IMPACTS OF LAND USE/LAND COVER CHANGE ON STREAM FLOW (THE CASE OF MEKI RIVER, RIFT VALLEY BASIN, ETHIOPIA)

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TOTHEDEPARTMENT OF HYDRAULIC AND
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ADVISORS’ APPROVAL SHEET

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

This is to certify that the thesis entitled “IMPACTS OF LAND USE LAND COVER CHANGE ON STREAM FLOW (THE CASE OF MEKI RIVER, RIFT VALLEY BASIN, ETHIOPIA)” submitted in partial fulfillment of the requirements for the degree of Master's with specialization in HYDRAULICS ENGINEERING, the Graduate Program of the Department/School of HYDRAULIC AND WATER RESOURCES ENGINEERING, and has been carried out by FENTAHUN YEHUNIE Id. No GPHYDrR/008/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence he can submit the thesis to the department.

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Name of co-advisor	Signature	Date
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We, the undersigned, members of the Board of Examiners of the thesis open defense by FENTAHUN YEHUNIE have read and evaluated his MSc thesis entitled "IMPACTS OF LAND USE LAND COVER CHANGE ON STREAMFLOW (THE CASE OF MEKI RIVER, RIFT VALLEY BASIN, ETHIOPIA)". This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOI	Area of interest
CCRS	Canada Centre for Remote Sensing
CRV	Central Rift Valley
DEM	Digital Elevation model
ET	Evapotranspiration
GLUE	Generalized Likelihood Uncertainty Estimation
IHACRES	Identification of unit Hydrograph and Components
IRS	Indian Remote Sensing
ITCZ	Inter-Tropical Convergence Zone
LISS	Linear Imaging Self Scanning Sensor
LULC	Land Use/ Land Cover
MoA	Ministry of Agriculture
MoWIE	Ministry of Water, Irrigation, and Energy
NCR	National Capital Region
NMA	National Meteorological Agency
NSE	Nash and Sutcliffe simulation efficiency
PARA SOL	Parameter Solution
PRMS	Precipitation modeling system
RSR	Root mean square error standard deviation Ratio
RVLB	Rift valley lake basin
SMAX	Soil water holding capacity
SRM	Snowmelt Runoff Model
SRTM	Shuttle Radar Topography Mission
SUFI	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
USLE	Universal soil loss equation
WATBA	Water Balance model

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DECLARATION

I hereby declare that this thesis prepared for the partial fulfillment of the requirements for MSc. Degree in Hydraulic Engineering entitled “Impacts of land use land cover change on streamflow (the case of Meki River, rift valley basin, Ethiopia)" is prepared with my effort except for secondary sources that have been acknowledged, as listed in the bibliography. I have made it independently with the close advice and guidance of my advisors.

Name: Fentahun Yehunie Signature: _____________ Date: ______________

ABSTRACT

Land use land cover change has an impact on the alteration of watershed streamflow. In the last 24 years,Meki catchment experienced significant land use land cover change, which is the major contributor of runoff for Lake Ziway. This study quantified basin runoff volume using the SWAT model and assessed the effect of land use land cover change on the streamflow. Geographic Information system (GIS) was integrated with the SWAT model to carry out the study. Arc GIS10.3 and ERDAS IMAGINE2014 were used to process soil raster data set and prepare land use land cover map from Land sat image acquired in 1996, 2006, and 2020 respectively and gives the following classes of land(agricultural land, built-up area, wetland, shrubland, forest, grazing land, water body and bare land). Land use classification was performed using a supervised classification system and accuracy assessment was done using a confusion matrix. The classification result indicated the expansion of agricultural land, built-up area, and water bodies. Using the three-land use land cover maps, the SWAT model was set up and run. Sensitivity analysis was made on a monthly basis using 10 model parameters where only eight parameters were identified that influence the flow. The model calibration was done from 2000 to 2008 and the validation period from 2009 to 2012.The calibration and validation results showed a good match of simulation with observation with Nash-Sutcliff efficiency 0.75and 0.69coefficient of determination (R^2) 0.81 and 0.78 for calibration and validation respectively. The calibration and validation results showed a good match of simulation. The result showed that the mean wet monthly flow increased by 19.21% (from 26.79m3/s for lulc of 1996 to 37.73m3/s for lulc of 2020) and the mean dry monthly flow decreased by 48.69% (from 15.81m3/s for lulc of 1996 to 12.76m3/s for lulc of 2020). Generally, the study result indicated that the flow during the wet season increased whereas during the dry season decreased. The study results showed a change in flow with a change in land use/cover. It was concluded that the streamflow of the Meki river increase in a seasonal scale as a result of land use land cover changes.

Keywords: SWAT model, Meki watershed, ERDAS IMAGIN14, SWAT cup, land use/ landcover,streamflow.

1. INTRODUCTION

1.1. Background

Water is a very essential resource for all living things. It is a finite resource and must be managed in a sustainable way to meet human as well as environmental needs. Land use/cover change associated with the intensification of agriculture, cattle raising and urbanization, could have a profound influence on the hydrological processes and changes the land surfaces in small watersheds and at a regional level (Mendoza, 2002) Streamflow plays an important role in establishing some of the critical interactions that occur between physical or ecological processes and social or economic processes (Choia and Dealb, 2008).

The purpose of water resources management is often to mitigate or prevent the adverse impacts of excessive runoff or shortage of water. Hydrological models have served as a valuable tool in water resources management for many years and are usually used to simulate the impacts of proposed land use/ land cover and climate change scenarios and to evaluate management strategies. Over the past, few decades there have been many activities that have modified the land use/land cover in the region of Oromia (Jansen et al, 2009). This has a direct impact on the lakes downstream. Therefore, it is very important to understand the functioning of these lake catchments and their hydrological response under different land use/cover change scenarios.

The land use/cover of the study area can be categorized mainly as agricultural, wetlands, shrublands, grazing land, built-up area, bare land, forest, and water bodies. Some Irrigation activities are practiced along with the courses of the Meki River. Some studies on sustainable watershed management have been done in areas where resources are optimally utilized for the benefit of the people and the development of a region, as a whole. To achieve optimal utilization of resources, studies were undertaken to decide alternative land use options in a watershed by visual interpretation techniques using GIS.

A similar study was undertaken in the National Capital Region (NCR) Delhi, where urban LULC change detection was done by (Mohan, 2005), under planning for rural and urban communities. Land and water resources degradation are the major problems in the Ethiopian Central Rift Valley Basin. The area is one of the most important from its water resources development point of view. The lake's surface water level has dropped across the Central Rift Valley because of water extraction for irrigation (Legesse, D. and Ayenew, T, 2006).

Agricultural expansion (irrigation system), urbanization, poor land-use practices, and improper management systems have a significant impact on basin hydrology. Farmlands and settlements expanded which is mostly associated with the decrease in forestland (Kassa, 2007).

The purpose of this research is to classify, detect and evaluate the change of land use/land cover and its impacts on the streamflow of Meki watershed using both ERDAS IMAGINE software and Swat model with ARC GIS 10.3 for classification of land use /land cover and sensitivity analysis respectively. SWAT model was selected due to its ability to characterize complex watershed phenomena and simulate surface runoff.

1.2. Statement of the Problem

LULC change is a major problem concerning the change in the global environment. According to Praveen (2013), LULCCs respond to socio-economic, political, cultural, demographic, and environmental conditions and forces, which are largely characterized by high human populations. Several studies are carried out on hydrology of the watershed by utilizing LULC data in the different regions of the World and Ethiopia using the Soil and Water Assessment Tool (SWAT)(Tibebe et al, 2017) which allocates problems of land use land cover in the watershed. Many hydrological studies have shown that LULC changes have affected the hydrology of various watersheds of the World Ambika (2012). The LULC change can alter both the infiltration and runoff amount by following the falling of precipitation Hougton (1995). Mahmoud et al.(2011)tested a field-based approach for classifying land cover using Terra SAR-X imagery. Akinyemi (2008) used Landsat images from different years (1987, 2003, and 2016) to study LULC change in the central Albertine Rift in northwestern Rwanda.(Cheruto et al., 2012) assessed LULC changes using geographic information systems (GIS) and remote sensing techniques in Makueni County, Kenya.

The LULC classification is perhaps among the most well-known applications of geospatial applications. The Meki watershed, which is the major contributor to runoff for Lake Ziway is a very important area in connection with its water resources. The basin experienced land use and land cover change over the past decades. The basin is intensively cultivated and there is a high expansion of settlement in the basin. The hydrological processes are highly related to land use and land cover change. The Meki River showed flow variation since the hydrological processes are sensitive to land use and land cover change D. Legesse et al. (2010). Because of the change in land use/land cover of Meki watershed, it is difficult for water resources and management designers how much amount of streamflow is recorded throughout the year so that, to combat this problem it is advisable to know the impact of land use land cover change on streamflow of the Meki watershed. The basin is undergoing land-use change due to intensive cultivation and urbanization because of population growth that has an impact on the hydrologic response of the basin. The conversion of forested land into irrigation agricultural activities and urbanization has a great influence on the land use and land cover of the basin as well as on basin hydrology D.Legesse et al. (2010). Therefore, there is a need for the basin to formulate strategies to manage water resources in the basin. Therefore, this study quantifies basin runoff volume using the SWAT model and assesses the effect of land use/land cover change on the streamflow.

1.3. Objectives

1.3.1. General Objective

The general objective of this research was to investigate the impacts of land use/land cover change on streamflow on the Meki River.

1.3.2. Specific Objectives

The specific objectives of this research include:

1. To classify land use land cover in 1996, 2006, and 2020 using ERDAS Imagin software.
2. To detect the land use/land cover change on the Meki River flow.
3. To evaluate the effect of land use/land cover change on streamflow.

1.4. Research Questions

A research question is an answerable inquiry into a specific concern or issue. So this study will try to discuss and answer the under listed research questions.

1. How is the land use land cover in 1996, 2006, and 2020?
2. How is the land use land cover change on the Meki River flow?
3. What is the effect of land use/land cover change on streamflow?

1.5. Scope and Limitation

The study area covers the Meki River Basin; its scope is limited to certain accessible areas and proximity to a cluster of villages during the verification stage because of limitations of time, resources, and financial constraints. However, all efforts are made to perform the present study systematically with adequate scientific inputs and realistic facts under such limitations.

1.6. Significance of the Study

The study contributes to meet out a part of land management within the study area, particularly for those areas that are changed due to the change in land use land cover of the study area. The study also will be significant to make aware people, a private company, government organization, and non-governmental organization, and the community of the study area, the change in land use land cover will lead to tremendous climatic factors and flow change. The present study may also serve as a guide to develop and extend a similar type of hydrologic study for other regions in the country, which will help in the speedy development of land use management practices.

2. LITERATURE REVIEW

2.1. General Description of Land use/land cover

Ethiopia has a very diverse set of ecosystems ranging from humid forest and extensive wetlands to the desert Tefera (2011) and within these mosaic environments, LULC changes are a pervasive and common phenomenon where agricultural activities and settlements dominate rural landscapes affecting ecosystem services. Ecosystems provide a wide range of multiple services that vary in quantity and quality depending on the type of ecosystems and their status MA (2005). The land is finite and non-renewable resources deliver services needed for human wellbeing. Different land classes are quite different in their service provision and provide a unique service that cannot be replaced by others Costanza et al.(2014) and certain services are local specific (pollination of crops) and others are global (mitigation of global climatic change) Tolessa et al.(2017). Many of the land resource services are important for sustaining life on earth and maintaining the integrity of the ecosystem.

Land use is commonly defined as a series of operations on land, carried out by humans, intending to obtain products and/or benefits through using land resources. Land cover is commonly defined as the vegetation (natural or planted) or man-made constructions (buildings, etc.) that occur on the earth's surface. Water, ice, bare rock, sand, and similar surfaces also count as land cover. In Ethiopia, empirical evidence shows that there has been considerable LULC in different parts of the country Girmay et al.(2010).These changes have important environmental consequences at local, regional, and global scales (Bewket and Abebe, 2013). At the local scale, land-use changes affect watershed runoff, micro-climatic resources, groundwater tables, processes of land degradation, and landscape-level biodiversity (Lambin and Geist, 2008). A few decades ago, the Central Rift Valley (CRV) basin is known for its dense acacia woodlands that have now been transformed into agricultural and grazing lands (Gebreslassie, 2014). These have serious eco-environmental problems that threatened the region’s sustainable social and economic development Peng et al. (2011). Transitions between different land use/land covers were evaluated by comparing image values of one data set with the corresponding value of the second data set in each period to measure areas converted among the different land uses.

2.2. Drivers of Land Use/Cover Changes in Ethiopia CRV

In Ethiopia, the land is used for agricultural purposes, for construction of buildings and roads, and extra purposes. In the country, most of the land is used for subsistence farming. With the population growth and slow technological adoption that can increase production, there is deforestation for more products that means the conversion of the forest to agricultural land and expansion of urban settlements. The researches conducted by different researchers in different parts of the country indicate that there were LU/LC changes in the country. For instance, Hadgu (2008) identified that decrease of natural vegetation and expansion of agricultural land cover over 41 years in Tigray, the northern part of Ethiopia. The other research indicated that the expansion and intensification of agricultural land are due to population growth (Efrem, 2010) in the semiarid of Central Rift Valley of Ethiopia and (Molla, 2014) Concluded that LU/LC dynamics in the Central Rift Valley Region of Ethiopia was due to population pressure which caused agricultural expansion into marginal land and more severe land degradation.(Kassa, 2007) indicated that farmlands and settlements have expanded which was mostly associated with the decrease in forest in Hare watershed Southern Rift Valley Lakes Basin and deforestation was due to rapid population growth.

2.3. Land Use and Land Cover Change Studies in Ethiopia

In Ethiopia, the land is used for agricultural purposes, for construction of buildings and roads, and extra purposes. In the country, most of the land is used for subsistence farming. With the population growth and slow technological adoption that can increase production, there is deforestation for more products that means the conversion of the forest to agricultural land and expansion of urban settlements. The researchers conducted by different researchers in different parts of the country indicate that there were LU/LC changes in the country. For instance, Hadgu (2008) identified that decrease of natural vegetation and expansion of agricultural land cover over 41 years in Tigray, the northern part of Ethiopia. The other research indicated that the expansion and intensification of agricultural land are due to population growth (Efrem, 2010) in the semiarid of Central Rift Valley of Ethiopia and (Molla, 2014) Concluded that LU/LC dynamics in the Central Rift Valley Region of Ethiopia was due to population pressure which caused agricultural expansion into marginal land and more severe land degradation.(Kassa, 2007) indicated that farmlands and settlements have expanded which was mostly associated with the decrease in forest in Hare watershed Southern Rift Valley Lakes Basin and deforestation was due to rapid population growth.

2.3.1. Land use/land cover change analysis

Land cover change, associated with the intensification of agriculture, cattle raising, and urbanization, could have a profound influence on the hydrological processes in small watersheds and at a regional level (Mendoza et al., 2002). Land-use change analysis was conducted using the post-classification image comparison technique (Lilles et al., 2014). Images of different reference years were first independently classified. The classified images were compared between each study period. Transitions between different land use/land covers were evaluated by comparing image values of one data set with the corresponding value of the second data set in each period to measure areas converted among the different land uses. Quantified values of the changes between the different LULC classes were used for statistical analysis to reveal the extent of the dynamics in the study areas. The percentage of change within the same LULC class between two-time points is calculated as follows, the values were presented in terms of hectares (Ha) and percentages (%). Positive values suggest an increase whereas negative values imply a decrease in the extent of a given land-use type.

2.4. Land Use and Land Cover Change Impacts on Hydrology

Water on earth exists in a space called the hydrosphere and lithosphere, circulates, and forming the hydrologic cycle. The cycle has no beginning and no ending and can be affected by different factors. Among those factors, manmade activities, land use, and land cover change can affect hydrological processes such as infiltration, runoff, and groundwater recharge. Different studies indicate that land use and land cover change have an impact on hydrologic components. For instance,(Adamu, 2013) concluded that land use and land cover changes have major impacts on hydrological processes, such as runoff and groundwater flow Melesse,(2012) concluded that the decrease of forest land and grassland was accompanied by the increase in agricultural and built-up areas and this change in land use and land cover increased surface runoff during wet seasons and reduced base flow during the dry seasons. Gebrie,(2016) Concluded that land use and land cover change have a great influence on streamflow especially during the wet season than the dry season. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. Land use and land cover (LULC) changes influence hydrological processes by altering interception rates, soil water, evapotranspiration (ET), infiltration, and groundwater, leading to changes in surface runoff and streamflow. Land cover change refers to the modification of the existing land cover or complete conversion of land cover to a new cover type.

Land cover change, associated with the intensification of agriculture, cattle raising, and urbanization, could have a profound impudence on the hydrological processes in Small watersheds and at the regional level. Land use/land cover changes occur in the country, Ethiopia, as a whole, and the 11-study area in particular due to the increasing population, which has almost doubled in the country over the past 40 years Fairweather et al.(1999). It is thus essential to analyze the possible impacts of these changes at different scales. In this study, different scenarios of land-use change will be used in the watershed to assess the impact of this change on the Rain fall-run off hydrology of the Meki watershed. The effect of land use land cover especially in the mountainous part of the watershed will have a significant effect on the rainfall-runoff response of the watershed.

