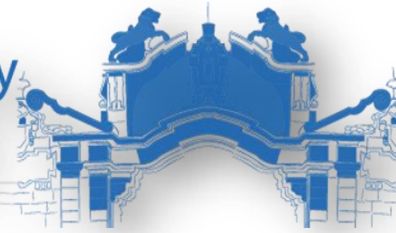




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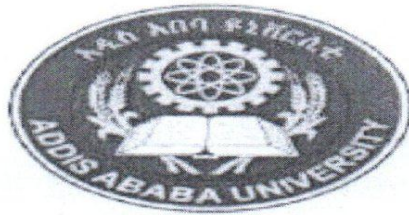
A Thesis Submitted to School of Civil and Environmental Engineering Graduate Studies of Addis Ababa Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Geodesy and Geomatics Engineering

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MARCH, 2022




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Declaration

I declare that the work which is being presented in the thesis entitled “ Modeling land-use land-cover change and assessment of its impacts on hydrology using GIS and Remote sensing techniques; A case of Muger catchment, Ethiopia” submitted to Addis Ababa University Institute of Technology, School of Civil and Environmental Engineering in partial fulfillment for the award of the degree of Masters of Science in Geodesy and Geomatic Engineering is entirely my work that has not been submitted for any academic purpose anywhere else. All references, including citations of published and unpublished sources, have been appropriately acknowledged in the work.

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Candidate

Signature

Date

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Abstract

Assessing the impacts of LULC change on hydrology plays a great role in the effective planning and management of hydrological resources of the catchment. The change of LULC has a direct effects on the different hydrological processes that occur during and after rainfall, such as surface discharge, evaporation, evapotranspiration, groundwater infiltration, and surface runoff. Therefore, modeling the land-use land-cover change and assessment of its impacts on hydrology is critically an important issue at the current time. This study deals on modeling the land-use land-cover change and assessment of its effects on the hydrology for Muger catchment by using GIS and remote sensing techniques through integrating with the SWAT hydrological model. It was conducted using the spatio-temporal data such as slope, land-use land-cover, soil, meteorological and hydrological data from the different sources. The maximum likelihood classification, change detection, and SWAT hydrological model was deployed to perform this analysis. Finally, the sensitivity analysis, model calibration, and validation were being conducted. There is a strong relationship between the measured and simulated monthly flows based on the calibration results with the NSE of 0.81 and R^2 of 0.86 for Aleltu River; NSE of 0.63 and R^2 of 0.84 for Muger River and NSE of 0.66 and R^2 of 0.79 for Sibilu River. In addition, the validation result reveals that the measured and simulated flow are in good agreement with the NSE of 0.73 and R^2 of 0.89 for Aleltu River; NSE of 0.66 and R^2 of 0.88 for Muger River and NSE of 0.87 and R^2 of 0.89 for Sibilu River. The change of the LULC is the driving force to change an ecosystem and environmental processes in different ways. Therefore, this study facilitates the society within Muger catchment for conducting proper land management practices as well as proper utilization of the water resources.

Keywords: *Calibration, GIS, Modeling, Remote sensing, SWAT, Validation*

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List of acronyms

ABM: Agent-based model (ABM)

ANN: artificial neural network

CA: Cellular Automata

DEM: Digital Elevation Model

EMWIE: Ethiopia Ministry of Water, Irrigation, and Energy

GIS: Geographic Information System

GPS: Global Positioning System

HBV: Hydrologiska Bayraans Vattenbalans-avediling

HEC-HMS: Hydraluic Engineering Centre - Hydrologic Modeling System

HRUs: Hydrological Response Units

LULCC: Land Use Land Cover Change

LUCM: Land-use Change Models

NMA: National Meteorological Agency

NSE: Nash-Sutcliffe Efficiency

R^2 : Coefficient of Determination

SWAT: Soil and Water Assessment Tool

USGS: United States Geological Survey

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

The change in land-use land-cover has been a universal and important socio-economic phenomenon around the world at current times. According to Bihanta and Soffianian (2014) study, the rapid changes in land-use land-cover continuously exerted an influence on the natural ecosystem and this become a global issue that needs great consideration. The interaction of many factors such as political, economical, social, and cultural factors affects the urban land-use land-cover dynamics at various spatio-temporal scales (Al-sharif et al., 2013). The relationship between land-use land-cover change and hydrology is complicated, with connections at many different spatial and temporal levels(Berga, 2011).

The change in land-use land-cover encourages socio-economic advancement and the standard of life. Even though, it is the most powerful and visible anthropogenic force that has caused the basic changes from natural to artificial land covers. As this change is continuously occurring from time to time it resulted in environmental and socio-economic impacts such as loss of vegetation and farmland, local and regional climate change, the decline in biodiversity, hydrological circle alternation, etc. (Li, 2014). Land-use land-cover change directly affected the amount of evaporation, transpiration, groundwater, infiltration, and surface runoff.

The change of land-use land-cover is continuously increasing from time to time at current times. This change becomes a world issue since it has different environmental impacts. Many studies show that changes in land-use and land-cover caused by both natural and anthropogenic processes are a significant role in changing environmental conditions such as climate, hydrological cycle, and others throughout the world. Ethiopia also like other countries of the world faces serious problems due to this dynamic nature of LULC for a long period of time. As a result, assessing the impacts of LULC change on hydrology is critical in the management of the catchment water resources(Gashaw, 2018).

The Muger catchment is one of the highly degraded parts of the country due to the rapid change of LULC that is facilitated by the different factors at the current times. There is a few study in the study area that do not effectively realize the impacts of LULC change on the hydrological processes within the catchment. Therefore, a concise idea about the changing of LULC and its resulting outcome is very necessary to provide support for the proper management of the environment and decision-making process. This study try to analyze the nature of LULC change for the different periods and the impact that it has on the catchment hydrology using the GIS and remote sensing techniques through integrating the spatio-temporal data with the hydrological model.

To handle this condition in a proper manner modeling the land-use land-cover change and assessment of its impacts on the environmental hydrology is very necessary at the current times. This helps the concerned body which assists them in the preparation of the effective planning and management policy for future use. Therefore, this study specifically focuses on modeling the land-use land-cover change and assesment of its impacts on hydrology in Muger catchment by integrating the hydrological modeling software with GIS and remote sensing techniques.

1.2. Statement of the problem

The spatio-temporal dynamics of the land-use land-cover change have a direct effects on the hydrology of the catchment in a different way. It affects the different hydrological processes such as surface discharge, evaporation and transpiration, interception, runoff, precipitation, and transpiration. Due to this occurrence, it is critical to forecast the hydrological effects of land-use and land-cover change on the catchment in order to develop and execute effective strategies for reducing negative impacts on water resources. Therefore, thorough analyses and understanding of the hydrological impacts of LULC changes are very important for making an effective plan and control of water resources at current and in the future times for the catchment.

The rapid dynamics of the LULC change directly affect the rate of evaporation, ground water recharge, infiltration, and surface runoff that occurred during the occurrence of rainfall and after the occurrence of rainfall events (Tadesse, 2019). According to Abraha (2007), changes in land-use land-cover contributing with the expansion of agriculture, overgrazing, deforestation, and urbanization have a significant impact on hydrological processes both at global and local levels.. Several studies were conducted over different study area to realize the effects of land-use land-

cover change on different hydrological processes using the spatio-temporal data through integrating with hydrological model (Asmare, 2020; Gashaw, 2018; Rabo, 2018).

The change of land-use land-cover have a great influence in different ways on the natural ecosystem in Ethiopia like other developing countries of the world. Also, within Muger catchment the different activities such as deforestation, expansion of rural and urban settlement, overgrazing of the grasslands, and agriculture are increasing continuously from time to time. Within the catchment the expansion of urban development is also observed at several place in a fast manner which leads to a higher impervious area that decreases the amount of ground water recharge and increased surface runoff. This continuous variation affected the water of the catchment which results in increasing the extent of the water management problem.

Kumela (2011) conducted a study on the performance comparison of conceptual rainfall-runoff models on Muger sub-catchment. Similarly, Said (2018) also conducted a study on runoff and sediment yield modeling using an artificial neural network on this catchment. Thus, there was no study conducted specifically on the study area previously regarding the modeling land-use land-cover change and assessment of its impacts on hydrology with respect to the past and future using the spatio-temporal data through integrating with SWAT hydrological model. Therefore, this study will be intended specifically to model land-use land-cover change and assessment of its impacts on hydrology for Muger catchment using GIS and Remote Sensing techniques by integrating with SWAT hydrological models.

1.3. Objectives of the study

1.3.1. General objective

The main aims of this study is to model land-use land-cover change and assessment of its impacts on hydrology in Muger catchment by using the techniques of GIS and remote sensing through integrating with the SWAT hydrological model.

1.3.2. Specific objective

- ✚ To examine the trend of land-use land-cover change from 1990 to 2021.
- ✚ To analyze the effects of changes in land- use land-cover on hydrology from 1990 to 2021
- ✚ To calibrate and validate the SWAT model by the streamflow data of Muger catchment

1.4. Research questions

- ✚ What are the trends of the past and present land-use land-cover change of the catchment look like?
- ✚ How does the land-use land-cover change affect the hydrology of the catchment from 1990 to 2021?
- ✚ How can the streamflow data be used to calibrate and validate the SWAT model ?

