



Impact of Land Use and Land Cover Change on Hydrological Processes
of the Upper Awash Sub-Basin, the Case of Melka Hombole Watershed,
Ethiopia

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of the Upper Awash Sub-Basin, the case of Melka Hombole watershed,
Ethiopia

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This is to certify that the thesis prepared by Eshetu Belete, entitled: Impact of Land Use and Land Cover Change on Hydrological Processes of the Upper Awash Sub-Basin, the case of Melka Hombole Watershed, Ethiopia and submitted in partial fulfillment of the requirements for the degree of Degree of Master of Science (water Resources Management) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

I, Eshetu Belete, do here by declare to the Senate of Addis Ababa University that this thesis work is entirely original work and all other materials are properly acknowledged. Moreover, this work has not been submitted for any academic degree award at any University.

I, Eshetu Belete, hereby declare that the research project entitled Impact of Land Use and Land Cover Change on Hydrological Processes of the Upper Awash Sub-Basin, Ethiopia has been carried out by me under supervision of Dr. Ermias Teferi, Center for Environment and Development Studies, Coordinator for Water Resources Management Graduate program, during the year of 2019/2020 as a part of Masters of Science in water resources management. I further declare that this work has not been submitted to any other University or Institution for academic degree award.

ESHETU BELETE

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Date _____

Abstract

The increase in comprehensive socio-economic activities have resulted in considerable changes in the land use and land covers of Melka hombole watershed of the Upper Awash sub-basin of Ethiopia for the last years. This study examines, thus, the changes in hydrological processes in response to changes in land use and land covers during the period 1995-2015 by integrating remote sensing, GIS and Hydrological modeling. Land use land cover classifications for 1995, 2005, and 2015 were conducted by employing supervised approach of classification image. The accuracy assessment result revealed that the overall accuracy of 87.71% was achieved for the current image classification. Kappa coefficient was found 0.97. Post classification comparison technique was applied to detect the changes in land use land cover. The LULC change analysis revealed that the cultivated land, urban and water body have increased by 14.23%, 3.05% and 0.12% respectively and that of grass land, woody vegetation, wetland and bare lands decreased by 9.15%, 8.34%, 0.06% and 0.04% respectively during the study period of 1995-2015. The three generated land cover maps were, then, used to run the Arc SWAT model so as to evaluate the impacts of the detected land use and land cover changes on the stream flow. Sensitivity analysis, calibration, and validation of the model simulation were conducted and 12 parameters were identified to be sensitive for the stream flow and were used for further model calibration and validation. Calibration was executed using the observed stream flow data of Hombole gauging station from 1998 to 2007 leaving 3 years of warm up period. Consequently, validation was undertaken from 2008 to 2015. Both the calibration and validation results revealed a good match between measured and simulated stream flow expressed by a coefficient of determination (R^2) of 0.82 and that of Nash-Sutcliffe Efficiency (ENS) value of 0.81 for the calibration, and a value of 0.76 and 0.75 for the validation period respectively. Then the model was run to obtain the values of surface runoff and ground water return flows for the three respective time periods. The result indicated that the mean monthly stream flow for wet season has increased by 19.63% and has decreased 30.74% for dry months. Total water yield of the watershed has increased by 21.67%. Generally, surface runoff has increased by 38.69% while lateral flow decreased by 21.82% during the study period owing to the increase of cultivated and urban lands and decrease of vegetation cover. The annual actual evapo-transpiration has decreased by 16.34% from 1995 to 2015. Therefore, the results confirmed that the hydrological processes of the study area have changed due to land use and cover changes undertaken in the past two decades.

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Acronyms

DEM	Digital Elevation Model
DEW02	Program designed to calculate dew point temperature
DN	Digital Number
EMR	Electromagnetic Radiation
ENS	Nash - Sutcliffe Efficiency
ETM+	Enhanced Thematic Mapper Plus
GCPs	Ground Control Points
FAO	Food and Agricultural Organization
GIS	Geographical Information System
HBV	Hydrologiska Byråns Vattenbalans-avdelning
HEC_HMS	Hydraulic Engineering Centre-Hydrologic Modeling System
HRU	Hydrological Response Unit
IGBP-IHDP	International Geosphere-Biosphere and the International Human Dimension Program
LULCC	Land use and Land Cover Change
MoA	Ministry of Agriculture
MoWIE	Ministry of Water, Irrigation and Electricity
NASA	National Satellite Agency of the United States of America
PcpSTAT	Program designed to calculate daily precipitation
PET	Potential Evapo-transpiration
R ²	Coefficient of Determination
RGB	Red, Green and Blue Colors
RS	Remote Sensing
SDGs	UN Sustainable Development Goals
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
TM	Thematic Mapper
WXGEN	Weather Generator

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Land use and land cover change is a phenomenon that occurs throughout the world and with a potential to affect the ecological functioning of the system significantly. The change has increased markedly in the 20th century, both in terms of extent and intensity. It is often thought of as a local problem, but has now accumulated to become a global problem (Geist et al., 2006). This phenomenon has a direct impact on the diversity of plants and animals as well. Moreover, land use and land cover change (LULCC) has significant impact on a watershed hydrology by affecting the magnitude and pattern of surface runoff, groundwater and soil moisture content (Setyorini et al., 2017). It can just alter runoff patterns of an area by changing the stream flow which can result in increased risk of flooding. LULC change is caused by a number of natural and human driving forces (Meyer and Turner, 1994). Among the drivers, rapid socio-economic development is the one which include, for example, conversion of crop land/agricultural land to urban area due to urbanization, as well as changes within classes like a change in crops type. Land use and land cover changes are high especially in the developing countries with agriculture based economics and rapidly increasing populations. Studying the effects of LULC changes on water resources is necessary for hydrological modeling and has gained considerable importance in the past decades. Land use changes could result in an increase of water scarcity and thus contribute to a deterioration of living conditions particularly in areas where water availability is already limited. To elaborate the situation, Defries and Eshleman (2004) highlighted the importance of understanding the impact of land use changes on water resources as a key research topic now and for the future as well. Similar to many other developing countries, Ethiopia has been experiencing environmental degradation problems like soil erosion, loss of forests and many other vegetation covers, and water resource including LULC conversion (MoARD and WB, 2007). While the natural drivers such as a climate change has effect on especially water resources over a long period of time, the human drivers have immediate and often direct effects. Of the human factors, population growth has become the most important issue in Ethiopia (Tekle and Hedlund, 2000).

Abraha (2007) has emphasized the importance of conducting such studies in Ethiopia case as well. Almost all of such studies conducted in Ethiopia found that LULC conversion process is very intense in the highlands of Ethiopia (Aklilu et al., 2007). Consequently, a systematic understanding of past, present and future LULCC is necessary in order to better manage the potential effects on hydrology, biodiversity, carbon fluxes, climate change, and many other essential ecological processes. Like other parts of Ethiopia, the upper Awash Basin, and its major tributaries have been subjected to major environmental stress. The demand for natural resources by the increasing and fast growing population has imparted a major challenge to effective and sustainable land management. This high pressure on the resources in the upper basin has led to the exploitation of fragile watersheds and ecosystems resulting in loss of vegetation and subsequent soil erosion in the lower part of the Awash River Basin (Kinfu, 1999).

The study area, which is Melka Hombole watershed in this case, is mainly characterized by rapid socioeconomic development compared to the other part of the Awash Basin. It is densely populated and has intensive agricultural activity due to the endowed resources of the area and access to various infrastructures. Due to this, loss of top fertile soil through erosion, siltation of reservoirs like Koka, frequent flood risk and hazard during the rainy season, shortage of water supply for irrigation and power generation during the dry season which resulted from a reduction in reservoir capacity are common and have been major challenges (Beyene et al., 2018). This study, therefore, aims at assessing the nature and extent of LULCC and its impact on hydrological processes for a period from 1995 to 2015 using remote sensing, GIS and Arc SWAT tools in an integrated manner as a tool.

1.2 Statement of the Problem

Awash River basin is the most intensively utilized among the major river basins of Ethiopia. Kefyalew (2003) in his study of integrated flood management in Ethiopia reported that the Upper Awash sub-basin is densely populated and has intensive agricultural activity. Another study on drought analysis of the Awash River basin showed that deforestation, expansion of agricultural, residential and industrial areas have been common features in the Upper Awash sub-basin (Desalegn et al., 2009). Generally, the study area is characterized by small to large agricultural activities and urbanization with a relatively high rainfall (Belete and Semu, 2013). Some of those

consequences like flooding, sedimentation and fluctuation of stream flows are closely related to the continuous change in land use and cover (Berga, 2011). The high magnitude of urban expansion observed in cities like Addis Ababa from 1995 to 2017 was estimated at a rate of 4.5% with an average urban area increase of 37.8% and (Terfa et al., 2019). A study in Addis Ababa city using SWAT model result indicated that 25% increase in peak flow due to land use change of the city mainly urbanization (Birhanu et al., 2016). With most of those consequences in place, the change in land use and land cover has yet continued thereby significantly affecting the hydrology of the area.

Various studies have been conducted so far in the study area with regard to the impact of land use and land cover changes on the basin hydrology. As a finding of his study, Berga (2011) indicated that the surface run off generally increased from 23% in 1986 to 64% in 2000 due to the land use and cover changes in Akaki Catchment. Similarly, due to the LULCC in the study area, the monthly stream flow has increased by 16.13% in the wet season and decreased 20.8% in the dry season from 1986 to 2009 (Beyene et al, 2018). However, only few studies are conducted in the study area and those studies focused on the impacts of the LULCC on stream flow only given less attention to other hydrological processes like evapo-transpiration and total water yield of the watershed. Moreover, the study area is in a rapid rate of Land use and cover changes even after the previous studies are conducted which requires incorporating recent changes so as to fill the gap of access to up to date information. To this end, the need to have up-to-date information on the impacts of LULC on the hydrology in order to enlighten adaptation of sustainable strategies for water resources and land use planning so as to control the effects of increasing anthropogenic activities on the ecosystem functions becomes imperative.

Therefore, these gaps imply that additional study that can show the interaction between LULCC and hydrological processes by incorporating up-to-date LULC changes is required to have more information that help understand the consequent impacts which in turn can help sustainable development and management of the study area. Generally, this study strives to fill the aforementioned gaps to enable decision makers have access to alternative reliable information to help them make informed decisions to ensure sustainable development of the study area meeting the most important Sustainable Development Goals (SDGs).

1.3 Objective of the Study

1.3.1 General Objective

The general objective of this study was to assess the impact of land use and land cover changes on the hydrological processes in the Melka Hombole watershed of upper awash sub-basin.

1.3.2 Specific Objectives

- To detect land use and land cover changes of the study area between the period 1995 and 2015.
- To apply the SWAT model in simulating the hydrological response of LULCC in the study area.
- To evaluate the impact of land use and land cover changes on the stream flow of the study area.
- To evaluate the impact of land use and land cover changes on the Evapo-transpiration of the study area.
- To evaluate the impact of land use and land cover changes on the total water yield of the study watershed.

1.3.4 Research Questions

- Is there a significant change in LULC Melka Hombole watershed in the period between 1995 to 2015?
- Do the changes in land use and land cover affect the hydrological processes of the study area?
- How does the trend of hydrological processes of the study watershed look like in response to land use and land cover changes for the time period of 1995 to 2015 in the study area?

1.4 Significance of the Study

Understanding the characteristics, extent and pattern of change in land use and land cover is a vital element for efficient and sustainable water resource planning, managing and decision making. This, therefore, leads to the need to obtain comprehensive up- to -date information about LULCC and its impact on the hydrologic system. Therefore, by taking this need in to account, this study needs to play a vital role in providing valuable information that help ensure sustainable development and management of the natural resources in the study area.

1.5 Organization of the Thesis

This research paper is organized into five chapters. Chapter one is an introduction section where the background of the study, statement of the problem, objectives of the study, key research questions and significance of the study are discussed. In chapter two, review of related literature has been discussed in depth. This section has addressed the basic definition and concepts of land use and land cover changes, overview of land use and land cover changes in Ethiopia, the application of remote sensing techniques and GIS to land use and land cover changes studies and the common hydrological models. Discussion of the selected Arc SWAT model and its application globally and in Ethiopia context has also been explained in this section.

Chapter three is about material and methods in which description of the study area, satellite image processing, classification and accuracy assessment, selection criteria of hydrological model for the study, collection and analysis of SWAT model input data, SWAT model set up and processing and model performance evaluation are discussed in detail. This section finally elaborated the evaluation of stream flow due to LULCC.

The fourth chapter presents the results and discussion of the land use and land cover change analysis, stream flow modeling and evaluation of stream flow against the land use and land cover changes. It also includes flow parameters sensitivity analysis, calibration and validation of stream flow simulation and finally the performance evaluation of the model are discussed here. The last chapter which is chapter five provides conclusions and recommendations of this specific study.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1 Hydrological Processes

A catchment is a basic unit of landscape particularly for investigations of hydrologic processes. Typically, the topographic boundary of a catchment coincides with the hydrologic boundary causing any precipitation falling on to the catchment to be routed to a stream where it is transported out of the catchment. Hydrologic cycle is an important natural process of hydrology which has no beginning or end with its complex processes occurring continuously. The major components of the hydrologic cycle are precipitation, evaporation, transpiration, soil water, groundwater, and stream flow. In the cycle, water evaporates from oceans and land surface to the atmosphere in the form of water vapor and lifted until it gets condensed and then returns back to the land and oceans in the form of precipitation where it may be intercepted by vegetation, become run off or infiltrated in to the ground through the soil where part of it becomes as subsurface flow and discharged into streams. Finally, all the surface and sub-surface runoff flow out to the sea or else evaporate into the atmosphere as the cycle continues (Chow et al., 1988). The study of hydrological cycle and hydrological response of a catchment have become very complex due to complicated inter-relationship between various hydrological components such as precipitation, evaporation, transpiration, infiltration, and runoff. Stream flow is the integrated result of all meteorological and hydrologic processes in the catchment. Horton (1933) developed a hypothesis stating that the source of runoff during storms is the excess rainfall over infiltration capacity of basin surficial materials and that the water infiltrated would become groundwater which was the source of the base flow part of the hydrograph. Horton's thesis is effectively a two-component mixing model. However, Hewlett (1961) showed that water draining from the soil, i.e. unsaturated flow, also contributed to base flow. The combination of two separate processes whereby water is lost from the soil surface by evaporation and from the crop by transpiration is referred to as evapo-transpiration (Allen et al., 1998). The conceptual frame here is that evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface.

This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water will predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration. Both climate and land use change have adverse implications on the natural hydrologic system in terms of variation in the runoff regime, evapo-transpiration (ET), subsurface flow, infiltration, etc (McColl and Aggett, 2007). Hydrological processes at a catchment scale are no longer stationary when the changes taking place in the catchment are highly variable in nature (Mauser and Bach, 2009).