2.5. Application of remote sensing for LULC change detection

According to Canada Centre for Remote Sensing (CCRS,1999) Remote sensing is the science (and to some extent, art) of acquiring information about the earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Change detection analysis is important in monitoring and managing the natural resources of the earth. Some of its applications to mention are monitoring shifting agriculture, estimation of deforestation, and other environmental changes (Jingan et al., 2005). Natural changes can have a wide impact on natural resources. Thus, concerning LULC and natural resource and ecosystem management, there is an important need for timely, permanent, and truthful monitoring of changes occurring. However, the problems challenging the change detection process are where is the change? , How much? , when did it occur? , and how great is its impact on the ecosystem? Lambin(2006). Thus, the remote sensing techniques take on increasing importance in natural resource monitoring programs and in answering the above questions.

The advantage of using remote sensing in land use/land cover is that information from the same area could be easily obtained at different times, and this is important in change detection applications. Furthermore, remote sensing can provide the required data in a short time with reasonable accuracy (Anisur & Billah, 2004). The advent of high spatial resolution satellite imagery and more advanced image processing and GIS technologies has resulted in a switch to more routine and consistent monitoring and modeling of land use/land cover patterns. Remote sensing has been widely used in updating land use/cover maps and land use/cover mapping has become one of the most important applications of remote sensing (Choi & Lo, 2004).

2.6. Image Classification

Image classification is the process of sorting pixels into a finite number of individual classes or categories of data based on their data file values. In remote sensing, there are various image classification methods, supervised, unsupervised, and hybrid. Unsupervised classification is computer controlled and the limitation is, we cannot control the computer's selection of pixels into clusters. In a supervised image classification system, the user relies on her/his prior knowledge and skills and can select a group of pixels belongs to a particular land use/land cover. In this system, the user should have a good knowledge of the land cover to be studied. Supervised classification is the most common type of land use classification system and depends on prior information about the land use and land cover.

2.7. Land use land cover

Land use/cover is one of the most critical factors in reducing soil erosion. According to Asis(2007), vegetation reduces soil erosion by protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the ground, reducing the speed of the surface runoff, roots bind the soil particle together, maintaining roughness of the soil surface, and improving the physical, chemical and biological properties of the soil. The cover management factor one of the land-use factors of erosion represents the effect of plants, soil biomass, ground cover, and soil disturbing activities on erosion (USDA-NRCS, 2000).

2.7.1. General Description of ERDAS imagine software

It is aimed primarily at geospatial raster data processing and allows the user to prepare, display, and enhance digital images for use in GIS or CAD software. It is a toolbox allowing the user to perform numerous operations on an image and generate an answer to specific geographical questions. By manipulating data placement in the imagery, it is possible to see features that would not normally be visible. The level of brightness or reflectance of light from the surfaces in the image can be helpful with vegetation analysis, prospecting for minerals, etc. Other usage examples include linear feature extraction, generation of processing chains ("spatial models" in ERDAS IMAGINE), import/export of data for a wide variety of formats, rectification, mosaicking of imagery, stereo and automatic feature extraction of map data from imagery.

2.7.2. Previous studies using ERDAS Imagin software

The geographical positioning system (GPS) is used to take control (ground truth) points; ERDAS Imagine 9.1 was used for image processing and classification. QGIS 2.18 Software was used for GIS raster and vector data analysis and mapping. IDRSI Selva 17.00 was used for the prediction of LULC change. Satellite imageries of 1985, 1995, 1999, 2005, and 2017 were downloaded from USGS and GLCF images were already ortho rectified using ground control points and digital elevation model (DEM) data to correct for relief displacement. The satellite image data were imported to Erdas Imagine 9.1 image processing software to create a layer stack for each year.

The Coordinate Reference System of all images was UTM Zone 37 with the WGS84 datum. Image subsetting and image enhancement (histogram equalization) techniques were applied to the raw TM, ETM+, and OLIL and sat images (Alemayehu et al., 2018).ERDAS Imagine 9.1, QGIS 2.18, and IDRSI Selva 17.00,Software was used for satellite image processing, map preparation, and LULC change prediction respectively.

2.8. Land cover scenario

Land use/land cover changes occur in the country as a whole and the Ziway Shala basin in particular (Woldu Tadesse, 1990) due to the increasing population, which has almost doubled in the country over the past 40 years (CSA, 1999). It is thus essential to analyze the possible impacts of these changes on streamflow at different scales.

Assuming that the currently intensively cultivated land between 2000 and 3000 m a.s.l. was once covered by dense woodland and by introducing the corresponding parameters to this change, the model produced an increase in daily evapotranspiration of 2.2% and a decrease in the mean daily river flow of about 11.8% concerning the simulated value. This decrease could be attributed to the increased water retention capacity by the more vegetated areas thereby reducing quick flow. However, the impacts of land cover change on streamflow are a rather contentious one as is well illustrated by some previous works Siebert et al. (2008). This kind of change detection modeling could give a better result if used with a model that dynamically treats vegetation. Here, the changes made are static and assume a one-time change. However, it still is considered a better way of evaluating these impacts.

2.8.1. Land use /land cover change

Land use and land cover can be defined as how land is utilized. For example, residential and industrial land use would be considered one type of developed land use. Land cover is slightly different. A park could be a forest, in this land, use is a park and land cover is a forest. Land use and land cover change are significant in catchment studies. The hydrological regime and sediment flux change drastically following the farming activities within a basin. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. According to data from long term observations done in paired catchments, in the forest zone of Central Russia Golosov et al.(2006).

Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land. Hydrological effects of land use/land cover change manifested in many ways and at different spatial and temporal scales. Most obvious is the immediate and direct effects on the quantity and quality of catchment's runoff. For example, land cover change is the most significant factor driving hydrologic changes such as runoff volume, timing, and variability (Fohrer, 2001). The simplest method to assess these effects on the hydrologic response of catchment is by comparing streamflow and runoff generated from the catchment areas with the contrasting land-use types (Barkhordari, 2003). The main causes of land-use change are due to manmade and natural causes, where manmade causes are mainly attributed to the reach for resources to meet human needs. For instance, deforestation is a result of the need for timber for construction, fuelwood, and clearing for agricultural development and for settling the ever-increasing population (Chemelil, 1995) and increase in foreign direct investments or land grabbing increased deforestation in the investment area (Gobena, 2010).

The hydrological regime and sediment flux change drastically following the farming activities within a basin. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. According to data from long term observations done in paired catchments, in the forest zone of Central Russia Golosov et al.(2006). Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land. Hydrological effects of land use/land cover change manifested in many ways and at different spatial and temporal scales. Most obvious is the immediate and direct effects on the quantity and quality of catchment's runoff. For example, land cover change is the most significant factor driving hydrologic changes such as runoff volume, timing, and variability (Fohrer, 2001).

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Previous studies on land use land cover change

Flooding, fire, climate fluctuations, and ecosystem changes may also initiate modifications upon the land cover. There are also incidental impacts on land cover from other human activities such as forest and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by troposphere ozone resulting from automobile exhaust (Meyer, 1995). (Kemmerer,2009) observed the conversion of cropland to grassland in Arges¸ County in Romania, which he related to the rapid changes in socio-economic, demographic, and institutional conditions after 1989. Similarly, (Brown, 1995) states that more recent changes in land use have been dominated by losses of agricultural land.

In particular, in eastern China, there has been an unprecedented conversion of arable land into built-up uses following rapid industrialization. While (Kebrom Tekle et al.2000) reported increases in the size of open areas and settlements at the expense of shrub lands and forests in twenty-eight years (between 1958 and 1986) in Kalu District, (Prakasam, 2010) studied land use/land cover change over 40 years in Kodaikanal Taluk, Tamil Nadu. In this study, major changes have been observed like the area under built-up land and harvested land has increased whereas the area under forest and water body has decreased.Javed et al. (2012) Studied land use land cover change due to mining activities from 2001 to 2010. The study revealed that significant decrease has been observed in dense forest area, cultivated land, and water body, however settlement, wasteland land, and uncultivated land has increased mainly due to anthropogenic activities. (Bisht et al,2001) have carried out land cover change analysis of Gurur Ganga watershed in Uttaranchal.

(Dhinwa et al.1992)studied land-use change of Bharatpur district, the analysis in the study reveals that forest cover has been depleted whereas wasteland undulating terrain with or without scrub and rock outcrops has been increased from 1986 to 1989 Land use/land cover change detection process of identifies the differences in the state of an object or phenomenon by observing it at different times (Singh, 1989)Change detection is an important process in monitoring and managing natural resources and urban development because it provides a quantitative analysis of the spatial distribution of the population of interest. (Macleod,1998) list four aspects of change detection which are important when monitoring natural resources. They include; firstly, detecting the changes that have occurred; secondly, identifying the nature of the change; thirdly, measuring the area extent of the change, and lastly, assessing the spatial pattern of the change.

(Prakasam,2010) Studied land use/land cover change over 40 years in Kodaikanal taluk, Tamil Nadu. In this study, major changes had been observed like an area under built-up land and harvested land has increased whereas the area under forest and water body has decreased Javed et al.(2012) Studied land use land cover change due to mining activities from 2001 to 2010. The study revealed that significant decrease has been observed in dense forest area, cultivated land, and water body, however settlement, wasteland land, and uncultivated land has increased mainly due to anthropogenic activities.

2.8.2. Types of hydrological model

According to (Chow et al. 1988), stochastic and deterministic models are often considered to be at the top level of the classification tree, following the way they treat the randomness of hydrologic phenomena. Stochastic models use local hydrometric data to predict flows. These models allow for some randomness that results in different outputs and is based on analysis of past events, commonly rainfall and river discharge Ahmed et al.(2001). Deterministic models generally produce a single output of runoff for a given rainfall under identical physical environments. Without going to too much detail, deterministic hydrologic models can be classified into three main categories Cunderlik (2001).

Lumped models: lumped hydrologic model simulation evaluated only at an outlet of the basin that is without explicitly accounting for the response of individual sub-basins and parameters that do not vary spatially within the basin. Parameters of lumped models often do not represent the physical features of hydrologic processes and usually involve a certain degree of empiricism. According to (Haan et al.1994), the impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin and the most commonly employed procedure is an area-weighted average. Lumped models are not usually applicable to event scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically-based models Beven k.(2000).Water Balance model (WATBA), Snowmelt Runoff Model (SRM), Identification of unit Hydrograph and Components from Rainfall, Evaporation and Streamflow data (IHACRES) are examples of lumped hydrological models

Distributed models: distributed hydrological model parameters are fully allowed to vary in space at a resolution usually chosen by the user. The distributed modeling approach attempts to incorporate data concerning the spatial variation of parameters together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models require large amounts of data for parameterization in each grid cell (Beven, 2000). However, the governing Physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

Semi-distributed models: parameters of semi-distributed models are partially allowed to vary in space by dividing the basin into many smaller sub-basins. Semi-distributed model structures are more physically based than the structure of lumped models and less demanding input data than fully distributed models. The Semi-distributed model can be grouped into Kinematic Wave theory models and probability distributed models. According to (Beven,2000), the Wave theory models are simplified versions of surface and/or the subsurface flow equations of physically-based hydrologic models. In the case of the probability-distributed models, spatial resolution is considered by using probability distributions of input parameters across the basin. Examples of semi-distributed models are SWAT(Arnold et al., 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), and TOPMODEL (Cunderllk, 2003).

2.8.3. Hydrological model selection

The choice of a suitable hydrological model depends on the function that the model needs to serve. Several hydrological models are simulating the hydrological process at different spatial and temporal scales. Various criteria can be used for choosing the proper hydrological model for a specific problem. Further, some criteria are also user-dependent and subjective, such as the personal preference for the graphical user interface, computer operation system, input-output management, and structure, and clarity for users.

2.8.4. Previous studies using the SWAT model

The study conducted by applying the SWAT model to evaluate the impacts of land-use changes on the hydrology and erosion in the Nile River Basin Marwa et al.(2011) concluded that decreasing forest cover can cause the risk of increasingly frequent flooding. A study conducted on Angereb Watershed Haile et al. (2012) concluded that the wet season flow increased by 39% for the most recent year, while the dry season flow decreased appreciably by 46%. According to this study, the reason is due to the conversion of forest to agriculture which intern increased surface runoff during the wet season and reduced base flow during the dry seasons.

The result also indicated that the decrease in forestland and grasslands accompanied by an increase in agricultural and built-up areas.(Tolera kabeto, 2018)concluded that The result shows that the mean wet monthly streamflow increased by 17.15% (from 50.38m3/s in1995 to 59.02m3/s in 2015) and the mean dry monthly flow decreased by 28.15% (from 22.91m3/s in 1995 to 16.46m3/s in 2015)during the study period (1995-2015) on Ketar river basin due to LU/LC change when compared wet season streamflow is less sensitive than dry season flow due to the reason groundwater contribution during the dry season was reduced because of less infiltration that largely caused less cover. The base flow decreased while surface runoff increased because of urbanization, agricultural land expansion, and decrease of forest evergreen.

2.9. General description of the SWAT model

The SWAT (Soil and Water Assessment Tool) model is one of the river basin or watershed scale models developed by the United States Department of Agriculture - Agricultural Research Service (USDA-ARS) in Temple, Texas during the 1970s (Arnold et al., 1998). The SWAT model is physically based, semi-distributed, and can continuously simulate streamflow, sediment yield, nutrient, pesticides, and agricultural management in watersheds with varying soils, land use, and management conditions over long periods (Neitsch, et al, 2011).In the SWAT model simulation, the specific watershed information such as hydrology, weather, topography, soil, vegetation, and land-use practices are required. Based upon drainage areas of the attributes, the model divides the watershed into several sub-basins. Also, the sub-basins are further divided into several Hydrologic Response Units (HRUs) based on land use/ cover, soil, and slope characteristics. The hydrologic processes that can be simulated using the SWAT model contain precipitation, evapotranspiration, evaporation, surface runoff, percolation, lateral flow, groundwater flow, and channel routing (Arnold et al., 1998). The model routes the maximum amount of sediment in reach as a function of the peak channel velocity and estimates sediment yield for each HRU using MUSLE (Williams, 1995).

2.9.1. SWAT Model Selection Criteria

SWAT model was successfully used for various studies of water resources area Kassa(2007) applied SWAT model in analyzing the impact of land use and land cover change on streamflow in the case of Hare River watershed, Ethiopia and proved the model's acceptance in hydrological performance Damtew (2015) was applied to Ketar watershed to evaluate its simulating capacity through calibration and validation on monthly basis and recommended to use the model for further simulations and analysis of land use/land cover change on the hydrologic regime of Ketar watershed for future research.Also, the model software with some tutorial video is freely available on the SWAT website (Soil and Water Assessment Tool http://swat.tamu.edu/) to download. Besides**:** The selection of hydrological model taking into consideration the following four fundamental selection criteria Cunderlik (2007):

- Does the model predict the variables required by the project? (Required model outputs important to the project and therefore to be estimated by the model)
- Is the model capable of simulating single-event or continuous processes? (Hydrological processes that need to be modeled to estimate the outputs adequately)
- Can all the inputs required by the model be provided within the time and cost constraints of the project? (Availability of input data)
- Does the investment appear to be worthwhile for the objectives of the project? (Price)

For this study, the SWAT model was selected since it fulfills the above criteria. Besides, the model was selected because, it is physically based, semi-distributed and belongs to the public domain, computationally efficient and it requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed and used to classify and show the land use land cover change and adopt best management practice for the watershed.

2.9.2. Limitations of the SWAT model

SWAT model has the following limitations Arnold et al. (1998):

- The SWAT model is popular due to the multi-disciplinary coverage of processes representing hydrology, soil science, sediment transport, crop growth, in-stream water quality, and agricultural management, but it has a limitation on its non-spatial representation of the HRU inside each sub-catchment.
- The user is responsible for ensuring that any physical parameters entered are correct and meaningful since the model is not able to check the meaningfulness of values entered by the user.
- Sensitivity analysis, manual and auto-calibration tools in the SWAT model are time demanding when modeling complex catchments with several HRUs. This tool should be upgraded at least with a visual and objective functional representation of the results. The SWAT-CUP tool is a significant improvement for the calibration procedures; however, coupling SWAT and SWAT-CUP is needed to increase the efficiency of the modeling.

2.9.3. SWAT Development and Interface

The SWAT model is a semi-distributed; time-continuous watershed simulator operating on a daily time step (Arnold, J. G., Srinivasan, R, Muttiah, R.S and Williams, J.R, 1998). It is developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. The model is physically based and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds. The major components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The program is provided with an interface in Arc GIS Arnold (2012) for the definition of watershed hydrologic features and storage as well as the organization and manipulation of the related spatial and tabular data.

2.9.4. Application of Hydrological Model (SWAT)

SWAT model has been applied in agricultural watersheds and has been successfully calibrated and validated in many areas of the world. The studies indicated that the SWAT model is capable of simulating the hydrologic process from the complex and data-poor watershed with reasonable model performance statistical values. (Ndomba, 2002), was applied to the SWAT model in the modeling of Pangari River (Tanzania) to evaluate the applicability of the model in the complex and data-poor watershed.Adegun et al.(2014), was used SWAT models to predict water balance and water yield of a catchment area in Nigeria. It was suggested that the SWAT model could be a promising tool to predict water balance and water yield in the sustainable management of water resources. (Getachew Tegegne, 2013), was applied SWAT model on Lake Tana Reservoir Water Balance and reported that the overall model performance was satisfactory. Similarly, Tibebe (2010) also applied the SWAT model to evaluate surface runoff generation and soil erosion rates for a small watershed (Keleta Watershed) in the Awash River basin, Ethiopia, and recommended that the SWAT model provide a useful tool for soil erosion assessment from watersheds and facilitates planning for sustainable land management. (Damtew Fufa, 2015), was applied SWAT model for hydrological modeling of Katar watershed, Lake Ziway catchment, and recommended the use of the SWAT model for further future research. The above literature review indicated that the SWAT model is capable of simulating the hydrological process with reasonable accuracy and can be applied to large and complex watersheds.