1.5. Significance of the study

Recognizing the state of land-use and land-cover change will aid decision-makers in developing and implementing the best strategy for managing and eradicating the negative influence on natural resources. The ability to understand how land-use and land-cover change affects catchment hydrology would help the local governments in developing and implementing appropriate planning and management policies. This helps to mitigate the negative consequences of land-use land-cover change on the catchment's water resources.

Therefore, modeling the hydrological impacts of land-use land-cover change using GIS and remote sensing techniques plays an important role in managing and handling the negative effects on the water of the catchment. The result of the study will support the Muger catchment in planning, developing, and managing water resource initiatives. It can also be served as a source for those who want to pursue further research in related fields in Muger catchment.

1.6. Scope of the study

This study spatially focuses on the Muger catchment and thematically it deals on modeling land-use land-cover change and assessment of its impacts on hydrology in Muger catchment by using GIS and remote sensing techniques through integrating with hydrological modeling software.

1.7. Organization of the thesis

This study includes five main chapters. Chapter one deals on the introduction, statement of the problem, research objective, research question, significance, and scope of the study. Chapter two also discusses in detail about the related literature review. The detailed description of the study area, data source, and method of data analysis was presented in chapter three as a whole. Chapter

four explains the result and discussion whereas chapter five includes the conclusion and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Land-use land-cover change

Land-use and land-cover are phrases that are used interchangeably. However, land-cover refers to bio-physical features such as plants, bare soil, hard surfaces, and water bodies that occur on the earth's surface. The land-use refers to the utilization of the land through changing the land surface processes such as biogeochemistry, hydrology, and biodiversity by human activities such as agriculture, forestry, settlement, and grazing. In short, the land-cover defines the bio-physical substance that covers the earth's surface whereas the land-use describes how people utilize the land (Bekalo, 2009; Sahalu, 2014).

Land-use land-cover change (LULCC) describes the quantitative conversion in the area extent that may result either from land conversion or modification. The change in land-covers and land-uses has been increasing rapidly due to socio-economic advancement and biophysical factors. The land-use land-cover change and its modeling (LULCC-M) approach has been considered by the scientific community as a way to realize environmental changes at various stages. They implemented this transition at four different levels: local, regional, national, and global. The study of LULC change is regarded a crucial feature to observe parameters in order to realize total changes (Hailu et al., 2018).

Globally, regionally, and locally the changes in land-use and land-cover become a severe environmental concern. Human activities have been rising and changing the terrain for a long time, with the majority of these changes occurring in the tropics. In the catchment, ground survey methods and other spatio-temporal resolution data were used to realize the land-use land-cover change (Ayele et al., 2019; Kundu et al., 2015).

The interplay of anthropogenic and bio-physical parameters such as social, economical, and political influences generates LULC change processes according to Dibaba et al. (2020). The main factors of change in land-use land-cover is human and animal population, various agricultural techniques, urbanization, drought occurrence, and inadequate land-use planning in Ethiopia. However, various places have different driving factors as well as consequences.

The change in land-use land-cover (LULC) is generally grouped into alterations and variations. Alteration describes a conversion from one category to another (e.g. from forest to grassland) whereas variation describes a change within one land-use or land-cover category (e.g. from rain-fed cultivated area to irrigated cultivated area) due to changes in its physical or purposeful qualities. This dynamic nature in land-use land-cover systems have a vital environmental consequences through their impacts on soil and water, biodiversity, and microclimate (Rabo, 2018).

The biophysical cover on the Earth's surface is continuously changing at local, national, and global scales as a direct or indirect consequence of human activities. Since the mid-20th century, Ethiopia has experienced rapid land transitions like many other developing countries in Africa. This causes a significant impacts on the people, economy, and environment throughout the country. Currently, mapping this change become a crucial to analyze the magnitude, intensity, and direction of landscape matrix transformation (Damte and Kim, 2020). Even while LULC changes vary widely over the world, the end result is usually the use of natural resources to meet rising demands driven by population growth, frequently at the expense of poor environmental conditions. As a result, biodiversity has been lost, land has been degraded, and forests have been fragmented (Demissie et al., 2017).

2.2. Cause of land-use land-cover change

The change in land-use land-cover is always caused by multiple interacting factors originating from different levels of organization of the coupled human-environment systems. It was the outcome of complex linkage between a variety of biophysical and socio-economic factors that might occur at different spatio-temporal scales which vary in space and time according to specific human-environment conditions. These include human activities such as an expansion of cultivated land, the decrease of natural vegetation, and the expansion of settlement due to exerted population pressure (Girum Metaferia, 2018). Because human needs cannot be met without modifying land-covers, the impacts of land have increased dramatically due to population growth, technological advancements, and other factors, altering entire landscapes that have an impact on biodiversity, nutrient, and hydrological cycles, as well as climate change (Berga, 2011).

The natural and human-induced forces are the factors that cause the change in land-use and land-covers. These changes are often driven spatio- temporally by biophysical and human directions and more over it also varies spatially depending on location-specific factors. The natural factors like rainfall intensity, steep relief, soil types as well as climate change are also facilitating the change in land-use land-covers(Tessema et al., 2020).

The change in LULC may also affected by the factors such as land tenure arrangement, livelihood strategies, access to the market, and population increase. The increase of population density facilitates the increase in residential, industrial, and institutional building which was considered as the drivers of LULC changes (Gashaw, 2018). Also according to Aga (2019) pointed drivers and factors contributing to land-cover changes include increasing population and livestock, reduced distances from various infrastructures such as roads and markets/urban areas, and topographic factors (i.e. as slope, and land degradation).

Humans changing the earth's surface for agricultural activities and settlement for several years. The alteration of grassland, woodland, and forest to agriculture, grazing, and urban settlements has increased considerably in recent decades. This rapid conversion has been putting the attention about the role of land-use change in driving losses in biodiversity, soils and their fertility, water and air quality (Bekalo, 2009).

Population growth has resulted in more land-use and land-cover change in most developing countries, such as Ethiopia, than other variables. In addition, most countries of African, Asian, and Latin American have significant statistical relationships between population growth and land-cover change. Agricultural lands are increasing at the expenditure of vegetation and grassland due to the increased demands of food production (Rabo, 2018).

The population growth and its response to economic opportunities driving the change in LULC rapidly. Throughout many parts of Ethiopia, the conversion of forestland, grazing land, and bush lands to cultivated farmland is now a commonly practiced. Policies relating to human settlement, land ownership, agriculture, technological advancements, cultural, political, and socio-economic institutions are among the other major driving elements(Fasika Alemayehu, 2019).

2.3. Land-use land-cover change in Ethiopia

The change in land-use land-cover has been also challenging in Ethiopia at current times. About 40% of the land in the country was covered by forests at the start of the 19th century. The increasing rate of forest and land degradation resulted to the decline of plant and animal species. To realize the of processes of change that helps to improve a land management practice gathering the historical patterns of change and its model provide good support that helps to give a good decision (Ayele et al., 2019).

Most of the country's economy is focused on agriculture that is based on traditional farming (plow). The rapid growth of the urban population with an increase of migration of rural population to cities for a better life and the encouraging land lease policy to investors become important to study the dynamics of land-use land-cover. Also it provide a support to realize it's impacts in Ethiopia which help to design management and monitoring policies (Sahalu, 2014).

Several studies regarding the change in land-use land-cover that were conducted at different a places in Ethiopia was depending on data availability and tools. However, most of the studies were deals on afforestation and deforestation, the expansion of cultivation, land degradation, and natural ecosystems and other related consequences. Even though based on their study they were confirmed that the cultivated land, rural and urban settlements as well as open lands expanded in large amounts whereas the natural vegetation suchas forest, wood land, and shrub land is decreasing.

2.4. Land-use land-cover change in muger catchment

The upper blue Nile basin rich in natural resources including land, vegetation, genetic diversity, and water, all of which are found in a complex biophysical and socioeconomic environment under several constraints. Among the key influences are population expansion, deforestation, land degradation, soil erosion and nutrient depletion, and climate variability. Consequently, the intended sustainable development in various parts of Ethiopia and specifically in Muger catchment is confronted with the intensive LULCC in recent years. The abundant water resources in Ethiopia were not played a good role on the advancement of the national economy relative to other country. Therefore , the country intended to place more attention on water resource development as a very crucial strategy for socio- economic development. The

importance of the waters for facilitating the sustainable development depend on the proper management and the planned development projects (Dibaba et al., 2020).

2.5. Hydrological process in a watershed

The rate of infiltration, surface runoff and total sediment loads transported from a watershed affected the degree and type of land-cover. Deforestation result in a rise in annual mean discharge and interception governs the water extent that may loss from the system through evapotranspiration and protects surface materials from the erosive effects of raindrops. Because of the increased canopy roughness and deeper root systems that draw on soil moisture, tall forests have higher evapotranspiration rates than other plant or land-use categories. Water channels to the ground are reduced when they are removed from the area, and stream flow from the catchment is enhanced. As pointed out in the study the intercepted rainfall by plants evaporated and did not generate runoff, while dried leaves and grass change the soil structure and make the land rough, so rainfall can seep into the soil(Nurye, 2019).

According to Nega (2016) pointed on the study the precipitation that reaches the earth surface is partially intercepted by vegetation and the extent intercepted by a plant largely depends on plant form. The water that is held on plant leaf can trickle down reaching the ground or evaporate whereas other parts of water fall directly on the ground. The evaporation rate depends on wind speed, solar radiation, heat, and humidity in the air, or enters into the soil, or flows down the land surface as runoff. Through the infiltration, the water extent that penetrates into the soil surface is related to soil properties such as texture, structure, moisture content, soil permeability, and porosity. Also, the rate of penetration is affected by the conditions at the soil surface. For instance, a compacted soil surface or frozen soil conditions reduce the rate of penetration. The high vegetation covering keeps the soil surface from high compaction during heavy raindrops that slows down the flows of water over the soil surface and the plant roots provide the openings in the soil. The intensity and the duration of precipitation also affect the infiltration rate.

