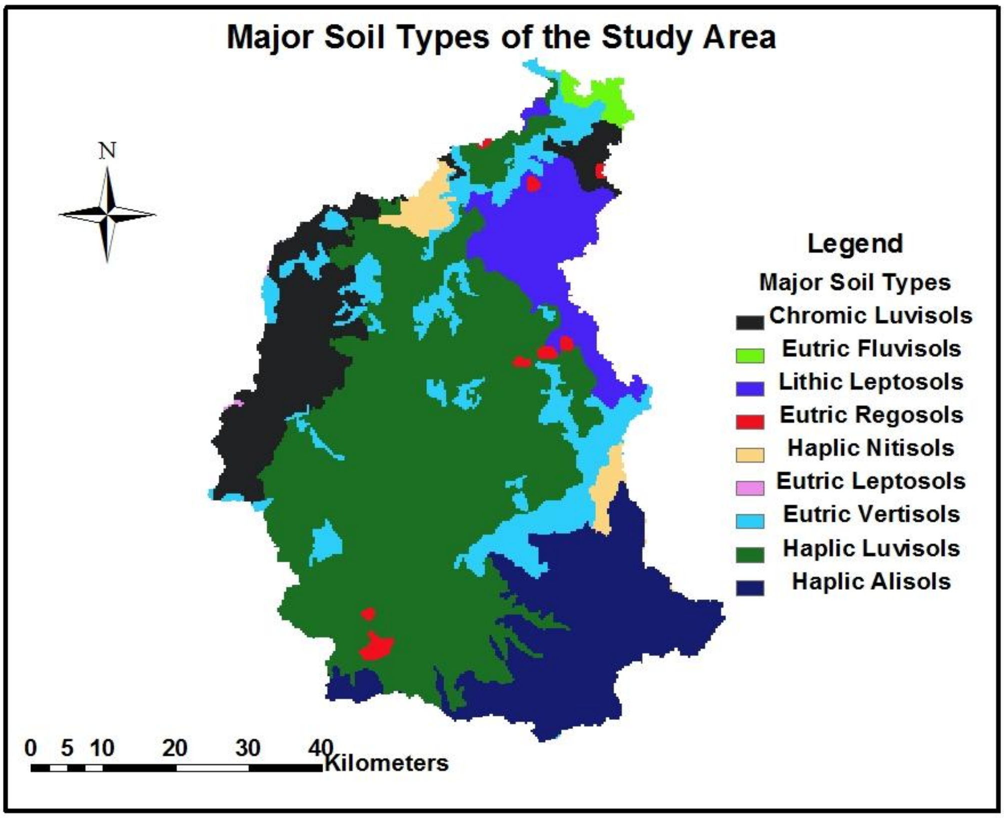


Figure 8. Map of the soil types of Gilgel Abbay watershed

Table 5. Soil types of Gilgel Abbay watershed with their symbols and areal coverage

Soil type	Symbol	Area	
		ha	%
Chromic Luvisols	LVx	43611.56	11.54
Eutric Fluvisols	FLe	3628.00	0.96
Lithic Leptosols	LPq	29968.78	7.93
Eutric Regosols	RGe	3136.71	0.83
Haplic Nitisols	NTh	6349.00	1.68
Eutric Leptosols	LPe	188.96	0.05
Eutric Vertisols	VRe	45916.85	12.15
Haplic Luvisols	LVh	183176.12	48.47
Haplic Alisols	ALh	61940.51	16.39

3.4.4. Land Use and Land Cover

Land use is one of the highly influencing the hydrological properties of the watersheds. It is one of the main input data of the SWAT model to describe the Hydrological Response Units (HRUs) of the watersheds.

The SWAT model has predefined four letter codes for each land use category (Table 6). These codes were used to link or associate the land use map of the study area to SWAT land use databases. Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model.

Table 6. Land use/cover classification of Gilgel Abbay watershed as per SWAT model

Land use / Land cover	Land use according to SWAT database	SWAT code
Cultivated land	Agricultural land close to grown	AGRC
Forest	Forest mixed	FRST
Shrub land	Forest deciduous	FRSD
Grass land	Pasture land	PAST
Water & marshy land	Water	WATR

3.4.5. Hydrological Data

The stream flow data of the Gilgel Abbay watershed is needed for the calibration and validation of the model. The daily stream flow data (1986-2001) is quite sufficient and were collected from the Minister of Energy and Water Resources of Ethiopia for the Gilgel Abbay watershed.

3.5. Model Setup

3.5.1. Watershed Delineation

The watershed and sub watershed delineation was performed using 30 m resolution DEM data using Arc SWAT model watershed delineation function. First, the SWAT project set up was created. 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 stream definition and the size of sub basins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of the streams. Using a threshold value suggested by the Arc SWAT interface (8312.5 hectares), the Gilgel Abbay watershed was delineated in to 27 sub watersheds having an estimated total area of 3779.1649km^2 (Figure 9). But the total area of the watershed as obtained from the Minister of Energy and Waters Resources (MoEWR) was estimated to be 3865.5 km^2. There is a slight deviation between the delineated and that obtained from the MoEWR database. The difference in the total area between the delineated and the database may be due to the difference in the DEM resolution or the watershed delineator model used.

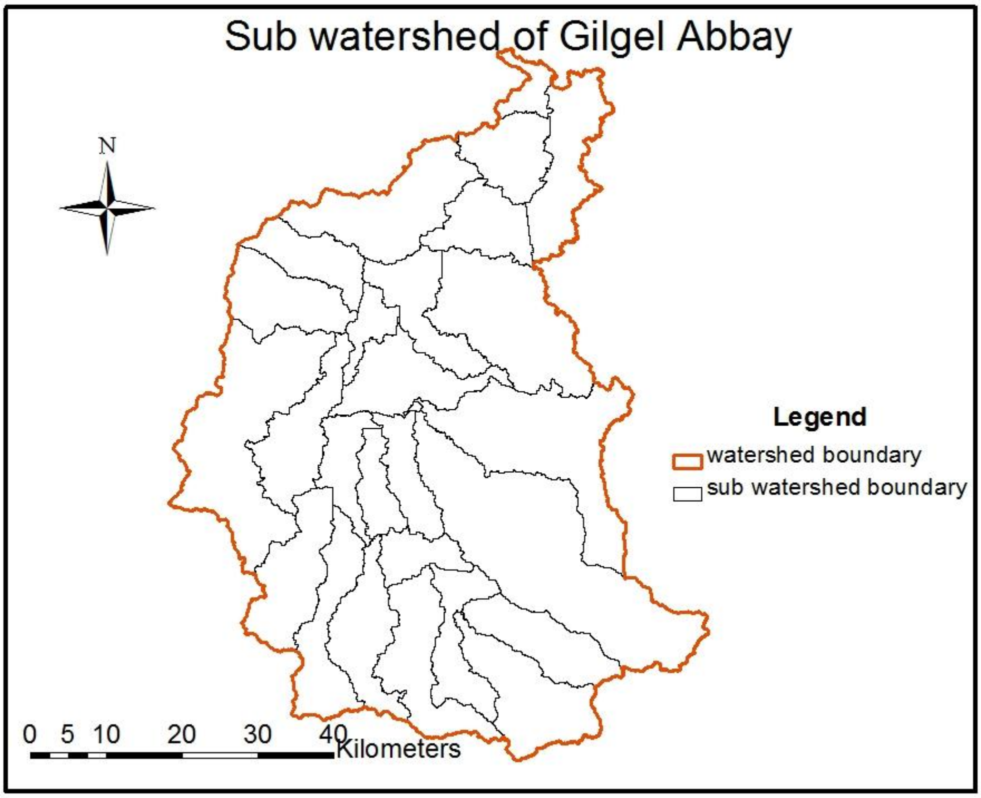


Figure 9. Sub watersheds map of the Gilgel Abbay watershed

During the watershed delineation process, the topographic parameters (elevation, slope) of the watershed and its sub watershed were also generated from the DEM data. Accordingly the elevation of the watershed ranges from 1684 to 3525 above mean sea level, the highest elevation is at the Adam mountain and the lowest at the watershed outlet, Lake Tana. Slope classification was carried out based on the height range of the DEM used during watershed delineation. The slope values of the watershed were reclassified in percent. It reclassified in to five classes (Table 7).