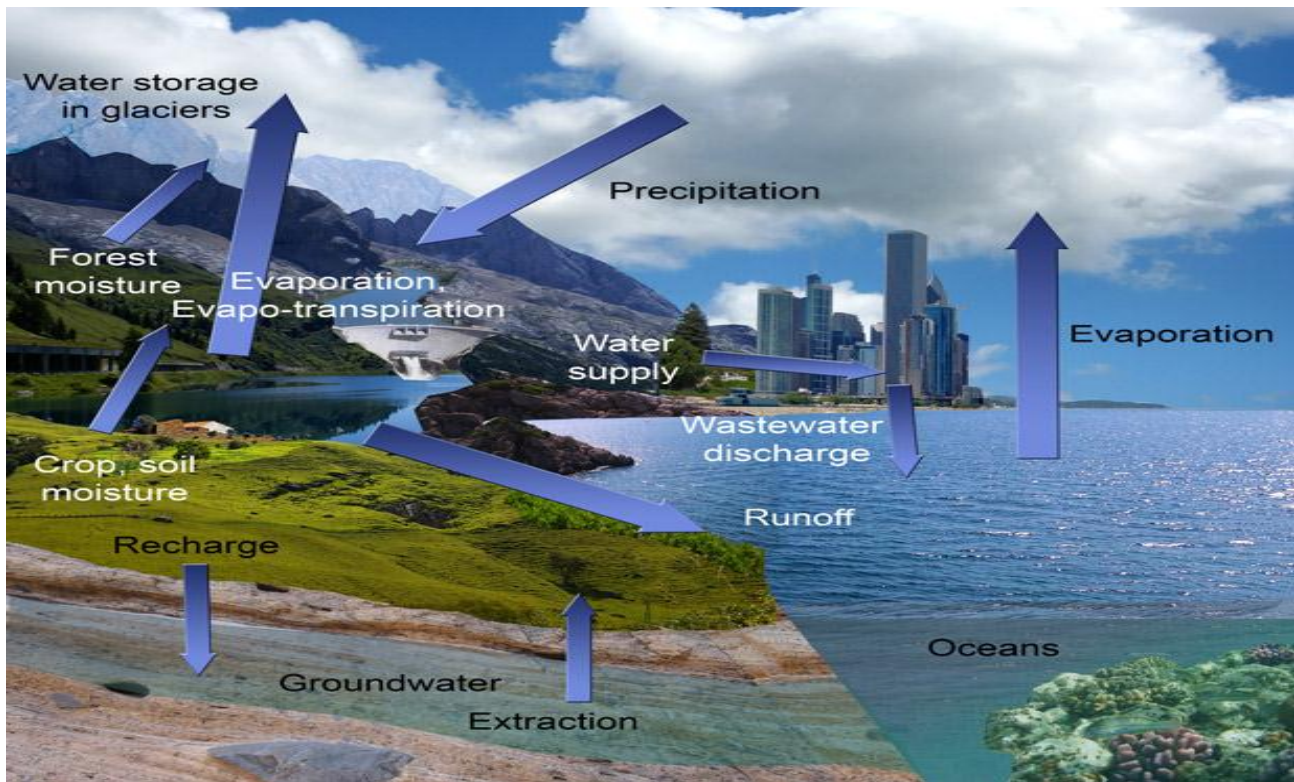


Figure1. Hydrologic Cycle (Source: UNESCO the United Nations world water development report 2020: Global Hydrology and Water Resources).

2.2 Land Use and Land Cover Change

Land cover refers to the physical and biophysical cover on the earth including distribution of vegetation, water, bare soil and artificial structures whereas land use refers to the intended use of the land cover type by human beings such as agriculture, forestry and building construction (IGBP-IHDP, 1999). According to Meyer and Turner (1994), there are two common groups of land use and land cover changes. Conversion is just a change from one cover or use category to another. On the other hand, modification refers to a change within one land use or land cover category such as from rain-fed agriculture to irrigated agriculture. There are also other definitions given to land use and land cover. Land-use change is the immediate cause of land-cover change.

Therefore, the changes in land use and land cover systems have important environmental consequences imposing impacts on soil and water, biodiversity, and microclimate (Lambin et al., 2003). Land use and land cover dynamics is a result of complex interactions between several biophysical and socio-economic conditions which may occur at various temporal and spatial scales.

Land use and land cover change is known to alter the cycle of hydrological processes, including transpiration, interception, and conservation (Tomer & Schilling, 2009). Deforestation can increase stream flow, which may lead to short-term positive feedbacks. Moreover, the clearing of forests raises the risk of damaging floods and causes increased soil erosion. Reduced precipitation, resulting from decreased evapo-transpiration (ET), can also be caused by deforestation (Panday, Coe, Macedo, Lefebvre, and de Almeida Castanho, 2015). Conversely, reforestation and intensive agricultural rehabilitation can dramatically increase ET and continental precipitation. The effects of ET are more likely to lead to changes in surface runoff. On the other hand, vegetation types and distributions may affect air humidity, temperature, precipitation, and consequently, the hydrological cycle. It is, thus, important to understand the impacts of LUCC factors on hydrological changes in order to accurately quantify the respective role. The common driving forces to land use and cover changes could be economic, technological, demographic, scenic and or other factors. For that matter, different literatures have identified the main causes of LULCC in our world. As an example, land cover changes have been influenced by both the increase and decrease of a given population as a result of which agricultural lands are expanding at the expense of vegetation and grass lands (Lambin et al.,

2003). Similarly, according to Meyer and Turner (1994), there is a significant statistical correlation between population growth and land cover conversion in most of African, Asian, and Latin American countries. Therefore, in most developing countries like Ethiopia, population growth has been a dominant cause of land use and land cover changes than other factors (Sage, 1994).

According to Abebe (2005), both surface runoff and ground water flow (the two main components of stream flow) are significantly affected by land cover types. Among the land use changes for example increase of crop lands and decrease of forest, results in increased stream flow. Land cover change, associated with intensive agriculture, cattle raising and urbanization, could have an intensified impact on the hydrological processes in small watersheds and at a regional level (Mendoza et al., 2002). 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). Land use change directly impacts the evapo-transpiration regime; likewise, the degree and type of ground cover has an enormous impact on the initiation of surface runoff (Fohrer et al., 2001). Generally, land use and land cover changes have a wide range of impacts on environmental and landscape attributes including the quality of water, land and air resources, ecosystem processes and functions.

2.3 Land Use and Land Cover Change Studies in Ethiopia

In Ethiopia, land is used for agriculture, pasture, as forest area, buildings and infrastructure sites or for recreational purposes. Most of the land under agriculture use in the country is being used by smallholder farmers. Researches that have been conducted in different parts of the country showed that there were considerable land use and land cover changes. According to a study conducted by Gebrehiwet (2004), the land use and land cover changes of that occurred from 1972 to 2000 in Yerer Mountain and its surrounding resulted in expansion of cultivated land at the expense of the grasslands. Another studies indicated, croplands have expanded at the expense of natural vegetation like forests and shrub lands. Kidanu (2004) and Abebe (2005) in the northern part of Ethiopia are to be mentioned in this regard. Similarly, Denboba (2005) in south western part of Ethiopia have conducted a study and all reported that the majority of land use changes to agriculture in Ethiopia are at the expense of natural vegetation (forests and shrub lands) and grazing lands. On the other hand Berga (2011) reported in his study that Akaki catchment had experienced a significant change in land use and land cover over the past three

decades especially in agriculture, vegetation and urban lands. The analysis indicated that rapid conversion of forest and grass land covers to urban and cultivated land uses has occurred. Consequently, the proportion of cultivated land was drastically changed from 9 % in 1986 to 55 % in 2001 at the expenses of forests and vegetation. A study conducted on upper awash also indicated that a significant LULCC has occurred during the period of 1986-2009 (Beyene et al., 2018). Therefore, most of the empirical evidences indicated that land use and land cover changes and socio-economic dynamics have a strong relationship.

2.4 Application of Remote Sensing and GIS on LULCC Studies

Remote Sensing is defined as the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired through a device (sensor) that is not in direct contact with the object, area, or phenomenon under investigation (Bawahidi, 2005). It provides a large amount of data about the earth surface often very useful for in depth analysis and change detection. It plays a vital role in providing accurate and reliable information with cost effective and lesser time as compared to the conventional environmental data collection methods. RS technology usually has sensors on platforms which record electromagnetic radiation. Electromagnetic radiation (EMR) is the energy transmitted through space in the form of electric and magnetic waves. The electromagnetic spectrum is normally range of electromagnetic radiations extending from cosmic to radio waves. The measured and recorded energy reflected from an object or feature is converted and stored as a digital number (DN) value, which ranges from 0-255. Each pixel, hence, has a single DN value related to the specific energy measured and recorded (Ahmed, 2001). Hence, remotely sensed imagery plays an essential role to acquire information based on temporal and spatial distribution (Atasoy et. al., 2006). Researchers those studied natural resource dynamics (environmental change, land use/cover change and forest reduction) at national, regional and local level using Remote sensing and Geographical Information System techniques to the extent possible. It is observed that, Remote Sensing and GIS is the most modern technology widely used in natural resource management and monitoring and is a helpful tool in detecting and analyzing spatiotemporal land use/land cover dynamics and evaluation of land use and land cover changes at catchment levels (Teferi et.al., 2013). Even though, there are many satellites in the space providing remote sensing data, they have different applications based on their system of data acquisition. Among the available satellite systems, the most popular is the Land sat, which was operated since early 1970s. Its long term operation and advancement makes Land sat very important for most environmental systems analysis.

2.5 Hydrological Models

Hydrological modeling is mathematical representation of hydrological processes including precipitation, infiltration, interception, evaporation, runoff, etc. Among the objectives of hydrological models, getting a better understanding of the hydrologic processes and how changes occur in a watershed, predicting hydrological processes and providing important information for studying potential impacts of changes like LULC are the major ones (Tadele, 2007). Based on spatial representation, hydrological models can be classified in to three main categories (Cunderlik, 2003). Lumped models use an aggregated description of catchment/watershed by using representative values of parameters and state variables based on calibration process and thus catchment response is computed only at the outlet. SCS_CN based models are lumped type. These models are not usually applicable to event-scale processes. Therefore, most of such models are not suitable for analyzing the impacts of climate and land use changes on the hydrological regime. In the case distributed hydrological models, parameters are fully allowed to vary in space at a resolution usually chosen by the user. Distributed models generally require large amount of (often unavailable) data. The governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy. On the other hand, 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. Semi-distributed models use lumped parameters for each homogeneous sub-basin (Hydrologic Response Unit) within the whole catchment area. The main advantage of such models is that their structure is more physically-based than the structure of lumped models. Moreover, they are less demanding on input data than fully distributed models. SWAT model, HEC-HMS and HBV are the commonly adopted semi-distributed models.

Hydrological models are also divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. An event-driven model simulates individual precipitation-runoff events and their emphasis is placed on infiltration and surface runoff and is not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate a longer period, which enables to predict watershed response both during the wet and dry seasons (Cunderlik, 2003). Generally, spatially distributed models are the best in terms of understanding the impacts of land use/land cover changes.

2.6 General Selection Criteria of Hydrological Models

The selection of a particular model is an important step to get acceptable outputs to a given phenomenon. According to Cunderlik (2003), even though there are no universally agreed criteria for making a choice between the different hydrological models, some general guidelines can be stated. However, the criteria are always project-dependent. On the other hand, some of the criteria are user-dependent. Among the various project-dependent selection criteria, the four common and fundamental ones that answer the following questions can be considered:

Does the model predict the variables required by the project? Such as peak flow, etc

Is the model capable of simulating single-event or continuous processes?

Can all the input data required by the model time and cost effective?

Does the investment/cost appear to be worthwhile for the objectives of the project?

2.7 SWAT Model Application Worldwide

The SWAT model is known for its best use in agricultural watersheds and has been successfully calibrated and validated in many areas of the USA and other continents (Tripathi et al., 2003). Different global studies indicated that the SWAT Model is capable of simulating hydrological processes and sediment yield from even complex and data poor watersheds with reasonable model performance. Therefore, SWAT has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences and large number of articles published in peer-reviewed journals (Gassman, 2007). However, SWAT model parameters show varying sensitivity in different years of simulation suggesting the requirement for dynamic updating of parameters during the simulation is important (Cibin et al., 2010). The same study also indicated that sensitivity of parameters during various flow regimes (low, medium and high flow) is also found to be uneven, thereby suggesting the need for a multi-criteria approach to the calibration of the model.

2.8 Overview of SWAT Model Application in Ethiopia

A study on model based characterization and monitoring of runoff and soil erosion in response to LULCC in the Modjo watershed found that the Arc SWAT hydrological model was found useful for successful simulation of the Spatio-temporal patterns of runoff generation and soil erosion in response to LULC change in the study area such as for watershed planning and management (Gessesse et. al., 2014). Similarly, according to Gessese (2008), the SWAT model performed well to predict the Legedadi reservoir sedimentation.

Another study conducted on modeling of the Lake Tana basin with SWAT model showed that the model was successfully calibrated and validated (Setegn et al., 2008). The study concluded that the model can produce reliable estimates of stream flow and sediment yield from complex watersheds. The study further reported that the model was proved to be worthwhile in capturing the process of stream flow and sediment transport. A study on Rainfall-runoff relation and runoff estimation for Holetta River, Awash subbasin, using SWAT model also reported to found a reliable result for hydrological processing of the watershed (Tibebe et.al., 2017). Similarly, Tekle (2010) in his modeling of the Bilate watershed also reported that SWAT Model was able to simulate stream flow at reasonable accuracy. Berga (2011) in his modeling of the Akaki catchment also proved the model performance using regression coefficient and the Nash-Sutcliffe. Similarly, Geremew (2013) studied Gilgel Abay watershed of Tana basin using SWAT model and reported that the 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 0.91 for the calibration and validation respectively. Therefore, the literatures reviewed and presented above showed that the SWAT model is capable of simulating hydrological processes with reasonable accuracy and can be applied to even large and complex watersheds.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

Melka Hombole watershed is located in the upper sub basin part of the Awash basin and geographically it is located in longitude of $38^{\circ} 5' 45''$ to $50^{\circ} 7' 8''$ and latitude of $9^{\circ} 6' 7''$ to $10^{\circ} 4' 8''$ with a total area coverage of 7,604.1 km². The elevation ranges from 1688m to 3576m amsl. Below is the figure for location map of the study area. The source of the Awash River lies at an altitude of around 2500 masl in plateau to the west of Addis Ababa. It first flows east, draining the Becho plains and is joined by several small tributaries before entering Koka Reservoir. After being released through Koka Dam, which came into operation in 1960, it descends into the Rift Valley. The fall of the river in this reach is used for hydropower generation at Koka and series of run-of river schemes designated as Awash II and Awash III. The river then turns gradually northwards, flowing at much-reduced gradient along the base of the western highlands. In the reach between Koka and Awash Station, the Awash River is joined by small tributaries like Keleta, Wererso and Arba draining the highlands, which define the catchment boundaries to the east (Halcrow, 2006).