The amount of runoff generated by a watershed relies on the extent of precipitation taking place over a watershed. When the rainfall is on the ground losses take place before it ends up as runoff. The initial abstraction is the precipitation (i.e. interception, surface depression storage, evaporation, infiltration), which occurred before the start of the runoff. The interception is also

the part of rainfall that is retained temporarily by vegetation (leaves and stems) and infiltration is the part that enters into the soil (ground). The surface depression storage is the precipitation part that is recollected by the puddles, lakes, and ponds. Whereas evaporation is the portion of water that is evaporated from soils and open water bodies. The initial abstraction value is evaluated by the drainage area soil type and vegetation cover and as it is satisfied, the excess rainfall appears on the surface as direct runoff (Gebreslassie, 2017).

According to Gashaw (2018) pointed on the study evaporation and transpiration (ET) occurred from the water bodies, vegetation covers, and soil surface due to the effect of the sun's solar energy. The evaporated air condensed to form clouds that reach the earth's surface as precipitation and this precipitation takes various forms such as rain, snow, hail, sleet, dew, etc. However, most precipitation occurs in rain form.

2.6. Effects of land-use land-cover change on hydrology

The land-cover characteristics have many a great relationship with the hydrological cycle. The types of land-cover directly evaluate the degree of interception, infiltration, and runoff. The number of water yields in surface and baseflow are controlled by change in LULC, and hence the amount of water available for ecosystem system and human consumption. The change in land-cover occurred commonly by human activity may affect rainfall-runoff relationships. This may resulted in variation in canopy cover, degradation of the vegetative cover, and increased soil disturbance that increase surface runoff and soil erosion. For instance, densely vegetative cover resist the soil from the raindrop impact and reduces the rate erosion of the soil. The shortage of soil moisture in agricultural lands is higher than in forests there by generating more runoff. Deforestation also has its own impact on hydrological processes, leading to declines in rainfall, and more rapid runoff after precipitation (Tadesse, 2019; Tizazu, 2018).

The conversion of forest lands to urban uses increases surface albedo (reflection of solar radiation), decreases net radiation, reduces latent heat, enhances summer storm intensity, and causes heat island effects. Removing forest vegetation cover reduces plant transpiration and canopy interception and alters soil infiltration capacity which results in a dramatic increase in surface flow due to the reduction of loss of water and infiltration. These occurred through the alteration of the topography and surfaces because of new construction, demolition, and redevelopment (Atsbha, 2019).

The degree of infiltration, run-off, evaporation rate, and precipitation pattern are affected by the variation in the vegetation cover. The change in land-use land-cover may have both immediate and long-lasting influences on the terrestrial hydrology which is changing the balance between precipitation, evaporation, transpiration, and the resultant run-off. In short-term, the land-use land-cover dynamics may change the hydrological cycle either through rising high flows rates or through diminishing the low flow rates (Asmare, 2020).

The information about the type of occurrence of change, where and when they occur, the rates at which they occur, and the social and physical forces that drive those changes are necessary to recognize how LULC affects and interacts with global earth systems (Berga, 2011). The linkage between land-use land-cover and hydrology is of greater interest worldwide as it can provide an advice for management actions to avoid or minimize the negative effects of specific land-use activities on the hydrology of a certain region. However, there are uncertainties on the impact of specific land use practices to different processes of the hydrological cycle because of the complexity of water levels and the base flow of streams(Nigussie, 2009).

The land-use land-cover change impacts on the regional water balance is the most vibrant research in the international hydrological fields. Such investigation shows that changes in regional vegetation ecosystems driven by changes in land-use and land-cover have a significant impact on the regional hydrological cycle. In addition to creating unexpected multi-directional consequences on water balance components, the alteration in LULC has social and economic benefits. Forest clearance for firewood, subsistence agriculture, commercial, agricultural expansion, urbanization, and overgrazing by livestock are some of the modifications that have a huge impact on water resources, the productivity of land, and damage on ecosystems (Warku, 2019).

Physical changes, particularly those resulting from rapid urbanization, impacted the water budget by reducing rainfall interception due to the removal of trees and natural vegetation, changing drainage patterns, losing natural surface depressions that temporarily store surface water, reducing rainfall absorption capacity, and creating impervious surfaces (rooftops, roads, sidewalks, and driveways), among other things. The hydrological processes are influenced by LULC change by changing the interception rates, soil water, evapotranspiration, infiltration, and groundwater, leading to changes in surface runoff and stream flow (Metaferia, 2018). The land-

cover can affect both the degree of infiltration and runoff occurring after rainfall events and the degree of land-cover can affect rates of evaporation. Land cover has a number of characteristics that aid in the regulation of both above and below ground water flows. Tree canopy and leaf litter, for example, lessen the effect of raindrops on the ground, reducing soil erosion, while roots hold the soil in place while simultaneously absorbing water(Muhammed, 2018).

According to Nurye (2019) propose on the study for developing sound watershed management computing the impacts of land-use change and land-cover practices on the hydrological reaction of the catchment has been an area of interest for hydrologists in recent years. This information is used for proper management of the water that exist over the catchment and for controlling the effect that may face the catchment due to the change of land-use land-cover.

2.7. Hydrological model

Hydrological models are useful tools for assessing water resources, understanding hydrological processes, and projecting the effects of land-use land-cover changes on water resources. Due to the spatio- temporal variability of the parameters involved in the transformation of the rainfall-runoff process, modeling catchment response to change in land-use land-cover was achieved with great difficulty. The catchment's hydrologic modeling has been created for a variety of reasons and takes several shapes. They are generally designed to recognize the hydrologic phenomena at work in a catchment and to generate synthetic hydrologic data sequences to aid design or forecasting. It's also utilized to figure out how changes in the catchment might influence these events(Abebe, 2014; Gebrekristos, 2014).

Hydrologic engineers are needed for a variety of tasks, including planning and designing new hydraulic conveyance and water-control facilities, operating and/or evaluating existing hydraulic conveyance and water-control facilities, preparing for and responding to floods, and regulating floodplain activities. A historical record of flow, stage, or precipitation may be sufficient to meet the information requirement in some cases. More commonly, watershed runoff must be predicted to provide the information. For example, a flood-damage reduction study may require to assess the increased volume of runoff for proposed changes to land use in a watershed (Tizazu, 2018). According to Gebrekristos (2014), hydrological models are useful techniques for water resources assessment, understanding of hydrological processes, and prediction of the impact of changes in land-use and climate.

Various types of models can be used depending on the desired output, the current database, input factors, and the needed analysis. Hydrological models, for example, categorized into three classes based on their geographical description: lumped models, semi-distributed models, and distributed models. The entire catchment is taken as a single unit in lumped models, geographical variances are averaged or ignored, and basin response is only assessed at the outlet. Semi-distributed models allowed to realize spatial variation in the catchment by partitioning the basin into many sub-basins. In distributed models, the user defines the spatial variation of processes, input, boundary conditions, watershed features, and output, which deals on the resolution of available data. Semi-distributed models are more practically based than lumped models and use less raw data than fully distributed models. Also based on the duration of simulation hydrological models could be classified as event-driven and continuous-process models (Mehari, 2018).

According to Berga (2011), semi-distributed models allow for some spatial variation by splitting the area into a set of smaller sub-catchment. The fundamental benefit of these models is that they have a more physically grounded structure than lumped models, and they require less input data than fully dispersed models. Semi-distributed models include SWAT, HEC-HMS, and HBV. The SWAT model which is used in this study is the widely used hydrological models and applied for several watersheds around the world for several years. It is a semi-distributed continuous-process model and selected from other models because it is more physically based than lumped models and less demanding on input data than fully distributed models. The SWAT is associated with ArcGIS and has the capability to accept data from remote sensing and GIS.

2.8. Soil and water assessment tool model (SWAT)

The SWAT is a physically-based continuous time series watershed model that runs on a daily time step. It can model the movement of runoff, sediment, minerals, pesticides, and bacteria throughout agricultural watersheds. Also, the SWAT model delineates a watershed and further sub-divides those watershed into a smaller sub-basins. The SWAT model generates numerous hydrologic response units (HRUs) in each sub-basin based on homogenous land-use land-cover, soil, and topographic variables. It requires several inputs data to represent watershed conditions such as DEM, land-use and land-cover, soils, and climate data. The SWAT model's interface is

compatible with ArcGIS, which can incorporate a variety of geospatial data to accurately depict the watershed's properties(Rabo, 2018).

SWAT is a relatively new model for assessing watershed hydrology. It is the best model among the various hydrological models because of its ability to apply to large-scale watersheds (> 100 km²), compatibility with GIS interface, continuous-time simulations, generation of the largest number of sub-basins, and capability to analyze the watershed spatially in sufficient detail (Desta and Lemma, 2017). According to Welde and Gebremariam (2017) proposed on the study SWAT model needs spatio-temporal data including DEM, land-use land-cover map, soil data, hydrological , and climatic data.