Table 7. The slope classes of the Gilgel Abbay watershed

Classes	**Slope range (%)**	**Area**	
		ha	**%**
Class 1	0-2	20747.60	5.49
Class 2	2-8	193909.00	51.31
Class 3	8-15	96708.80	25.59
Class 4	15-30	48108.80	12.73
Class 5	> 30	18442.3	4.88

3.5.2. Hydrologic Response Units Analysis

The sub watersheds were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. In general the threshold level used to eliminate minor land use and land covers in sub basin, minor soil with in a land use and land cover area and minor slope classes with in a soil on specific land use and land cover area. Following minor elimination, the area of remaining land use and land covers, soils and slope classes are reapportioned so that 100 % of their respective areas are modelled by SWAT. Land use, soil and slope characterization for the Gilgel Abbay watershed was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. These tools allowed loading land use and soil maps which are in raster format in to the current project, evaluates slope characteristics and determining the land use/soil/slope class combinations in the delineated sub watersheds.

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 based 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. However, Setegn *et al*, 2008, suggested that HRU definition with multiple options that account for 10% land use, 20% soil and 10% slope threshold combination gives a better estimation of runoff and sediment components. Therefore, for this study, HRU definition with multiple options that accounts for 10% land use, 20% soil and 10% slope threshold combination was used. These threshold values indicate that land uses which form at least 10% of the sub watershed area and soils which form at least 20% of the area within each of the selected land uses will be considered in HRU.

Hence, the Gilgel Abbay watershed was divided in to 281 HRUs, each has a unique land use and soil combinations. The number of the HRUs varies with in the sub watersheds.

3.5.3. Weather Generator

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed one (Danuso, 2002). The Model requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. This study used measured data for all climatic variables. However, the weather data obtained for the stations in and around Gilgel-Abbay watershed had missed records in some of the variables. Therefore, these missed values were filled with the weather generator utility in the Arc SWAT Model from the values of weather generator parameters. Weather data of three stations (Adet, BahirDar and Dangla) with continuous records were used as an input to determine the values of the weather generator parameters. Hence, for weather generator data definition, the weather generator data file wgnstations.dbf was selected first. Subsequently, rain fall data, temperature data, relative humidity data, solar radiation data and wind speed data were selected and added to the model.

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. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently.

To generate the data, weather parameters were developed by using the weather parameter calculator WXPARM and dew point temperature calculator DEW02, which were downloaded from the SWAT website. The WXPARM program calculates the monthly daily average and standard deviation as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month by reading of the daily values of the variables from the three stations (Adet, Bahir Dar and Dangla). Average Daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity. Moreover, daily solar radiation was calculated from the daily available sunshine hour’s data.

3.5.4. Sensitivity Analysis

Calibration is necessary to optimize the values of the model parameters which help to reduce the uncertainty in the model outputs. However, such type of model with a multiple parameters, the difficult task is to determine which parameters are to be calibrated. In this case, sensitivity analysis is important to identify and rank parameters that have significant impact on the specific model outputs of interest (Van Griensven *et al*., 2006). 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 9 years from 1986 to 1994 of the watershed gauging station were used to compute the sensitivity of the stream flow parameters.

In the sensitivity process, by entering the Arc SWAT interface sensitivity analysis window, first the SWAT simulation was specified for performing the sensitivity analysis and the location of the sub basin where observed data was compared against simulated output. Then, selected parameters were entered for the sensitivity analysis with the default lower and upper parameter bounds. Hence, 26 flow parameters were included for the analysis with default values as recommended by (Van Griensven et al., 2006). Up on the completion of sensitivity analysis, the mean relative sensitivity (MRS) values of the parameters were used to rank the parameters, and their category of classification. The category of sensitivity was defined based on the (Lenhart *et al*., 2002) classification presented below (Table 8).

Table 8. SWAT parameters Sensitivity class

Class	**MRS**	**Sensitivity category**
I	0.00≤ MRS <0.05	Small to negligible
II	0.05≤ MRS <0.20	Medium
III	0.2≤ MRS <1	High
IV	MRS >1	Very high

Based on the above classification, parameter producing MRS values of medium, high and very high were selected for calibration process.

3.5.5. Model Calibration and Validation

Following the sensitivity analysis result, model calibration was done to obtain optimum values for sensitive parameters. SWAT provides three options for calibration: auto-calibration, manual calibration and combination of these two methods. For this study, first manual calibration was done to fine tone some of the parameters. First, some model parameters were adjusted by manual calibration. In this procedure, parameters values were adjusted by changing one or two parameters at a time within the allowable ranges either by replacement the initial value or addition or by multiplication of the initial value as per designed in the interface.

Then, auto calibration procedure was used. The calibration was done on monthly time steps using the average measured stream flow data of the Gilgel Abbay watershed covering from January 1987 to December 1994. Auto calibration was performed for sensitivity flow parameters that produced medium, high and very high mean sensitivity index values. Arc SWAT includes a multi objective, automated calibration procedure that was developed by (Van Griensven, 2006). The calibration procedure is based on a Shuffled Complex Evolution Algorithm (SCE-UA) and a single objective function. The auto calibration tool in SWAT can be run in either the Parasol or the Parasol with uncertainty analysis mode. For this study, the Parameter Solution (ParaSol) option was selected (Van Griensven *et al.,* 2006). This method was chosen for its applicability to both simple and complex hydrological models. In this procedure, by entering the Arc SWAT interface Auto-Calibration window, first the SWAT simulation was specified for performing the auto-calibration and the location of the sub basin where observed data could be compared against simulated output. Then, the desired parameters for optimization, observed data file, and methods of calibration were selected. Hence, 10 flow parameters were considered in the calibration process. After the auto calibration runs completed, the model was run using the best parameter output values and the simulations were compared with observed stream flow data using Nash and Sutcliffe coefficient of efficiency (ENS) and coefficient of determination (R^2).

Validation was also done to compare the model outputs with an independent data set without making further adjustment of the parameter values. Model validation is comparison of the model outputs with an independent data set without making further adjustment which may adjust during calibration process. The measured data of average monthly stream flow data of 7 years from January 1995 to December 2001 were used for the model validation process. In this process, the two model performance values were also checked here to make sure that the simulated values are still within the accurate limits.

3.6. Model Performance Evaluation

To evaluate the model simulation outputs in relative to the observed data, model performance evaluation is necessary. There are various methods to evaluate the model performance during the calibration and validation periods. For this study, two methods were used: coefficient of determination (R^2) and Nash and Sutcliffe simulation efficiency (ENS).