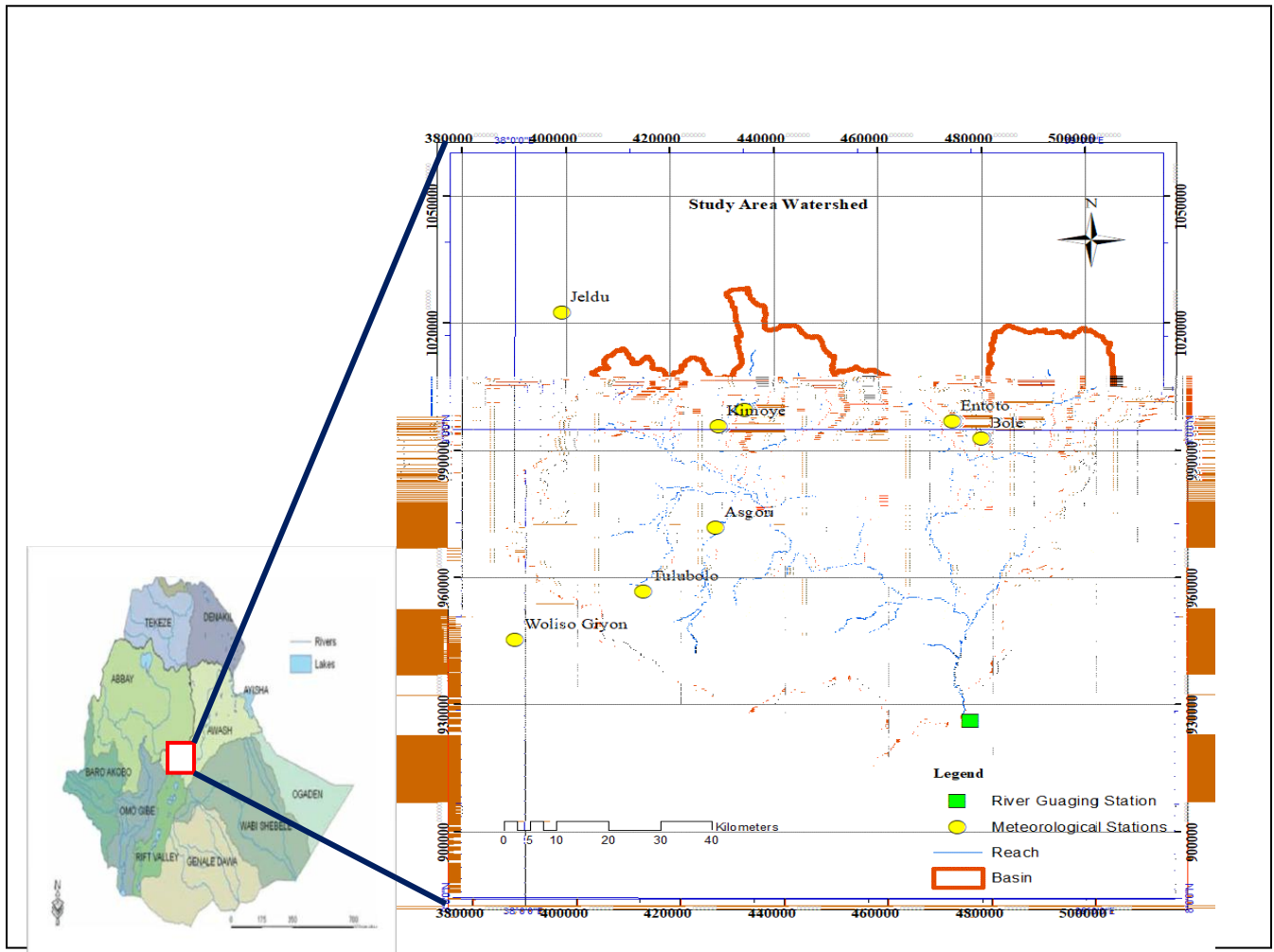


Figure 2: Location Map of the Study Area (Melka Hombole Watershed)

The climate of the study area is influenced by the Inter-Tropical Convergence Zone (ITCZ) which is a zone of low pressure that makes the convergence of dry tropical easterlies and moist equatorial easterlies. This zone migrates northwards across the basin thereby causing the small spring rains in March. Similarly, at the north most part of the basin, it results in a heavy summer rain during June and July. Following the heavy summer rain it, moves southwards through August to October restoring the drier weather which extends until the next spring. The area has four different rainfall regimes. The first regime includes seven rainy months from March to September with peaks in April and August. The second regime is also known to have seven months between March and September but having a peak value in August only. Similarly, the

third regime incorporates seven months but with an intervening month making it bi-modal and extends from February to April and from June to September. Finally, the fourth regime has only six rainy months between March to April and June to September (Halcrow, 2006). Generally, the mean annual rainfall varies between 929.22 to 1208.02 mm. The annual and monthly rainfalls are characterized by variability. The monthly rainfall distributions indicate that June to September is the wettest months of the year in all the selected 6 stations. The mean annual temperature is between 16.97°C to 19.18 °C (NMA). There is relatively little variation in mean annual humidity which is 60.2% like in Addis Ababa. However, seasonal variation is higher in the area (Halcrow, 2006). The mean annual wind speed at Koka is like 1.2 m/s and the windiest months being in June and July with mean monthly values of 1.9. At downstream of Koka reservoir, the mean monthly wind speed value is over 2 m/s. The potential evapo-transpiration (PET) generally varies from 1200 mm over the western and northern highlands to more than 2200 mm. At the study area, the mean annual PET is as much as twice of the mean annual rainfall (Halcrow, 2006).

The mean monthly distribution of rainfall and temperature for the study area is shown in the Figure below.

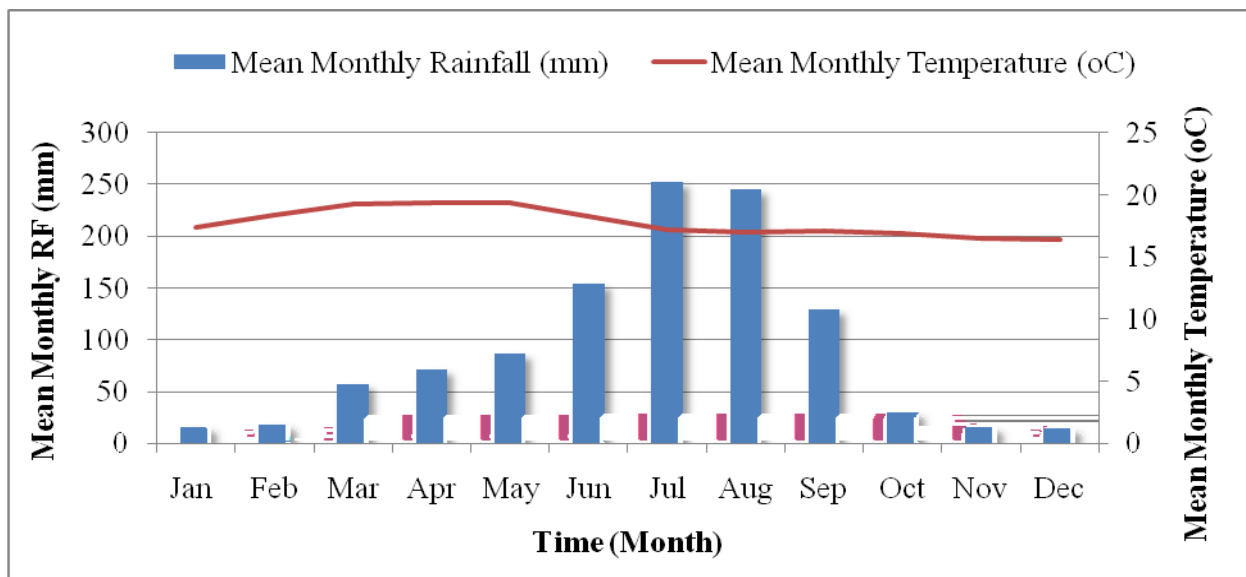
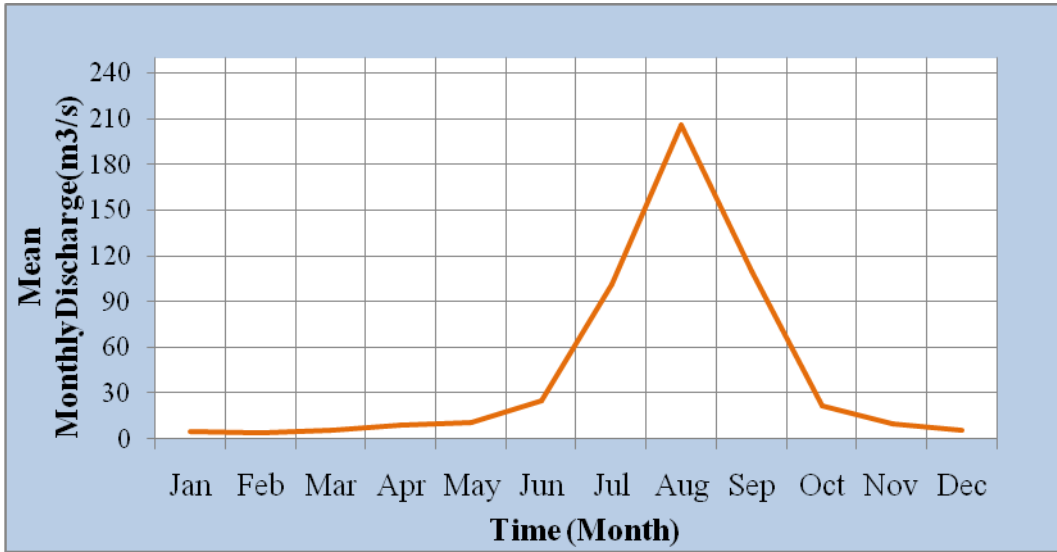


Figure 3. Mean Monthly Rainfall and Temperature of the study area between 1995 -2015.



(a)



(b)

Figure 4: Mean monthly (a) and annual (b) stream flow at hombole gauging station for the period 1995-2015

Agriculture, the most important sector of the Awash Basin economy, employs over 85% of the rural population (Halcrow, 2006). Both arable and livestock farming is widely practiced. Among crop farming includes cultivation of cereals, oil crops, pulses, vegetables, fruit, cotton and sugarcane are the main ones. In the lowland areas, Pastoralism and Agro-Pastoralism are widespread. The basin is the most developed one in Ethiopia due to availability of land and water resources coupled with its strategic location. The current net irrigated area is estimated at around 200,000ha (Awash Basin Authority, 2017). Of the irrigated land, 80% is managed by state enterprise and the rest by small holder farmers. Compared to the other parts, the upper valley has a higher proportion of perennial crops dominated by sugarcane grown by state farms. There are also significant areas covered by citrus fruits, vegetables, maize, groundnut and cotton grown in the upper valley. The middle awash valley is known to grow cotton dominantly covering about 85% of the irrigated land. Maize, banana and vegetable are also grown in the middle valley. In the lower valley of the basin, cotton is the dominant one with almost 90-92% coverage of the irrigated land.

3.2 Data Sources

Most of data inputs used in the hydrological (such as SWAT) model is directly or indirectly extracted from remotely sensed data. Some of the important data used in the hydrological modeling such as digital elevation model (DEM) are obtained from remote sensing. Remote sensing technology is commonly applied in studying land use and land cover changes, reporting and analysis of results including inputs to Geographic Information System (GIS) and also provides a basis for model building. For this study different data including topographic data (DEM), land use and land cover data, soil data and daily climatic data of variables like precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation were required. Accordingly, the DEM and the satellite imageries were obtained from the NASA website. The images were then ortho-rectified to UTM (Universal Transverse Mercator) projection using datum WGS 84 (World Geodetic System) zone 37N to enable it fit the SWAT model. The land use and land cover data were then generated using GIS and other relevant map of the study area. The stream flow was collected from the Ministry of Water, Irrigation and Energy. The required soil data was collected from a project and Harmonized World Soil Database (HWSD). Finally, the daily climatic data were collected from the National Meteorological Agency of Ethiopia.

3.2.1 Digital Elevation Model

Digital elevation model is required for the watershed delineation by using Arc SWAT watershed delineator tools. Accordingly, an SRTM raster format of DEM (30m*30m resolution) was obtained from NASA website for the specific study area. The data was then projected to Universal Transverse Mercator (UTM) on spheroid of WGS84 zone 37N.

3.2.2 Land use and Land cover maps as SWAT Input Data

Land use and land cover is one of the main factors influencing the hydrological properties of a watershed. In hydrological models like Arc SWSAT, it is also one of the main input data to describe and define the Hydrological Response Units (HRUs) of the watershed. The Arc SWAT model normally has predefined four letter codes for each land use category as presented in Table 4. These codes were used to associate the land use and land cover map of the study area to SWAT model land use database embedded in the model. While preparing the land use lookup-table, the land use types were made compatible with the input format need of the model.

Table 1. Land use/Cover Classification, SWAT Code and area coverage of the study area

Land use / Land Cover	Land use according to SWAT Database	SWAT code	Area(ha)	%
Water Body	Water	WATR	1456	0.19
Built up area	Urban	URBN	25510	3.34
Woody vegetation	Forest ever green	FRSE	32006	4.21
Grass land	Pasture/range land	GRAS	40854	5.37
Wet land	Herbaceous wet land	WEHB	1366	0.18
Cultivated land	Agricultural land close to grown	AGRC	655446	86.25
Bare land	Barren	BARR	3479	0.46

3.2.3 Soil Data as SWAT Input Data

Soil data of the study area comprising of physical and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content are the required input data for the Arc SWAT model. For this study, hence, it was obtained from MoWIE, Water and land resource center of Addis Ababa University and HWSO. Soil physico-chemical and hydrological properties were obtained from various sources like FAO-UNESCO soil databases, Berhanu et al. (2013) and Agricultural Transformation Agency of Ethiopia. Accordingly, Vertisols, Luvisols and Leptosols were found being the dominant soil types in the study area. Consequently, a user defined soil database was prepared for each soil layers and added to the SWAT user soil database.

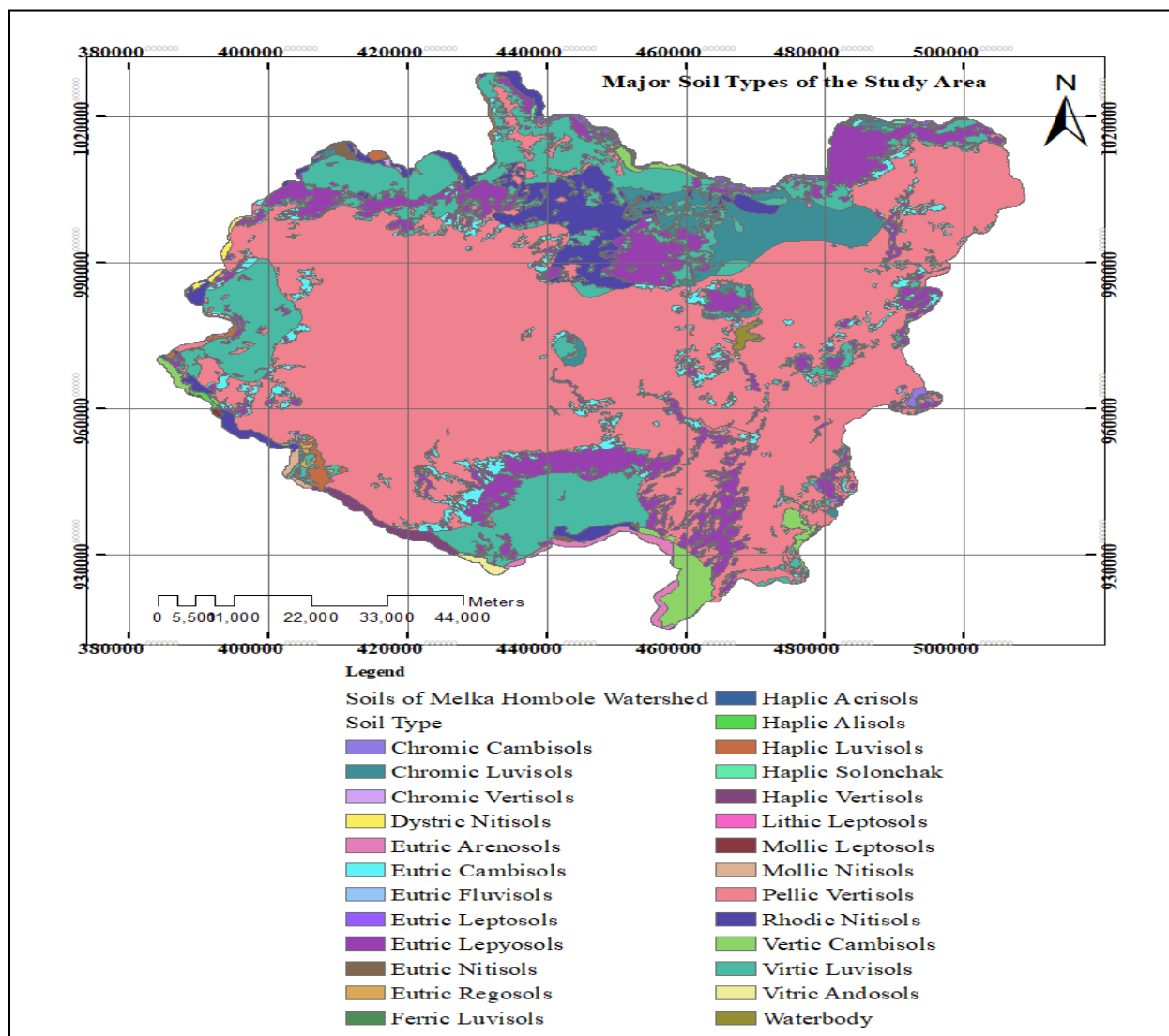


Figure 5. Soil Map of the study Area Land and Water resources center of AAU)

Table2. Soil types of the study area with symbols and areal coverage

Major Soil Type	Soil Code	Area	
		Hectare	Percentage (%)
Chromic Cambisols	CMc	582.07	0.07
Chromic Luvisols	LVx	30570.50	4.03
Chromic Vertisols	VRc	76.20	0.01
Dystric Nitisols	NTd	11.44	0.002
Eutric Arenosol	ARe	443.13	0.06
Eutric Cambisols	CMe	31855.51	4.2
Eutric Fluvisols	FLe	489.30	0.06
Eutric Leptosols	Lpe	113.21	0.01
Eutric Lepyosols	LYe	84639.13	11.13
Eutric Nitisols	NTe	1092.76	0.13
Eutric Regosols	RGe	758.12	0.1
Ferric Luvisols	LVf	11.00	0.001
Haplic Acrisols	ACh	11.13	0.001
Haplic Alisols	ALh	11.10	0.001
Haplic Luvisols	LVh	1965.04	0.25
Haplic Solonchak	Sch	204.80	0.02
Haplic Vertisols	VRh	804.77	0.09
Lithic Leptosols	Lpq	11.00	0.001
Mollic Leptosols	LPm	11.00	0.001
Mollic Nitisols	NTm	61.94	0.01
Pellic vertisols	VRp	453749.90	59.67
Rhodic Nitisols	NTr	30194.51	3.94
Vertic Cambisols	CMv	8063.82	1.02
Vitric Luvisols	LVv	114228.58	15.01
Vitric Andosols	ANv	110.19	0.01
Water body	WATER	1303.42	0.17

3.2.4 Weather Data

Daily climatic data is an important input data required by the Arc SWAT model to simulate hydrologic processes like stream flow which is the main focus area of this study. The data included daily precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. These data were obtained from the National Meteorological Agency of Ethiopia for the study area. The climatic data used for this study covered years from January 1995 to December 2015 which is 21 years of duration. The selected meteorological stations of the study area include Intoto observatory, Woliso Giyon, Addis Ababa Bole, Asgori, Kimoye and Tulubolo as shown in figure 10 below. The first three stations are first classes that have records on all climatic variables, whereas the others are third class stations. The table below depicts the general information of selected stations of the study area.