2.9.5. SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

Distributed watershed models are increasingly being used to support decision making in land-use change. These models should pass through careful calibration and uncertainty analysis. Large scale distributed models are difficult to calibrate and to interpret the calibration because of large model uncertainty, input uncertainty, and parameter non-uniqueness. To perform parameter calibration and uncertainty analysis different programs are introduced. SWAT-CUP is one of the programs, which is currently used by different researchers. SWAT-CUP is a public domain and any calibration, uncertainty, or sensitivity can be linked to SWAT. The program links Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Sequential Uncertainty Fitting (SUFI2), and Markov Chain Monte Carlo (MCMC) procedures to SWAT (Abba Spour, 2015). It enables sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models. SUFI method determines uncertainty through the sequential and fitting process in which iteration and unknown parameter estimates are achieved before the final estimates.

2.9.6. Model Performance Evaluation

For evaluation of model performance, (Da Silva, 2015) describes model evaluation guidelines for quantification of accuracy in watershed modeling. The evaluation was performed by visual and statistical comparison of the measured and simulated data. The graphical method provided an initial overview. The statistical criteria were used to evaluate the performance of the model. The Nash and Sutcliffe simulation efficiency (NSE) describes the deviation from the unit of the ratio of the square of the difference between the observed and simulated values and the variance of the observations. The value of the coefficients varies from minus infinity to one with the latter value indicating perfect agreement between the simulated and observed data. A smaller NSE value indicates a poorer fit between the simulated and observed data. It is possible to obtain the negative value of the NSE indicating that the average of the observational data provides a better fit to the data compared to the simulated data. The percent bias (PBIAS) describes the tendency of the simulated data to be greater or smaller than the observed data, expressed as a percentage. The optimum PBIAS value is zero and low values indicate that the model simulation is satisfactory. Positive values indicate a tendency of the model to underestimate while negative values are indicative of overestimation. This test is recommended due to its ability to reveal any poor performance of the model. No existing standards are describing the range of the values of the statistical parameters that would indicate the acceptable performance of the model (Loague, 1991).

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Meki River basin, which is part of the Ziway-Shalla basin, is located in the northern part of the Main Ethiopian Rift. The area extends from a chain of mountains upstream, called the Gurage Mountains, to the low-lying Ziway Lake. It is scattered over ONRS and SNNPR. The total gauged basin area of Meki is about 2154 Km^2. It is located between 8°58”27.4’ to 8° 29”45’N Latitudes and38°57.8”12’ to 38°48”24’Longitudes (D.Legesse, 2010).

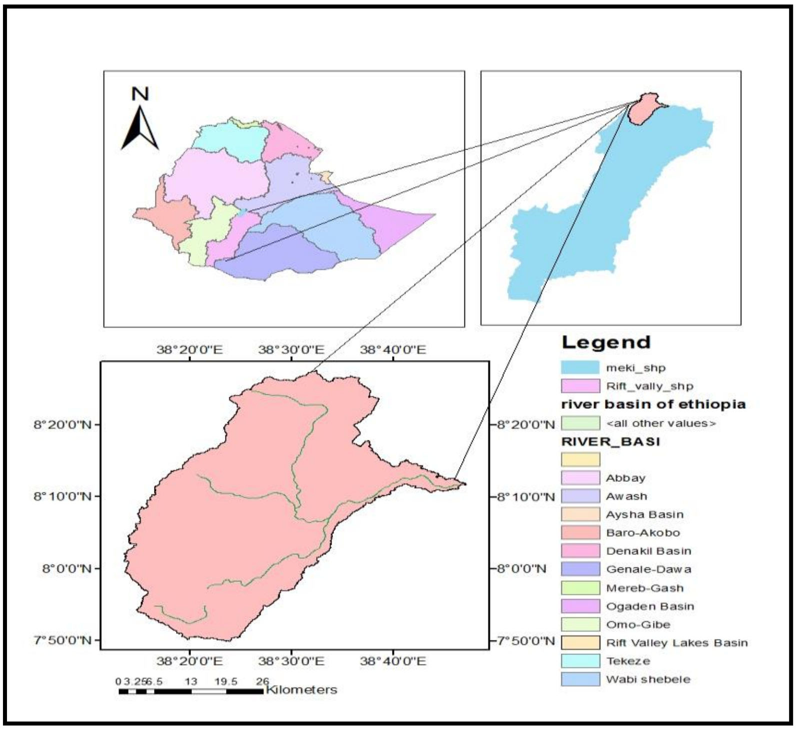

Figure 3.1: Location map of the Meki River basin.

3.1.2. Topography of the study area

The topography of the area is primarily determined by the rift system of faulting. The study area lies within altitudes ranging from 3600 m a.s.l. in the west to 1600 m a.s.l. in the rift floor with a mean elevation of 2056 m a.s.l. The upper riches of the basin are steep and mountainous while the lower basin is flat with a broad valley. The western plateau of the Gurage highlands with elevation ranging from 3500 to 3600 m a.s.l. are the perennial sources of the Meki River while the tributaries in the escarpment and rift floor are intermittent sources. The Meki River drains the western mountains and escarpments including a vast swampy area and travels for about 100 km before draining to Ziway Lake. The highland is characterized by higher drainage density than the escarpments and the flat rift floor areas. Rift faults have affected the drainage of the area both by determining the river courses and by impounding river water and causing some marshy areas (Chernet, 2008).

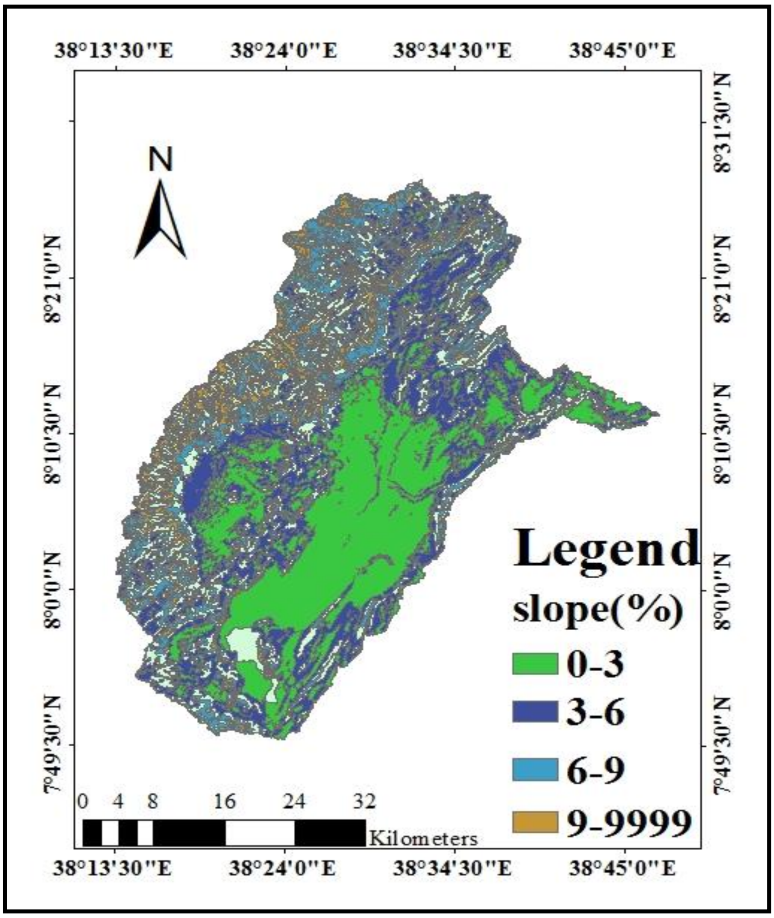

Figure 3.2: Topography of the study area

3.1.3. Land use/ Land Cover

For Land use/ land cover highly control the runoff and evapotranspiration, identification and interpretation of land use pattern of the area were prepared based on satellite images and various land use/ land cover classes delineated includes, Bare Land, Built-up Area, Agricultural land, Forest, Grazing Land, Shrub Land, Wetland, and Water Body.

3.1.4. Soil

Soil data is also used as an input associated with all the information describing the physical and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density, and organic carbon content for different layers of each soil type. This map is also obtained from the Hydrology Department of the Ministry of Irrigation Water and

Energy of Ethiopia (MoIWE). The six dominant soil types include Andosols, Cambisols, Fluvisols, Leptosols, Luvisols, and Vertisol.

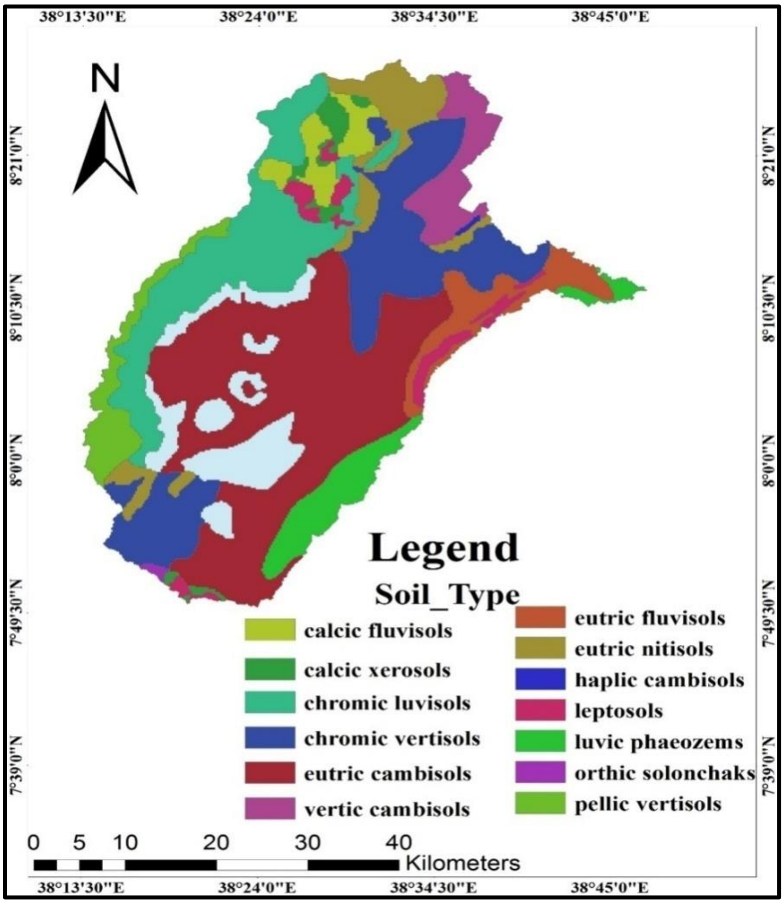

Figure 3.3: Soil map of the Meki watershed

3.2. Climate and Hydrology of the Study Area

3.2.1. Climate

The climate of the study area consists of three ecological zones: humid to dry humid, dry sub-humid or semi-arid, and semiarid or arid lands (Makin , 1976). Temperature and rainfall in the area show strong variations with altitude. The mean annual temperature ranges from about 15^{o}c in the highlands to around 20^{o}c in the rift. The average annual rainfall also varies spatially and ranges from around 650mm in the rift floor to more than 1200mm in the highlands. The Indian and Atlantic Oceans are the sources of moisture for almost all rains in Ethiopia (Degefu, 1987). Three main seasons characterize the study area: the first one is the long rainy season in summer, which lasts from June to September. The “summer “season is primarily controlled by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ), which lies to the north of Ethiopia at that time. According to (Degefu (1987), the “rain represents 50–70% of the average yearly total. The second is the dry period, which extends between October and February and is known as “Winter”. In “Winter” the ITCZ lies to the south of Ethiopia when the northeasterly trade winds traversing Arabia dominates the region. (Degefu (1987) indicated that occasional rains during this period bring 10–20% of the yearly average. The “Winter” season is known as the main harvest season in the area. The third season, which is known as “Spring” is of a “small rain” season accounting for 20–30% of the annual amount and stays from March to May.

3.2.2. Data Availability

The climatic data availability in the study area is presented in Table 3.1 below

Table 3.1: Data availability in the study area

Climate Variable	TIME SCALE	DATE LENGTH	STATION
RAINFALL	DAILY	1990-2017	ABOMSA
	DAILY	1990-2017	KULUMSA
	DAILY	1990-2017	LEMEN
	DAILY	1990-2017	HOMBOLE
TEMPERATURE	DAILY	1990-2017	ABOMSA
	DAILY	1990-2017	KULUMSA
	DAILY	1990-2017	LEMEN
RELATIVE HUMIDITY	DAILY	1990-2017	ABOMSA
WIND SPEED	DAILY	1990-2017	ABOMSA
SUNSHINE	DAILY	1990-2017	ABOMSA

3.2.3. Data Completion

Data completion is the primary step before the application of any data for hydrological studies. Most of the aforementioned data is complete. However, some variables exhibit missing records in the time series. Various methods are available to estimate missing rainfall records of gauged Stations. The method used for the analysis of data in this study is the normal-ratio method.

3.2.3.1. Checking Homogeneity of Stations

If the probability of occurrence of a storm of a given intensity is the same throughout an area. Then the area is said to be homogeneous. If the frequencies as well as the intensities of area, all the rains are the same at all places in such an area. One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall record and plotted to compare the stations with each other (Garg, 1976).

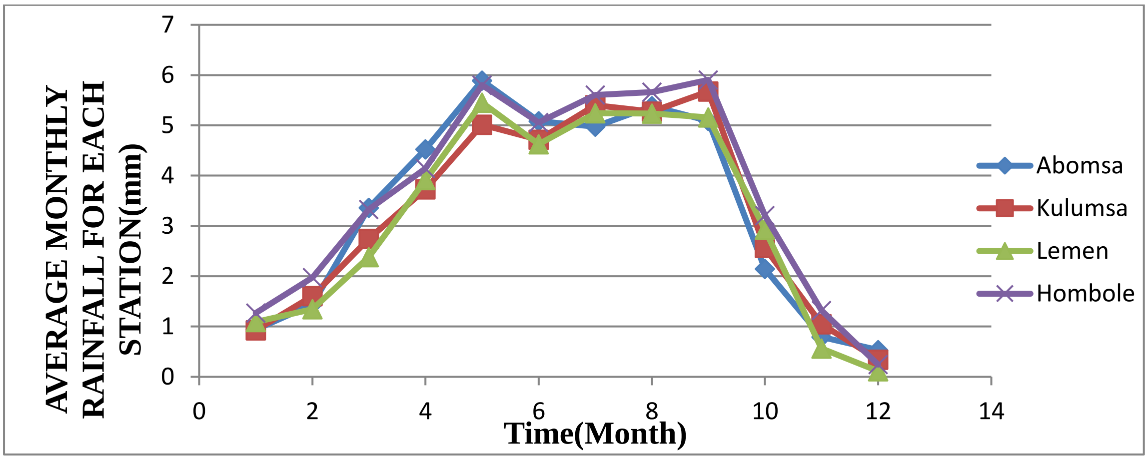

Figure 3.4: Non-dimensional plots of selected stations in the watershed

3.2.3.2. Test for consistency of record

A significant change may occur in and around a particular rain gauge station. Such a change occurring in a particular year will start affecting the rain gauge data, being reported from that particular station. After several years, it may be felt that the data of that station is not giving consistent rainfall values. To detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique, called the double mass curve method is generally adopted (Garg,1976). $P' = (\frac{Mo}{Mc})Px$……………….Equation 3.2 Where: P' corrected precipitation at station x Px is originally recorded precipitation at station x, Mo is the original slope of the double mass curve and Mc is the corrected slope of the double mass Curve. The stations used in this study have not undergone a significant change during the study period (1990 – 2017). The lines are smooth with no station displaying a strong or long-lasting break-in slope.

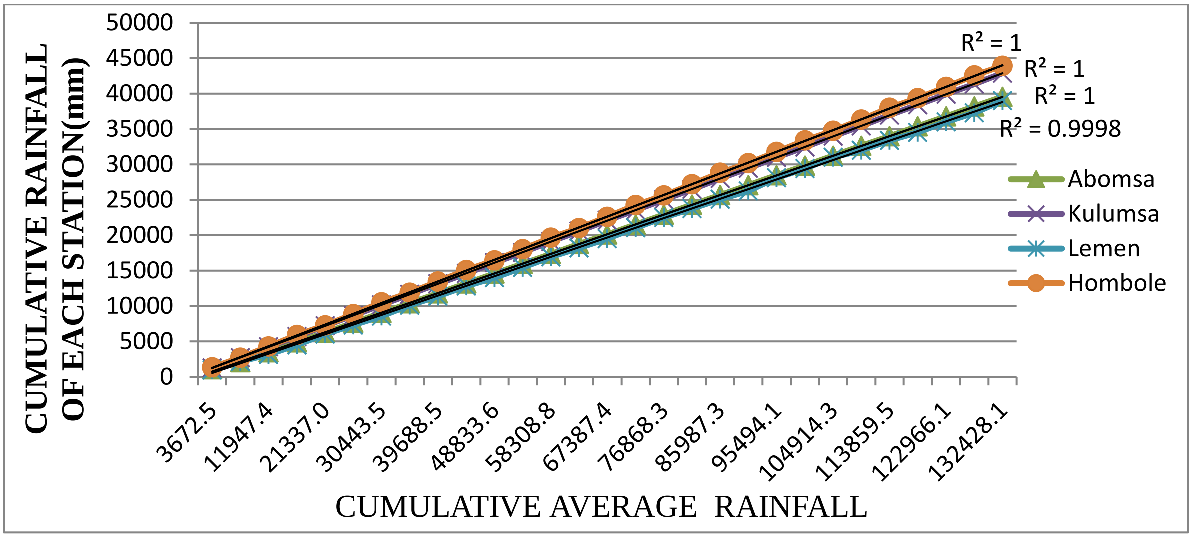

Figure 3.5: Double mass curve of stations of the watershed

3.2.3.3. Estimating Missing Rainfall Data

Measured precipitation data are vital to many problems in hydrologic analysis and design. Since there are costs related to data collection, it is imperative to have complete records at every station. However, the actual condition in most of the data records is not satisfied for different reasons. For gauges that require periodic observation, the failure of the observer to make the necessary visit to the gauge may result in missing data. Vandalism of recording is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record (Mc Cuen, 1989). Several methods have been proposed for estimating missing rainfall data. The most common methods are the simple Arithmetic Mean Method and Normal-Ratio Method and Normal-Ratio Method are used for filling in missing data in this study.