The determination coefficient (R^2) describes the proportion the variance in measured data by the model. It is the magnitude linear relationship between the observed and the simulated values. R^2 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 the following equation:

$$R^2 = \frac{\Sigma\,[Xi - Xav]\,[Yi - Yav]}{\sqrt{\Sigma[Xi - Xav]^2}\ \sqrt{\Sigma[Yi - Yav]^2}} \quad (7)$$

Where, Xi – measured value (m^3/s)
Xav – average measured value (m^3/s)
Yi – simulated value (m^3/s) and
Yav – average simulated value (m^3/s)

The Nash – Sutcliffe simulation efficiency (ENS) indicates that how well the plots of observed versus simulated data fits the 1:1 line. ENS is computed using the following equation:

$$ENS = 1 - \frac{\Sigma\,(Xi - Yi)^2}{\Sigma\,(Xi - Xav)^2} \quad (8)$$

Where, Xi – measured value
Yi – simulated value and
Xav – average observed value

The value of ENS ranges from negative infinity to 1 (best) i.e, $(-\infty, 1]$. 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 measured value and generally viewed as acceptable performance (Santhi *et al*., 2001).

3.7. Evaluation of Stream Flow due to LULCC

Simulation of the impacts of land use and land cover change on stream flow was one of the most significant parts of this study. As discussed above, Gilgel Abbay has experienced land use and land cover changes from 1986 to 2001. There was high expansion of agricultural lands in the expenses of other lands during the study periods considered.

The study was carried out for two different two years i.e. 1986 and 2001. The two generated 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 2001, two independent simulation runs were conducted on a monthly basis using both land use and land cover maps for the period of 1986-2001 keeping other input parameters unchanged. Seasonal stream flow variability of 1986 and 2001 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 two simulation outputs.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Land Use and Land Cover Analysis

4.1.1. Accuracy Assessment

The accuracy assessment is used to determine the correctness of the classified image. It was performed using confusion matrix. Using the original mosaic image and the Google Earth Image as a reference, randomly selected points were compared with the corresponding classification. 81 and 83 points were selected for the validation of 1986 and 2001 images respectively. Table 9 and 10 show a confusion matrix for the two Landsat images.

- **Overall accuracy**

The overall accuracy gives the overall results of the confusion matrix. It is calculated by dividing the total number of correct pixels (diagonals) by the total number of pixels in the confusion matrix. The results show that the overall accuracy for the maps of 1986 and 2001 were 85% and 90% respectively. According to (Anderson *et al*, 1976), the minimum accuracy value for reliable land cover classification is 85 %. The other authors (eg. Bedru, 2006), explains that the expected accuracy is determined by the users themselves depending on the type of application the map product will be used later. Accuracy levels are accepted by users may not acceptable by other users for certain task (Bedru, 2006). Therefore, based on table 9 and 10, the classification carried out in this study produces an overall accuracy that fulfils the minimum accuracy level defined by Anderson for both land cover maps of Gilgel-Abbay watershed.

- **Producer's Accuracy**

The producer's accuracy tells us how well a certain area can be classified. It is obtained by dividing the number of correctly classified pixels in the category by the total number of pixels of the category in the reference data. The producer's accuracy is also known as an Omission Error, which is the probability of a reference pixels being classified correctly. It gives only the proportion of correctly classified pixels. The overall result of the producer's accuracy ranges from 67 % to 100%. The lowest values were misclassified due to similar spectral value of different land cover classes. For instance, swampy with forest, crop cultivation areas with forest cover, crop lands during dry season with bare land (which is classified as grass land), etc somehow affects the level of classification.

- **User's Accuracy**

It is the ratio between the total number of pixels correctly belonging to a class (diagonal elements) and the total number of pixels assigned to the same class by the classification procedure (row total). This quantity explains the probability that a pixel of the classified image truly corresponds to the class to which it has been assigned. In this study, the user's accuracy ranges from 73% to 95%. The lowest value "water and marshy land" were, to some extent, misclassified because of the similarity spectral properties of water and marshy land and forest.

Table 9. Confusion matrix for the classification of 1986

		REFERANCE DATA						
		CL	WM	F	SL	GL	TOTAL	USER'S ACCURACY
CLASSIFICATION DATA	CL	17	2	1			20	85%
	WM	1	10	1			12	83%
	F		2	11	2		15	73%
	SL			1	12		13	92%
	GL	1	1			19	21	90%
	TOTAL	19	15	14	14	19	81	
PRODUCER'S ACCURACY		89%	67%	79%	86%	100%		OVERALL ACCURACY=85%

Note: CL=Cultivated land; WM=Water & marshy land; F=Forest, SL=Shrub land; GL= Grass land.

Table 10.Confusion matrix for the classification of 2001

		REFERANCE DATA						
		CL	WM	F	SL	GL	TOTAL	USER'S ACCURACY
CLASSIFICATION DATA	CL	18		1			19	95%
	WM		12	1	1		14	86%
	F	1		19			20	95%
	SL	1			14		15	93%
	GL	1	1	1		12	15	80%
	TOTAL	21	13	22	15	12	83	
PRODUCER'S ACCURACY		86%	92%	86%	93%	100%		OVERALL ACCURACY=90%

Note: CL = Cultivated land; WM = Water and marshy land; F = Forest, SL = Shrub land; GL = Grass land.

4.1.2. Land Use and Land Cover Maps

Figure 10 and 11 shows the two landuse and land cover maps 1986 and 2001 that have been generated from Landsat TM and ETM+ imagery classification respectively. It is easily shown that the increase of cultivation land and decrease of forest area, grass land, shrub land, and water and marshy land over the last 16 years. The land use and land cover map of 1986 in the figure 10 shows that the total cultivated land coverage class was about 9 % of the total area of the watershed. It increased rapidly and became 55 % of the watershed in 2001 landuse and land cover map (Figure 11). This is mainly because of the population growth that caused the increase in demand for new cultivation land and settlement which in turn resulted shrinking on other types of landuse and land cover of the area. On the land use and land cover map of the year 1986 the total forest coverage was about 6 % of the total area of the watershed. On the land use and land cover map of the year 2001 it reduced to almost 5% of the total area. This is most probably because of the deforestation activities that have taken place for the purpose of agriculture.

In general, during the 16 years period the cultivated land increased almost 46 % where as the forest land decreased 2 %. The individual class areas and change statistics for the two periods are summarized in table 11.