Table 3. Selected Meteorological stations names, locations and weather variables

Station Name	Latitude (Dec.deg)	Longitude (Dec.deg)	Rainfall	Max. Temp	Min. Temp	Relative humidity	Wind Speed	Sunshine hours
Intoto Observatory	9.01891	38.7475	✓	✓	✓	✓	✓	✓
Bole	8.981081	38.79871	✓	✓	✓	✓	✗	✓
Woliso Giyon	8.55	37.98333	✓	✓	✓	✓	✓	✓
Kimoye	9.008	38.33783	✓	✓	✓	✗	✗	✗
Tulubolo	8.6545	38.2065	✓	✓	✓	✗	✗	✗
Asgori	8.79	38.3342	✓	✓	✓	✗	✗	✗

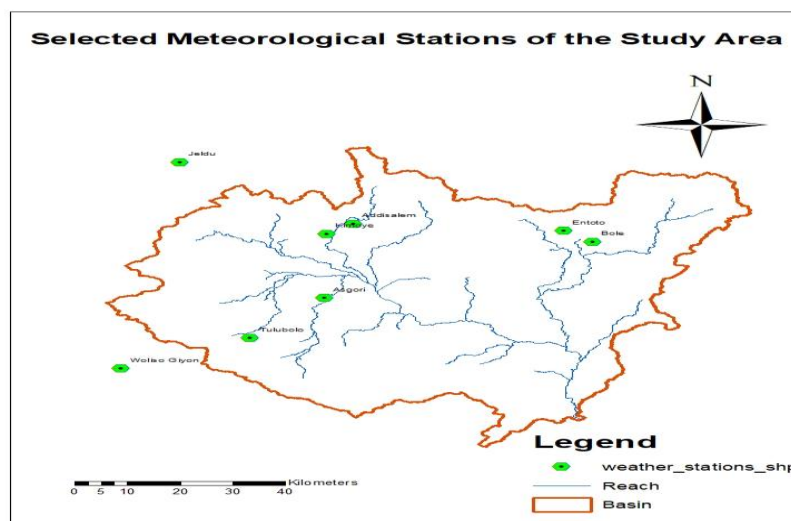


Figure 6. Location Map of Selected Meteorological stations in the Study Area

3.2.5 Hydrological Data

The stream flow data of the study area is needed for the calibration and validation of the SWAT model. Accordingly, the daily stream flow data (1995-2015) at Hombole gauging station was collected from the Ministry of Water, Irrigation and Energy of Ethiopia.

3.3 Methods

3.3.1 Filling Missing Weather Data

The climatic data collected from the selected six meteorological stations in the study area have missing data. However, since SWAT model has a built-in program called weather generator (WGEN), all the missing values were filled with a missing data identifier, -99. The weather generator first independently generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rainfall for the day. Finally, wind speed data is generated independently.

3.3.2 Checking the Consistency of Data

Double Mass Curve analysis (DMC) is the most common method of checking inconsistency of climatic records. The principle of double mass analysis is to plot accumulated values of the station under investigation against accumulated values of another station, or accumulated values of the average of other stations, over the same period of time. A change in the proportionality between the measurements at the suspect station and those in the region is reflected in a change of the slope of the trend line of the plotted points. The data series, which is inconsistent, is adjusted to consistent values by proportionality. Accordingly, double mass curve plot was made for the selected and were found consistent to each other.

3.3.3 Model Selection

Hydrological models have been developed for different reasons and have different forms. They are mathematical descriptions of the different components of the hydrologic cycle. However, hydrological models are generally developed to meet the primary objectives of enabling better understanding of the hydrologic processes and for hydrologic prediction in a watershed. Among the different hydrologic models, Arc SWAT model is selected for this study.

And the main reasons for selection of the model include:

- It has been applied in studies related to assessment of land use and land cover changes in different parts of the world including in Ethiopia and is proved for sufficiency of performance.
- The model can simulate the required hydrological process in the study watershed
- It has advantage of less demanding of input data.
- It is readily and freely available.

3.3.4 Description of SWAT Model

The Soil and Water Assessment Tool (SWAT Model) is one of the recently developed models released at the USDA-ARS by Dr. Jeff Arnold for the USDA Agricultural Research Service (Arnold et al., 1998; King et al., 2000). It is a distributed physically based model that 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 (Neitsch et al., 2005). SWAT is a basin-based, continuous-time model that operates on a daily time step to predict the impact of resource management on water, sediment and agricultural chemical even in the context of large complex watersheds. The interface of SWAT model is compatible with Arc GIS. It is embodied in Arc GIS that can integrate various readily available geospatial data to accurately represent the characteristics of the watershed. It further describes the impacts of spatial heterogeneity in two scale level subdivisions. First, the watershed is divided into a number of sub-basins based on drainage areas of the attributes. Then, each sub-basin is further divided into a number of Hydrologic Response Units (HRUs) based on unique land use, soil and slope characteristics. The SWAT model generally simulates eight major components: namely hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The major hydrologic processes that can be simulated by the SWAT model include surface runoff, evapo-transpiration, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998). One of the most important advantages of the model is that it can be used to model watersheds with less monitoring data.

SWAT needs digital elevation model (DEM), land use and land cover map, soil and climate data of the study area for simulation of the physical processes. The data are used as an input for the analysis of hydrological simulation of surface runoff and groundwater recharge. The model divides hydrological simulations of a watershed into two major phases which are the land and

the routing phases. The land phase just controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel of each sub basin. On the other hand, the routing phase considers the movement of the water, sediment and agricultural chemicals through the channel network to the watershed outlet. The land phase of the hydrological simulation is modeled based on the following water balance equation (Neitsch, et. al, 2005).

$$SW_t = SW_o + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad \text{Equation (1)}$$

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

SW_o is the initial water content (mm)

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 evapo-transpiration on day i(mm)

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

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

3.3.4.1 Surface Runoff

Surface runoff is the portion of rainwater that is not lost due to interception, infiltration and evapo-transpiration (Solomon, 2005). It generally occurs when the rate of precipitation exceeds that of the rate of infiltration. The SWAT model presents two methods for estimating the surface runoff of the study area. The Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911) are the ones offered for the modeler. For this study, the SCS curve number method was adopted based on the availability of daily step rainfall data unlike the Green and Ampt method which requests sub-daily time step rainfall. The general equation for the SCS curve number method is expressed by the equation:

$$Q_{surf} = (R_{day} - I_a) 2 / (R_{day} - I_a + S) \quad \text{Equation (2)}$$

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 generally varies spatially and temporally due to changes with land surface features such as soils, land use, slope and management practices and the changes in soil water content. Mathematically it is expressed as:

$$S = 25.4 * (1000/CN - 10) \quad \text{Equation (3)}$$

Where, CN refers to the curve number for the day which is the function of land use practice, soil permeability and soil hydrologic group. The initial abstraction, I_a , is usually approximated as $0.2S$ and hence the above equation 3 is described as:

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

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

3.3.4.2 Potential Evapo-transpiration

Potential Evapo-transpiration represents the water that evaporates from plants (transpiration) and the one from water bodies and soil. Evaporation is, interestingly, the primary mechanism by which water is removed from a watershed. Hence, an accurate estimation of evapo-transpiration is critical for the assessment of water resources and the impact of land use change on them. Although there are many methods developed to estimate potential evapo-transpiration (PET), the SWAT model provides three options for the calculation of PET. These are Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and the Hargreaves (Hargreaves et. al., 1985) method. The methods have different level of climatic data requirements. While Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind speed and the Priestley-Taylor method requires solar radiation, air temperature and relative humidity, Hargreaves method requires only air temperature.

For this study, therefore, the Penman-Monteith was selected as it is a widely used method and all the required climatic data are available.

3.3.4.3 Ground Water Flow

To simulate the ground water process in a watershed, the SWAT model splits the groundwater in to two main aquifer systems namely; a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer that contributes return flow to streams outside the watershed (Arnold et al., 1993). The water balance equation for a shallow aquifer system is expressed below as:

$$aq_{sh,i} = aq_{sh,i-1} + W_{rchrg} - Q_{gw} - W_{revap} - W_{deep} - W_{pump,sh}$$

Equation (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).

3.3.4.4 Flow Routing Phase

The second component for the hydrologic system simulation of a watershed used by the model is the routing phase. It comprises of the movement of water, sediment and other constituents like nutrients and pesticides in the stream network of the watershed.

Here again two options are offered to route the flow in the channel networks. The variable storage and Muskingum are the methods provided. While the variable storage method uses a simple continuity equation in routing the storage volume, the Muskingum method models the flow as a combination of both wedge and prism storages. According to this method, when a flood wave advances into segment of a reach, the inflow exceeds outflow and hence a wedge of storage is produced.

Therefore, as the flood wave recedes, 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 which is formed by a volume of constant cross-section along the reach length. This study adopted the variable storage method for the sake of simplifying modeling of the study area. The method was developed by Williams et al. (1969) and the equation is given by:

$$\Delta V_{stored} = V_{in} - V_{out} \quad \text{Equation (6)}$$

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 (m^3 water), and

V_{out} is the volume of outflow during the time step (m^3 water).

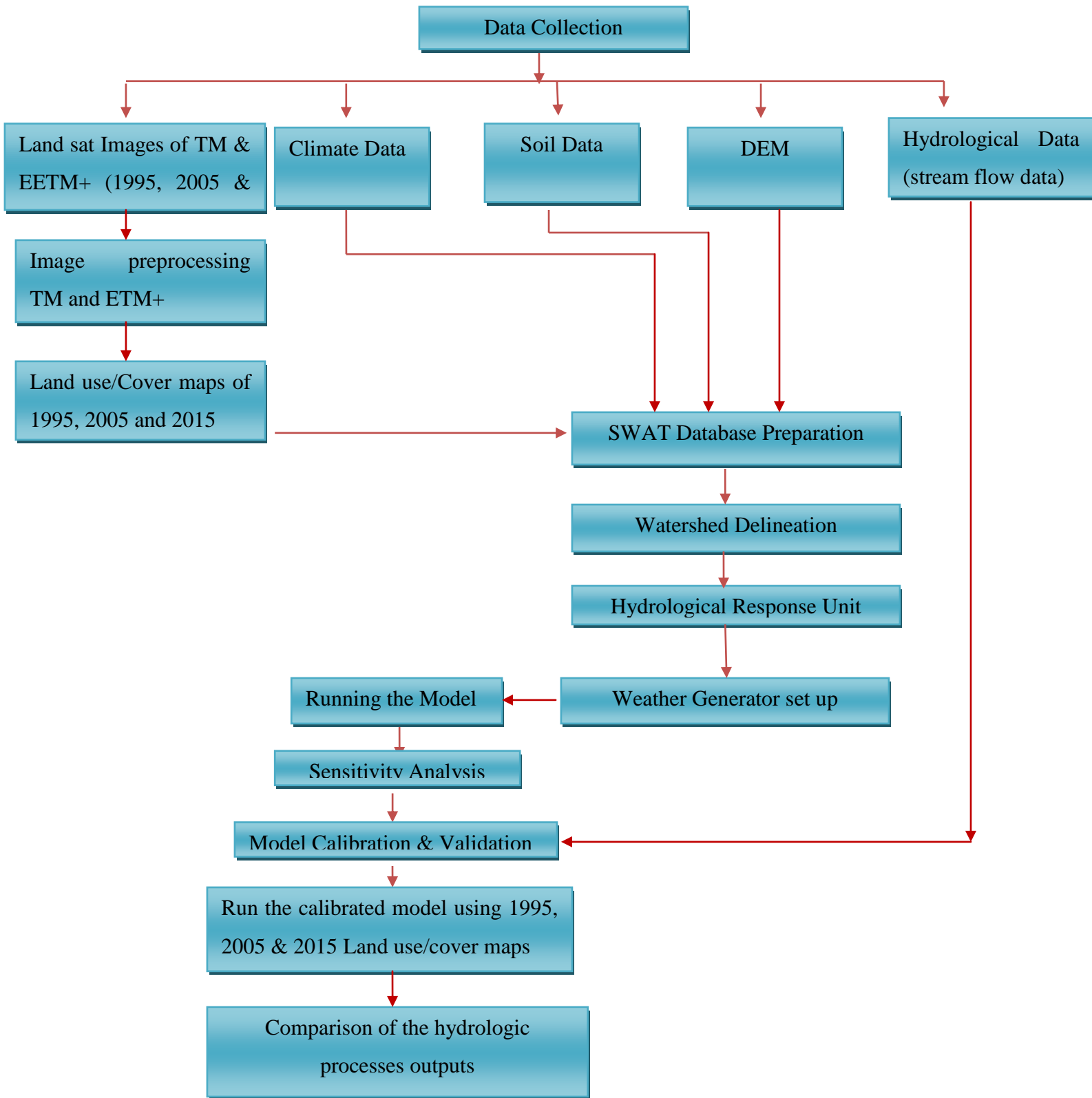


Figure 7. Overall Frame Work of the Study

3.3.5 Image Processing

Land use and land cover data or maps of different time periods of the study area were an important input data for the model simulation and hence the maps were prepared by processing satellite images. For the purpose of ease differentiation and change detection of the land use and land cover of the area, land sat imageries of six bands were used for the period of 1995-2015. Land sat TM and ETM⁺ sensors were selected for the study period. The satellite images were downloaded in zipped files from the United State Geological Survey (USGS) website and extracted to Tiff format files. For simple discrimination of the surface features, the satellite images were composed using the RGB false color composition. Accordingly, the acquisition / / 2 / 1 The figure below also shows the map for path and row of the study area used to download the satellite image.