Normal – Ratio Method

The normal ratio method is preferred to be used where the mean annual precipitation of any of the adjacent stations exceeds the station in question by more than 10% and it is Normal ratio methods are expressed by the following relationship: $p_x = \frac{1}{m}\sum_{i=1}^{m}\frac{Nx}{Ni}Pi$ Where, Px =Missing value of precipitation to be computed. Nx = Average value of rainfall for the station in question for the recording period. Ni=N1, N2…Nn= Average value of rainfall for the neighboring station pi=1, 2…n... P1, P2...Pn = Rainfall of neighboring stations 1, 2…n during missing period N= Number of stations used in the computation and M= no of surrounding stations.

3.2.3.4. Rainfall

The Long-term mean monthly rainfall is computed at Abomsa, Kulumsa, Lemen, and Hombole Climatic Stations. Meki sub-watershed with a minimum and maximum annual precipitation of 859.3 mm and 1088.1 mm respectively. The wet season is from June to September. Based on the National Metrology Agency during the period (1990-2017) is presented in Figure 3.4. The peak average Monthly rainfall appears through the months, August-September for Abomsa station and July-September for Kulumsa station.

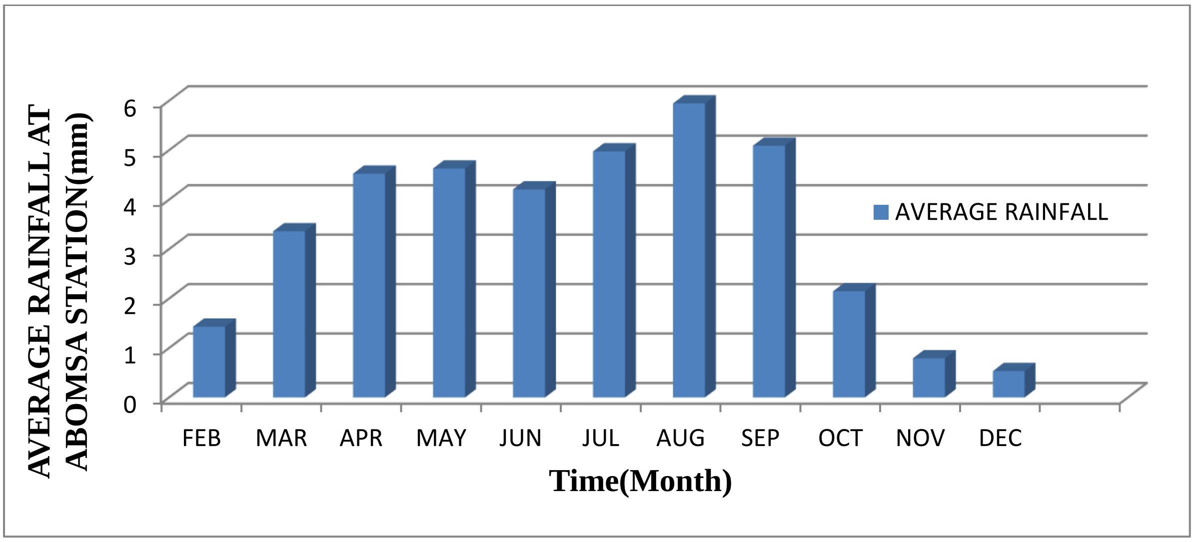

Figure 3.6: Long term mean monthly Rainfall (intra-annual variability) at Abomsa

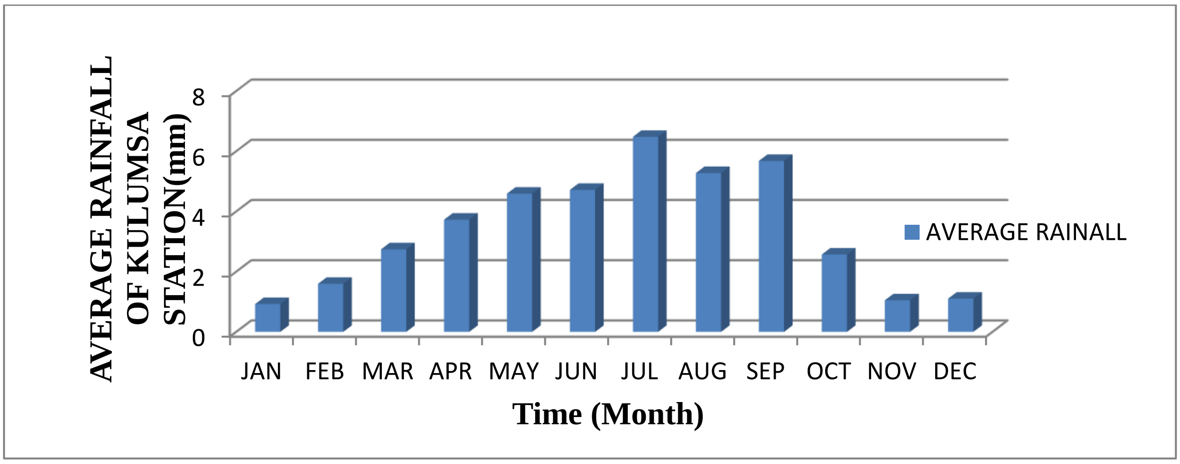

Figure 3.7: Long term mean monthly Rainfall (intra-annual variability) at Kulumsa

3.2.3.5. Temperature

The highest mean maximum monthly temperature at Abomsa station computed during the period1990-2017 was observed in February (25.52°C) and the lowest mean maximum temperature observed in August (18.79°C). Similarly, the highest mean minimum temperature Computed during the same period was observed in April (11.69°C), and the lowest mean monthly minimum temperature observed in December (9.09°C). The computed long-term mean annual temperature during the same period is 18.5 °C.

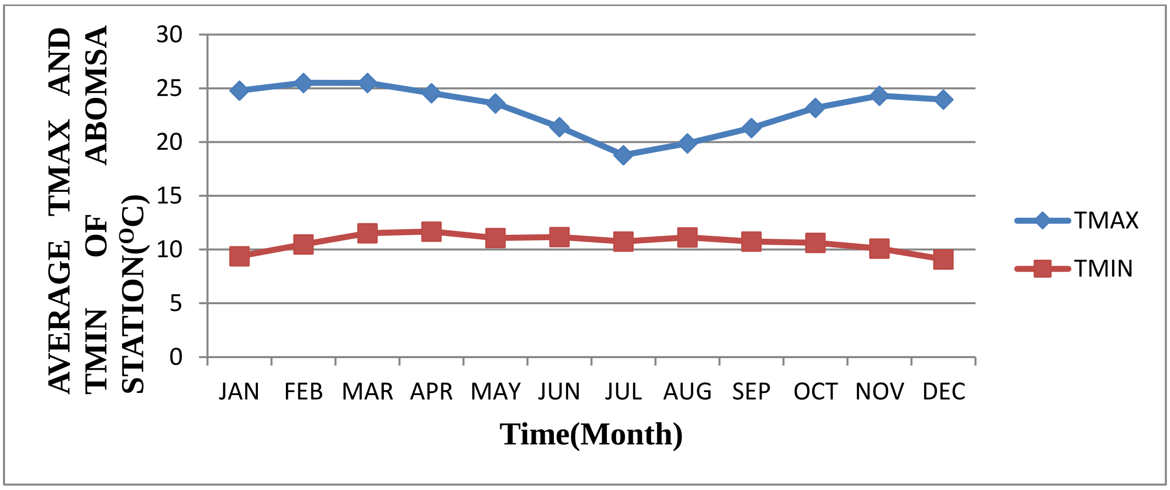

Figure 3.8:Long-term mean monthly maximum and minimum temperature (intra-annual variability) at Abomsa Station

3.2.4. Methods

3.2.4.1. General

To achieve the objectives of the study, the overall methodology of the research study is described in Figure 3.7 below

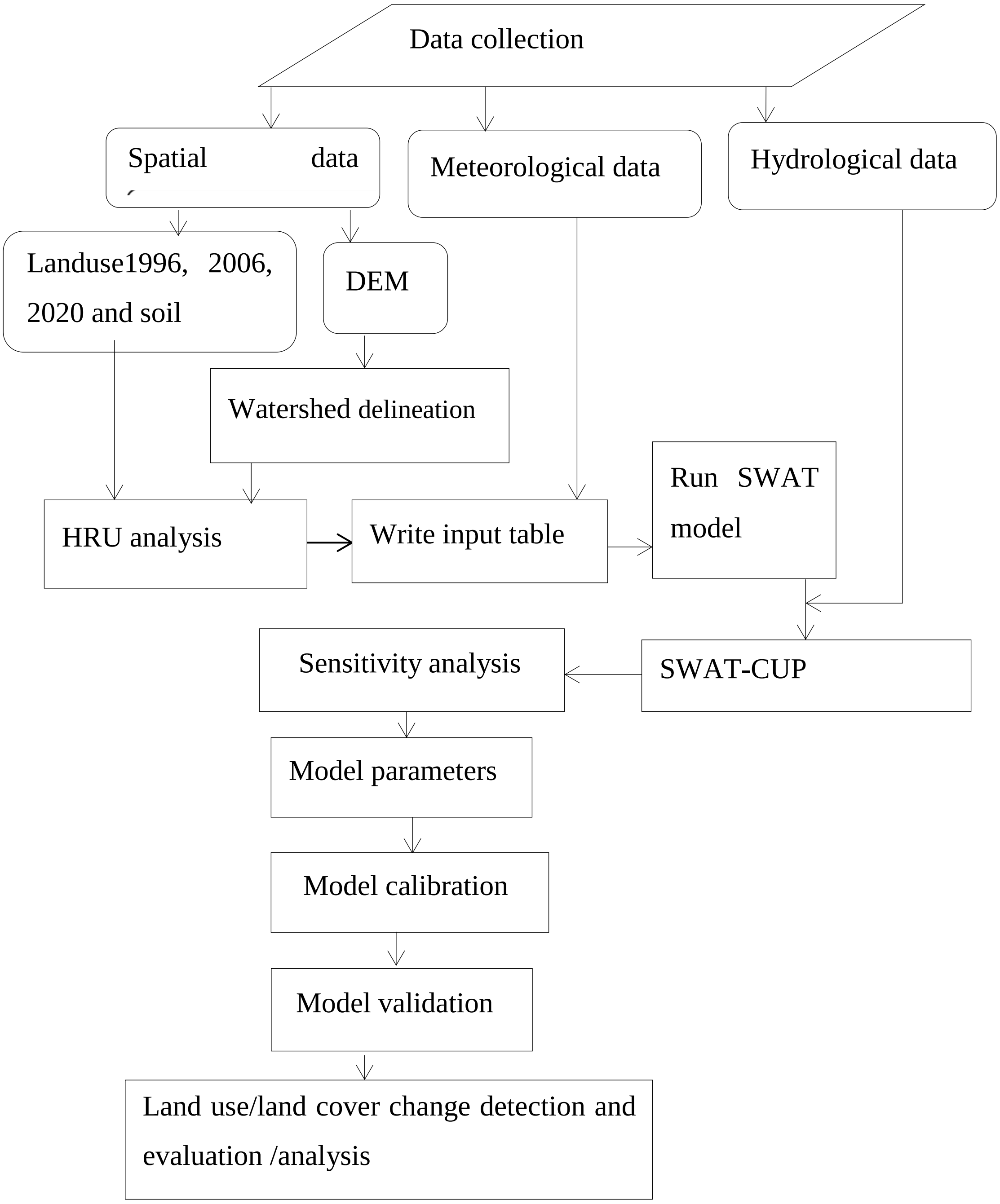

Figure 3.9: Formwork of the research

3.3. Data Collection and analysis

Primary and secondary data sources were used to collect data and to accomplish the research objectives. Primary data collection techniques are Personal fieldwork experience in the area and field visited to verify ground truth data. Whereas, published Books, Articles, and journals were used as secondary data.

3.3.1. Hydro-meteorological data

Hydrological data (river discharge) and meteorological data (precipitation, temperature, relative humidity, wind speed, sunshine hours) are collected from the Ministry of Water Irrigation and Energy (MoWIE) and National Meteorological Agency (NMA) respectively. The Meteorological data collected from National Meteorological Agency has a longer time series data for the catchments of Meki watershed of the four meteorological stations in the watershed were Abomsa, Kulumsa, Lemen, and Hombole gauging stations. For this study, a daily time series of Meteorological data of 27 years was collected.

3.3.2. Spatial data

The spatial data such as Digital Elevation Model (DEM), land use land cover, and soil data were important in watershed modeling. A 30 m x 30 m resolution of Meki watershed DEM was downloaded from United States Geological Survey (USGS), SRTM (Shuttle Radar Topography Mission).The extracted Meki watershed DEM was used for watershed delineation. 1996, 2006, and 2020 landsat images were collected from Ethiopian mapping agency and soil data were collected from the Ethiopian Ministry of water, irrigation, and energy (MoWIE) GIS department. The land use land cover maps of each year were classified using ERDAS IMAGIN software and a soil map of the Rift valley lake basin (RVLB) was clipped for the study area.

3.4. Data analysis

3.4.1. Meteorological data analysis

Filling of missed data

Data missing occurs due to the interruption of measurements caused by natural and human-induced factors. Missed precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible since it is necessary to fill in this missing record. Many methods are available for estimating missed rainfall data like the arithmetic mean method, normal ratio method, and inverse distance weighting method. For this study, the normal ratio method was used to fill missing data because of the mean annual precipitation at any of the index stations differs from that of the mean annual precipitation of the missed station by more than 10% (Equation 3.1).

$$P_X = \frac{1}{N}\left(\frac{N_X}{N_A}P_A + \frac{N_X}{N_B}P_B + \frac{N_X}{N_C}P_C + \cdots + \frac{N_X}{N_N}P_N\right) \qquad (3.1)$$

where, P_X is the precipitation for the station with the missed record, P_A, P_B, P_C….., P_N are the corresponding precipitation at the index stations and,N_A, N_B, N_C,………, N_N and N_X are the long-term mean monthly precipitation at the index stations and station x. The temperature, relative humidity, sunshine hours, and wind speed data were filled with station average and linear regression methods.

3.4.2. Flow Data Analysis

Filling of missed data

Before beginning any hydrological analysis, it is important to make sure that the datas are sufficient and homogenous with no missing data. Based on visual examination, streamflow records of Lake Ziway Nr Ziway gauging station have a good quality of flow data that shows a strong correlation. The station has a small number of missing data in the study baseline (1998-2007). Discharge in Meki River depends on the rainy season that occurs in June to August and September to October and light rains are experienced in other seasons. For this study filling of the missing data at Lake Ziway NR Ziway, a gauging station was made by using the linear regression method (Equation 3.2).

$$Y = -0.6527X + 25.32 \qquad (3.2)$$

Where$Y$ is missing data, X is the available data used to fill the missed record.

Data screening

Streamflow observations quality assessment for manual of machine errors may exist in the streamflow collected from a respective organization such errors like misplaced decimal numbers, very huge unrealistic numbers, and very high flow records during dry months and low flow record during rainy months. Thus, performing streamflow observations quality assessment before using it for required purposes is a crucial step. Therefore, for this study, the recorded flow at Lake Ziway Nr Ziway gauging station for 10 years is roughly checked by visual detection and all year’s flow records are look good.

Outliers test

The outlier test examines the presence of high and low outliers in the measured streamflow data. It is used under the assumption that the logarithms of the original series are normally distributed. For the natural logarithm of the variable, the upper and lower limits of outliers are given as:

$X_{higher} = exp(\bar{X} + K_n * S_y)$……………………………………………..……… …… (3.3)

$X_{lower} = exp(\bar{X} - K_n * S_y)$………………………………………………….….….. (3.4)

Where, $\bar{X}$ and S_y are the mean and standard deviation of the natural logarithm of the original variable respectively. $K_n$is the frequency factor representing the outlier test statistic that depends on the sample size n.

$K_n = -0.9043 + 3.345\sqrt{logn} - 0.4046logn$ ………………………………..……..… (3.5)

For this study, 12 years of measured streamflow data were checked based on the above outlier test equation and the results show there is no higher and lower outlier in the recorded data.

3.5. Soil and water assessment tool (SWAT) model

According to (Arnold et al. (2012), the SWAT model is developed to quantify land management practices impacts on water, sediment, and agricultural chemical yields in watersheds with varying soils, land use, and management practices over long periods. The major components of the SWAT model are hydrology, climate, sediment movement, crop growth, nutrient cycling, agricultural management, and pesticide dynamics.