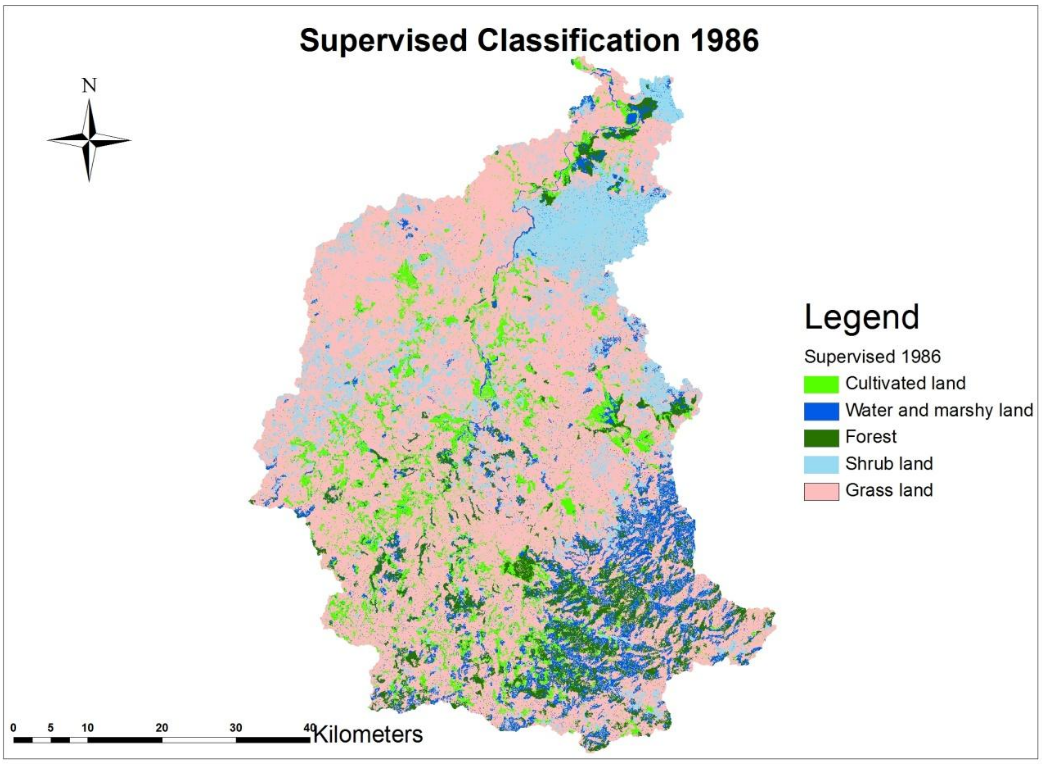


Figure 10. Land cover map of Gilgel Abbay watershed in 1986

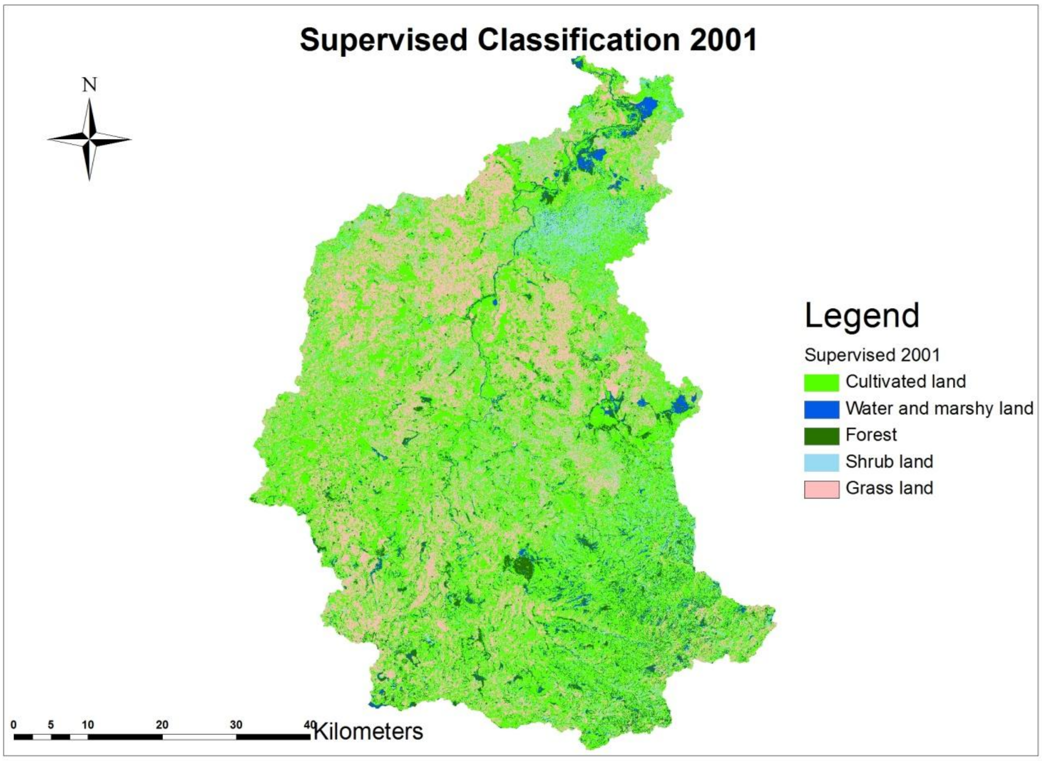


Figure 11. Land cover map of Gilgel Abbay watershed in 2000

Table 11. Area of land covers types and change statistics of Gilgel Abbay watershed for the period of 1986 and 2001.

Land cover types	**1986**		**2001**		**2001 – 1986**	
	Km^2	**%**	**Km^2**	**%**	**Km^2**	**%**
Cultivated land	348.65	9.23	2084.76	55.17	1736.11	45.94
Water and marshy land	325.1	8.6	138.76	3.67	-186.32	-4.93
Forest	230.54	6.1	185.67	4.91	-44.87	-1.19
Shrub land	535.83	14.18	318.81	8.44	-217.0	-5.77
Grass land	2338.94	61.89	1051.08	27.81	-1287.86	-34.08

The results of the previous studies showed that the same fact. For example, Denboba (2005) reports 75 % of the Shomba catchment in the south western part of Ethiopia was converted to farmlands and settlements from other land uses between the years 1967 to 2001. Zeleke and Hurni (2001) reported that 99 % of the forest covers was converted to agricultural land at Dembecha area in the northern part of the country between 1957 and 1995. Bewket (2003) identifies agricultural conversion of 79 % of the Riverine forests of the Chemoga watershed within the Blue Nile basin in about 40 years (1957 – 1998).

4.2. Stream Flow Modeling

4.2.1. Sensitivity Analysis

Sensitivity analysis was performed on flow parameters of SWAT on monthly time steps with observed data of the Gilgel Abbay River gauge station. For this analysis, 26 parameters were considered and only 10 parameters were identified to have significant influence in controlling the stream flow in the watershed. Table 12 presents parameters that resulting greater relative mean senility values for monthly stream flow.

Table 12. List of Parameters and their ranking with MRS values for monthly flow

Parameters		Lower and Upper bound	Rank	MRS index	Category
Name	**Description**				
ALPHA_BF	Base flow alpha factor (days)	0-1	1	2.05	Very high
CN2	SCS runoff curve number (%)	±25	2	0.416	High
ESCO	Soil evaporation compensation factor	0-1	3	0.356	High
CH_N2	Manning's roughness coefficient	0-1	4	0.346	High
CH_K2	Effective hydraulic conductivity of the main channel (mm/hr)	0-150	5	0.304	High
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0-1000	6	0.156	Medium
GW_DELAY	Ground water delay (days)	0-10	7	0.15	Medium
SOL_AWC	Soil available water capacity (water/mm soil)	±25	8	0.114	Medium
SOL_Z	Total soil depth (mm)	±25	9	0.105	Medium
SURLAG	Surface lag	0-12	10	0.0939	Medium

The result of the sensitivity analysis indicated that these 10 flow parameters are sensitive to the SWAT model i.e the hydrological process of the study watershed mainly depends on the action of these parameters. Alpha factor (ALPHA_BF), Curve number (CN2), soil evapotranspiration factor (ESCO), Manning's roughness coefficient (CH_N2) and Effective hydraulic conductivity of the main channel (CH_K2) are identified to be highly sensitive parameters and retained rank 1 to 5, respectively. The other parameters such as threshold depth of water in the shallow aquifer required for return flow (GWQMN), ground water delay (GW_DELAY), soil available water capacity (SOL_AWC), total soil depth (SOL_Z), and surface lag (SURLAG) are identified as slightly important parameters that were retained rank 6 to 10, respectively. The remaining parameters (16 parameters) were not considered during calibration process as the model simulation result was not sensitive to these parameters in the watershed.