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Description of the study area

The Muger catchment is found in the Abay basin southeast corner and covers a total area of 8188 km². The upper Awash basin, which flows to the southeast, is connected to its aquifer system. Muger River is a north-flowing tributary of the Abay River basin in central Ethiopia, which is notable for its deep gorge. The watershed is geographically located between 38°50'10"E – 38°30'20"E longitude and between 9°18'45"N – 9°5'7"N latitude. Figure 3.1 that given below shows that location of Muger catchment (Amare & Simane, 2018).

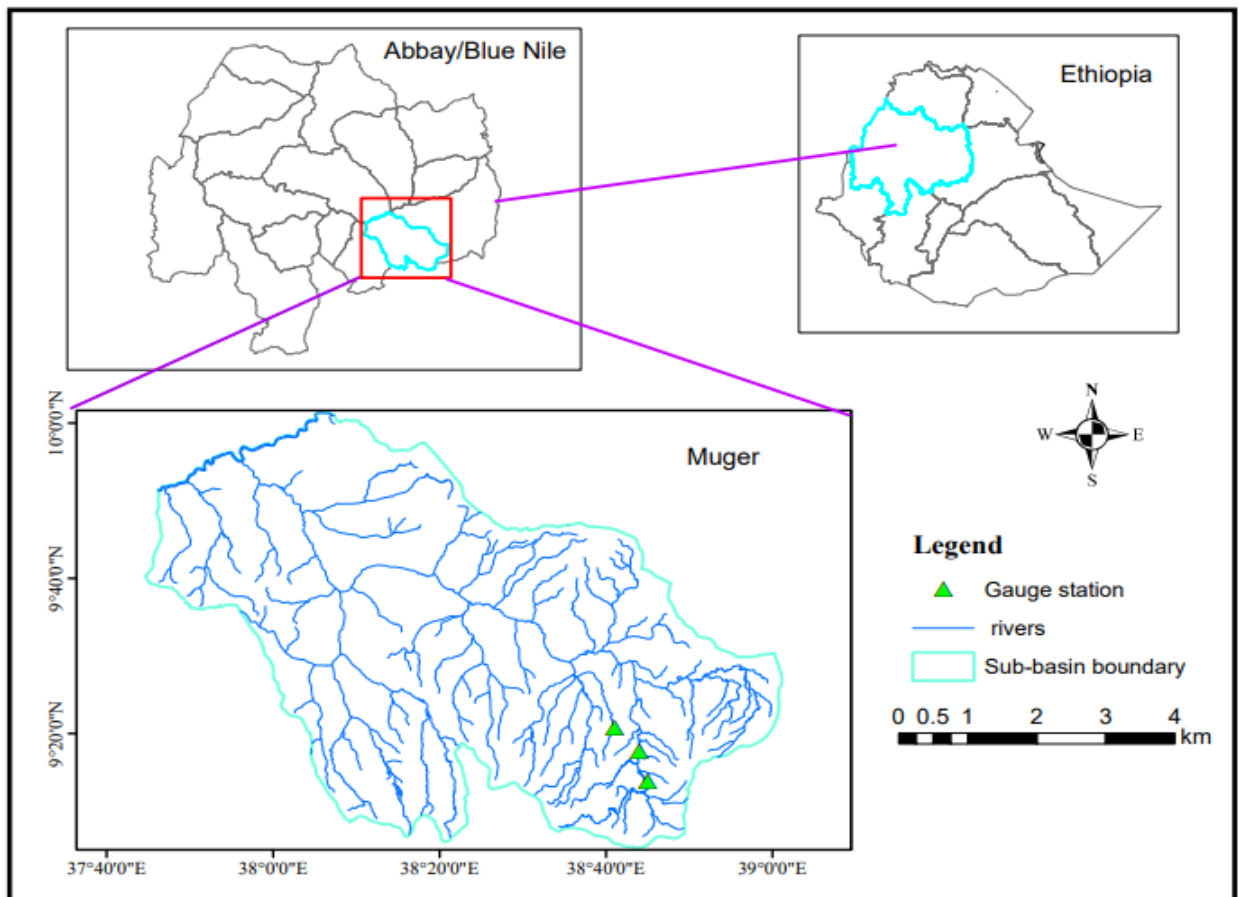


Figure 3.1: Location map of the study area

3.1.1. Topography

The Muger catchment covers 8,188 square kilometers. The Muger river, which drains from the southeast of the catchment into the Abbay river, is the main river in the catchment. This catchment is located between 953 and 3550 masl. The sub-eastern basin's and southern highlands are higher in height, ranging from 2600 to 3550 meters. The Muger river's lowlands are less than 1700 meters above sea level.(Amare & Simane, 2017). The elevation map of the Muger catchment that shows its topography were given by Figure 3.2 as shown below.

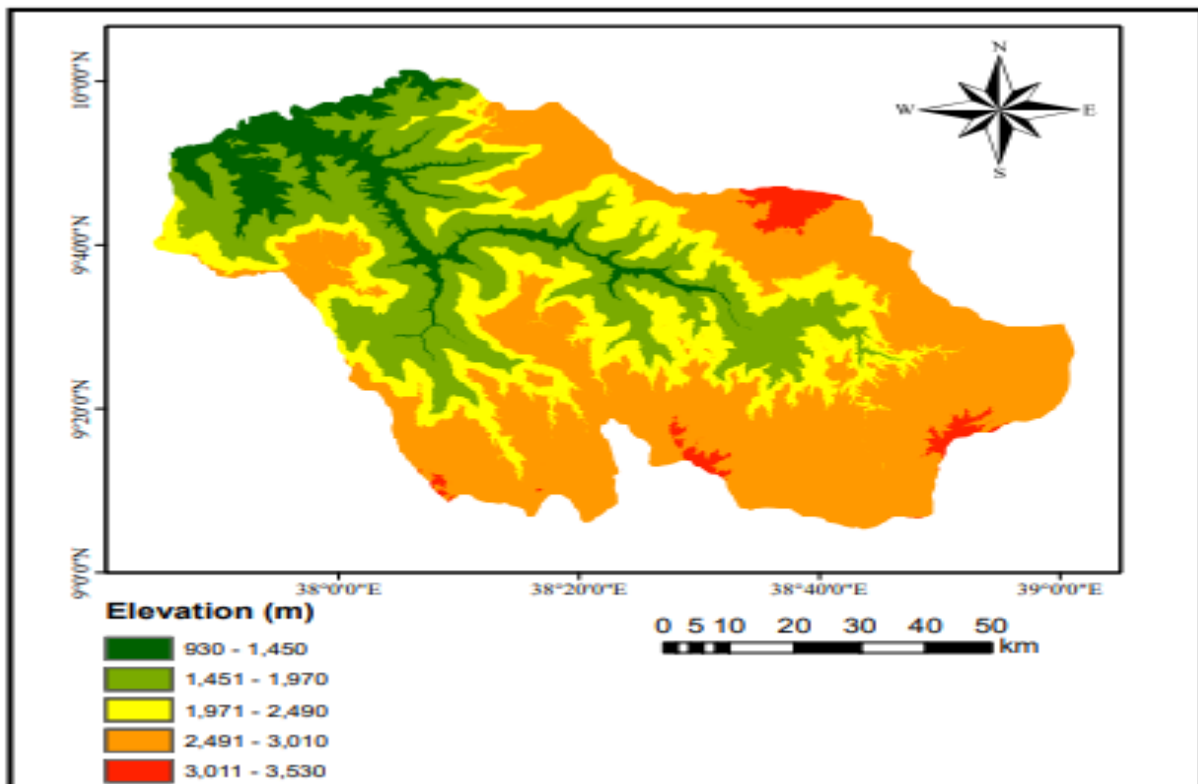


Figure 3.2: Topography of Muger Catchment

3.1.2. Rainfall

The yearly rainfall in the catchment ranges from 833 mm to 1326 mm. Along the river and lowlands, yearly rainfall is lower, ranging from 833 mm to 1000 mm. The catchment's highlands receive a relatively high amount of rainfall.

3.1.3. Temperature

The catchment's maximum and minimum temperatures range from 16°C - 31.5°C and 3°C - 16.5°C, respectively. Along the river, temperatures range from 28°C - 31.5°C, with a minimum of 13°C - 16.5°C.

3.1.4. Evaporation

The evapotranspiration (PET) in the sub-potential catchment ranges from 1215 to 1970 mm per year. PET is greater than 1800 mm/yr along the river, where the temperature is high, and is less than 1450 mm/yr in the eastern part of the catchment (Amare & Simane, 2017).

3.1.5. Soil and geology

The catchment's soils are leptosols, luvisols, vertisols, fluvisols, and alisols. Leptosols are highly soil types found in the sub-basin. Luvisols are the second most common soil type. Some portions of the sub-catchment also have small patches of cambisols, nitosols, and rigosols. The detail representation of the map that shows the distribution of the soil within Muger catchment were given below by Figure 3.3 as shown below. Also, the geology of the catchment is mainly dominated by basalt and sandstone. There are alluvium deposits in the southern and eastern parts of the sub-catchment (Amare & Simane, 2017).