3.5.1. Hydrological components of the SWAT model

In the SWAT model hydrological simulation of watershed divided into the land phase and routing phase (Neitsch, et al, 2005). The land phase of the hydrological cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel from each sub-basin. The routing phase of the hydrologic cycle controls the movement of water, sediments, nutrients, and organic chemicals through the channel network of the watershed to the outlet.

Land Phases of the Hydrological Cycle

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

$SW_t = SW_0 + \sum_{i=1}^{t}\left[R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw}\right]$…………..……..…………………….(3.9) where,SW_t =is the final soil water content (mm H_2O),$SW_0$is the initial soil water content on a day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on a day I (mm H_2O),Q_{surf} is the amount of surface runoff on a day I (mm H_2O),$E_a$is the amount of evapotranspiration on a day I (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on a day I (mm H_2O), and Q_{qw} is the amount of return flow on a day i (mm H_2O).

Surface runoff

Surface runoff occurs when the rate of precipitation exceeds the rate of infiltration. To estimate the surface runoff SWAT model offers the SCS curve number procedure (USDA-SCS, 1972). Using daily rainfall, SWAT simulates surface runoff volumes, and peak runoff rates for each HRU.The SCS curve number equation is given as:

$$Q_{surf} = \frac{(\mathrm{R}_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (3.10)$$

Here Q surf is accumulated runoff or rainfall excess (mm H_2O), R_{day} is rainfall depth for the day (mm H_2O), I_a is an initial abstraction that includes surface storage, interception, and infiltration before runoff (mm H_2O), and$S$ is the retention parameter (mm H_2O).The retention parameter varies spatially due to changes in soils, land use, management, and slope as well as due to changes in soil water content, temporarily. It will be calculated by:

$$S = 25.4\left[\frac{1000}{CN} - 10\right] \qquad (3.11)$$

Where $CN$is the curve number for the day

The SWAT model uses the United States Natural Resource Conservation Service classification, which classifies soils into four hydrologic groups A, B, C, and D based on infiltration characteristics of the soils. Group A, B, C, and D soils have high, moderate, low, and very low infiltration rates respectively (Neitsch et al., 2005). The classification defines a hydrological group of soils having similar runoff potential under similar storm and land cover conditions. The initial abstraction, I_a, is approximated as 0.2S and the Equation 3.12 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2\,S)^2}{(R_{day} - 0.8\,S)} \qquad (3.12)$$

A runoff will occur only when R_{day}>Ia. Thus, there is some amount of rainfall Ia (initial abstraction before pounding) for which no runoff will occur (Chow et al., 1998).

Peak runoff rate

The peak runoff occurs during a storm event and is used to calculate sediment loss. SWAT model calculates the peak runoff rate with a modified rational method for each HRU Equation 3.13 (Neitch et al., 2011):

$Q_{peak} = \frac{a_{tc} * Q_{surf} * A}{3.6 * t_{conc}}$ ……………………………..…….………………………. (3.13)

Where, Q_{peak} is peak runoff rate (m3/s), a_{tc} the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm H_2O); A is the sub-basin area (km^2),t_{conc} is the time of concentration (hr) and 3.6 is the conversion factor. SWAT estimates the value a_{tc} by using:

$a_{tc} = 1 - exp\left(2 * t_{conc} * lan(1 - a_{0.5})\right)$…………..……………..……………(3.14)

Where,$a_{0.5}$is the fraction of daily rain falling in the half-hour highest rainfall intensity.

Time of concentration

The time of concentration (t_{conc}) is the summation of the overland flow time of the longest point in the sub-basin to reach a stream channel (tov) and the upstream channel flow time required to reach the outlet point (t_{ch})Equation 3.15.

$t_{conc} = t_{ov} + t_{ch}$ ………………………………………………………………….…… (3.15)

To compute t_{ov} and t_{ch}SWAT model uses the following equations

$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}}$ ……………………………….……………………………..…... (3.16)

$t_{ch} = \frac{L_{ch}}{3600 * V_{ch}}$…………………………..………………………………..……... (3.17)

Where, $L_{slp}$is the average sub-basin slope length (m); $V_{ov}$is the overland flow velocity (m/s), $L_{ch}$is the average flow channel length (km); $V_{ch}$are the average flow velocity (m/s) and 3600 and 3.6 are unit conversion factors.

Percolation

Percolation is the downward movement of water in the soil. SWAT calculates percolation for each soil layer in the profile. For each soil, layer water allows percolating when the water content of the layer exceeds field capacity of that layer when the layer below is not saturated and mathematically expressed as follows (Neitsch et al., 2005):

SW excess = $\begin{cases} SW - FC, SW > FC \\ 0, SW \le FC \end{cases}$ ………………….……………………………. (3.18)

Where, SW excess is the drainable volume of water in the soil (mm H_2O),SW is the water content of the soil layer (mm H_2O) and FC is the water content at field capacity. Storage routing methodology by (Sloan and Moore,1984)is used the SWAT model for calculating the volume of water moves from one layer to the other layer below is expressed as follows:

$$W_{perc} = SW_{excess}\left[1 - exp\left(\frac{-\Delta t}{t_t}\right)\right] \dots\dots\dots\dots (3.19)$$

where, $W_{perc}$is the amount of water percolating to the underlying layer (mm H_2O), Δt is the length of the time step (hr) and $t_t$is the travel time for percolation.

Bypass flow

Bypass flow is the vertical movement of free water along with macro pores through the unsaturated soil layer. When simulating the bypass flow, SWAT calculates the crack volume of the soil matrix for each day of simulation by layer. On days in which precipitation events occur, infiltration and surface runoff are first calculated for the soil. Part of the surface runoff equivalent to the cracks volume enters the soil profile as bypass flow and the rest remains overland flow. Cracks are filled following their presence in the consecutive layers (Bronswijk, 1989; Neitch et al., 2011).

Lateral flow

Lateral flow occurs in soil layers with high hydraulic conductivities and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturated zone above the impermeable layer and which is the source of water for lateral subsurface flow. Lateral flow moves through the soil layers and joins the nearest channel.

SWAT model calculates the amount of lateral flow released to the main channel as:

$$Q_{lat} = \left(Q'_{lat} + Q_{latstore,i-1}\right) * \left(1 - exp\left[{}^{-1}/_{t_{lag}}\right]\right) \dots\dots\dots\dots (3.20)$$

where,Q_{lat} is the amount of lateral flow discharged to the main channel on the given day (mm H_2O), Q'_{lat} is the amount of lateral flow generated in a sub-basin on a given day (mm H_2O), $Q_{latstore,i-1}$ the lateral flow stored or lagged from the previous day (mm H_2O), t_{lag} the lateral flow lag time.

Evapotranspiration

Different approaches are used to estimate evapotranspiration (ET). SWAT computes evapotranspiration (ET) using three methods; the Priestley-Taylor method (Priestley and Taylor, 1972), Hargreaves method (Hargreaves,1987), and the Penman-Monteith method (Monteith, 1965). Penman-Monteith's (1965) method requires solar radiation, air temperature, relative humidity, and wind sped; (Priestley-Taylor method (1972) requires solar radiation, air temperature, and relative humidity; whereas (Hargreaves,2003)method requires an air temperature only. For this study, the penman-Monteith method was used to estimate evapotranspiration.

The Penman-Monteith equation that estimates evapotranspiration is given as follows:

$$ET = \frac{0.408(R_{net}-G)+\gamma\frac{900}{(T+273)}U(e_s-e_a)}{\Delta+\gamma(1+0.34U)} \qquad (3.21)$$

where ET is daily reference crop evapotranspiration [mm day^{-1}], R_{net} is net radiations flux [MJm-2 day^{-1}], G is heat flux density in the soil, it is very small and can be neglected [MJ m^{-2} day^{-1}], T is mean daily air temperature [^{O}C],$\gamma$is psychometric constant [KPA ^{o}C^{-1}], U is wind speed measured at 2 m height [ms^{-1}] e_s is the saturation vapor pressure $e_a = e_s$ *RH/100 [KPA],RHis relative humidity [%]andΔ is the slope of the saturation vapor pressure curve [KPa^{o}C^{-1}].

3.6. SWAT calibration and uncertainty procedures (SWAT-CUP)

SWAT-CUP software was developed to perform calibration, validation, sensitivity analysis, and uncertainty analysis, and also its performance was better than the auto-calibration modulus embedded in the SWAT model (Zhou et al., 2014)The SWAT-CUP program contains different algorithms such as Sequential Uncertainty Fitting (SUFI-2) (Abbaspour,2014)Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 1992), Parameter Solution (Parasol) Griensven(2006) and Markov chain Monte Carlo (MCMC) are interfaced with SWAT model. Uncertainty of the model estimation rise from model parameters, the model itself, and input data. Uncertainty analysis algorithms are used to decrease modeler uncertainty by eliminating some probable source of modeling and calibration errors. For this study, the SUFI-2 algorithm used because of the uncertainty in the SUFI-2 program considers all sources of uncertainty. According to (Abbaspour,2014), these uncertainties can be quantified in SUFI-2 by a measure of P - factor and R - factor. The P-factor is the percentage of measured data bracketed by 95PPU or 95% prediction uncertainty. Whereas, R- factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. It means the R-factor measures the strength of uncertainty analysis and calibration. When simulation matches with the observed, the resulting value of R- factor close to zero and P- factor close to 1 and it indicates a low level of uncertainty has contained in the simulation.

3.7. SWAT model inputs

SWAT model input data are Digital Elevation Model (DEM), soil, land use/cover, slope, and weather data for simulation whereas Streamflow is required for calibration and validation purposes at the outlet of the watershed.

3.7.1. Digital elevation model (DEM)

DEM is defining the topography of the watershed by describing the elevation of any point at a given specific spatial resolution as a digital file. For this study, a 30 m x 30 m resolution DEM was input for the SWAT model to calculate the flow accumulation, stream networks, to delineate the watershed into several sub-basins based on elevation.

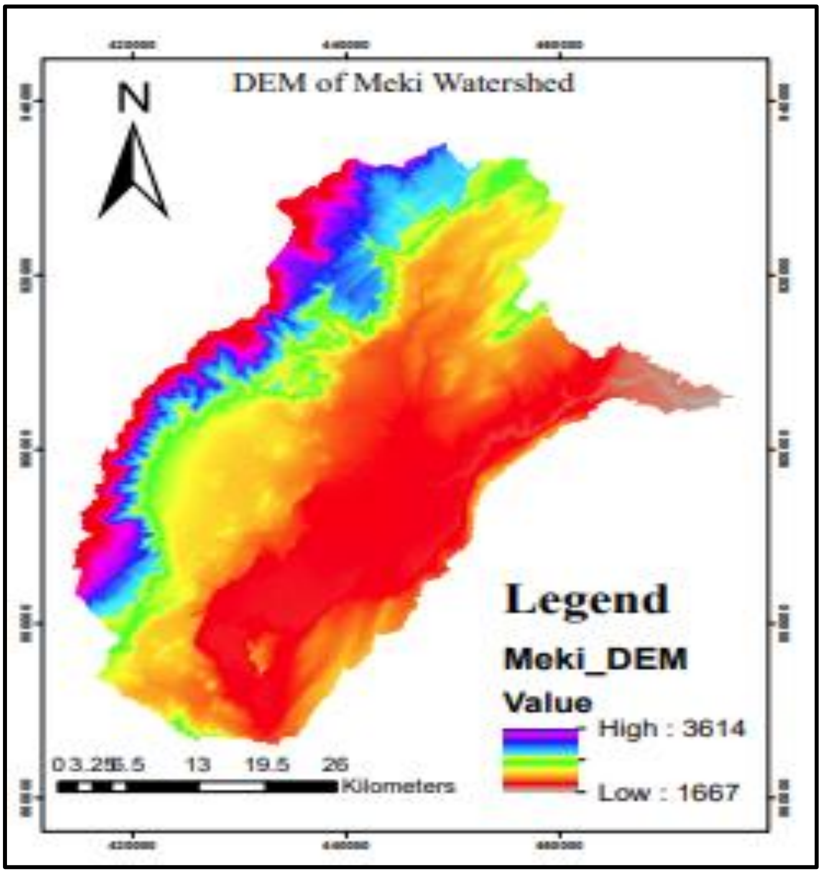

Figure 3.10: Digital Elevation Model (DEM) of the Meki watershed

3.7.2. Land use/cover data

Land use/cover significantly affects surface erosion, runoff, and evapotranspiration in the watershed. The land use/cover map gives the spatial extent and classification of the various land use/cover classes of the study area. For this study 1996, 2006 and 2020 land sat image of the watershed land use/cover map was obtained from the Ministry of Agriculture (MoA) with a 30m spatial resolution. By using ERDAS IMAGIN2014software Meki watershed land use/cover map was classified using supervised classification. It is one of the input data for the SWAT model with inclusive properties. The model already has predefined SWAT four-letter codes for each land use/cover classification in such a way that the land use/cover classification used in the study area was assigned in the SWAT database.

Types of Image classification

Land cover maps are commonly created from remotely sensed data through unsupervised or supervised classification techniques (Jensen, 1996).

Supervised Classification

In this study, analyses of the different LULC classes were performed using supervised classification method. The previous study (Damtew Fufa, 2015)and (Hal crow, 2008) were used as a reference for classification numbers. The supervised classification was applied after a defined area of interest (AOI) which is called training classes. In supervised land use classification, defining of training sites, extraction of the signature editor, and classification of the image was performed using the Maximum Likelihood classifier. Finally, eight classes of LU/LC such as forest, agriculture, build-up area, grazing land; wetland, bare land, shrubland, and water body were produced. Since there may be misclassification of pixels in supervised classification, there should be accuracy assessment.

Unsupervised Classification

The unsupervised classification approach is an automated classification method that creates a thematic raster layer from a remotely sensed image by letting the software, which identifies statistical patterns in the data without using any ground truth data Lilles et al. (2004). This method calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels concerning the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified. The final clusters are used to classify the image with classifiers such as the minimum distance or maximum likelihood. The output however requires post-classification operations to make the results more meaningful.

Accuracy Assessment

The accuracy assessment was used to determine the correctness of the classified image. It was performed using a confusion matrix. Using the Google Earth Image as a reference, randomly selected points were compared with the corresponding classification. For classification accuracy, an assessment error matrix was produced for all images in this study. GPS points used in the classification accuracy assessment were independent of ground truth points used in the classification. The Kappa coefficient was also used to assess classification accuracy Peesapati et al. (2015). It expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification (Congalton, 1991). The Kappa statistic incorporates the off-diagonal elements of the error matrices (that is, classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. The overall accuracy and Kappa statistics is calculated by using (Jensen, 2003) formula as follows:

$$Overallaccuracy = \frac{Numberofpixelscorrectlyclassified}{Totalnumberofpixel}$$

Kappa (Kˆ): It reflects the difference between actual agreement and the agreement expected by chance and estimated as $K^{\wedge} = po - pe/1 - pe$

Where Po = proportion of correctly classified pixels and determined by diagonal in error matrix; Pe = proportion of correctly classified pixels expected by chance and incorporates off-diagonal.

Overall accuracy

The overall accuracy gives the overall results of the confusion matrix. It was calculated by dividing the total number of correct pixels (diagonals) by the total number of pixels in the confusion matrix. The result showed that the overall accuracy for the maps of 1996, 2006, and 2020 was 87.5%, 90.56%, and 92.23% respectively. According to(Anderson et al., 1976), the minimum accuracy value for reliable land use land cover classification is 85 %. The other authors (eg. Bedru(2006)), explains that the expected accuracy is determined by the users themselves depending on the type of application the map product would be used later. Accuracy levels are accepted by users may not acceptable by other users for a certain task Bedru (2006). Therefore, based on table 4.1 and the table in the appendix's the classification carried out in this study produces an overall accuracy that fulfills the minimum accuracy level defined by Anderson for three land cover maps of the Meki watershed.

Producer's Accuracy

The producer's accuracy tells us how well a certain area could be classified. It is obtained by dividing the number of correctly classified pixels in the category by the total number of pixels of the category in the reference data. The producer's accuracy is also known as an Omission Error, which is the probability of a reference pixel being classified correctly. It gives only the proportion of correctly classified pixels. The overall result of the producer's accuracy ranges from 80.7% to 100%. The lowest values were misclassified due to the similar spectral value of different land cover classes. For instance, a wetland with bare land, water with bare land, forest with shrubland, etc. somehow affects the level of classification.

$$\text{Producer's accuracy} = \frac{\text{Number of corrected pixel in the diagonal}}{\text{column total in the matrix}}$$

User's Accuracy

It is the ratio between the total number of pixels correctly belonging to a class (diagonal elements) and the total number of pixels assigned to the same class by the classification procedure (row total). This quantity explains the probability that a pixel of the classified image truly corresponds to the class to which it has been assigned. In this study, the user's accuracy ranges from 73.3%-99.2%, 83.2%-99.8% and 88.3% to 100% and a kappa coefficient of 0.89, 0.87, and 0.9 for 1996, 2006, and 2020 respectively. According to (Monserud,1990) kappa values greater than 0.85 are rated as very good indicators of the classified image in reporting the ground truths.

$$\text{User'saccuracy} = \frac{\text{Number of corrected pixel in the diagonal}}{\text{row total in the matrix}}$$

3.7.3. Soil data

Soil governs runoff generation in the watershed. SWAT model requires different soil physical and chemical properties soil texture, available water content, hydraulic conductivity, bulk density, and organic carbon content for different layers of each soil type. The Ethiopia soil map is obtained from the MoWIE GIS department and used to clip the Meki watershed soil map.