These parameters are related to ground water, runoff and soil process and thus influence the stream flow in the watershed. The result of the analysis was found that ALPHA_BF is the most important factor influencing stream flow in the Gilgel Abbay watershed. The ALPHA_BF is a direct index of ground water flow response to changes in recharges. The Gilgel Abbay watershed is characterized with tertiary basalt and volcanic regional geology that have good potential for ground water recharges. In addition, (Setegn *et al.,* 2008) through modeling of Gilgel Abbay watershed found ALPHA_BF to retain rank 3. The other most influencing stream flow parameter in this analysis is the curve number (CN2). According to (Setegn et al., 2008) and (Surur, 2010), CN2 retain rank 1. These may be an additional support to the result of the sensitivity analysis.

4.2.2. Calibration and Validation of Stream Flow Simulation

The simulation of the model with the default value of parameters in the Gilgel Abbay watershed showed relatively weak matching between the simulated and observed stream flow hydrographs. Hence, calibration was done for sensitive flow parameters of SWAT with observed average monthly stream flow data. First, some sensitivity flow parameters were adjusted by manual calibration procedure based on the available information in literatures. In this procedure, the values of the parameters were varied iteratively within the allowable ranges until the simulated flow as close as possible to observed stream flow. Then, auto calibration was run using sensitive parameters that were identified during sensitivity analysis. Table 13 presents the result of calibrated flow parameters.

Table 13. List of parameters with calibrated values for average monthly stream flow

Parameters		Lower and upper bound	Calibrated value
Name	Description		
ALPHA_BF	Base flow alpha factor (days)	0-1	0.1
CN2	SCS runoff curve number (%)	± 25	-10
ESCO	Soil evaporation compensation factor	0-1	0.8
CH_N2	Manning's roughness coefficient	0-1	0.02
CH_K2	Effective hydraulic conductivity of the main channel (mm/hr)	0-150	11.14
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0-1000	10
GW_DELAY	Ground water delay (days)	0-10	0.93
SOL_AWC	Soil available water capacity (water/mm soil)	±25	+10
SOL_Z	Total soil depth (mm)	±25	+15
SURLAG	Surface lag	0-12	4.3

During this step, the model was run for period of 9 years from 1986 to 1994. However, as the first year was considered for model warm up period, calibration was performed for 8 years from 1987 to 1994. The calibration result for monthly flow is shown in the figure 12. 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 0.95 and coefficient of determination (R^2) of 0.93 as shown in Table 14.

The model validation was also performed for 7 years from 1995 to 2001 without further adjustment of the calibrated parameters. The validation result for monthly flow is shown in the figure 13. The validation simulation also showed good agreement between the simulated and measured monthly flow with the ENS value of 0.90 and R^2 of 0.91 as shown in Table 14.

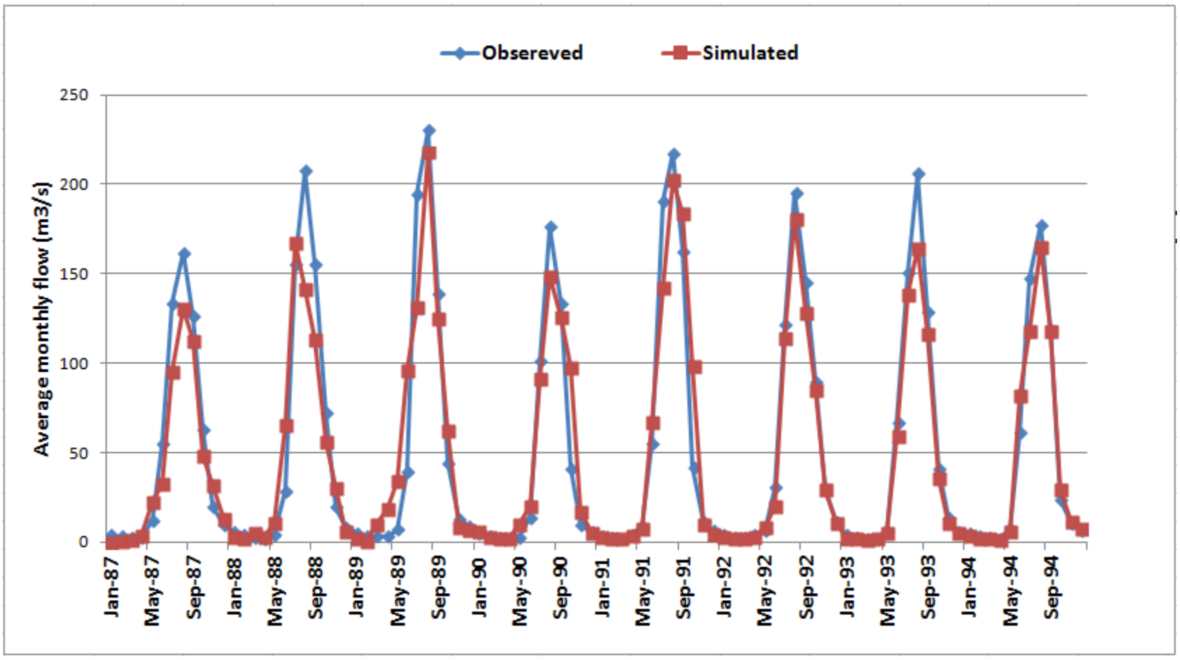


Figure 12. The result of calibration for average monthly stream flows

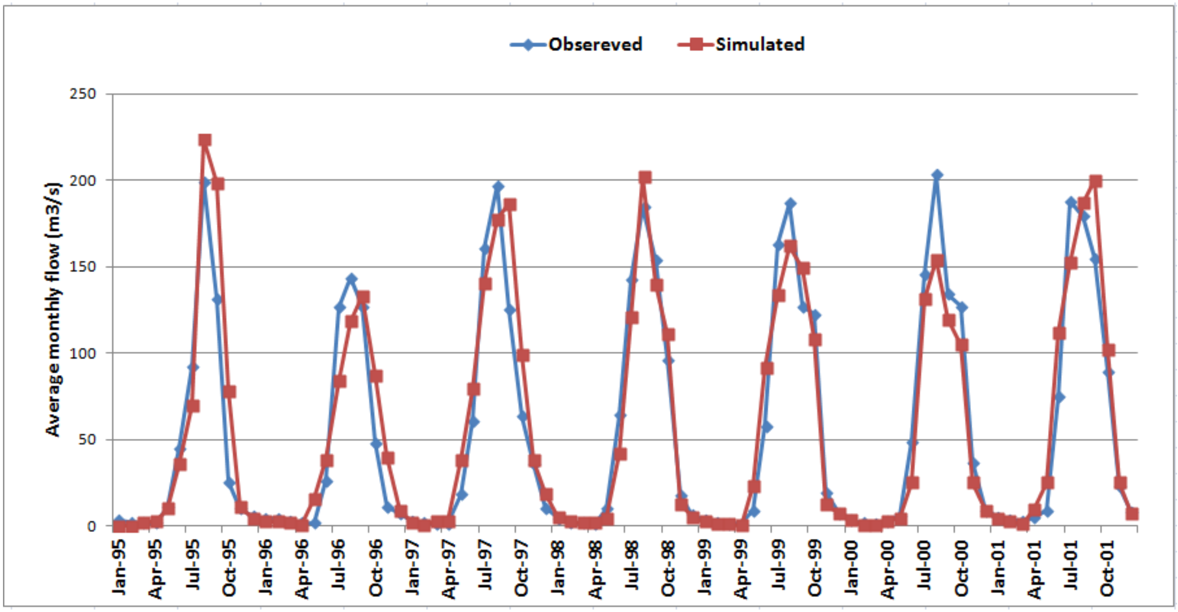


Figure 13. The result of Validation for average monthly stream flows

The measured and simulated average monthly flow for Gilgel Abbay was obtained. During the calibration period, they were 52 and 49.31 m^3/s, respectively. The measured and simulated average monthly flow for the validation period was 54.41 and 56.05 m^3/s, respectively. These indicate that there is a reasonable agreement between the measured and the simulated values in both calibratation and validation periods (Table 14).