Table 4. Summary of the profile of satellite image acquisition

Path/Row	Acquisition date	Sensor	Resolution (m)	Producer
168/054 169/054	January 01, 1995	Landsat 5, TM	30	USGS
168/054 169/054	February 02, 2005	Landsat 7, ETM ⁺	30	USGS
168/054 169/054	January 28, 2015	Landsat 8, OLI ⁺	30	USGS

3.3.6 Land Use and Land Cover Classes

Generation of land use and land cover maps for the study area was taken as required input data. Land use and land cover change detection generally requires developing and defining homogeneous land use and land cover units as a priority task. For this purpose, therefore, sources such as remote sensing, relevant information of previous researches in the study area and local knowledge of the area were employed to identify the land use and cover. Accordingly, the land use and land covers types classified are described as follows:

Table 5: Description of land use and land cover types

S/No	Type	Description
1	Water body	It represents areas which are permanent water like lakes, ponds as well as rivers and its main tributaries.
2	Urban (Built up area)	It characterizes areas with a permanent concentration of people, residential buildings and houses ; and other man-made infrastructure and the like.
3	Woody Vegetation	Refers to land covered with dense trees including ever green forest land, mixed forest, plantation forests as well areas with tree but open and dense, dry regions with undergrowth of grasslands. Densely spaced and scattered trees but dominated by single species that are commonly found in the lowlands are categorized under this land use. Finally, areas with shrubs, bushes, small trees with little wood and mixed with some grasses are classified here as woody vegetation.
4	Grass land	Refers to areas covered with grass and bare lands that have little grass or no grass cover. It also includes other small seized plant species.
5	Wet land	represents marshy lands, swamps and all the time wet and covered by usually grass found along riversides, lakes etc.
6	Cultivated (Crop) land	are areas used for crop cultivation, both annuals and perennials coupled with dense and long trees with dominantly Enset, crop mixed with chat, Enset mixed with chat along with areas dominantly covered by coffee, banana and mango which are closely associated with the cultivated fields are categorized here due to the difficulty of identifying such kind of land cover during classification.
7	Bare land	It is an area of thin soil, sand, or rocks or the area with no dominant vegetation cover on at least 90% of areas covered lichens or mosses, unusable and uncovered lands and areas with highly degraded lands with exposed rock or soil.

3.3.7 Image Classification

Image classification is a process of assigning pixels to predefined land use and cover classes. To obtain a better accuracy in the classification process, consistency and commitment is required in addition to its difficulty and time consumption nature. Therefore, as factors such as classification methods, algorithms, collection of training sites affect the result significantly, adequate concern was taken to minimize errors. For the image classification, supervised approach was adopted so as to have acceptable classification accuracy. This method is used to cluster pixels in a data set into classes corresponding to user defined area of interest or training sites which are selected as representative areas to be mapped in the output. Supervised classification was done using Maximum Likelihood algorithm. Training classes were defined prior to performing supervised classification. Accordingly, seven categories were identified based on the nature and similarity of the use and cover types.

3.3.8 Accuracy Assessment

Accuracy assessment of the classified images was conducted using the confusion matrix (error matrix) approach taking the original mosaic and the Google Earth images and other relevant maps of the study area as references. The study has adopted the most widely used method of image classification accuracy assessment technique called error matrix or confusion matrix (Manandhar et. al., 2009). The analysis was done with Arc GIS geo-processing tools. From the

$\frac{U}{U + V}$ accuracy were determined. The overall accuracy was applied to indicate the accuracy of the whole classification result. It is calculated by identifying the number of correctly classified pixels and then divided by the total number of pixels involved in the error matrix analysis.

U represents that same class with the ground truth or reference data. The third accuracy measure, $\frac{U}{U + V}$, denotes the probability that a pixel on reference data has been correctly classified. In addition, a Kappa coefficient was used for further accuracy assessment. Kappa measures the percentage of data values in the main diagonal of the table and then adjusts these values for the amount of agreement that could be expected due to chance alone. The formula is presented below.

Generally, a value of K between 0.2 and 1 is considered acceptable.

$$K = \frac{P_o - P_e}{1 - P_e}$$

Where: K is Kappa coefficient

P_o is sum of diagonal values

P_e is the sum of the products of columns and rows

As a general rule, minimum of 50 to 75 samples per each classified map class is recommended sufficient enough for the matrix analysis. Accordingly, 50 samples were taken from each class for the accuracy assessment of the image classification and the three accuracy measures were determined.

3.3.9 Change Detection Analysis

Remotely sensed satellite images are very important in obtaining land use and land cover change detection at various spatial and temporal scales. In this study three time periods change detection has been made i.e. for 1995, 2005 and 2015 years. These time periods were chosen based on the availability of quality satellite image and other data like weather and hydrological data in the study area. The LULC change detection was performed using post classification cross-tabulation approach in Arc GIS software. This method was employed as it is widely used and easy to understand. The classified images were compared in the three time periods and change statistics was computed by comparing the values of area of one LULC data set with the corresponding value of the next data set for each period. The rate of change of each land use and land cover was calculated using the following formula.

$$\text{Percent change} = \frac{X - Y}{Y} * 100$$

Where, X is the final area of LULC and Y initial area of LULC

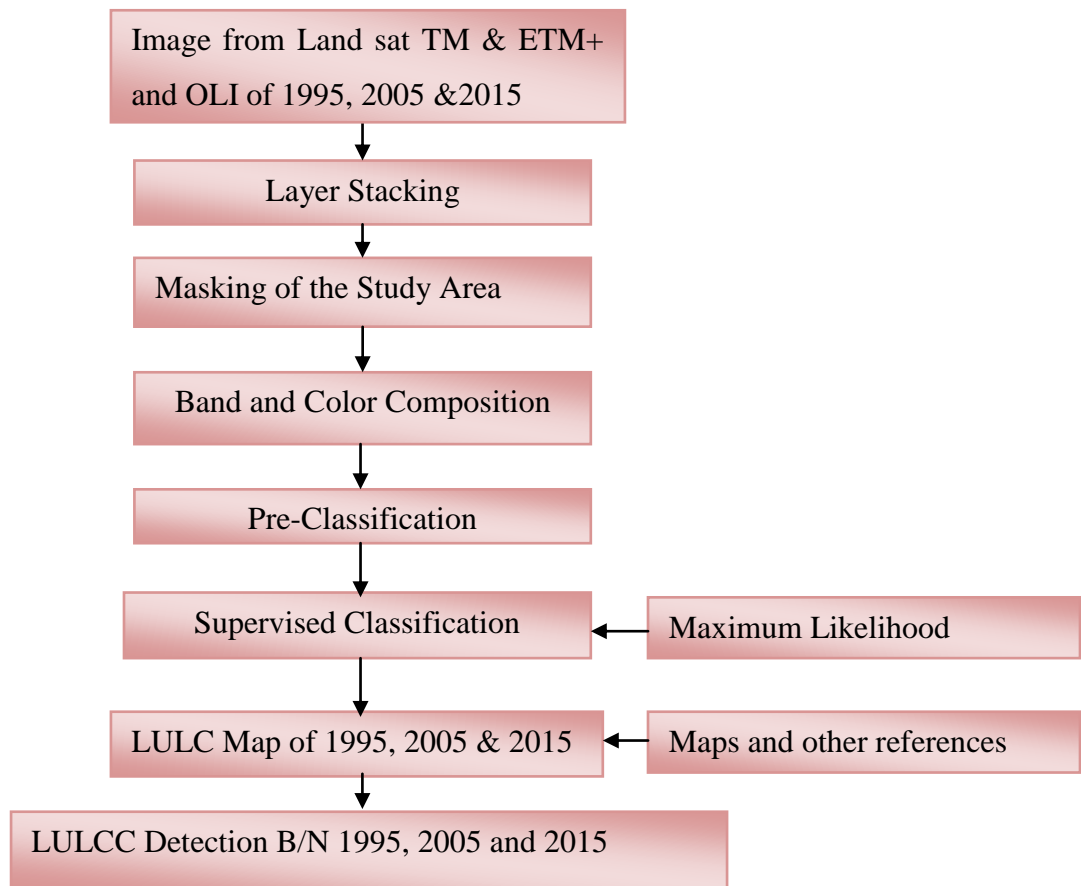


Figure 8: Flow chart for land use and land cover classification and change detection process.

3.4 Arc SWAT Model Set Up

3.4.1 Watershed Delineation

At first, the Arc SWAT model was made to set up the project of the study area. The watershed delineation process generally consists of five major steps, i.e. DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. Consequently, watershed and sub watershed delineation was performed using the SRTM 30 m by 30m resolution DEM data using the watershed delineation tool embedded in the model. Therefore, using the watershed delineation tool, the study area was delineated in to 57 sub basins having an estimated total area of 7,601.17 km² applying the 8312.5ha default area threshold value suggested by the Arc SWAT interface. The topographic parameters like elevation and slope of the study area were also generated from the DEM data. Therefore, the elevation of the watershed ranged from 1688m to 3576m above mean sea level, with the highest elevation laying at the Becho plateau and the lowest at the watershed outlet, Melka Hombole.

After watershed delineation was conducted, the slope classification was carried out based on the DEM of the study area as a pre requirement for the definition of hydrologic response units. Therefore, the slope value of the study area were reclassified in percent in to the following five classes considering the general topography of the area and the objectives of the study as well and is presented in Table below.

Table 6. Slope Classes of the study area (developed based on FAO and relevant sources)

Classes	Slope range (%)	Area	
		Ha	%
Class 1	0-5	297904.35	39.40
Class 2	5-10	223349.04	12.60
Class 3	10-15	95265.96	13.40
Class 4	15-30	101326.80	5.07
Class 5	> 30	38310.55	29.54

3.4.2 Analysis of Hydrologic Response Units

After the delineation of the watershed is completed, sub watersheds were divided into different hydrologic response units (HRUs) through assignment of threshold values for soil, land use and slope. This helps to eliminate minors or insignificant portions of the watershed area. Then, the remaining area is reapportioned so as to model 100 % of their respective areas by the SWAT model. By loading land use and land cover and soil maps in to the set project, HRUs were created. Promptly two common options were provided in the model to define the HRUs. The first was by assigning a single HRU and the other was with multiple HRUs option. In this study, therefore, the multiple HRUs option was employed aiming at obtaining reliable results of simulation.

Then, as per the recommendation of the SWAT user for most modeling application, a 20 % land use/land cover threshold, a 10 % soil threshold and a 20 % slope threshold was

adopted. Finally, the study area was divided into 273 HRUs, each with a unique combination of land use and soil.

3.4.3 Weather Generator

The weather generator model called WXGEN of the arc SWAT model solves the problem of missing data by generating data from the observed ones (Danuso, 2002). It just requires the daily data of all climatic variables from measured data or generated values using monthly average data. Accordingly, measured data for the climatic variables of the study area including daily rainfall, maximum and minimum temperature, relative humidity, wind speed and solar radiation were collected for the study period and used in this study. To generate the climatic data, weather parameters were developed by using the pcpSTAT01 program and dew point temperature calculator program (DEW02). Both the programs are often used with SWAT modeling as an alternative to easily obtain required parameters for user weather database by using monthly climatic data. The pcpSTAT01 program calculates statistical parameters of average daily precipitation data used by SWAT in the userwgen.dbf. Similarly, DEW02 is a program designed to calculate the average daily dew point temperature per month using maximum and minimum daily temperature data and daily humidity data as well. The daily weather variables from the selected six meteorological stations were used to generate the weather database for the simulation process.

3.4.4 Sensitivity Analysis

Sensitivity analysis is a method of minimizing the number of parameters to be used in the calibration step by making use of the most sensitive parameters largely controlling the behavior of the simulation process. This helps to reduce the uncertainty in the model outputs. Sensitivity analysis is hence important to identify and rank parameters that have significant impact on the specific model outputs of interest (Van Griensven et al., 2006). This study conducted sensitivity analysis prior to the calibration process for the sake of identifying more important parameters for model calibration. The average monthly stream flow data for 10 years from 1998 to 2007 of the hombole stream flow gauging station to compute the sensitivity of the parameters. The SWAT-CUP application was employed to conduct the sensitivity analysis.

In the sensitivity analysis process, selected parameters were entered for the analysis with the default lower and upper parameter bounds. Therefore, selected 26 flow parameters were considered for the analysis with default values as recommended by Van Griensven et al. (2006).

3.4.5 Model Calibration and Validation

Model calibration was done for the purpose of obtaining optimum values. There are different approaches to calibration of models of which the deterministic approach is now outdated and unacceptable as it results in a single set of parameters claiming to represent the best simulation. Consequently, the stochastic approach which recognizes the errors and uncertainties in modeling works tries to capture lack of understanding of the processes in natural systems. However, there is an intimate relationship between calibration and uncertainty (Abbaspour, et. al., 2015). Therefore, any analysis with a calibrated model must include the uncertainty in the result by propagating the parameter uncertainties. SWAT-CUP program was adopted for the sensitivity analysis and the module of the program performs sensitivity analysis. Two types of sensitivity analysis are normally allowed namely Global Sensitivity and One-at-a-time sensitivity analysis. In this study the global method was adopted. Global sensitivity analysis was performed after iteration. Parameter sensitivities are determined by calculating the following multiple regression system, which regresses the Latin hypercube generated parameters against the objective function values (in file goal.txt):

$$g = \alpha + \sum_{i=m}^{i=1} \beta_i b_i$$

A t-test is then used to identify the relative significance of each parameter b_i . The sensitivities given above are estimates of the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing. This gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters. A multiple regression analysis is used to get the statistics of parameter sensitivity. The t-stat is the coefficient of a parameter divided by its standard error. It is a measure of the precision with which the regression coefficient is measured.

probably different from 0 and the parameter is sensitive. It could be possible to compare the t-stat of a parameter with the values in the Student's t-distribution table to determine the p-value. The Student's t-distribution describes how the mean of a sample with a certain number of observations is expected to behave. The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05) indicates that the null hypothesis can be rejected. Conversely, a larger p-value suggests that changes in the predictor are not

associated with changes in the response. So that parameter is not very sensitive. A p-value of < 0.05 is generally accepted point at which to reject the null hypothesis. With a p value of 0.05, there is only a 5% chance that results to come up in a random distribution, so that can be said with a 95% probability of being correct that the variable is having some effect. In this analysis, the larger (in absolute value) the value of the t-stat, and the smaller the p-value, the more sensitive is the parameter. Sequential Uncertainty Fitting Version -2 (SUFI-2) optimization program of the SWAT-CUP was used. It is an optimization algorithm of stochastic calibration approach in which uncertainty in parameters, expressed as ranges (uniform distributions), accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. Propagation of the uncertainties in the parameters leads to uncertainties in the model output variables, which are expressed as the 95% probability distributions. These are calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable generated by the propagation of the parameter uncertainties using Latin hypercube sampling. This is referred to as the 95% prediction uncertainty, or 95PPU. These 95PPUs are the model outputs in a stochastic calibration approach. It is important to realize that we do not have a single signal representing model output, but rather an envelope of good solutions expressed by the 95PPU, generated by certain parameter ranges. The more variables (representing different processes) include in the objective function, the more likely we are to avoid the wrong processes. In SUFI2, two factors were considered to get reasonable result. *P-factor* is the percentage of observed data enveloped by the SWAT modeling result, the 95PPU and *R-factor* is the thickness of the 95PPU envelop. The SWAT _CUP program suggests for *P-factor*, a value of $>70\%$ for discharge, while having *R-factor* of around 1. The study employed R^2 and NS as objective function. Following the calibration, Validation was done to compare the model outputs with an independent measured data set using the same program. This helps to make sure that the simulated values are within the acceptable limits. For the model validation process, the measured data of average monthly stream flow of 7 years (from January 2008 to December 2015) were used including the warm up period.