3.7.4. Weather data

Climate data required for the SWAT model are daily rainfall, maximum and minimum temperature, wind speed, relative humidity, solar radiation. For this study, precipitation data were available in all meteorological stations, but the Abomsa gauging station has full weather data (precipitation, temperature, relative humidity, sunshine hours, and wind speed).

3.8. SWAT model setup

3.8.1. Watershed delineation

Watershed delineation using DEM is the initial step in the SWAT model for watershed simulation. The watershed delineation process includes five major steps: DEM setup, stream definition, outlet and inlet definition, watershed outlet selection, and definition and calculation of sub-basin parameters. SWAT allows the user to delineate the watershed and sub-basins using DEM to carry out advanced GIS functions to aid the user in dividing watersheds into several hydrological connected sub-basins for use in watershed modeling by SWAT model (Arnold et al., 2012). The DEM of Meki watershed is loaded into ArcGIS 10.3 as a grid format. The model processes the DEM map grid to remove all the non-draining zones (sinks). Stream network was defined for the whole DEM by the SWAT model using the concept of flow direction and accumulation. The size, number of sub-basins, and details of the stream network depend on the threshold area (Winchell et al., 2007). The user should define the threshold area to define the minimum drainage area required to form the origin of the stream. The smaller threshold area gives more detail of the drainage network, large numbers of the sub-basins, and Hydrologic Response Unit (HRU). However, this demands more processing time. The threshold area of 4,222ha was taken for this study. The Meki watershed outlet point was manually added and selected for finalizing the watershed delineation. Finally, the model automatically delineated a watershed area of 2154 km^2 with 29 sub-basins (Figure 3.11).

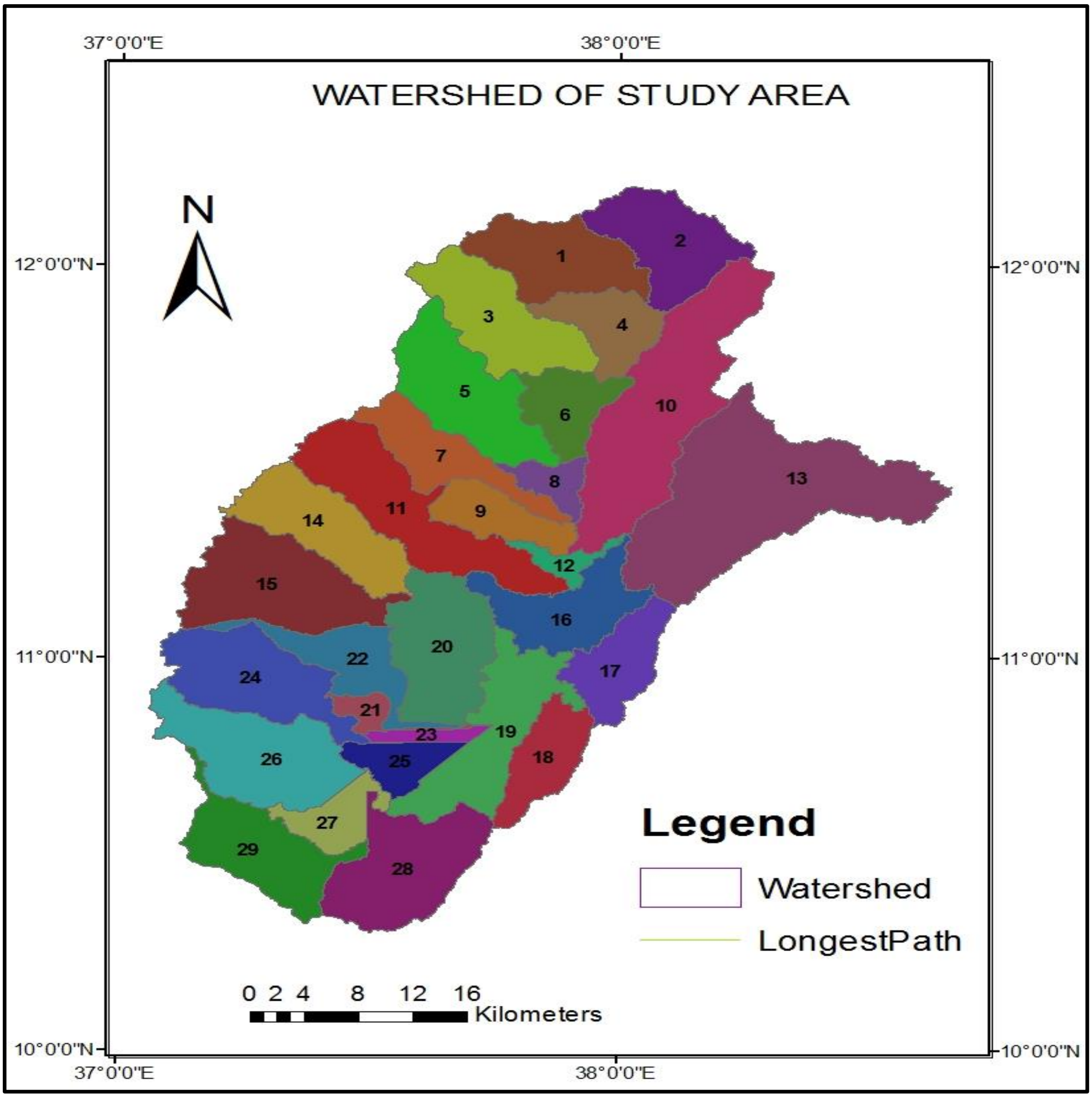

Figure 3.11: Watershed of the study area

3.8.2. Hydrologic response unit (HRU) analysis

Once the watershed is delineated, then HRU analysis takes place. HRU analysis requires land use, soil, and slope data and divides each sub-basin into the number of HRU with a unique land use/cover, soil, and slope combination. Produced HRU is crucial for simulation of the SWAT model; because it determines how much the land use, soil, and slope categorized will respond to precipitation, infiltration, runoff, and other hydrologic processes during the simulation. Delineated watershed by Arc SWAT model and prepared land use were overlapped 100%. The land use map was named into eight classes SWAT four code letters (Figure 3.12).

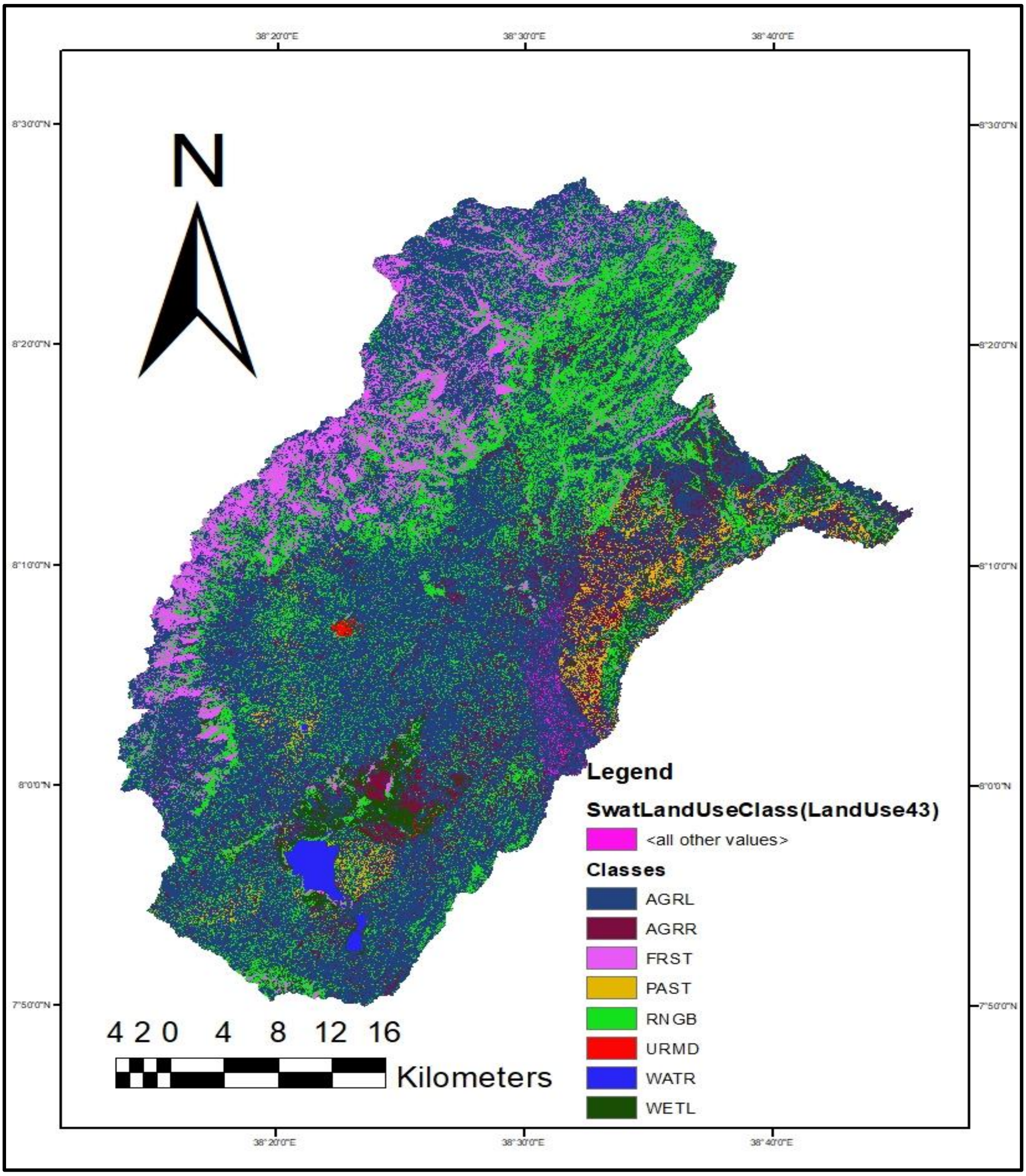

Figure 3.12: Reclassified land use four-letter code of 2020 by SWAT model

Moreover, HRU analysis in the Arc SWAT model includes divisions of HRUs by slope classes. Slope discretization of the watershed is 0-3, 3-6, 6-9, and >9% (Figure 3.13).

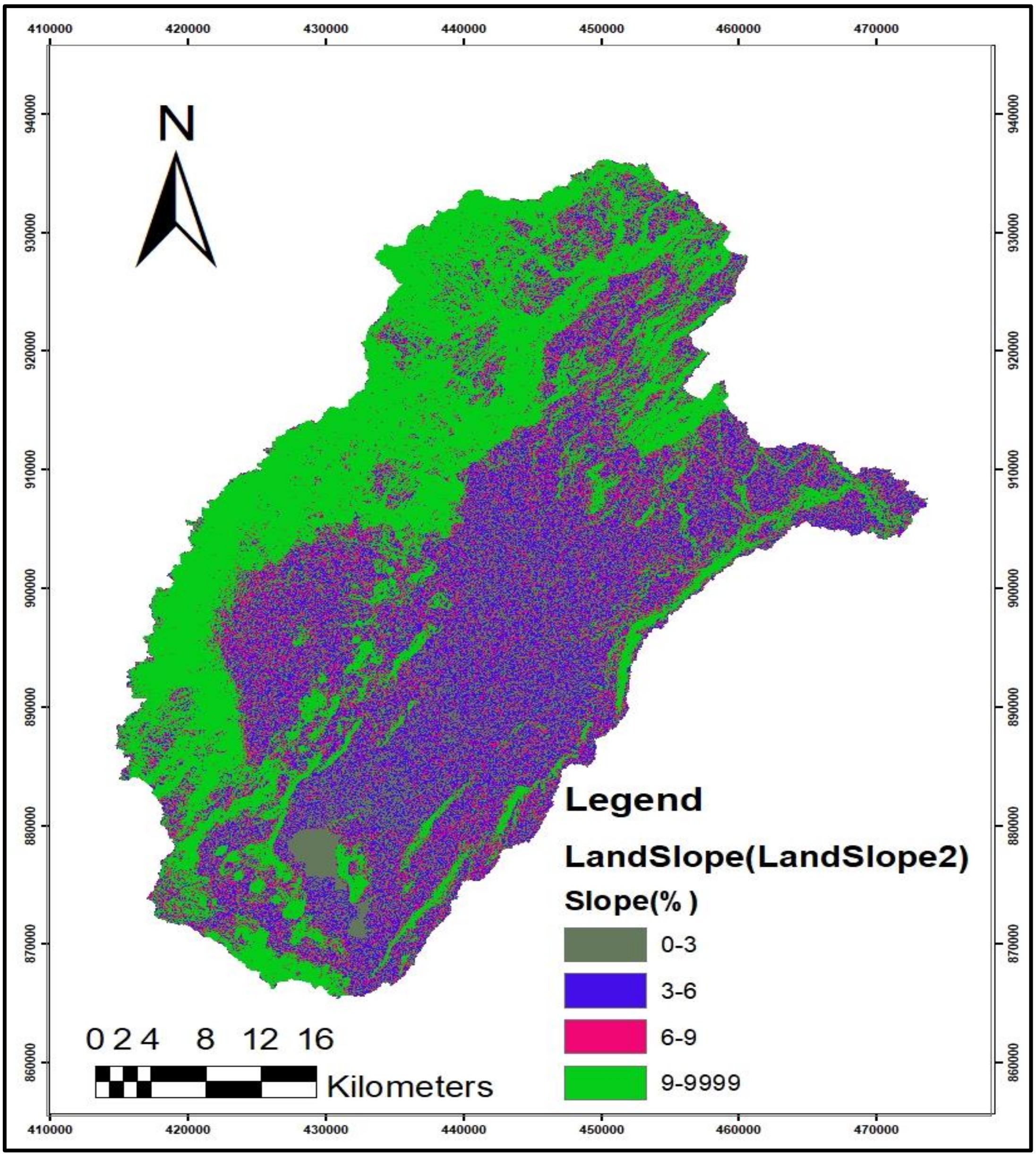

Figure3.13: Reclassified slopes for Meki watershed of 2020 by SWAT model

There are two methods to define the distributions of HRUs: one can be assigned only single HRUs for each subwatershed considering the dominant land use, soil, and slope. The second way is by assigning multiple HRUs for each subwatershed considering the sensitivity of the hydrologic process based on certain threshold values of land use, soil, and slope combinations. For this study, multiple HRUs were selected. In multiple HRU definitions10 percent land use, 10 percent soil, and 5 percent slope threshold were used as adequate for most applications. Each sub-basin can then have one or more HRUs defined within it. Finally, 127 HRUs for 29 sub-basins were created and the full HRU map of the watershed as indicated (Figure 3.14) below.

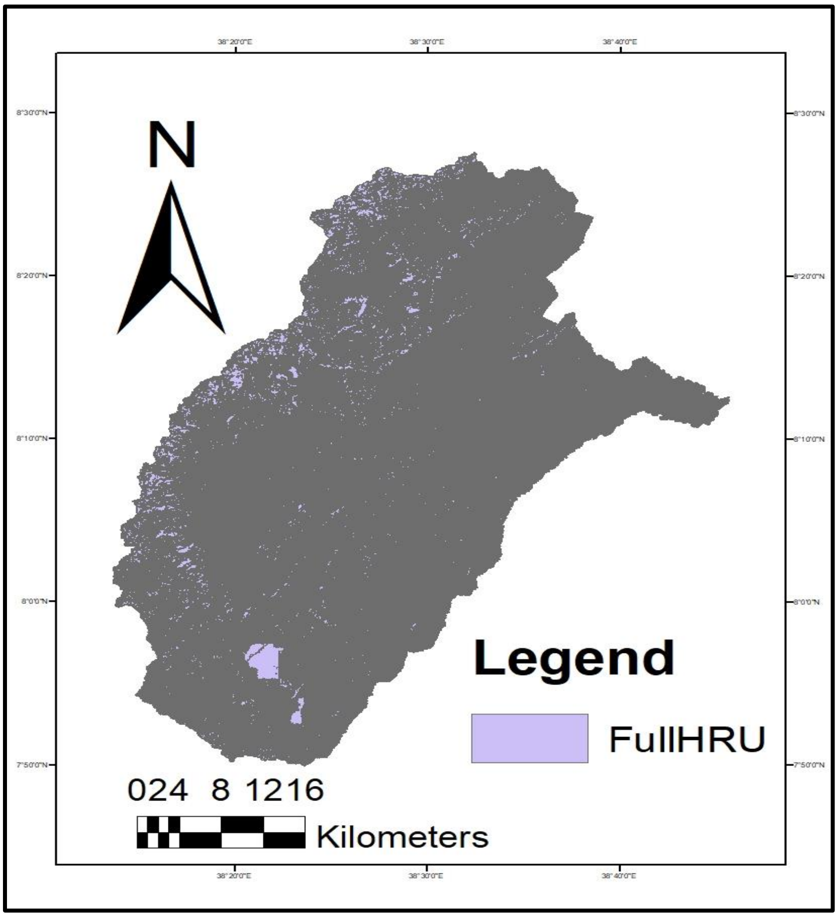

Figure3.14: Full HRU map of the Meki watershed of 2020

3.8.3. Weather data definition

3.8.3.1. Weather generator

The weather generator (WGEN) in the SWAT model is used to generate climatic data and to fill missing values in the measured records (Sharpley et al., 2003). In Meki watershed some stations have no full weather data like relative humidity, solar radiation, and wind speed so by selecting a synoptic station that has full weather data to generate the above data using a weather generator. For this study, Abomsa meteorological station was a synoptic station, which has full weather data and generates data for the other stations having precipitation and temperature data only. The weather generator developer called precipitation statistical analysis model (PCPSTAT) was used for statistical analysis of daily precipitation data needed to create user weather station files for the SWAT model. Dew point (dew02) was an additional parameter required for the weather generator. It is used for generating average daily maximum and minimum temperature, humidity, and dew point in

Month (Lijalem, 2006) The available sunshine hour data was converted to solar radiation by using Angstrom- Prescott empirical equation. Weather stations geo-referenced using latitude, longitude, and elevation data. Prepared weather parameters have been loaded into a WGEN user of the SWAT database and weather data for the rest stations found in the study area automatically generated. The required parameters for the weather generator are listed in Appendix B.