Table 14. Comparison of Measured and simulated monthly flow for calibration and validation simulations

Period	Average monthly flow (m^3/s)		ENS	R^2
	Measured	Simulated		
Calibration (1987-1994) Period	52.00	49.31	0.95	0.93
Validation (1995 - 2001) Period	54.41	56.05	0.90	0.91

As can be indicated in the Table 14, the model performance values for calibration and validation of the flow simulations are adequately satisfactory. This indicates that the physically processes involved in the generation of stream flows in the watershed were adequately captured by the model. Hence, the model simulations can be used for various water resource management and development aspects.

Studies that conducted in different parts of the country showed that similar results. For example, Asres and Awulachew (2010) reported that the SWAT model showed a good match between measured and simulated flow of Gumera watershed both in calibration and validation periods with (ENS = 0.76 and R^2 = 0.87) and (ENS = 0.68 and R^2 = 0.83), respectively. Through modeling of the Lake Tana basin, Setegn *et al*, (2008) indicated that the average monthly flow simulated with SWAT model were reasonable accurate with ENS = 0.81 and R^2 = 0.85 for calibration and ENS = 0.79 and R^2 = 0.80 for validation periods.

The following figures showed that the values of the scatter plots of the measured and simulated monthly flows data for the calibration and validation periods. There is a fire linear correlation between the two datasets (measured and simulated).

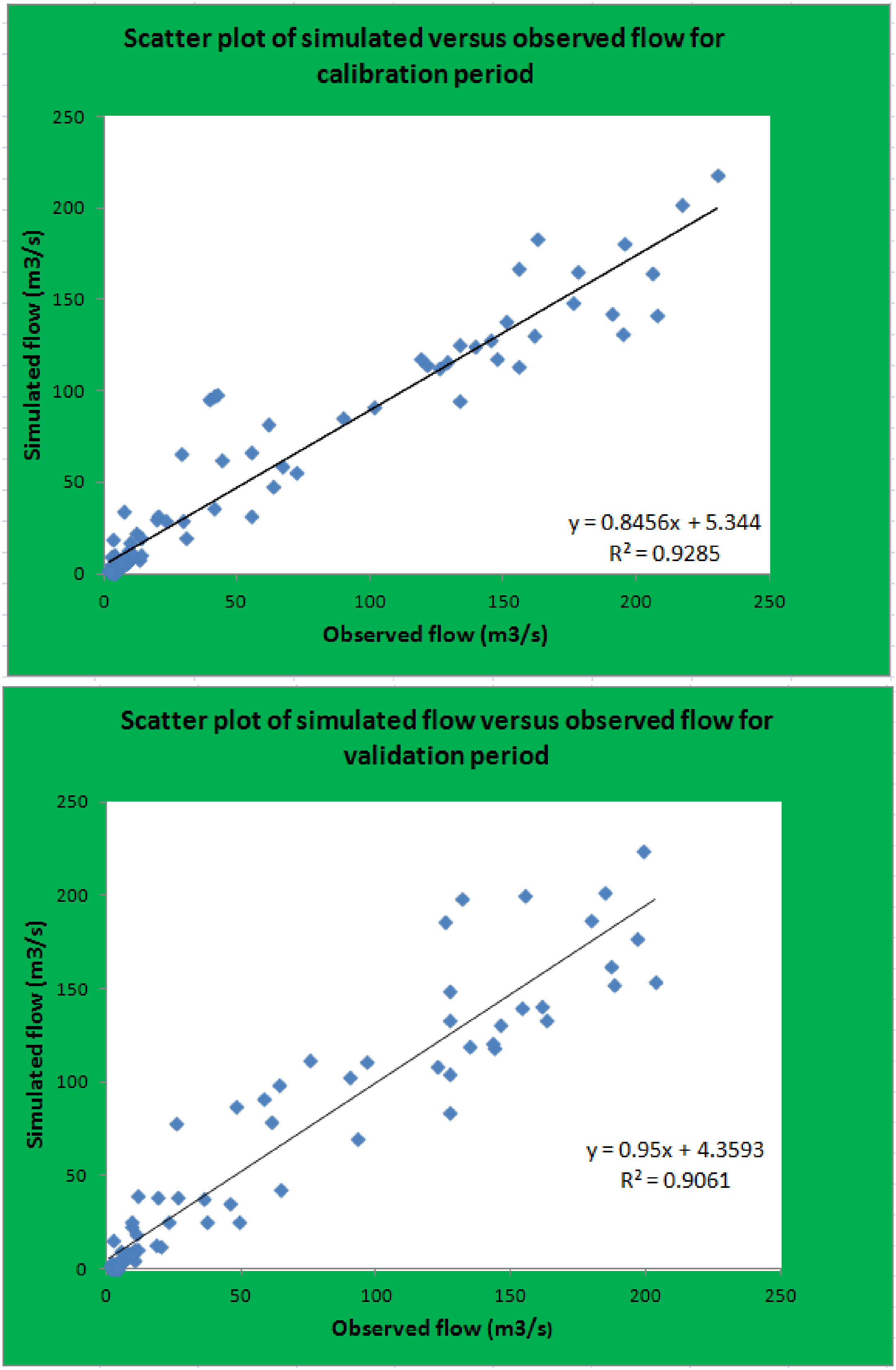


Figure 14. Scatter plots of the calibration and validation periods show the correlation between of the observed flow and the simulated flow

In general, the Model performance assessment indicated that there is a good correlation and agreement between the monthly measured and simulated flows.

4.3. Evaluation of Stream Flow due to Land Use and land Cover Change

One of the most important things of the study was to evaluate the impact of land use and land cover changes on Gilgel Abbay watershed. The evaluation was done in terms of the impact of land use and land cover changes on the seasonal stream flow and variations on the major components of stream flow including surface runoff and groundwater flow during the period (1986 – 2001). Land use and land cover has a great influence on the rainfall-runoff process.

4.3.1. Change in the Seasonal Stream Flows

After calibrating and validating of the model using the two land use and land cover maps for their respective periods of 1987 to 1994 and 1995 to 2001 respectively, SWAT was run using the two land cover maps (1986 and 2001 maps) for the period of 1986 to 2001 while putting the other input variables the same for both simulations to quantify the variability of stream flow due to the changes of land use and land cover. This process gave the discharge outputs for both land use and land cover patterns. Then, these outputs were compared and the discharge change during the wettest months of stream flow taken as June, July and August and driest stream flow are considered in the months of January, February and March were calculated and used as indicators to estimate the effect of land use and land cover change on the stream flow. Table 15 presents the mean monthly wet and dry month's stream flow for 1986 and 2001 land use and land cover maps and its variability (1986 -2001).