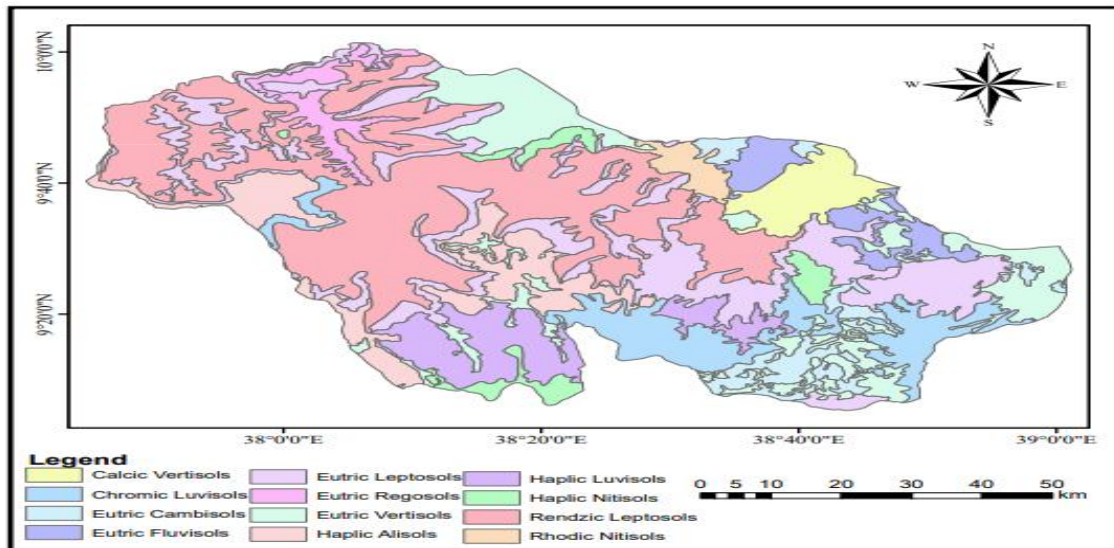


Figure 3.3: Soil types in muger catchment

3.1.6. Administrative structure of the catchment

The catchment is grouped into three zones, according to the present zonal structure: North shoa, West shoa, and Oromia regional state of the surrounding Finfine special zone. The Muger catchment covers a large area which includes 15 weredas. The total population of the sub-catchment is 2,442,247 people. Farmers practice small-scale and subsistence mixed agriculture in the sub-catchment, which is largely rural in nature. Crop farming and animal keeping are the primary sources of income in the area(Amare & Simane, 2017).

3.2. Data

The primary and secondary sources of data have been used to conduct this study. The primary data that were used for this study are the ground truth data that is used for performing an accuracy assessment for LULC classified map. The secondary data that was needed for this study includes Landsat satellite imagery, DEM, meteorological, hydrological, and soil data. Generally, the necessary data, data sources, and the purpose for which the data were used for this study are given in Table 3.1 in detail.

Table 3.1: Shows the required data for the study

No.	Data Type	Data Source	Purpose
1.	Landsat satellite image	USGS (United States Geological Survey)	To produce land-use land-cover map of the study area for the different years
2.	DEM	Ethiopia Ministry of Water, Irrigation, and Energy (EMWIE)	Used to delineate the catchment and analyze drainage characteristics
3.	Soil	Ethiopia Ministry of Water, Irrigation, and Energy (EMWIE) and FAO	To realize the physical and chemical characteristics of the soil for the catchment
4.	Hydrological data (Stream flow data)	Ethiopia Ministry of Water, Irrigation, and Energy (EMWIE)	SWAT model calibration and Validation
5.	Meteorological data (daily rainfall, max., and min. temperature, relative humidity, sunshine hours, and wind speed)	Ethiopia National Meteorological Agency (NMA)	To use it as input for SWAT model to conduct a hydrological impact assessment

3.2.1. Land –use land-cover data

Land-use land-cover is highly essential input data used by the SWAT to characterize the catchment's hydrological response units (HRUs), which aid in the realization of various hydrological processes. The landsat satellite image was downloaded for free from the USGS to create a land-use land-cover map of the study area for various years. To link the grid values to the SWAT land-cover land-use database, a look-up table was created that specifies the 4-letter SWAT code for each category of land-cover land-use.

Table 3.2: Landsat imagery characteristics

Year	Landsat Type and its Sensor	Path	Row	Date of Acquisition	Resolution	Source
1990	Landsat5 TM	168&169	53&54	1990-01-5	30m	https://earthexplorer.usgs.gov/
2000	Landsat 5 TM	168&169	53&54	2000-01-28	30m	https://earthexplorer.usgs.gov/
2010	Landsat7 ETM+	168&169	53&54	2010-01-05	30m	https://earthexplorer.usgs.gov/
2021	Landsat 8 OLI/TIRS	168&169	53&54	2021-01-19	30m	https://earthexplorer.usgs.gov/

3.2.2. Digital elevation model (DEM)

DEM is used to show the topographical arrangement of the surface of the earth in relation to any datum. It is provided as a raster or regular grid of point heights and serves as the basic input data for the SWAT hydrological model. It is important inputs data used by SWAT when dividing the catchment into sub-catchments. A 30m*30m DEM obtained from the Ethiopian Ministry of Water, Irrigation, and Energy (EMWIE) was used to define the catchment, which covered the whole Muger catchment.

3.2.3. Soil map data

The shape file format showing soil type distribution throughout the catchment was acquired from the Ethiopian Ministry of Water, Irrigation, and Energy (EMWIE) of GIS department. Using the shape file from the FAO's world soil database (1995) and the digital soil map from the world database, the various characteristics of the catchment's soil at different levels of each soil type were extracted. The map's soil layer was identified in a separate lookup database, making it simple to assign soil group information for the catchment.

3.2.4. Hydrological data

The hydrological data (streamflow) for the Muger catchment acquired from the hydrology department of Ethiopia Ministry of Water, Irrigation, and Energy (EMWIE). This information used in the SWAT model for calibration and validation.

3.2.5. Metrological data

The Ethiopian National Meteorological Agency (NMA) provided meteorological data for the stations inside and surrounding the catchment, including rainfall, maximum and minimum temperatures, relative humidity, wind speed, and solar radiation.

3.3. Software and materials

The materials that were used for this study include computer hardware and software. The hardware that was being used for this study is a laptop and handled GPS. Generally, Table 3.3 shows the detail description of the software that were used for analyzing the different data such as ArcGIS 10.5, Arc SWAT 10.5, ERDAS imagine 2015, and SWAT- CUP.

Table 3.3: Shows the software and material that were used for the study

No.	Software and Material	Purpose
1	Arc GIS 10.5	Data editing, analysis, visualization, and storage
2	ERDAS 2015	Used for conducting digital image preprocessing, and LULC classification
3	Arc SWAT and SWAT CUP	To conduct watershed delineation, HRU analysis, sensitivity, calibration, and validation
4	Google Earth	Visualization of the study area in detail
5	Handled GPS	Collect ground controls points (GCPs)
6	MS office 2016	Writing, chart preparing, graphs and statistical analysis

3.4. Method of the study

3.4.1. Satellite image preprocessing

The satellite image is full of errors and it needs a certain correction before using for various applications. Pre-processing techniques are applied before using the raw satellite data for the analysis and extraction of information. Image pre-processing involves two major processes which are geometric correction and radiometric correction or haze correction. The sensor's perspective, the scanning system motion, the platform motion (platform height, attitude, and speed), the relief, or the earth's curvature and rotation can all produce geometric distortions in remote sensing imageries. This mainly involves correcting geometric errors in raw picture data, radiometrically calibrating the data, and removing noise from the data. Generally, preprocessing tasks includes image restoration, geometric rectification, radiometric correction, and noise removal (Ayele Abebe, 2017).

3.4.2. Land-use land-cover classification

The practice of assigning pixels of a continuous raster image to predetermined land cover classes from remotely collected digital imagery is known as image classification. Since image classification is generated using remotely sensed data, many factors cause difficulty to achieve a more accurate result. For instance, the characteristics of a study area, availability of high resolution data, ancillary and ground reference data, suitable classification algorithms, the analyst's experience, and time constraints. These factors highly determine the type of classification for image classification (Ayele Abebe, 2017).

The classification of an image is the mechanism of categorizing pixels in an image into different ground cover classes. The discrete classes or themes of land-use and land-cover categories are extracted from remotely sensed digital data. To compare with others or calculate spatial properties using alternative statistical approaches, the classified image is transformed to vector features. Image classification is difficult and time-consuming operation, and selecting a suitable classification method is necessary to increase classification accuracy. This would also allow the analyst to successfully realize the changes (Mulu, 2018).

Also according to Nurye (2019) pointed on the study it is always a more difficult and time-consuming task to conduct an accurate LULC classification due to different reasons such as

classification methods, algorithms, collecting of training sites, etc. The appropriateness of various image classification methods depends on the goal of the land-use land-cover maps created for, the analyst's knowledge, the algorithm, and other factors. To accomplish the aim of the study land cover maps prepared based on the pixel-based supervised classification through a number of processes. The first step was a collection of training samples which is typically a representative for land-cover classes.

3.4.3. Accuracy assessment

Accuracy assessment is a quality assurance step in which classification outputs are compared with what is there on the ground at the time of imaging. Evaluation of the accuracy of classification is performed for the identified class and its confusion with other covers. Image classification using various classification methods or algorithms may classify or assign some pixels or groups of pixels to the wrong classes. To ensure the classification result will be free from the error that may arise during classification, the errors must be quantitatively determined in terms of classification accuracy. The omission or commission errors are the types of errors that occur in image classifications. The widely applied method to represent classification accuracy is by using an error matrix sometimes referred to as a confusion matrix (Mulu, 2018).