3.9. SWAT model simulation

In the SWAT model, the default input database files are built and the values of the required parameters can be entered and edited manually then simulation has been taken to generate the output of the SWAT model. The simulated result cannot be directly used for further analysis (White & Chaubey, 2005). Therefore, the simulated result (streamflow) should be evaluated through sensitivity analysis, model calibration, and validation.

3.9.1. Sensitivity analysis

Watershed simulation is influenced by model parameters. According to (Dilnesaw,2006) sensitivity analysis is a method of identifying the most sensitive model parameters that have a significant effect on model calibration. Model sensitivity analysis can be useful in understanding which model inputs are most important and to understand the potential limitations of the model. Determination of the most sensitive parameters for watershed is the first step in the calibration and validation process. The modeler should be identifying sensitive parameters to allow the possible reduction in the number of parameters that must be calibrated afterward reducing the computational time required for model calibration Lijalem (2006). In this study, a streamflow sensitivity analysis was performed by SWAT_CUP using the SUFI-2 algorithm. The sensitivity analysis was carried out for a period of six years (January 1, 2002, to December 31, 2008). Global sensitivity analysis uses t-stat and p-values to determine the sensitivity of each parameter (Abbaspour K. , 2014). The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance (Abbaspour K. , 2014).

3.9.2. Model calibration and validation

Streamflow was used for calibration and validation. The model parameters were automatically calibrated by using the SUFI-2 algorithm in SWAT-CUP for Six years and the sensitive parameters that govern the watershed were obtained and ranked according to their sensitivity rank. Calibration was done by adjusting the model sensitive parameter values until the simulated results match with observed data. Model validation is testing of the calibrated model results with an independent set of measured data (streamflow) without any further adjustment of parameters. For this study four years of the flow used for the validation period.

3.9.3. Evaluation of SWAT model performance

The SWAT model performance statistical measures selected for this study includes a coefficient of determination (R^2), Nash-Sutcliffe modeling efficiency (E_{NS}), Root mean square error observation standard deviation ratio (RSR), and percent bias (PBIAS) which were used to check the accuracy of streamflow calibration and validation.

Coefficient of determination (R^2): The R^2 value is an indicator of the strength of the relationship between the observed and simulated values. R^2 ranges from zero to one with higher values indicating better agreement.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Y_{sim} - \bar{Y}_{sim})(Y_{obs} - \bar{Y}_{obs})\right]^2}{\sum_{i=1}^{n}(Y_{sim} - \bar{Y}_{sim})^2 (Y_{obs} - \bar{Y}_{obs})^2} \dots \dots (3.22)$$

Nash-Sutcliffe model efficiency (E_{NS})

The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates that the plot of observed values to simulated values of the data fits the 1:1. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash . Sutcliffe, 1970).

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}\left((Yobs - Ysim)^2\right)}{\sum_{i=1}^{n}\left((Yobs - \bar{Y}obs)^2\right)} \dots \dots (3.23)$$

Percent bias (PBIAS): It measures the average tendency of the simulated data to be larger or smaller than the observed values. PBIAS is expressed in percentage; the lower the absolute value of the PBIAS is the better will be the model performance (Gupta , 1998).

$$PBIAS = \left[\frac{\sum_{i=1}^{n} Y_{sim} - \sum_{i=1}^{n} Y_{obs}}{\sum_{i=1}^{n} Y_{Obs}}\right] * 100 \dots \dots (3.24)$$

Root mean square error to observation standard deviation ratio (RSR): It is an error-index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{ob}}} = \frac{\sqrt{\sum_{i=1}^{n}(Y_{obs}-Y_{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Y_{obs}-\bar{Y}_{sim})^2}} \qquad (3.25)$$

where, Y_{obs} and Y_{sim} are the observed and simulated values respectively, $\bar{Y}$obs is the mean of n observed values; and $\bar{Y}_{sim}$is the mean of n simulated values.

Table 3.2: Model performance evaluation criteria Moriasi et al. (2007)

Rating	R^2	RSR	E_{NS}	PBIAS Flow
Very good	0.75 – 1	0 – 0.50	0.75 – 1	<10%
Good	0.65 - 0.75	0.50 – 0.60	0.65 - 0.75	10% - 15%
Satisfactory	0.50 - 0.65	0.6 – 0.70	0.50 - 0.65	15% - 25%
Unsatisfactory	< 0.60	≥0.70	< 0.50	>25%

3.9.4. Effects of Land Use/Land Cover Change on Stream Flow

The main goal of this study is to evaluate the impacts of land use and land cover change on streamflow in the case of the Meki River Basin. There was high urban and agricultural land expansion in the marginal lands during the study period. These changes in land use/cover influence streamflow. This study was conducted for three different years from 1996-2006 and 2006-2020. The three-land use and land cover maps, soil, climatic, and streamflow data values were used to evaluate the impacts of land use and land cover change on streamflow using the SWAT model. The model was calibrated and validated on daily and monthly time steps. After calibration and validation for Meki stream flow, three independent simulations were run on a monthly time step to evaluate streamflow variability due to land use and land cover change. 1996,2006, and 2020 land use/land cover were used as input variables in the SWAT model to compare output as a result of their differences in land use/cover change.

4. RESULTS AND DISCUSSIONS

4.1. Land Use Land Cover Change Classification

Mapping and classifying land use and land cover is very important in the hydrological study. Before the analysis of land use and land cover change, each homogeneous land use and land cover should be defined. Defining of the land use and land cover of the Meki catchment was done using remote sensing data and previous studies Damtew Fufa (2015) and (Hal crow, 2008). Therefore, eight land use and land cover types have been identified for the Meki catchment. The classified land use and land cover are described below:

Agriculture: Areas in the image that have crops present

Wetlands: An area where the groundwater level is at or near the surface for a long period (waterlogged and swampy) with a characteristic of aquatic plants

Grazing (Pasture) land: Areas covered with grass used for grazing

Bare land: areas that have little grass or no grass cover.

Forestland: Area covered with dense trees which includes mixed forest and plantation forest.

Shrubland: Areas covered with vegetation that have short leaved plants.

Built-Up area: Settlement areas of residential buildings

Water Body: Areas covered with water

4.1.1. Accuracy Assessment

The accuracy assessment is used to determine the correctness of the classified image. It was performed using a confusion matrix. Using the Google Earth Image as a reference, randomly selected points were compared with the corresponding classification. For classification accuracy, an assessment error matrix was produced for all images in this study. The confusion matrix Table of 2020 is shown below and a confusion matrix table of 1996 and 2006 classifications is shown in appendix D and E respectively.

Table 4.1: Confusion matrix for the classification of 2020 LULC

	BUA	WL	AGL	WB	SL	BL	F	GL	TOTAL	Users Accuracy
BUA	28	0	1	0	0	0	0	0	29	96.6%
WL	0	8	0	0	0	0	0	0	8	100%
AGL	4	0	39	0	0	0	0	0	43	90.7%
WB	0	0	0	11	0	0	0	0	11	100%
SL	2	1	0	0	33	0	0	0	36	91.7%
BL	0	1	1	0	0	25	0	0	27	92.6%
F	0	0	0	0	0	0	26	0	26	100%
GL	3	0	0	0	0	1	2	41	47	87.3%
TOTAL	37	10	41	11	33	26	28	41	227	
Producers Accuracy	75.8%	80%	95.1%	100%	100%	96.1%	92.9%	100%		

OVERALL Accuracy=92.95%

Kappa coefficient(Kˆ)=0.9

Note: BUA=built up area, AGL=agricultural land, WB=water body, SL=shrub land, BL=bare land, F=forest, GL=grazing land

4.2. Land Use/ Land Cover Map of 1996, 2006 and 2020

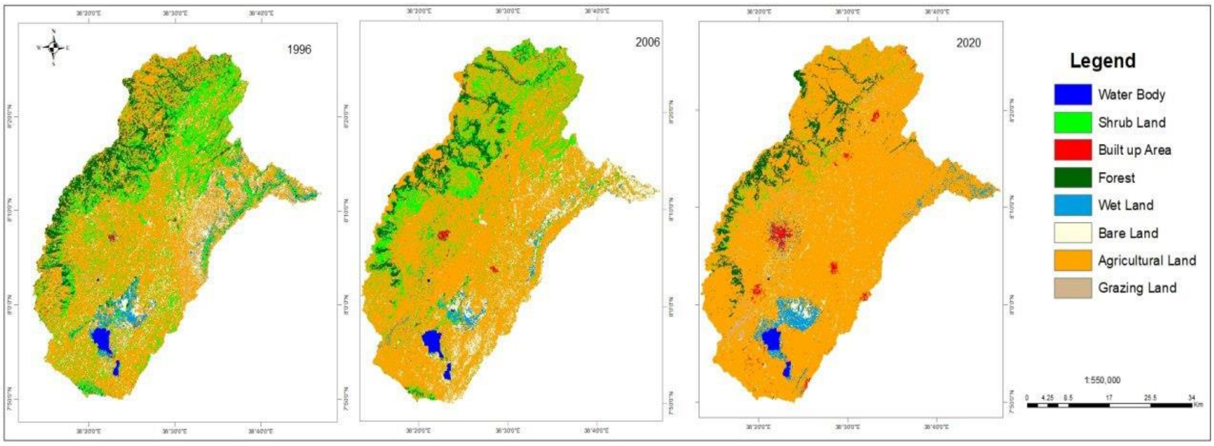

Figure 4.1: land use/land cover map of 1996, 2006, 2020

Table 4.2: land use/land cover change in hectare and %

Land use land cover	1996		2006		2020	
	Area_hec/year	%	Area_hec/year	%	Area_hec/year	%
Bare Land	2193.11	1.08	1672.19	0.82	1480.81	0.73
Built up Area	792.15	0.39	1660.00	0.82	2302.72	1.13
Agricultural land	126079.83	61.91	135168.40	66.38	165507.31	81.27
Forest	18460.34	9.07	10474.07	5.14	9245.32	4.54
Grazing Land	6572.83	3.23	5635.51	2.77	3453.33	1.70
Shrub Land	41402.81	20.33	40807.32	20.04	14038.34	6.89
Water Body	1556.23	0.76	1673.83	0.82	1708.41	0.84
Wet Land	6580.96	3.23	6547.40	3.22	5902.03	2.90
Total	203638.27		203638.27		203638.27	

4.3. Land use/land cover change detection

The distribution of land cover class as it is shown in figure 4.1, agricultural land cover was found in most parts of the watershed.

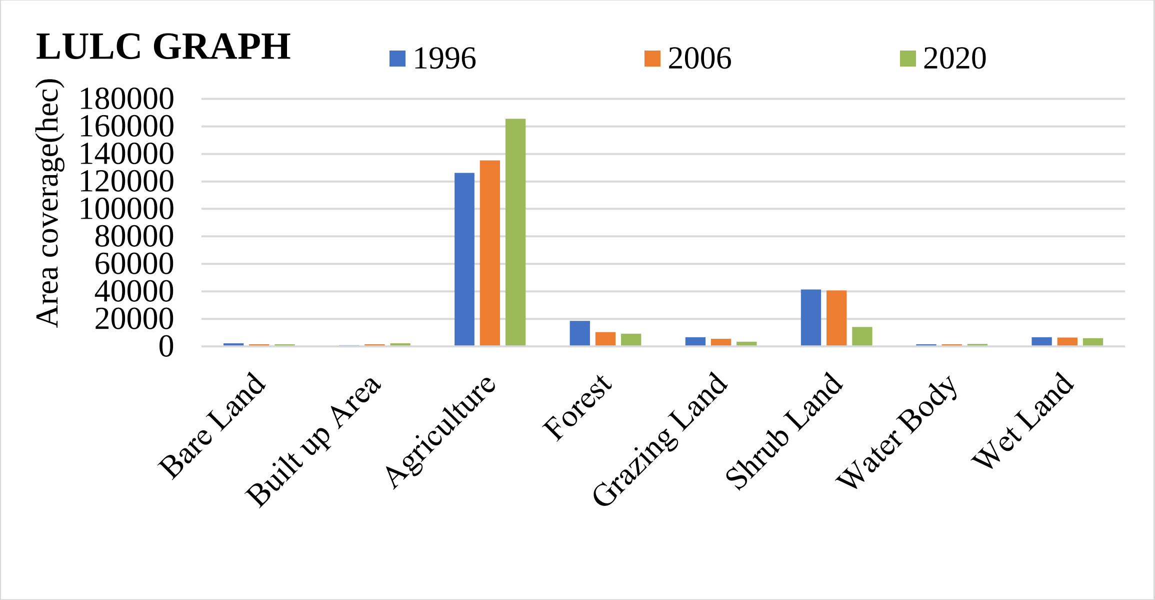

Figure 4.2: Graph showing LU/LC change

4.4. Land use/ land cover change analysis

Analysis of LULC patterns in the studied watershed indicated the growth of Agricultural land, built-up area, and water body at the expense of vegetative cover types over the last two decades. During these periods, agricultural land has expanded from 61.91% in 1996 to 66.38% in 2006. Between the 1996- 2006periods; it was increased by 4.47%, between 2006-2020 periods; it was increased by 14.89%, and between 1996- 2020; it was increased by 19.36%. The rate of increment during the 1996- 2006 periods was9088.57 ha/year and The rate of increment during the 2006- 2020 periods were 39427.48 ha/year Similarly, the built-up area had also increased by 0.43% from the 1996- 2006 periods, between the 2006-2020 periods; it was increased by 0.31% and between 1996- 2020; it was increased by 0.74%. During the 1996-2020periods, the built-up area had increased by 867.85 ha/year and during 2006- 2020periods 642.72 ha/year and also water body had increased by 0.06% from 1996-2006 periods, between 2006-2020 periods, it was increased by 0.02% and between 1996-2020; it was increased by 0.08%. During the 1996-2006 periods, the water body had increased by 117.63ha/year and the rate of increment during the 2006- 2020 periods was 34.55 ha/year. In contrast, forest, shrubland, bare land, grazing land, and wetland had decreased in the whole study periods. For example, forest coverage decreased by 3.93% from 1996 to 2006, by 0.6% from 2006 to 2020, and by 4.53% from 1996 to 2020.Similarly, shrubland also decreased at a rate of 595.49 ha/year between 1996 to 2006,and between 2006 to 2020 decreased at a rate of 26768.65 ha/year and between 1996 to 2020periods by 27364.14 ha/year.

4.5. Streamflow simulation

4.5.1. Sensitivity analysis

Streamflow sensitivity analysis was carried out to identify which model parameter is most sensitive in the Meki watershed. The model simulation was run for 12 years from 2000 to2012. Of these periods of simulation, the first two years (2000 and 2001) were set as a warm-up period. It was done for a period of eight years calibration period (January 1, 2000, to December 31, 2008). Based on the results obtained from sensitivity analysis using SUFI-2, the ranks of parameters assigned depending on *p-value* and t-stat. *P-value* indicates the significance of sensitivity and t- stat provides the measure of parameter sensitivity (Abbaspour K. , 2014). Larger in the absolute value of t-stat means the parameter is more sensitive and the *p-value* closer to zero means the parameter has more significance. Ten parameters were used to check sensitivity analysis and the parameters that influence runoff in the study area from the high, medium, and low were identified based on the associated p-value and corresponding high t-stat values (Abbaspour K. , 2014) shown in Table4.3 below.

Table 4.3: Identified sensitive flow parameters rank in the Meki watershed

Parameters	Description	t-stat	P-value	Sensitivity	Rank
ALPHA_BF	Alpha base flow recession constant	-17.56	0	High	1
CH_K2	Effective hydraulic conductivity of the main channel	-9.43	0	High	2
SOL_AWC	Soil available water content	8.36	0.043	High	3
GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur	4.243	0.054	High	4
SOL_Z	Depth from the soil surface to bottom of layer(mm)	3.01	0.163	Medium	5
CN2	SCS runoff curve numbers	2.45	0.46	Medium	6
GW_REVAP	Groundwater"revap" coefficient	1.76	0.78	Medium	7
ESCO	Soil evaporation compensation factor	1.43	0.92	Medium	8
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur	0.56	1.67	Low	9
CANMX	Maximum canopy storage	0.011	1.920	Low	10

4.5.2. Streamflow calibration and validation

Calibration

The calibration process aims to create an agreement between the simulated and observed value by adjusting the sensitive model parameters in the recommended range. The eight more influential model parameters from high to medium sensitive and which were used for further iterations in the calibration periods (Table 4.4).