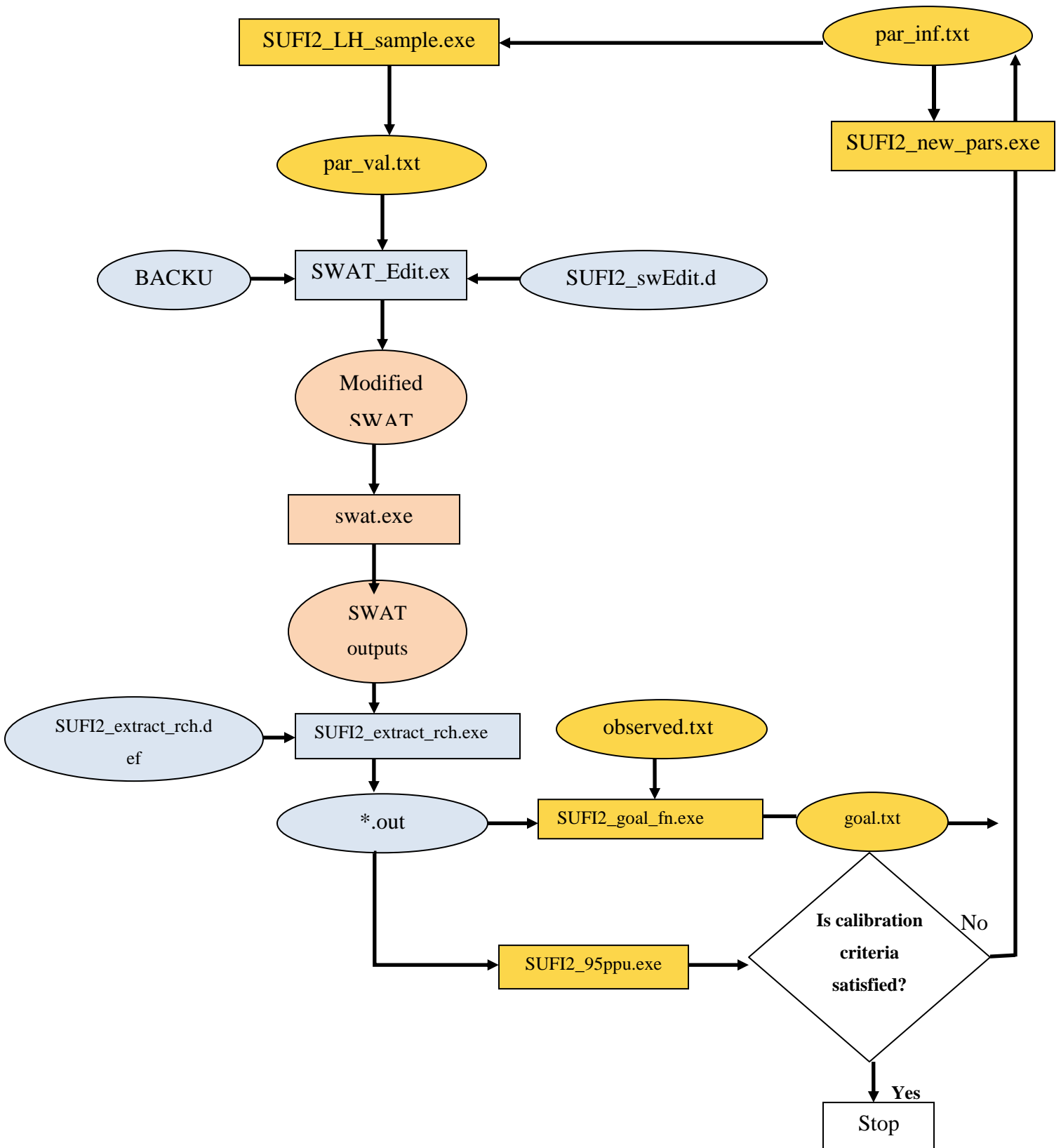


Figure 9. Step-by-step creating of SWAT-SUFI2 input files (Source: SWAT Calibration and Uncertainty Programs - A User Manual, 2012)

3.4.6 Model Performance

As models are only representatives of the real processes, limitations are observed in terms of performance. Therefore, this step is necessary to evaluate the model outputs against the observed data. Among the various methods of evaluating model performance during the calibration and validation periods, this study employed the commonly used methods namely, the coefficient of determination (R^2) and Nash and Sutcliffe simulation efficiency (ENS). The coefficient of determination (R^2) describes the magnitude of linear relationship between the observed and the simulated values. It ranges from 0 to 1, with the higher value indicating less error variance. The value of R^2 which is greater than 0.6 is considered sufficient and acceptable for hydrological modeling (Santhi et. al., 2001). Similarly, the Nash Sutcliffe simulation efficiency (ENS) indicates that how well the plots of observed versus simulated data fits. The values of ENS range from negative infinity to 1. And, a value of greater than 0.5 is generally considered as acceptable. The R^2 is calculated using the equation:

$$R^2 = \frac{\sum [X_i - X_{av}][Y_i - Y_{av}]}{\sum [X_i - X_{av}]^2 \sum [Y_i - Y_{av}]^2}$$

Equation 7

Where, X_i measured value (m³/s)
 X_{av} average measured value (m³/s)
 Y_i simulated value (m³/s) and
 Y_{av} average simulated value (m³/s)

ENS is computed using the following equation:

$$ENS = 1 - \frac{\sum (X_i - Y_i)^2}{\sum (X_i - X_{av})^2}$$

Equation 8

Where, X_i measured value
 Y_i simulated value and
 X_{av} average observed value

3.4.7 Evaluating the Impact of LULC Changes on Hydrological processes

The main focus of this paper as stated in the objective session is to assess the impact of the land use and cover change on the stream flow of the upper awash sub basin. Therefore, this evaluation was first done by comparing the average annual basin values for each of the land use scenarios of the study area. To simulate the impact of land use and land cover change, three different time periods, i.e. 1995, 2005 and 2015 were considered. For each map, three independent simulation runs were undertaken on a monthly basis using the generated land use and land cover maps keeping other input parameters constant. Consequently, seasonal stream flow variability due to the land use and land cover change was assessed. Next, comparison was made on surface runoff and ground water flow contributions to stream flow based on the three simulation outputs. The monthly discharge change during the wet months (June to August) and dry months (January to February) were calculated and used as indicators to estimate the effect of land use and land cover change on the stream flow. Similarly, the changes in ET and total water yield were compared based on simulation outputs.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Land Use and Land Cover Analysis

4.1.1 Accuracy Assessment

The image classification accuracy assessment was used to determine the correctness of the classified images. It was performed using confusion matrix. Using the Google Earth Image and relevant maps of the study area, 50 randomly selected points or GCPs were compared with the corresponding classification. All the three accuracy assessment types were then performed and have been presented below.

Table 7. Confusion matrix for the image classification of 2015

		Ground Reference								
		WB	U	WV	GL	WTL	CL	BL	Row total	User's accuracy
Classification result	WB	50	0	0	0	3	0	0	53	94.3
	U	0	47	0	0	0	0	0	47	100
	WV	0	0	43	0	5	0	0	48	89.6
	GL	0	1	1	43	0	3	0	48	89.6
	WTL	0	0	0	0	35	0	0	35	100
	CL	0	2	6	7	7	47	8	77	61
	BL	0	0	0	0	0	0	42	42	100
	Column Total	50	50	50	50	50	50	50	350	
	Producer's Accuracy	100	94	86	86	70	94	84		Overall Accuracy= 87.71

Note: WB=Water body; U= Urban land; WV=Woody Vegetation; GL= Grass land; WTL= Wet land; CL=Cultivated land and BL= Bare land

The result of Kappa coefficient was found to be 0.97 which is a very good agreement.

4.1.2 Land Use and Land Cover Change Detection

The figures below show the result for land use and land cover maps of 1995, 2005 and 2015.

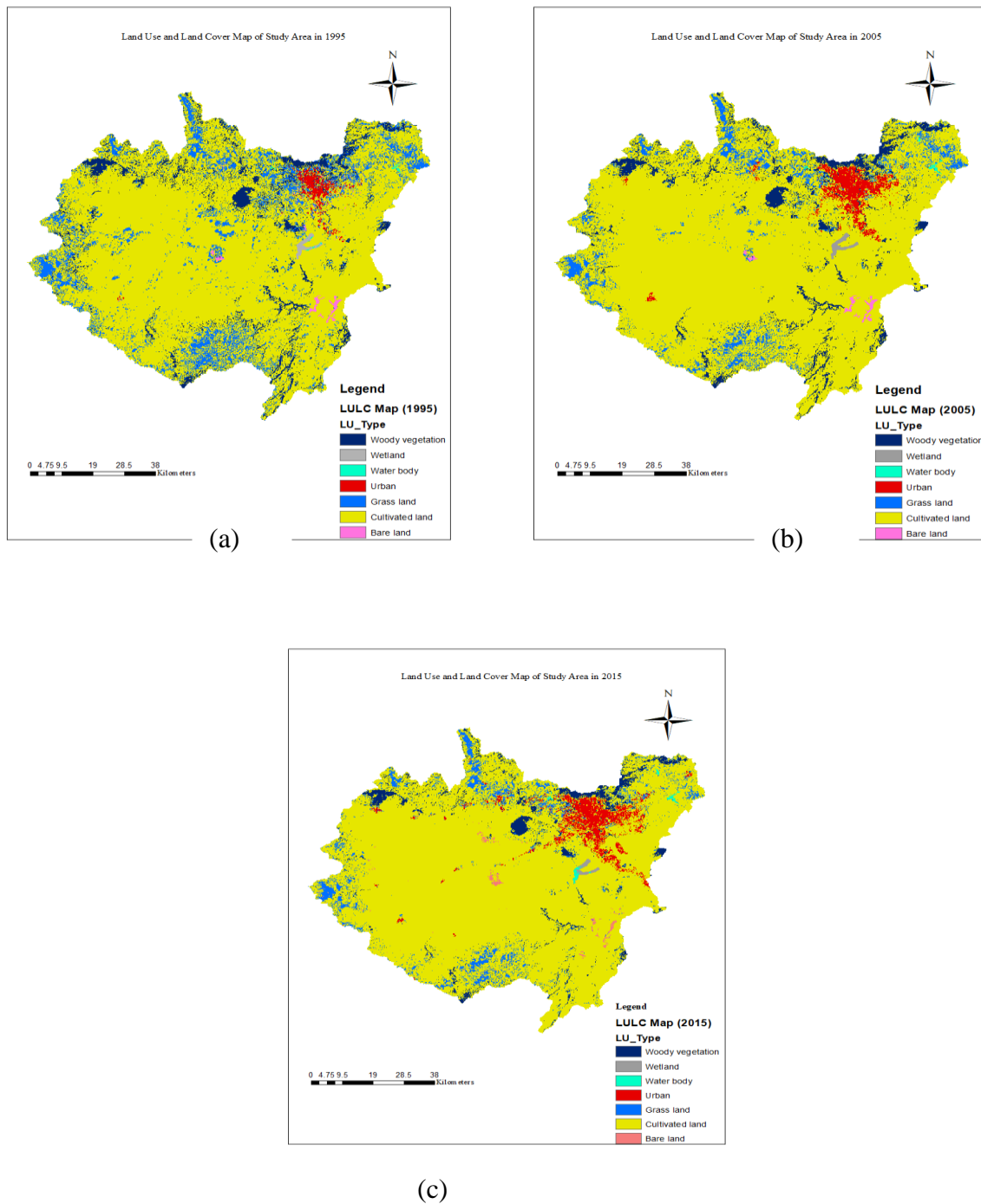


Figure 10. Land Use and Land Cover maps of the study area in 1995(a), 2005 (b) and 2015(c)

The result has shown that the cultivated land, urban and water body have been in an increasing trend throughout the study period. On the other hand woody vegetations (Forest, Wood land and Shrub land) and grass land have shown a decreasing trend in the same period which could be attributed to expansion of agriculture and urban areas. Wetland has generally declined by 0.06%. The bare land coverage of the area has on average decreased by 0.04% which might be due to deforestation and land degradation resulted from unsustainable of watershed management practices.

Grass land and woody vegetations were the land cover types which are dominant next to agricultural land. Their area coverage was 19.04% and 15.2% in 1995 respectively. However, their share has decreased to 9.89% and 6.86% respectively in 2015. This indicates that the changes in the land coverage of agriculture, urban, water body and bare lands most probably could be at the expense of those two land cover types. To elaborate more, it can be explained in such a way that the cultivated land has generally increased by 14.23% from 1995 to 2015 and that of urban increased by 3.05% for the same period which were significant changes occurred in the study area at the expense of woody vegetations and grass lands while woody vegetations and grass land have totally decreased by 9.15% and 8.34% in 2015 respectively in the study period. In general, during the last two decades, the cultivated land, urban area and water body have increased significantly whereas the woody vegetation and grass land have decreased in a significant manner.

A Study conducted in Hombole watershed indicated that forest, grass land and wet land have decreased by 42.8%, 18.23% and 1.9% while agriculture and urban lands increased by 30.01% and 0.78% respectively (Beyene et. al, 2018). Similarly, a study conducted in Akaki catchment reported that cultivated land has increased by 24.35% from 1973 to 2000; and grass land and forest have decreased by 32.2% and 17.7% respectively for the same period (Berga, 2011). The detail change statistics for the three time periods is summarized and presented in the table below.

Table 8. Area Coverage of LULC types and change statistics for the period of 1995 and 2015

Land Covers	1995		2005		2015		2005-1995		2015-2005		2015-1995	
	Km2	%	Km2	%	Km2	%	Km2	%	Km2	%	Km2	%
Water body	5.97	0.08	6.55	0.09	14.75	0.19	0.58	0.01	8.20	0.11	8.78	0.12
Urban land	101.52	1.34	211.31	2.78	333.91	4.39	109.80	1.45	122.6	1.60	232.39	3.05
Woody vegetation	1153.83	15.20	692.71	9.13	522.51	6.86	-461.12	-6.08	170.2	-2.26	-631.32	-8.34
Grass land	1445.35	19.04	852.56	11.23	752.74	9.89	-592.79	-7.81	99.82	-1.34	-692.61	-9.15
Wet land	18.19	0.24	20.50	0.27	13.59	0.18	2.30	0.03	-6.91	-0.09	-4.61	-0.06
Cultivated land	4851.19	63.82	5795.88	76.21	5941.28	78.06	944.69	12.39	145.4	1.84	1090.09	14.23
Bare land	24.96	0.33	21.49	0.28	22.23	0.29	-3.47	-0.05	0.74	0.01	-2.73	-0.04
Total	7601		7601		7601							

4.2 Hydrological Modelling

4.2.1 Calibration and Validation of Stream Flow Simulation

Calibration result of the SWAT model showed that acceptable values of R^2 and NS were obtained. A value of 0.82 and 0.81 was obtained for R^2 in calibration period from 1995 to 2007 (including 3 years of warm up period to mitigate unknown initial conditions) respectively and a value 0.76 and 0.75 were obtained for NS in the validation period from 2008 to 2015. Graphical presentation for calibration and validation simulation results is presented in the figures below.