According to Nurye (2019) pointed on the study also the most widely used classification accuracy is through using an error matrix which is used to derive a series of descriptive and analytical statistics. The number of pixels per class for the reference data is shown in the columns of the matrix, while the number of pixels per class for the classified image is shown in the rows. Overall, user's and producer's accuracy were determined to evaluate the classification accuracy. The overall accuracy is used to indicate the exactness of the whole classification and the other two measures indicate the accuracy of individual classes. The detail of its description were look like as given below.

User's accuracy

The number of correctly classified pixels in each class is divided by the total number of pixels classified in that category expresses the user's accuracy. It calculates the chance that a pixel on the ground categorized into a specific category really indicates that category (Tadesse, 2019). It is calculated by using the formula given by equation 3.1 below.

$$\text{User Accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of classified pixels in that category (the row total)}} \times 100 \quad (3.1)$$

Producer's accuracy

The producer accuracy indicates how effectively a reference pixels of the ground cover type are classified. According to Tadesse (2019) on the study it is computed by dividing the number of correctly classified pixels of certain land-use and land-cover type by the total number of pixels of the same land-use and land-cover type in the reference data as shown by equation 4.2.

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of classified pixels in that category (the column total)}} \times 100 \quad (3.2)$$

Overall accuracy

The overall accuracy which is used to show the accuracy of the whole classification is computed by dividing the total correctly classified pixels by the total number of pixels multiplied by a hundred. Mathematically, it is computed by the formula given below by equation 3.3;

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels (diagonal)}}{\text{Total number of reference pixels}} \times 100 \quad (3.3)$$

Kappa coefficients

The kappa coefficient, which is a measure of agreement, can also be used to evaluate classification accuracy. It expresses the ratio in error caused by a classification process versus the error generated by a purely random classification. It includes the element along the off-diagonal of error matrices (i.e., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Tadesse, 2019). Generally, the Kappa coefficient is calculated using equation 3.4 as shown below.

$$K = \frac{N \sum_{i=1}^r X_{ii} - \sum_1^r (X_{i+} * X_{+i})}{N^2 - \sum_1^r (X_{i+} * X_{+i})} \quad (3.4)$$

Where;

r = the number of rows in the error matrix

X_{ii} = number of observations in row i and column i (on the major diagonal)

X_{i+} = total number of observation in row i

$X+i$ = total number of observation in column i

N = total number of observations included in the error matrix

A Kappa coefficient of 1 indicates complete agreement, whereas a number near zero indicates agreement that is no better than would be predicted by chance. Therefore, for this study the ground data and the high-resolution Google earth image were employed to ensure the correctness of the LULC classification that would be applied.

3.4.4. Land-use land-cover change detection

Change detection is the practice of detecting differences in the condition of an object or phenomenon by studying them at various intervals of time using remote sensing techniques. Because of repetitive spatial coverage within a short period time and consistent image quality, change detection is considered one of the major applications of remotely-sensed data obtained from Earth-orbiting satellites. Because change detection is enforced by factors such as spatial, spectral, thematic, and temporal features, choosing appropriate method for change detection is critical in obtaining a more accurate change detection result. Depending on the technique used, different change detection approaches could result in different map of changes (Sahalu, 2014).

Change detection is a technique for identifying changes that occurred in a certain location over time. It's very necessary for detecting changes in various forms of land-use, such as an increase in urban built-up area or a decrease in agricultural land, and so on. By studying the same area at multiple time periods using satellite photos or aerial photography, the user can determine the change in land-use and land-cover in that location. Image differencing, Principal Component Analysis, Image regression, and post-classification comparison change detection methods are some of the most extensively used approaches for change detection by utilizing satellite pictures (Muhammed, 2018).

The change in LULC that had occurred in the catchment over the study period were discovered by utilizing a post-classification comparison strategy to meet the study's goal. In this study, post-classification comparison (map-to-map comparison) methods were favoured for a variety of reasons. The change in LULC that had occurred in the catchment over the study period were discovered using a post-classification comparison strategy to meet the study goal. For numerous reasons, post-classification comparison (map-to-map comparison) methods were preferred in this

investigation. This approach, for example, minimizes the problems of multi-temporal images acquired by numerous sensors under a variety of climatic and environmental conditions. Also it provides a useful information on the amount and type of change (i.e., 'from-to').

The quantification of amount of change has been applied to generate information about the land-use/land-cover change. According to Gashaw et al.(2018), the percent and rate of change of each land-use and land-cover were calculated by using equation 3.5 and equation 3.6 respectively as shown below.

$$\text{Percent change} = \frac{A_y - A_x}{A} \times 100 \quad (3.5)$$

Where;

A_x = Initial area of land use land cover

A_y = Final area of land use land cover

A = Total area

$$\text{Rate of change}(ha/year) = \frac{A_y - A_x}{T} \quad (3.6)$$

T: is the time interval between A_x and A_y in years

3.4.5. SWAT model input and analysis

3.4.5.1 Watershed delineation

The delineation of the watershed allows for the formatting of data in preparation for dividing the watershed into subunits. Subdivision allows for the differentiation of these areas so that the associated impact on hydrology can be more accurately measured and studied. The primary division made is on the sub-basin level, and is evaluated relative spatial location of each sub-basin, the direction of hydrologic flow, and the natural divisions of stream networks determined by elevation(Berga, 2011).

3.4.5.2. HRU analysis

A watershed is separated into multiple homogeneous sub-basins (hydrologic response units or HRUs) with unique soil, slope, and land use attributes to conduct simulation. The prepared land - use and soil layers were overlapped with the specified watershed using Arc SWAT. The layer produced by this process is necessary to the ultimate analysis performed by the SWAT model because it determines the land, soil, and slope category assigned to each HRU. This category

determines how land will respond to precipitation, runoff, infiltration, and other hydrologic processes during the simulation. Each sub-basin can then have one or more HRUs defined within it (Berga, 2011; Nigussie, 2009).

3.4.5.3. Weather data definition

Weather data necessary for running a basic SWAT simulation are precipitation, wind speed, relative humidity, solar radiation as well as maximum and minimum temperatures. Once the database setup is complete in Arc SWAT, the designated weather station locations are added to the monitoring point layer created during watershed delineation.

3.4.5.4. Weather generator

In developing countries, there is an absence of a full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed station.

3.4.5.5. Sensitivity analysis

The initial phase in the calibration and validation in SWAT is the determination of the most sensitive parameters for a given watershed or sub watershed. Hence, the user determines which variables to adjust based on expert judgment. Sensitivity analysis is a technique for determining the responsiveness of various factors in a hydrological process simulation. It is a mechanism of minimizing the parameters size to be used in the calibration step by making use of the most sensitive parameters largely controlling the behavior of the simulated process. This appreciably eases the overall calibration and validation process as well as reduces the time required for it. It also increases the accuracy of calibration by reducing uncertainty (Getachew, 2019).

To achieve the goal of the study sensitivity analysis performed for the catchment hydrology to determine the parameters needed to improve simulation results and better understand the behavior of hydrologic system and to evaluate the applicability of the model. Parameters for sensitivity analysis was selected by reviewing previously used calibration parameters and documentation from SWAT manuals.

3.4.5.6. Model calibration

Model calibration is a means of adjusting or fine-tuning model parameters to match with the observed data as much as possible, with a limited range of deviation. It is also

the modification of parameter values and comparison of the predicted output of interest to measured data until a defined objective function is achieved for the same condition. Calibration is an attempt to better parameterize a model to a specific set of local conditions, reducing forecasting uncertainty (Getachew, 2019; Muhammed, 2018).

During calibration, a systematic approach of adjusting model parameters was followed until the model outputs as nearly as possible matched the behavior of the observed data. A hydrological model's calibration procedure is represented as follows:

$$Q(x, t) = M(\theta, x, t) + \varepsilon(x, t) \quad (3.7)$$

Where; $Q(x, t)$ represented the flow measured at point x and time t , $M(\theta, x, t)$ is the estimate of flow through a set of parameters θ , and $\varepsilon(x, t)$ is the error at that point at the time interval.

3.4.5.7. Model validation

To use the calibrated model for estimating the effectiveness of future potential management practices, the model should be tested against an independent set of measured data without making further adjustments. It is the process of establishing that a particular site-specific model is capable of generating sufficiently accurate simulations. This is done by comparing the predictions against observed data that was not used in the calibration procedure, using the parameters that were obtained during the calibration phase (Getachew, 2019; Ibrahim, 2018). Model validation compares the field observations (data that was not utilized in calibration) to model predictions without changing any input parameter values to evaluate the calibrated model (Guug, 2020).

3.4.5.8. Model Performance Evaluation

The model was tested against an independent set of measured data to use the calibrated model. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases the model will be used for future predictions under different management scenarios.

Several approaches for evaluating the SWAT model's performance during the calibration and validation phases are available. For this work, two approaches were used to quantitatively analyze the SWAT model: Nash-Sutcliffe simulation efficiency (NSE) and coefficient of determination (R^2) (Beyene, 2016; Gashaw et al., 2018).

Coefficient of Determination (R^2)

The coefficients of determination describe the proportion of the total variances in measured data by the model. It is the magnitude linear relationship between the observed and the simulated values that range from 0 to 1. The R^2 is calculated using the equation:

$$R^2 = \frac{[\sum_i^n (Q_o - Q_{mo})(Q_s - Q_{ms})]^2}{\sum_i^n (Q_o - Q_{mo})^2 \sum_i^n (Q_s - Q_{ms})^2} \quad (3.8)$$

Where:

Q_o : is observed flow data in m³/s,

Q_{mo} ; is mean values of the observed data

Q_s ; simulated flow data in m³/s

Q_{ms} ; is mean values of simulated data.