Table 4.4: Summary of calibrated flow parameters

Parameters	Description	Range value	Fitted values	Rank
ALPHA_BF	Alpha base flow recession constant	0-1	0.05	1
SOL_AWC	Soil available water content	0-1	0.884	2
GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur	0-2	0.20	3
SOL_Z	Depth from the soil surface to bottom of layer(mm)	0-3500	1036.27	4
CN2	SCS runoff curve numbers	-0.2-0.2	0.13	5
GW_REVAP	Ground water “revap” coefficient	0.02-0.2	0.08	6
ESCO	Soil evaporation compensation factor	0-1	0.92	7
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur	0-500	49.75	8

Validation

Validation involves model run with unchanged flow parameters, which were adjusted during the calibration process. During the validation period from January 1, 2009, to December 31, 2012, the performance of the model was evaluated for the Lake Ziway Nr. Ziway gauging station of the watershed. According to (Moriasi et al., 2007) and (Santhi et al.,2001) the model performance evaluation criteria (Section 3.9.3; Table 3.2), the flow calibration, and validation for the Meki watershed at Lake Ziway Nr. Ziway station showed a very good performance with R^2 of 0.81, E_{NS} of 0.75, RSR of 0.49, and PBIAS of -9.6% for calibration and R^2 of 0.78, E_{NS} of 0.69, RSR of 0.43, and PBIAS of -8.7% for validation. The uncertainty of the calibrated and validated model in SUFI-2, 95PPUs, is the combination of uncertainties in the input data, model structure, and model parameters. The

uncertainty measure of SUFI-2 Showed that P-factor of 0.72and R-factor of 0.51for calibration and P-factor of 0.69 and R-factor of 0.46 for validation at the Lake Ziway Nr

Ziway gauging station. It means that about 71% of data of the calibration and 73% of data of the validation was bracketed by the 95PPU band with a better strength of estimation (R-factor <1) for both cases. This indicates the SWAT model has an acceptable level of uncertainty for estimation of the flow of the study watershed.

Gauging Stations	Simulation period	Uncertainty measures		Model performance indicators			
		p-factor	R-factor	R^2	E_{NS}	RSR	PBIAS
Lake Ziway Nr, Ziway	Calibration (2000-2008)	0.72	0.51	0.81	0.75	0.49	-9.6
	Validation (2009-2012)	0.69	0.46	0.78	0.69	0.43	-8.7

Table 4.5: Calibrated and validated model performance indicators value for monthly observed and simulated flow and model uncertainty measures.

Using monthly observed and simulated results, a hydrograph was developed for the calibration period of 2000 to 2008, and the validation period of 2009 to 2012 showed in Figure 4.3.

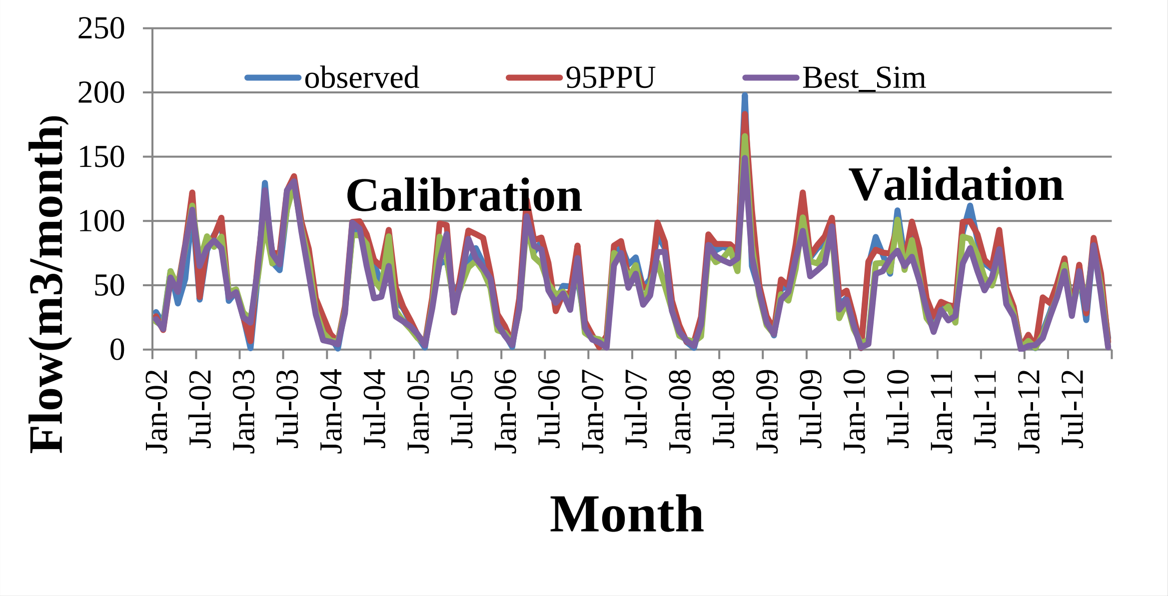

Figure 4.3: Monthly observed and simulated flow hydrograph during calibration and validation period (2000-2012) at Lake Ziway Nr, Ziway gauging station

4.6. LULC change impact on monthly streamflow of the watershed

Streamflow was simulated for the three land use/cover maps of 1996, 2006, and 2020. The mean annual streamflow for the three periods was calculated from the mean monthly streamflow data simulated for land use/cover maps of 1996, 2006, and 2020.

Table 4.6: Average simulated streamflow in the catchments Year LULC1996, LULC2006, LULC 2020 Change

Year	LULC 1996	LULC 2006	LULC 2020	Change (1996-2006)	(2006-2020)	(1996-2020)
Stream flow(m3/s)	49.7	53.32	58.83	3.62	5.51	9.13

From the result obtained, itis noted that there was an increment of 3.62m3/s,5.51m3/s, and 9.13m3/s from 1996-2006, 2006-2020, and 1996-2020 respectively. The analysis of the long term means annual simulated streamflow shows that an increasing trend in the period 1996-2020.Annual simulated discharges corresponding to 1996, 2006and 2020 land use/covers show an increasing rate of change in discharge for each year in the study period. This rate of change is due to the LULC change observed in the period 1996-2006 and 2006-2020. The output discharges of the stream were classified as the wettest months (July, August & September) and the driest months (October to June) to see the impacts on streamflow during these months. The result shows that the mean wet monthly streamflow increased by 19.14% (from 26.79m3/s for lulc map of 1996 to 37.73m3/s for lulc map of 2020) and the mean dry monthly flow decreased by 27.08% (from 15.81m3/s for lulc map of 1996 to 12.76m3/s for lulc map of 2020) due to LU/LC change when compared wet season streamflow is less sensitive than dry season flow due to the reason groundwater contribution during the dry season was reduced because of less infiltration that largely caused less cover.

Table 4.7: mean monthly-simulated surface runoff and groundwater flow using lulc 0f 1996, 2006, and 2020.

Lulc map of 1996		Lulc map of 2006		Lulc map of 2020		The difference in SURFQ. And GWQ.					
						1996-2006		2006-2020		1996-2020	
SURQ.	GW Q.	SURQ.	GW Q.	SUR Q.	GW Q	GW Q.	SUR Q.	SUR Q.	GW Q.	SUR Q.	GWQ.
10.12	11.2	13.45	10.13	16.4	8.1	-1.07	3.33	2.95	-2.03	6.28	-3.1

As can be seen from the above table the simulated SURQ and GW_Q using land-use and land cover map of 1996 were 10.12 mm and 11.2mm.While using land-use and land cover map of 2006 were 13.45mm and 10.13mm and land use land cover map of 2020were 16.4mm and 8.1mm respectively. The surface runoff is increased by 3.33mm from 1996-2006, 2.95mm from 2006-2020, 6.28mm from 1996-2020 (42.6%) respectively. The ground water discharge decreased by -1.07mm from 1996-2006, -2.03mm from 2006-2020, and -3.1mm from 1996 -2020 (31.9%) respectively. The variation was associated with the land use/land cover change during the study period. A simple base flow separation done on the Meki River discharge has also shown a similar trend for the base flow (Dribssa, 2006) However, the impacts of land cover change on streamflow are a rather contentious one is well illustrated by some previous works Seibert et al.(2008). This kind of change detection modeling could give a better result if used with a model that dynamically treats vegetation. Here, the changes made are static and assume a one-time change. However, it still is considered a better way of evaluating these impacts (Seibert and Jeffery, 2010).

Different studies have been worldwide conducted to evaluate the impacts of land use/land cover change on streamflow. The study conducted by applying the SWAT model to evaluate the impacts of land-use changes on the hydrology and erosion in the Nile River Basin Marwa et al.(2011) n concluded that decreasing forest cover can cause the risk of increasingly frequent flooding. A study conducted on Angereb Watershed Haile et al. (2012) concluded that the wet season flow increased by 39% for the most recent year, while the dry season flow decreased appreciably by 46%. According to this study, conversion of forest to agriculture, which intern increased surface runoff during the wet, season and reduced base flow during the dry seasons. The result also indicated that the decrease in forestland, wetland, bare land, shrubland, and grassland is accompanied by the increase in agricultural land, water body, and built-up areas. In general, from this study, the impact of land use/land cover change on hydrological components of Meki streamflow showed that the base flow and surface flow have been changed in the study period. The base flow decreased while surface runoff increased as a result of urbanization, agricultural land expansion, and the decrease of forest evergreen.

5. SUMMERY AND CONCLUSIONS

5.1. Conclusion

This paper focuses on LU/LC changes to Meki watershed, using the SWAT model, ERDAS software, and GIS 10.3. The results clearly show that LU/LC changes were significant during the period from 1996 to 2020 on the Meki watershed.

ERDAS IMAGINE2014 was used to process soil raster data set and prepare land use/cover map from Landsat image acquired in 1996, 2006, and 2020 respectively and gives the following classes of land (agricultural land, built-up area, wetland, shrubland, forest, grazing land, water body and bare land).

There is a significant expansion of agricultural land, built-up area and water body noticed and increased by 4.47%,0.43%, and 0.06% respectively from 1996-2006 and 14.89%,0.31%,0.02% respectively from 2006-2020 as well as 19.36%,0.74%, and 0.08% respectively from 1996-2020and the change in area coverage of the watershed is 39427.48ha/year,1510.57ha/year, 152.18ha/year respectively from 1996-2020. On the other hand, there is a decrease in shrubland, grazing land, wetland, bare land, and forest areas and decreased by 13.44%, 1.53%,0.33%,0.35%, and 4.53% respectively and the area coverage of the watershed is 27364.14 ha/year,3119.16 ha/year,678.93 ha/year,712.3 ha/year and 9215.02 ha/year respectively from 1996-2020.

Results of mean monthly runoff simulations seemed to correspond better with observed values with the Coefficient of determination (R^2) was 0.81 for the Calibration period, and 0.78 for the validation period respectively. The mean monthly contribution of surface runoff (SURQ) and the groundwater flow (GW_Q) to the Meki stream due to LULC change. The simulated SURQ. and GW_Q using land use and land cover map of 1996 were 10.12 mm and 8.2mm. While using land use and land cover map of 2006 were 13.45mm and 9.13mm and land use land cover map of 2020 were 16.4mm and 10.1mm respectively. The surface runoff increased by 3.33 mm from 1996-2016, 2.95mm from 2006-2020, 6.28mm from 1996-2020 (42.6%) respectively. The groundwater discharge increased by 0.93mm from 1996-2020, 0.97mm from 2006-2020, and 1.9mm from 1996 -2020 (31.9%) respectively.

This shows the SWAT model execution in the Meki Watershed was excellent in predicting flow. This study indicates the significant impact of the population and its development activities on LU/LC change. The quantification of LU/LC changes in the Mekiwatershed area is very useful for environmental management groups, policymakers, and the public to better understand the surrounding.

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APPENDICES

Appendix A: Monthly measured flow (m^3/sec) at LAKE ZIWAY, Nr. ZIWAY gauging station (2000– 2012)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Se
2000	1.223103	1.032258	0.818333	0.79	0.738333	0.802258	1.024839	1.398	1.
2001	1.123929	1.03	1.000333	0.94	0.974333	1.210645	1.696129	2.249667	2.
2002	1.188571	1.174194	1.151333	1.120645	1.102	1.097419	1.140645	1.156333	1.
2003	0.582143	0.449677	0.384483	0.359355	0.235	0.374194	0.858065	1.1697	1.
2004	0.756207	0.568387	0.545333	0.523871	0.398	0.373226	0.742581	0.951333	1.
2005	0.603571	0.529677	0.412667	0.559677	0.622	0.633871	0.993548	1.381667	1.
2006	0.889286	0.785484	0.919667	1.062581	0.997667	1.170968	1.802903	2.190667	2.
2007	1.508929	1.343871	1.275	1.179032	1.277667	1.493226	1.912903	2.324	2.
2008	1.453103	1.276774	1.108667	1.020645	0.953333	1.066452	1.46871	1.824667	1.
2009	1.391786	1.216452	1.125	0.948065	0.820333	0.774032	0.993871	1.138667	1.
2010	0.791786	0.842903	0.830667	0.984516	1.132667	1.265806	1.738387	2.246667	2.
2011	1.591786	1.452258	1.297	1.150645	1.102	1.214839	1.465806	1.859333	1.
2012	1.435161	1.198276	1.028065	0.943333	0.839032	0.672667	0.801935	1.332258	1.

Appendix B: Weather generator (WGEN) parameters used by the SWAT Model

TMPMX	24.79	25.51	25.49	24.55	23.61	21.41	19.64	19.88	21.32	23.18	24.30	24
TMPMN	9.79	10.89	11.94	12.09	11.50	11.18	11.20	11.14	10.77	10.64	10.11	9.5
TMPSTDMX	2.21	2.42	2.60	2.52	2.30	2.28	2.07	2.32	1.67	2.01	1.95	2.0
TMPSTDMN	2.05	1.86	1.62	1.35	1.38	1.21	1.30	1.26	1.26	1.69	1.71	2.4
PCPMM	27.21	38.36	99.36	130.11	136.71	119.14	145.82	175.57	144.64	63.64	22.39	15
PCPSTD	3.79	4.75	7.43	8.77	8.02	7.34	7.44	8.61	7.60	6.11	3.89	3.7
PCPSKW	6.34	5.32	3.43	3.07	2.79	3.43	2.39	2.90	2.47	4.20	7.75	11
PR_W1	0.07	0.11	0.22	0.28	0.33	0.43	0.54	0.56	0.50	0.09	0.05	0.0
PR_W2	0.44	0.47	0.56	0.61	0.63	0.55	0.60	0.68	0.62	0.65	0.48	0.3
PCPD	3.39	4.82	10.43	12.54	14.68	14.64	17.82	19.64	17.00	6.50	2.82	1.3
SOLARAV	3.76	4.98	9.85	11.21	10.49	9.21	9.19	10.65	9.92	6.26	3.38	2.7
DEWPT	57.86	58.12	67.26	68.01	73.56	75.09	73.68	75.53	68.30	60.42	56.70	57
WNDAV	1.30	1.44	1.59	1.37	1.19	1.70	1.54	1.35	1.01	1.86	1.74	1.9

Appendix C: Symbols and description of weather generator (WGEN) parameters

Symbol	**Description**
TMPMX	Average or mean daily maximum air temperature for a month (^{0}C)
TMPMN	Average or mean daily minimum air temperature for a month (^{0}C)
TMPSTDMX	The standard deviation for daily maximum air temperature for a month (^{0}C)
TMPSTDMN	The standard deviation for daily minimum air temperature for a month (^{0}C)
PCPMM	Average or mean total monthly precipitation (mm H2O)
PCPSTD	The standard deviation for daily precipitation for a month (mm H2O/day)
PCPSKW	The skew coefficient for daily precipitation in the month
PR_W1	Probability of a wet day following a dry day in the month
PR_W2	Probability of a wet day following a wet day in the month
PCPD	The average number of days of precipitation in the month
SOLARAV	Average daily solar radiation for a month (MJ/m^2/day)
WNDAV	Average daily wind for the month

Appendix D: Confusion matrix for the classification of 2006 LULC

	BUA	WL	AGL	WB	SL	BL	F	GL	TOTAL	Users Acuracy
BUA	12	0	0	0	0	0	0	0	12	100%
WL	0	4	0	0	0	0	0	0	4	100%
AGL	10	0	24	0	0	0	0	0	34	70.6%
WB	0	0	0	4	0	0	0	0	4	100%
SL	0	1	0	2	20	0	0	0	23	87%
BL	0	0	1	0	0	12	0	0	13	92.3%
F	0	0	0	2	1	0	12	0	15	80%
GL	2	0	0	0	0	0	0	30	32	93.8%
TOTAL	24	5	25	8	21	12	12	30	137	
Producers Accuracy	50.8%	95.1%	95.2%	50%	95.2%	89%	100%	100%		

OVER ALL Accuracy=90.46%

Kappa coefficient(K˄)=0.87

Note: BUA=built up area, AGL=agricultural land, WB=water body, SL=shrub land, BL=bare land, F=forest, GL=grazing land

Appendix E:Confusion matrix for the classification of 1996 LULC

	BUA	WL	AGL	WB	SL	BL	F	GL	TOTAL	Users Accuracy
BUA	10	0	0	0	0	0	0	0	10	100%
WL	0	1	0	0	0	0	0	0	1	100%
AGL	8	0	24	0	0	0	0	0	32	75%
WB	0	0	0	2	0	0	0	0	2	100%
SL	0	0	0	0	21	0	0	0	21	100%
BL	0	1	0	2	0	8	0	0	11	72.3%
F	0	0	0	3	0	0	10	0	13	77%
GL	2	0	0	0	0	1	5	22	30	73.3%
TOTAL	20	2	24	7	21	9	15	22	120	
Producers Accuracy	50%	50%	100%	71.4%	100%	89%	67%	100%		

OVER ALL Accuracy=87.2%

Kappa coefficient(Kˆ)=0.89

Note: BUA=built up area, AGL=agricultural land, WB=water body, SL=shrub land, BL=bare land, F=forest, GL=grazing land