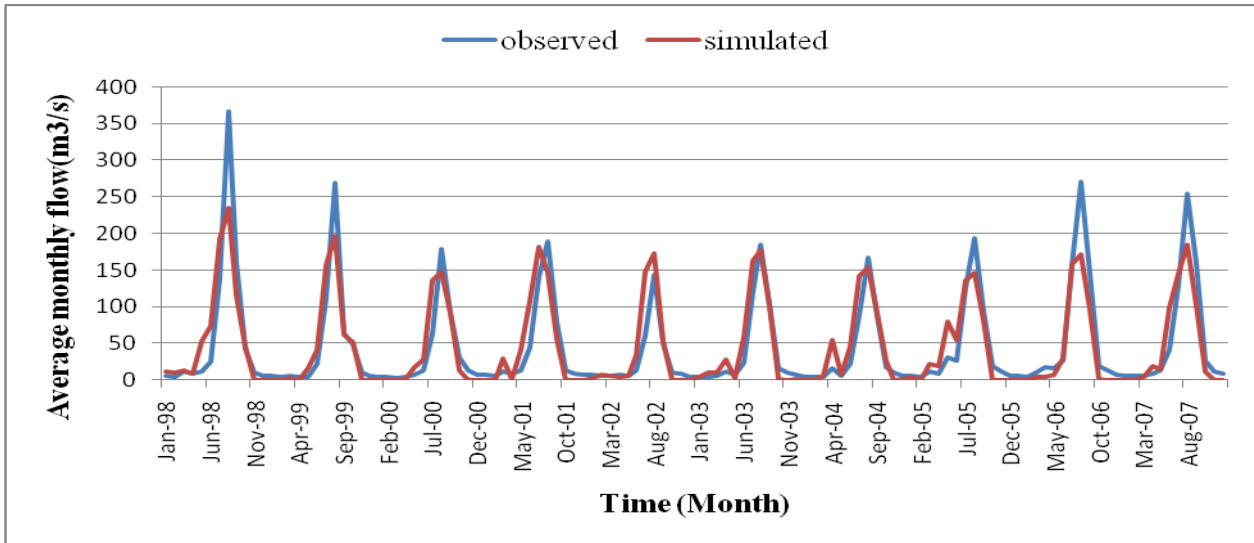


Figure 11. Result of calibration for average monthly stream flow for a period from 1998 to 2007

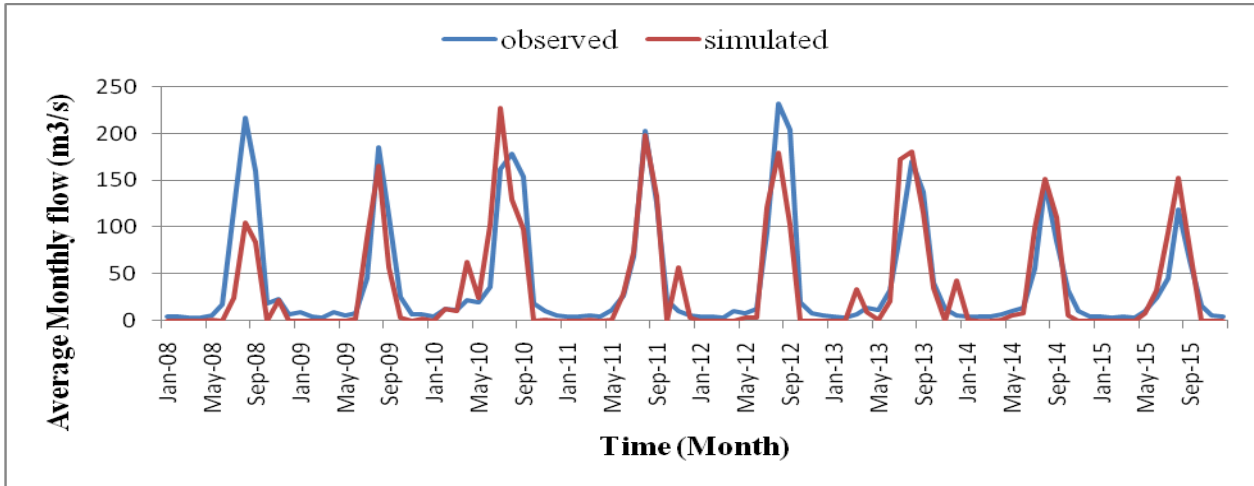


Figure 12. Result of Validation for average monthly stream flow for a period from 2008 to 2015

The measured and simulated average monthly flow for the study area in the calibration period was obtained to be 44.65 and 45.18 m³/s, respectively. Similarly, the measured and simulated average monthly flows for the validation period were 41.05 and 36.24 m³/s, respectively. These results showed that there is a sensible agreement between the measured and the simulated values in both calibration and validation periods.

Table 9. Measured and simulated monthly stream flow in calibration and validation

Period	Average monthly flow (m ³ /s)		R ²	ENS
	Measured	Simulated		
Calibration Period	44.65	45.18	0.82	0.81
Validation Period	41.05	36.24	0.76	0.75

As indicated in the above table, the model performance values for calibration and validation of the flow simulations are adequately satisfactory. This indicates that the physical 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 for different scenarios of the watershed.

Studies that were conducted in different parts of the basin also showed comparable results. For example, Berga (2011) reported that the SWAT model showed a good match between measured and simulated flow of Akaki catchment both in calibration and validation periods with ENS value of 0.81 and R² of 0.87 and ENS value 0.76 and R² of 0.85 respectively. Through hydrological modeling of the upper awash basin, Beyene et al. (2018) indicated that the average monthly flow simulated with SWAT model were reasonable accurate with ENS value of 0.77 and R² of 0.86 for calibration and ENS value of 0.76 and R² of 0.84 for the validation periods. Similarly, the study in Kesem watershed indicated that the SWAT model can represent the hydrological process well after obtaining ENS value of 0.71 and R² of 0.87 for calibration phase and ENS value of 0.77 and R² of 0.89 for validation. Therefore, it can be seen that the calibration and validation results of this study is in a good agreement with similar studies conducted in the basin. The following figures show the values of the scatter plots of the measured and simulated monthly flow data for the calibration and validation periods. It is observed that there is a fine linear correlation between the measured and simulated values.

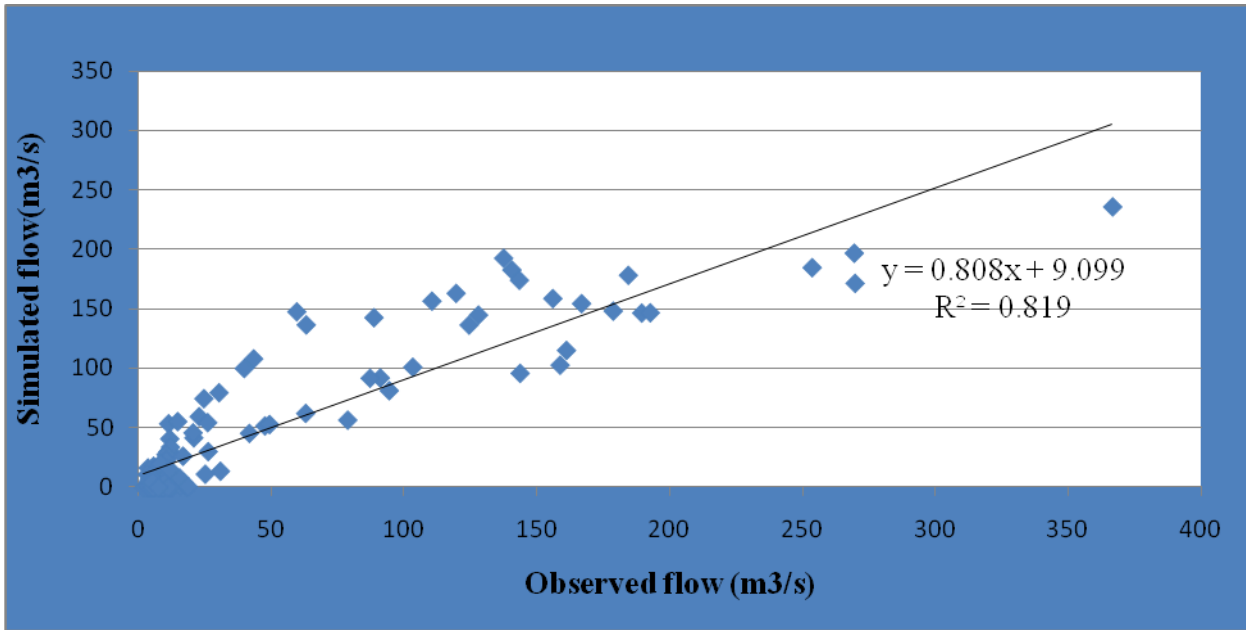


Figure 13. Scatter plot of observed and simulated discharge of calibration period of 1998-2007

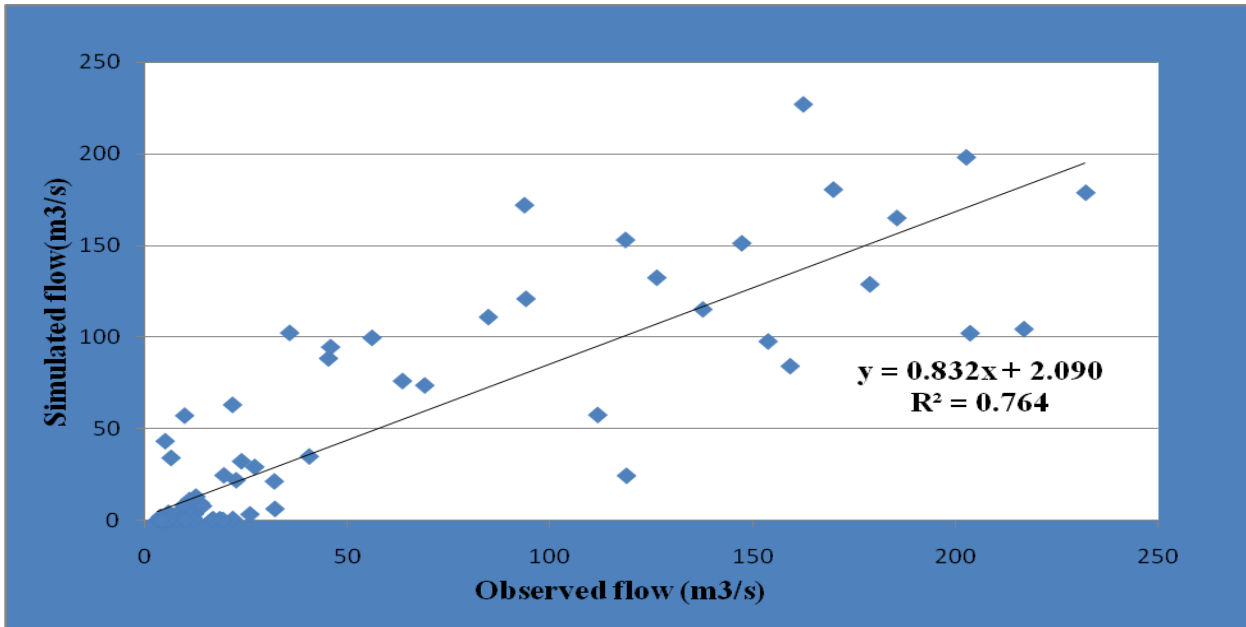


Figure 14. Scatter plot of observed and simulated discharge of validation period of 2008-2015

In general, the model performance assessment indicated that there is a good and acceptable correlation and agreement between the monthly measured and simulated stream flows in the study area.

4.2.2 Sensitivity Analysis

Sensitivity analysis was performed on flow parameters of the arc SWAT model on monthly time step based on the observed stream flow data of the Awash River at Melka Hombole gauging station. Consequently, Parameters which are integrally related to stream flow were initially considered and only 12 parameters were identified to have significant impact in determining the stream flow behavior of the study area. The table below presents parameters that have larger t-stat and lower *p* values and were put in ranks for the monthly stream flow.

Table 10. List of Sensitive Parameters and Ranking for Average Monthly Steam Flow

Parameters		Lower and Upper bound	Rank
Name	Description		
ESCO	Soil evaporation compensation factor	0 - 1	1
GW_REVAP		0.02 - 0.2	2
CN2	SCS runoff curve number (%)	-25 - 25	3
CH_K2	Effective hydraulic conductivity of the main channel (mm/hr)	0- 150	4
SOL_Z	Depth from soil surface to bottom of layer	-25 - 25	5
CANMX	Maximum canopy storage	0- 100	6
SOL_AWC	Available water capacity of the soil layer	-25 - 25	7
EPCO	Plant uptake compensation factor	0 - 1	8
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0-500	9
GWQMN	Treshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 - 5000	10
ALPHA_BF	Base flow alpha factor (days)	0 - 1	11
BLAI	Max leaf area index	0 - 1	12

The result indicated that the above flow parameters are sensitive to the SWAT model. Accordingly, Soil evaporation compensation factor (ESCO), (GW_REVAP), Curve number (CN2) and Effective hydraulic conductivity of the main channel (CH_K2) and Depth from soil surface to bottom of layer (SOL_Z) are identified to be highly sensitive flow parameters and thus ranked 1 to 5, respectively. On the other hand, Maximum canopy storage (CANMX), Available water capacity of the soil layer (SOL_AWC), EPCO (Plant uptake compensation factor), REVAPMN (Threshold depth of water in the shallow aquifer for "revap" to occur) and Treshold depth of water in the shallow aquifer that is required for return flow to occur (GWQMN) are determined to be moderately sensitive parameters and hence ranked from 6 to 8 respectively. Base flow alpha factor (ALPHA_BF) and Maximum leaf area index (BLAI) are identified to have very small to negligible impact on the stream flow characteristics of the watershed. The parameters are related to ground water, surface runoff and soil water processes that greatly influence the stream flow of the study watershed. The result showed that Soil evaporation compensation factor (ESCO), (GW_REVAP) and SCS runoff curve number are the most sensitive parameters influencing stream flow in the study area. The decrease in the value of ESCO indicates a decrease in evaporation in the study area. Similarly, the increase in the value of SCS runoff curve number implies the increasing trend of the surface runoff. Nevertheless, the calibrated value of the curve number shows a lower value of the number indicating the reduction in surface runoff in the simulation.

shallow aquifer in to the overlying unsaturated zone. During the period when the overlying the aquifer material is dry, water in the capillary fringe evaporate and diffuse upward. Consequently, the evaporated water is replaced by water from the underlying aquifer. However, as the GW_REVAP approached to zero, indicating the movement of water from the shallow aquifer is restricted. Often, this variable is one of the factors for the creation of different groundwater files for each HRU rather than the sub basin level. Similarly, Beyene et al (2018) reported that the Total soil depth (SOL-Z), Threshold depth of water in the shallow aquifer required for return flow (GWQMN), SCS runoff curve number (CN2), maximum canopy storage (CANMX), soil + F ,/ + D ,/ Maximum potential leaf area index (BLAI), Soil available water capacity (SOL_AWC) and Effective hydraulic conductivity of the main channel (CH_K2) are identified to have high to medium level of sensitivity to the model.

The study in Akaki catchment by Berga(2011) also reported CN, SOL_AWC, GWGMN, SOL_Z, ESCO, CH_K2, GW_REVAP and ALPHA_BF are most sensitive to the flow of the catchment. Hence, the result obtained in this study is almost comparable with the aforementioned studies and thus the model can predict hydrological processes of the study the watershed satisfactorily.

4.2.3 Changes in Hydrological processes in Response to LULCC

4.2.3.1 Change in the Monthly and Seasonal Stream Flows

Table below presents the mean monthly wet and dry months stream flows for 2005 and 2015 land use and land cover maps and its variability in the study period (1995 -2015).

Table 11. Mean monthly stream flow for wet and dry months and their variability (1995-2015)

Mean Monthly flow (m ³ /s)						Mean monthly flow change (%)			
LULC of 1995		LULC of 2005		LULC of 2015		2005-1995		2015-2005	
Wet Months	Dry Months	Wet Months	Dry Months	Wet Months	Dry Months	Wet Months	Dry Months	Wet Months	Dry Months
639.7	48.08	648.50	41.21	765.30	33.30	+1.38	-14.29	+19.63	-30.74

As indicated in table above, the mean monthly stream flow for wet months has increased by 19.63 % while in the dry season it has decreased by 30.74% which is attributed to the land use and land cover changes which is expressed by an increase in cultivated area, urban land and to some extent bare land and reduction of woody vegetations including forest, shrub land and wood lands in the study area during the study period. Therefore, the mean monthly stream flow of the watershed was increased from 82.94 m³/s to 99.45 m³/s by 19.91% in the study period.

4.2.3.2 Change in Surface Runoff and Lateral Flow and Total Water Yield

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). The table below presents the SURQ and GWQ of the stream flow simulated using 1995 and 2005 and 2015 land use and land cover maps.