A value of 1 indicates a perfect fit and therefore a very reliable model or less error variance where as a value of zero indicates that the model fails to accurately model the dataset (Aredehey et al., 2020).

Nash-Sutcliffe Efficiency (NSE)

The NSE determines the proportionate level of residual error compared to the measured variance in the data. The formula used to compute NSE is as follows:

$$NSE = 1 - \left[\frac{\sum_i^n (Q_o - Q_s)^2}{\sum_i^n (Q_o - Q_{mo})^2} \right] \quad (3.9)$$

Where: Q_o is the observed flow data in m³/s,

Q_s is simulated flow data in m³/s,

Q_{mo} is mean of observed flow.

The NSE value between 0 and 1 shows an acceptable model performance where as a value less than 0 shows poor performance of the model.

3.5. The overall framework of study

This study deals on modeling land-use land-cover change and assessment of its impacts on hydrology by using GIS and remote sensing techniques through integrating it with the SWAT hydrological models. To conduct this the spatio-temporal data were used as input data. The spatial data such as land-use land-cover, soil map, and DEM were used as input for HRU analysis. The maximum likelihood supervised land-use land-cover classification for the years 1990, 2000, 2010, and 2021 were conducted to get the land-use land-cover data for HRU. The temporal data including meteorological and stream flow data were also used. The stream flow data were used for the calibration and validation of the SWAT simulation result.

Generally, the overall methods that were deployed for modeling land-use land-cover change and assessment of its impacts on hydrology for Muger catchment using GIS and remote sensing techniques by integrating with the SWAT hydrological model were shown below by Figure 3.4.

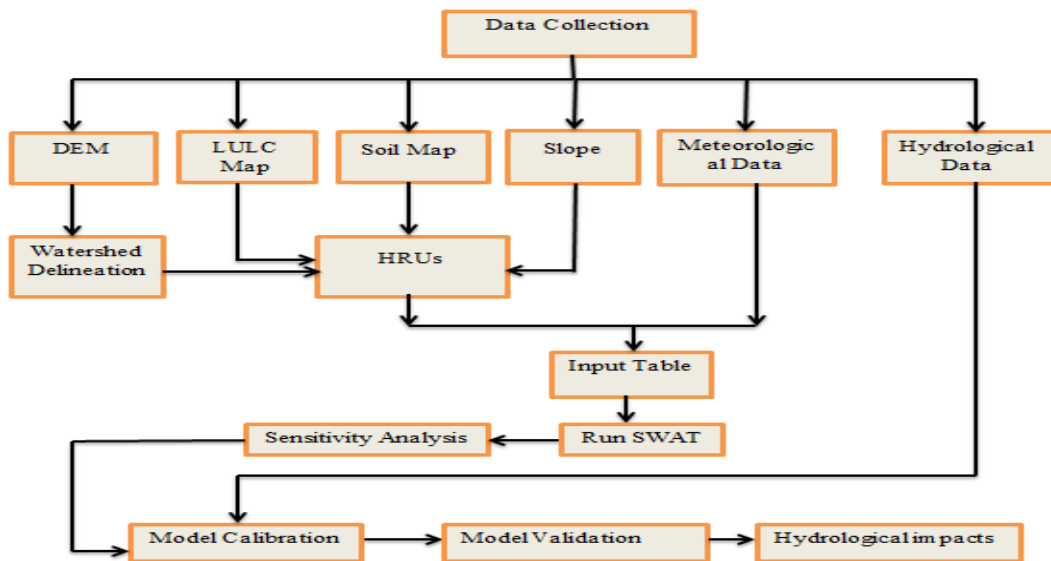


Figure 3.4: Shows the methodology of the overall study

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Land-use land-cover maps

The LULC maps were prepared after performing the supervised classification following the necessary preprocessing activity. Using the TM, ETM+, and OLI/TIRS Landsat satellite imagery, maximum likelihood classification techniques were used to classify the data. Forest, woodland, settlement, shrub land, grass land, crop land, and bare land are the land-use land-cover types found in the Muger catchment.

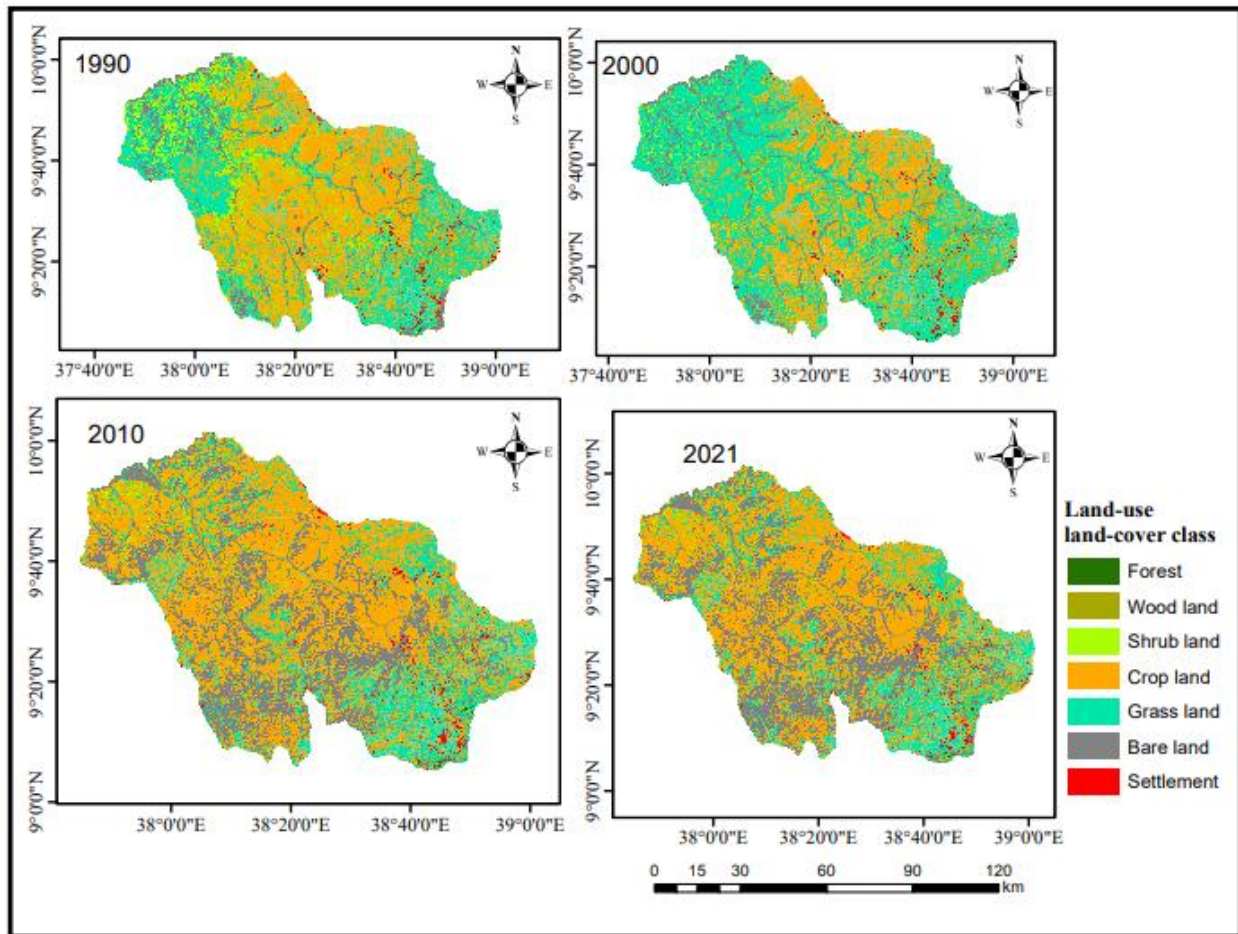


Figure 4.1: Land-use and land-cover map of Muger catchment (1990 - 2021)

The area coverage of land-use land-cover types are shown by Table 4.1 and its maps are shown by Figure 4.1 as shown above. The land-use land-cover analysis of the LULC map of 1990 shows that about 3.19% of Muger catchment was covered by forest, 12.76% by woodland, 14.78% by shrub, 56.99% by cropland, 10.99% by grassland, 1.12% by bare land and 0.17% by settlement. The cropland covers a relatively wide area which holds the majority of the catchment whereas the bare land and settlement cover the small area within these years.

Also as we realize from Table 4.1 of LULC map of 2000 about 3.25% of Muger catchment was covered by forest, 12.80% by woodland, 10.39% by shrub, 56.98% by cropland, 15.31% by grassland, 1.08% by bare land and 0.17% by settlement. Like the year 1990, most of the area was dominated by the cropland relative to the other LULC types found within the catchment. Similarly, the land-use land-cover map of 2010 shows that about 2.22% of Muger catchment was covered by forest, 7.01% by woodland, and 8.16% by shrub, 72.73% by cropland, 7.40% by grassland, 2.26% by bare land and 0.23% by settlement. Like the previous period also most of the area was dominated by the cropland relative to the other LULC types found within the catchment. Also, a bit decrease in woodland, shrub, and grassland was observed in the catchment.