Table 15. Mean monthly wet and dry month's stream flow and their variability (1986-2001)

Mean monthly flow (m3/s)				**Mean monthly flow change**	
Land use/cover map of 1986		**Land use/cover map of 2001**			
Wet months (Jun, Jul, Aug)	**Dry months** (Jan, Feb, Mar)	**Wet months** (Jun, Jul, Aug)	**Dry months** (Jan, Feb, Mar)	**Wet**	**Dry**
267.57	49.88	283.83	44.47	**+16.26**	**-5.41**

As can be indicated in the table 15, the mean monthly stream flow for wet months had increased by 16.26 m^3/s while the dry season decreased by 5.41 m^3/s during the 1986-2001 periods due to the land use and land cover change.

To assess the change in the contribution of the components of the stream flow due to the land use and land cover change, analysis were made on the surface runoff (SURQ) and ground water flow (GWQ). Table 16 presents the SURQ and GWQ of the stream simulated using 1986 and 2001 land use and land cover map for the same period.

Table 16. Surface runoff and Ground water flow of the stream simulated using 1986 and 2001 land use/cover map

Land use/cover map of 1986		**Land use/cover map of 2001**		**Change of SURQ & GWQ**	
SURQ (mm)	**GWQ (mm)**	**SURQ (mm)**	**GWQ (mm)**	**SURQ (mm)**	**GWQ (mm)**
40.85	48.68	47.06	45.40	**+6.21**	**-3.28**

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 2001 were 41 mm and 49 mm while using 2001 land use and land cover map were 47 mm and 45 mm, respectively. The contribution of surface runoff has increased from 41 mm to 47 mm whereas the ground water flow has decreased from 49 mm to 45 mm due to the land use and land cover change occurred between the periods of 1986 to 2001. This is because of the expansion of agricultural land over forest that results in the increase of surface runoff following rainfall events. 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. 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.

Different studies have been conducted in different parts of the country to evaluate the effects of land use and land cover changes on stream flow. A modelling study of Anger watershed, in Ethiopia, (Brook *et al*, 2011) introduced that the surface runoff increased and the base flow decreased due to the expansion of agricultural land and declined of forest land. Study on a Hare watershed, in Southern Ethiopia, (Tadele, 2007) reported that due to the replacement of natural forest in to farmland and settlements, the mean monthly discharge for wet months had increased while in the dry season decreased. In the study of Chemoga watershed, in Blue Nile basin, (Abebe, 2005) reported that large volume of surface runoff occurs during the storm events since the area under forest cover decreased.

Generally, the hydrological investigation with respect to the land use and land cover change within Gilgel Abbay watershed showed that the flow characteristics have changed, with increase in surface flow and reduction of base flows throught the selected period of study.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study, satellite 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 Gilgel Abbay watershed of Lake Tana basin. An integrated approach of GIS and remote sensing are excellent tools to map different land cover classes and to detect and analyse spatiotemporal land cover dynamics. These techniques were applied to enable and asses of the land cover dynamic effects on the hydrology of the watershed. The impacts of the land cover change on stream flow was analysed statistically using the hydrological model, SWAT. To do this analysis, first land use and land cover change during the past 16 years (1986 – 2001) was analyzed; then SWAT model were tested for its performance at the Gilgel Abbay watershed in order to examining the hydrological response of the watershed to changes in land use and land cover.

The study shows that land use and land cover changes in Gilgel Abbay watershed from 1986 to 2001 were identified from TM and ETM+ satellite images, respectively. The land use and land cover maps of the year 1986 and 2001 were produced and the accuracy assessments of the two maps were checked using the Confusion Matrix.

On the other hand, data preparation, sensitivity analysis, calibration, validation and evaluation of model performance were performed on the selected, SWAT, model. These analyses are done before the evaluation of the impacts of the land use and land cover changes on the stream flow of the watershed was analyzed. The GIS environment uses for the processing of DEM, land use and land cover, soil data layers and displaying model results. Based on the results, the following conclusions are drawn:

From the land use and land cover change analysis, it can be concluded that the land use and land cover of the Gilgel Abbay watershed for the period of 1986 to 2001 showed significantly changed. Cultivated land was drastically changed from 9 % in 1986 to 55 % in 2001 in the expenses of the other classes. The expansion of agricultural land and rural settlement has an impact on the decrement of forest land.

Thus, the forest land which constituted 6 % in 1986 diminished to 4 % in 2001. Thus, by the expense of forest land and other land cover types, the cultivated land includes areas for crop cultivation and the scatter rural settlement that are closely associated with the cultivated fields dynamically increased in the period of the last 16 years (1986-2001). This might be due to the population pressure has caused a high demand for additional land as a result shortage of cultivated land is the major problem for farmers in the study area.

The sensitivity analysis using SWAT model has pointed out ten most important parameters that control the stream flow of the studied watershed. On the other hand, model calibration and validation have showed that the SWAT model simulated the flow quit satisfactorily. Performance of the model for both the calibration and validation watershed were found to be reasonably good with Nash-Sutcliffe coefficients (ENS) values of 0.95 and 0.90 and coefficient of determination (R^2) values of 0.93 and 0.91for the calibration and validation respectively.

Following calibration and validation of the model, impacts of the land use and land cover change on stream flow was carried out. Land use and land cover changes recognized to have major impacts on hydrological processes, such as runoff and groundwater flow. The result of model for both periods of land use and land cover (1986 and 2001) indicated that during the wet season, the mean monthly flow for 2001 land cover was increased by 16.26 m^3/s relative to that of 1986 land cover period while the mean monthly flow decreased by 5.41 m^3/s during the dry season. The surface runoff increased from 41 mm to 47 mm, while the ground water decreased from 49 mm to 45 mm for the 1986 and 2001 land cover maps respectively.

5.2. Recommendations

Generally from this specific study the following recommendations could improve similar research for future work:

- Integrating land use change models with hydrologic models could be applied to predict the potential impacts of land use change on the stream flow, a vital ecosystem services in the watershed and the country in general. This helps for stakeholders and decision makers to make better choices for land and water resource planning and management. It can be applied to a variety of watersheds, where time-sequenced digital land cover is available, to predict hydrological consequences to LULCC.

- Changes of the land use and land cover in the study area and the country in general are 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.

- The other thing which is highly recommended is that the weather stations should be improved both in quality and quantity in order to improve the performance of the model. Hence, it is highly recommended to establish good meteorological stations.

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APPENDICES

Appendix 1. Symbols and description of Weather Generator parameters (WGEN) used by the SWAT model

S. No	Symbol	Description
1	TMPMX	Average or mean daily maximum air temperature for month (^{o} C).
2	TMPMN	Average or mean daily minimum air temperature for month (^{o}C).
3	TMPSTDMX	Standard deviation for daily maximum air temperature for month (^{o}C).
4	TMPSTDMN	Standard deviation for daily minimum air temperature for month (^{o}C).
5	PCPMM	Average or mean total monthly precipitation (mm H2O).
6	PCPSTD	Standard deviation for daily precipitation for month (mm H_2O/day).
7	PCPSKW	Skew coefficient for daily precipitation in month.
8	PR_W1	Probability of a wet day following a dry day in the month.
9	PR_W2	Probability of a wet day following a wet day in the month.
10	PCPD	Average number of days of precipitation in month.
11	SOLARAV	Average daily solar radation for month (MJ/m2/day).
12	DEWPT	Average daily dew point temperature in month (^{o}C).
13	WNDAV	Average daily wind speed in month (m/s).