Table 12. Surface runoff and Lateral flows (mm) for 1995, 2005 and 2015 LULC maps

Land use/cover map of 1995		Land use/cover map of 2005		Land use/cover map of 2015		Change in study period by %					
						2005-1995		2015-2005		2015-1995	
SURQ	LATQ	SURQ	LATQ	SURQ	LATQ	SURQ	LATQ	SURQ	LATQ	SURQ	LATQ
10.96	23.65	11.24	22.98	15.20	18.49	+2.6	-2.8	+35.23	-19.54	+38.69	-21.82

As the above table shows, the SURQ and LATQ components of the stream simulated using the 1995 land use and land cover map were 10.96 mm and 23.65mm while using the 2005 map, the values become 11.24mm and 50.16 mm, respectively. The contribution of surface runoff has increased from 11.61 mm to 22.98 mm and in contrary the ground water contribution flow has decreased from 23.65 mm to 22.98 mm due to the land use and land cover changes occurred between the years 1995 to 2005. Similarly, the SURQ and LATQ components of stream flow have shown an increasing trend between the years of 2005 and 2015. As a result of which the SURQ has increased from 11.24 mm in 2005 to 15.20 mm in 2015 whereas the LATQ has decreased from 22.98 mm in 2005 to 18.49 mm in 2015. When the overall change is evaluated in the study period of 1995 to 2015, the surface runoff has increased from 10.96mm to 15.20 mm and the ground water flow contribution has decreased from 23.65to 18.49 mm. This research has also assessed the impact of LULCC on the total water yield of the study watershed and has found that it has on average increased by 21.67% from annual magnitude of 595.02 mm in 1995 to 723.98mm in 2015 due to increased surface flow resulted from land use and land cover changes.

Generally, as a result of the LULC changes in the study period, the surface run off has increased by 38.69 % while the ground water flow contribution decreased by 21.82%. This can be attributed to the increase in urban and agriculture land uses and decline of woody vegetation which include forest and shrubs as well. The increase in the aforementioned land uses have an increasing impact of surface runoff and decreasing of infiltration resulted in decline of ground water flow. This can also be also explained in terms of the crop soil moisture condition. Crops need less soil moisture than large trees or forest that results in quick satisfaction of the soil

moisture deficit by rainfall in agricultural lands there by generating more surface runoff. And this in turn causes variation in soil moisture and groundwater storage. Furthermore, a slight increase in bare land and decreases in grass and wet lands can contribute to an increase in surface water flow in the watershed. It therefore generates more surface runoff. Additionally, increase in bare land resulting in decreased infiltration is another factor for runoff increment in the area. Therefore, stream discharge during dry months (which mostly comes from base flow) decreases, whereas the discharge during the wet months which mainly comes from surface runoff increases. Accordingly, the result demonstrated that the land use and land cover changes observed in the watershed have significant effects on rainwater infiltration rates, on the production of surface runoff, on the water retention capacity of the soil and ground water flow as well.

4.2.3.3 Change in Evapo-transpiration and total water yield of the watershed

The mean annual actual evapo-transpiration rate of the study area has decreased by 16.34% between 1995 and 2015 due to reduction of, especially, woody vegetation. The result is presented in the table below.

Table 13 Actual evapotranspiration response to LULCC from 1995 to 2015

LULC map of 1995	LULC map of 2005	LULC map of 2015	Change in study period by %		
			2005-1995	2015-2005	2015-1995
ET(mm)	ET(mm)	ET(mm)	ET(mm)	ET(mm)	ET(mm)
323.82	321.24	317.71	-0.8	-15.67	-16.34

Therefore, this result is in agreement with studies conducted in the study area. A study conducted in Hombole watershed reported that mean monthly stream flow was increased in the wet months by 16.13 % and decreased in dry months 20.8 % in the year 1986 and 2000 (Beyene et al. 2018). Similarly, Berga(2011) reported that the mean annual surface runoff has increased by 28% in Akaki catchment from 1973 to 2000 due to land use and land cover change.

Generally, the hydrological investigation with respect to the land use and land cover changes within the study watershed showed that the stream flow characteristics have changed, with an increase in surface flow during the wet season and reduction of base flow in the dry season which was found in to be agreement with the different studies reported above.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Remote sensing techniques and GIS were integrated with a SWAT hydrological model to evaluate the impact of land use and land cover changes on the stream flow of Melka Hombole watershed of Upper Awash Sub basin in this study. The impact of the land use and land cover changes on stream flow was ultimately analyzed statistically. Based on the overall results, the following conclusions were drawn:

From the land use and land cover changes analysis, it can be concluded that the land use and land cover of the study area have significantly been changed for the period of 1995 to 2015. Cultivated land was considerably increased in 14.23 % from 1995 to 2015 at the expenses of the other land uses. Similarly urbanization has expanded by 3.05 % in the study period. The expansion of rural settlements might be attributed to expansion of different infrastructure in the area which has paved the way for the population to settle following the infrastructure facilities. On the other hand, due to construction of additional water storage structures like dams in the watershed, the water body has on average increased by 0.12% during the period.

The result also indicated that expansion of agricultural and settlements areas could probably be at the expense of mainly, forest, shrub, and grass and to some extent wet lands which in contrast showed a decreasing rate in the study period. For that matter, the area coverage of grass and woody vegetation has on average decreased by 9.15% and 8.34 % in the last two decades. Similarly, the coverage of wet land has decreased by 0.06%. The deforestation in the area has resulted not in reduction of vegetation cover but also increased the bare land coverage by 0.04%. The decline of wet lands of the study area has reduced the excess water absorption capacity of the watershed in the wet season. However, due to construction of additional water storage structures like dams in the watershed, the water body area has increased by 0.12% during the period.

The sensitivity analysis has pointed out ten most important parameters that significantly affect the stream flow behavior of the watershed. Accordingly, Soil evaporation compensation factor

+ F ,/ + D ,/ F +F 5,/

hydraulic conductivity of the main channel (CH_K2), Depth from soil surface to bottom of layer (SOL_Z), Maximum canopy storage (CANMX), Available water capacity of the soil layer (SOL_AWC) , Treshold depth of water in the shallow aquifer that is required for return flow to occur (GWQMN), Base flow alpha factor (ALPHA_BF) and Maximum leaf area index (BLAI) are most sensitive ones that affect the stream flow of the study area. The performance evaluation of the model for both the calibration and validation periods were found to be reasonably good with Nash-Sutcliffe coefficients (ENS) values of 0.76 and 0.75 and coefficient of determination (R^2) values of 0.82 and 0.81 for the calibration and validation periods respectively.

The simulation results of the model for the three land use and land cover maps indicated that during the wet season mean monthly stream flow was increased while it has decreased during the dry season. Accordingly, the mean monthly stream flow has increased by 19.63 % in the wet season and decreased by 30.74% for the dry season. Generally, the mean monthly stream flow of the watershed has increased by 19.91% from 1995 to 2015. This change could be occurred due to the LULCC occurred in the study period.

As stream flow is a combined effect of surface runoff and ground water flow contribution, it was divided accordingly as base flow and surface runoff by the model. The model split ground water flow in to two aquifer systems and considered the shallow unconfined aquifer to estimate the ground water contribution to the stream flow in the form of base flow. With this process, the surface runoff contribution to stream flow has generally increased from 10.96 mm to 15.20 mm, where as the ground water flow contribution has decreased from 23.65 mm to 18.49 mm for the period of 1995 to 2015. As a result of increased surface flow, the total water yield of the watershed had increased by 21.67%. Therefore, it was concluded that land use and land cover changes mainly the expansion of cultivated and urban lands and reduction of vegetation cover have significant impact on the hydrological processes in general and stream flow in specific. The total water yield of the study watershed which is the measure for surface water volume has on average increased by 21.67% from 595.02 to 723.98 in the study period. Similarly, the annual actual evapo-transpiration result showed that it has decreased by 16.34 % that can be attributed to the land use and cover change especially decline of vegetation cover like forests.

5.2 Recommendations

This study has made the following recommendations which could be helpful for development plans and future research works in the study area:

- Even though only stream flow variable is calibrated and validated in this study, other variables like evapo-transpiration and sediment yield can also be considered to evaluate the impact of LULCC on them as they very important for sustainable land and water resources development and management.
- The researcher recommends the implementation of land efficient and intensive farming to control further expansion of cultivated lands which significantly affects the hydrology of the area. Moreover, enhancing agricultural productivity is very important.
- In order to minimize the impact of LULCC on hydrology of the study area, participatory integrated watershed management including appropriate soil and water conservation measures shall be applied.
- As urbanization in the study area has resulted in increased area of impervious land surfaces, it is recommended to properly plan and implement opportunities for pervious surfaces like open water spaces, green spaces, and consideration of pervious sub base materials for infrastructure construction.
- It is important to design and implement proper strategy for protecting and managing wetlands specifically and water resources generally so as to maintain the hydrological balance of the watershed.
- Hydro- meteorological stations should be improved both in quality and quantity throughout the basin in order to obtain reliable data which have great influence on the quality and performance of hydrological model simulations.

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APPENDICES

Appendix1. Location, Monthly and Annual Rainfall of Selected Meteorological Stations

Station	Latitude	Longitude	Elevation
Entoto Observatory	9.02	38.75	2386
Bole	8.98	38.80	2354
Woliso Giyon	8.55	37.98	2058
Jeldu	9.25	38.08	2952
Kimoye	9.01	38.34	2150
Tulubolo	8.65	38.21	2190
Addisalem	9.04	38.38	2372
Asgori	8.79	38.33	2072

Month	Mean Monthly Rainfall					
	Intoto	Bole	Woliso	Kimoye	Tulubolo	Asgori
Jan	12.70	14.00	18.92	17.86	12.48	20.14
Feb	20.56	21.98	16.29	24.83	11.20	17.23
Mar	61.57	54.12	53.06	64.01	42.33	66.34
Apr	74.44	79.12	74.04	64.22	63.98	74.48
May	81.56	85.36	105.43	77.44	97.00	74.46
Jun	149.72	119.53	183.09	131.50	198.96	143.01
Jul	276.77	234.24	278.30	230.95	266.79	227.16
Aug	286.16	248.84	255.49	203.56	263.43	216.64
Sep	186.37	123.57	141.17	104.37	111.38	111.58
Oct	37.12	31.21	43.29	26.43	21.94	18.48
Nov	12.46	5.54	14.04	45.25	4.83	11.66
Dec	11.91	10.15	8.20	47.54	7.80	5.70
Mean Monthly Rainfall(mm)	100.95	85.64	99.28	86.50	91.84	82.24

Year	Mean Annual Rainfall					
	Intoto	Bole	Woliso	Kimoye	Tulubolo	Asgori
1995	1145.6	1009.7	1070.6	1049.6	565.4	1111.3
1996	1548.5	1552.5	1446.7	1122.3	1217.4	1409
1997	952.4	877.1	1050.5	742.2	864.5	848.7
1998	1337.7	1379.8	1380.6	1242.2	1448.2	1197.8
1999	929.4	946.7	1404.8	769.6	1372.4	928.4
2000	1191.1	902.1	1136.1	946.9	1215.5	734.1
2001	1452	1102.7	1021.2	1014.2	819.4	895.6
2002	1016.1	891	1114.4	861.7	1021.5	932.9
2003	1173.3	939.1	1175.4	915	979.4	1126.6
2004	1158.5	835.1	1229.8	1083.4	1158.6	917.1
2005	1383.2	1084.1	1209.9	990.4	1122.3	900.9
2006	1341.2	1205.9	1400	988.9	1039	94.7
2007	1308.6	1135.6	1400	1098.9	855.3	1042.4
2008	1330.7	1004.6	1242.2	899.1	1139.1	940.3
2009	1240.6	947	978.5	971.1	978.7	846.3
2010	1381.2	1146.1	1383.7	1150.7	1394.8	1084.4
2011	1052.4	911.7	1135.8	1636	853.7	910.1
2012	1056.6	929.4	955	786.9	919.6	773.6
2013	1239.6	960.8	1320.7	1801.9	1683.6	1291.9
2014	1080.8	772.2	1123.9	916.7	1019.2	995.5
2015	1049	790.2	998.3	691.8	790.7	546.8
Mean Annual Rainfall(mm)	1208.02	1015.40	1198.96	1032.36	1069.44	929.92

Appendix2. Symbols and Description of the Arc SWAT Model Weather Generator parameters (WGEN)

S. No	Symbol	Description
1	TMPMX	Average daily maximum air temperature for the month (°C)
2	TMPMN	Average daily minimum air temperature for the month (°C)
3	TMPSTDMX	Standard deviation of daily maximum air temperature for the month (°C)
4	TMPSTDMN	Standard deviation of daily minimum air temperature for the month (°C)
5	PCPMM	Average total monthly precipitation (mm)
6	PCPSTD	Standard deviation of daily precipitation for the month (mm/day)
7	PCPSKW	Skew coefficient of daily precipitation in the 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 the month
11	SOLARAV	Average daily solar radiation for the month (MJ/m ² /day)
12	DEWPT	Average daily dew point temperature in the month (°C)
13	WNDV	Average daily wind speed in the month (m/s)

Appendix3. Description of Soils parameters used in Arc SWAT Model

S. No	Symbol	Description
1	NLAYERS	Number of layers in the soil (min 1 max 10)
2	HYDGRP	Soil hydrographic group (A, B, C, D)
3	SOL_ZMX	Maximum root depth of the soil profile
4	ANION_EXCL	Fraction of porosity from which an ions are exchanged
5	SOL_CRK	Crack volume potential of soil
6	TEXTURE	Texture of the layer
7	SOIL_Z	Minimum depth from soil surface to bottom of layer
8	SOL_BD	Moist bulk density
9	SOL_AWC	Available water capacity of soil surface to bottom of the layer
10	SOL_K	Saturated hydraulic conductivity
11	SOL_CBN	Organic carbon content
12	CLAY	Clay content
13	SILT	Silt content
14	SAND	Sand content
15	ROCK	Rock fragmented content
16	SOL_ALB	Moist soil albedo
17	USLE_K	Soil erodibility factor (K)

Appendix4. Monthly Average stream flow of Melka Hombole Watershed (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	4.256	4.516	3.085	14.903	5.490	10.687	72.228	190.232	75.443	7.756	3.276	2.858
1996	5.422	4.153	5.869	12.487	21.645	84.059	194.468	348.258	133.884	13.215	5.892	3.993
1997	4.040	3.221	2.967	5.497	4.105	15.694	57.713	119.275	32.380	10.029	10.684	6.097
1998	5.008	3.694	11.159	8.206	11.311	24.622	137.372	366.561	161.032	41.711	9.094	5.462
1999	4.978	4.096	4.580	3.439	3.557	20.799	110.425	269.336	62.899	47.577	8.643	5.115
2000	4.146	3.745	1.937	3.155	5.672	12.574	63.095	178.605	90.986	30.785	12.478	6.037
2001	5.734	5.237	11.070	7.518	11.730	43.331	140.462	189.318	78.700	11.719	8.213	6.118
2002	5.805	4.214	4.878	5.693	5.157	12.012	59.543	143.307	49.311	9.589	7.576	3.815
2003	3.609	3.198	4.834	10.317	6.664	22.767	119.498	184.303	103.198	15.669	8.855	5.995
2004	3.683	2.848	3.895	14.740	5.286	20.485	88.591	166.732	87.113	16.735	9.333	4.489
2005	5.129	3.794	10.434	7.709	30.293	26.006	124.393	192.583	94.340	18.214	11.143	5.632
2006	4.313	4.004	9.734	17.116	15.501	26.202	155.887	269.647	143.560	18.656	11.814	6.014
2007	4.996	5.471	5.152	8.221	11.825	39.807	127.918	253.468	158.638	25.097	11.105	7.492
2008	4.658	4.157	3.309	3.722	5.636	16.798	118.758	216.789	159.119	18.411	22.478	6.076
2009	9.508	4.249	3.435	9.523	5.308	7.415	45.254	185.453	111.656	25.885	6.163	6.772
2010	4.538	12.557	10.974	21.570	19.454	35.680	162.372	178.775	153.670	18.510	9.988	5.361
2011	4.826	3.956	5.425	3.784	11.230	27.061	68.991	202.573	126.228	21.676	9.775	5.776
2012	4.274	3.743	3.153	10.668	8.247	12.193	93.949	232.023	203.486	19.201	7.734	5.212
2013	4.215	3.392	6.424	13.630	11.815	31.919	93.578	169.783	137.590	40.517	12.157	4.976
2014	3.858	4.446	4.743	6.519	10.309	14.195	55.982	147.196	84.690	32.037	10.024	4.676
2015	3.936	3.253	4.826	3.715	9.645	23.809	45.774	118.507	63.501	16.527	5.736	3.970