Appendix 2. Soils parameters and legend used in SWAT model

NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrographic group (A, B, C, D)
SOL_ZMX	Maximum root depth of the soil profile
ANION_EXCL	Fraction of porosity from which an ions are exchanged
SOL_CRK	Crack volume potential of soil
TEXTURE	Texture of the layer
SOIL_Z	Minimum depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of soil surface to bottom of the layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Clay content
SILT	Silt content
SAND	Sand content
ROCK	Rock fragmented content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility factor (K)

Appendix 3. Soils parameter values used in SWAT model

Major soil types	Code	NLAYERS	HYDGRP	SOL_ZMX (mm)	ANION_EXCL (mm)	SOL_CRK (%)	TEXTURE	SOIL_Z (mm)	SOL_BD (g/cm3)	SOL_AWC	SOL_K (mm/hr)	SOL_CBN (%)	CLAY (%)	SILT (%)	SAND (%)	ROCK	SOL_ALB	USLE_K
Lithic Leptosol	LPq	1	B	500	0.01	0	C	200	1.25	0.11	5	2	50	33	17	5	0.13	0.22
Eutric Regosols	RGe	1	B	1300	0.01	0.01	Si-C	250	1.08	0.12	6.8	1.6	54	26	21	0	0.13	0.23
		2					Si-C	750	1.15	0.19	7	0.3	74	16	11	0.01	0.13	0.22
		3					Si-C	1300	1.17	0.19	7	0.10	72	16	13	0	0.13	0.22
Haplic Nitisols	NTh	1	C	2000	0.01	0	C	200	1.10	0.11	4.34	2	50	33	17	5	0.13	0.22
		2					SiL	900	1.27	0.11	4.54	1.5	23	50	27	0	0.13	0.22
		3					C	1000	1.28	0.11	5.16	1.3	60	25	15	0	0.13	0.22
		4					C	2000	1.22	0.11	4.24	0.5	71	20	9	0	0.13	0.22
Haplic Alisols	ALh	1	C	2150	0.01	0	C	200	1.1	0.11	4.34	2	50	33	17	5	0.13	0.22
		2					C	500	1.3	0.13	4.54	1.4	65	15	20	0.01	0.13	0.22
		3					C	900	1.3	0.11	5.16	1.1	61	20	19	0	0.13	0.22
		4					C	1600	1.3	0.12	4.24	0.6	75	20	5	0	0.13	0.22
		5					C	2150	1.3	0.14	4.36	0.4	79	14	7	0	0.13	0.22
Eutric Leptosol	LPe	1	C	650	0.01	0.03	C	200	1.1	0.11	25	2	50	34	17	5	0.13	0.22
		2					C	650	1.23	0.1	13	1.1	66	14	20	0.01	0.13	0.22
Eutric Vertisols	VRe	1	D	2422	0.01	0.03	C	250	1.08	0.12	6.8	1.7	54	26	21	0	0.09	0.20
		2					C	363	1.27	0.11	4.54	1.37	61	19	21	0	0.09	0.20
		3					C	847	1.28	0.10	5.16	1.41	63	17	20	0	0.09	0.20
		4					C	1029	1.22	0.10	4.24	0.88	63	8	29	0	0.09	0.20
		5					C	1392	1.13	0.10	4.34	1.17	63	9	28	0	0.09	0.20
		6					C	1635	1.1	0.11	4.24	1.24	60	13	27	0	0.09	0.20
		7					C	2422	1.1	0.09	4.04	0.34	64	17	20	0	0.09	0.20
Chromic Luvisols	LVx	1	B	1800	0.01	0.01	SiL	200	1.45	0.11	7	0.5	25	31	44	0.01	0.13	0.23
		2					CL	260	1.46	0.11	37.20	0.3	14	66	20	0	0.13	0.3
		3					CL-	460	1.45	0.10	34.8	0.21	19	59	22	0	0.13	0.3
		4					CL-	650	1.49	0.1	33.6	0.2	22	56	22	0	0.13	0.3
		5					C	950	1.48	0.1	36	0.2	17	57	26	0	0.13	0.3
		6					C	1350	1.49	0.1	36	0.12	17	57	26	0	0.13	0.3
		7					C	1800	1.47	0.1	36	0.1	16	59	25	0	0.13	0.3
Eutric Fluvisols	FLe	1	B	1700	0.01	0.01	LS	200	1.1	0.11	25	2	50	34	17	5	0.13	0.22
		2						500	1.04	0.11	25	2.3	50.8	22	27.1	0.01	0.13	0.2
		3						900	1.05	0.12	25	2.5	38.6	40	21.1	0.01	0.13	0.2
		4						1300	1.30	0.95	25	0.20	36.8	34	29.1	0.01	0.13	0.2

		5						1700	1.04	0.1	60	0.42	58 .8	30	11.1	0.01	0.13	0.2
Haplic Luvisols	LVh	1	B	900	0.01	0.01		200	1.45	0.11	30	0.5	25	31	44	0.01	0.13	0.3
		2						600	1.37	0.09	5.52	0.5	23	33	44	0.01	0.13	0.3

Appendix 4. Average monthly flow (m^3/s) of the Gilgel Abbay watershed

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	3.577	2.271	4.082	3.91	19.743	85.187	202.975	223.521	141.695	85.51	68.069	47.881
1987	3.972	2.989	2.521	2.203	11.929	55.246	133.661	161.736	126.111	63.249	19.976	9.304
1988	5.823	4.195	2.707	1.886	4.098	28.805	155.491	207.588	155.489	72.249	19.693	8.404
1989	4.901	3.041	3.255	3.007	7.213	39.41	194.842	230.191	139.247	44.28	12.919	8.613
1990	5.061	3.587	2.62	1.972	2.926	13.938	101.596	176.255	133.538	41.068	9.753	5.429
1991	3.688	2.5	2.05	4.396	8.86	55.34	190.637	217.297	162.761	42.12	11.047	6.322
1992	4.193	2.939	2.28	3.778	6.623	30.552	121.414	195.582	145.125	89.784	29.423	10.914
1993	3.83	2.327	1.803	1.791	6.005	67.166	150.911	205.904	128.698	41.187	13.861	5.387
1994	4.804	3.376	2.44	2.111	7.175	61.54	147.622	177.607	118.647	23.377	10.464	6.365
1995	3.566	2.518	1.878	1.949	11.065	45.214	92.639	198.979	131.772	25.43	10.224	5.64
1996	4.088	4.4755	2.818	1.918	1.855	26.174	126.711	143.65	127.208	47.946	11.442	7.099
1997	2.943	1.927	1.746	1.666	18.386	60.79	160.86	196.73	125.082	63.558	35.67	10.542
1998	4.479	2.531	1.852	1.285	10.135	64.3	142.696	184.564	153.731	96.139	18.317	6.541
1999	3.718	2.138	1.433	1.708	8.91	57.743	163.041	186.856	127.081	122.523	19.662	7.599
2000	3.424	2.026	1.489	3.097	6.079	49.045	146.032	203.221	134.165	126.978	36.709	8.953
2001	5.51	3.769	3.173	5.019	8.981	74.918	187.942	179.338	154.837	89.738	22.92	8.186