The LULC map of 2021 shown that about 2.15% of Muger catchment was covered by forest, 6.88% by woodland, 8.10% by shrub, 73.33% by cropland, 7.10% by grassland, 2.14% by bare land and 0.30% by settlement. Relative to the other LULC types found within the catchment the majority of the catchment was occupied by the cropland whereas the settlement and bare land covers a small area. The overall land-use land-cover change between the year 1990 and 2021 were summarized by Table 4.1 as given below.

Table 4.1: Land-use land-cover and their relative area between the years 190 - 2021 for Muger catchment

Land-use land-cover class	Area							
	1990		2000		2010		2021	
	Area(km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area (%)
Forest	261.13	3.19	266.47	3.25	181.42	2.22	175.68	2.15
Wood land	1044.83	12.76	1048.43	12.80	573.70	7.01	563.70	6.88
Shrub	1210.02	14.78	851.09	10.39	667.86	8.16	662.86	8.10
Crop	4666.26	56.99	4665.05	56.98	5954.83	72.73	6003.96	73.33
Grass land	899.60	10.99	1253.83	15.31	605.50	7.40	581.50	7.10
Bare land	91.62	1.12	88.57	1.08	185.28	2.26	175.28	2.14
Settlement	14.30	0.17	14.32	0.17	19.16	0.23	24.77	0.30

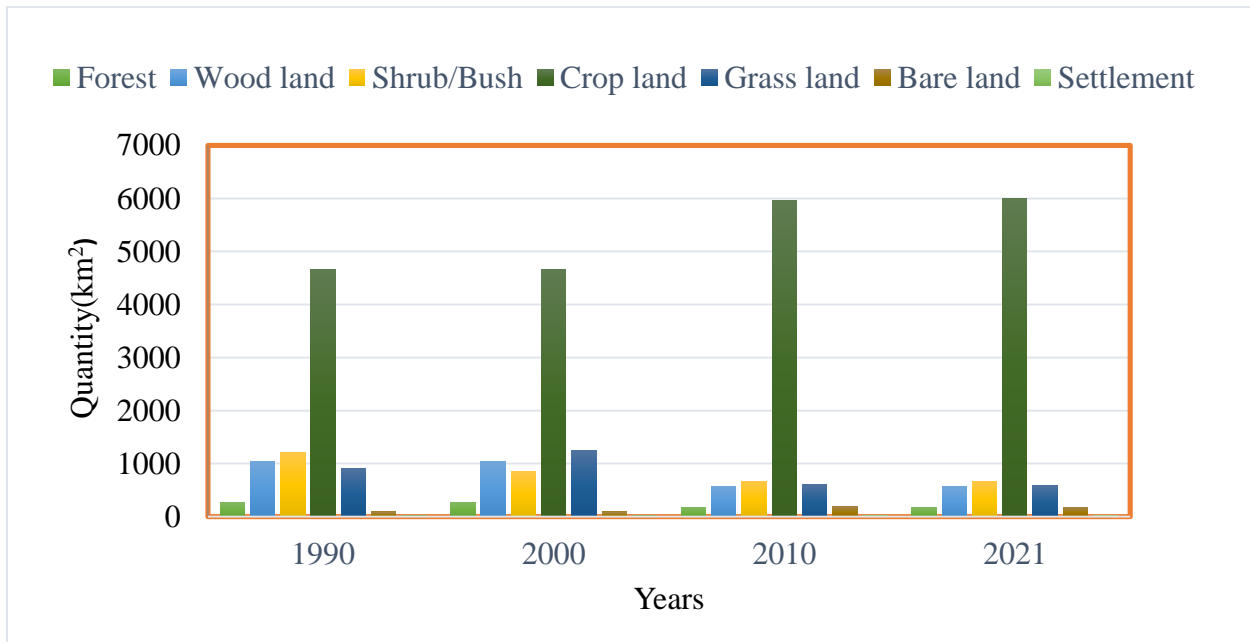


Figure 4.2: Land-use land-covers and their relative area in between the years 1990 – 2021

The relative distribution of the cropland over the catchment was increasing from the year 1990 to 2021 whereas the wood and shrubland are decreasing continuously from time to time. Generally, Figure 4.3 and Table 4.2 shows that the net change between the years 1990 and 2021.

Table 4.2: Land use-land-covers area net change for Muger catchment between 1990 – 2021

Land use land cover class	1990 - 2000	2000 - 2010	2010 - 2021	1990 - 2021
Forest	5.33	-85.04	-5.74	-85.45
Wood land	3.60	-474.73	-10.00	-481.14
Shrub	-358.93	-183.23	-5.00	-547.15
Crop	-1.21	1289.78	49.13	1337.70
Grass land	354.23	-648.33	-24.00	-318.09
Bare land	-3.05	96.71	-10.00	83.66
Settlement	0.02	4.84	5.61	10.47

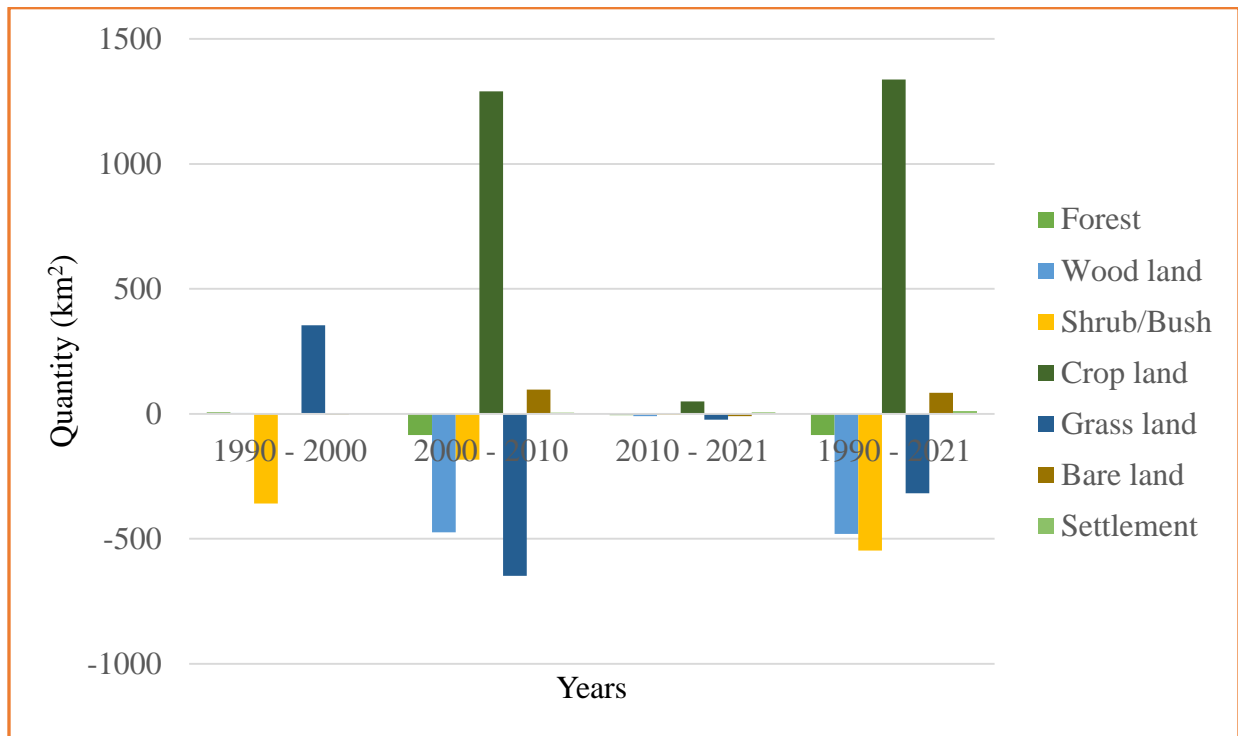


Figure 4.3: Land-use land-cover net change between 1990 and 2000; 2000 and 2010; and 2010 and 2021

4.2. Accuracy assessment

The accuracy assessment is used to realize how the imagery is correctly classified and was conducted to eradicate the classification faults due to the presence of a feature that has a similar spectral reflectance value or response due to different reasons. The error matrix was used to make this judgment, with the diagonals representing correctly classified values and the off-diagonals representing incorrectly classified values. Three types of accuracy and kappa coefficients were generated using the error matrix.

Therefore, for this study accuracy assessment was conducted for the 2021 classified Landsat image by using 410 reference data points that were collected by handled GPS through an error matrix. This was realized through an error matrix as shown below using Table 4.3 given below.

Table 4.3: Error matrix for the classified land use land cover map of 2021

	LULC Class Type	Reference Data(2021)								
		Forest	Wood land	Shrub land	Crop land	Grassl and	Bare land	Settlement	Total	U.A (100%)
Classified Data (2021)	Forest	60	2	1	0	1	0	2	66	90.91%
	Wood land	1	72	2	0	0	3	0	78	92.31%
	Shrub land	2	1	57	2	2	0	2	66	86.36%
	Crop land	1	2	1	67	2	0	3	76	88.16%
	Grass land	0	1	1	1	40	0	2	45	88.89%
	Bare land	0	0	0	0	1	27	1	29	93.10%
	Settlement	0	0	0	0	0	0	50	50	100.00
	Total	64	78	62	70	46	30	60	410	
	P.A (100%)	93.75 %	92.3 %	91.94 %	95.7 1%	86.96 %	90.00 %	83.33%		
	Overall	90.98%								
Kappa coefficient s	0.87									

4.3. Land-use land-cover change detection

The process of detecting differences in the state of an object or phenomenon by examining it at different times is known as land-use land-cover change detection. It entails the ability to quantify temporal impacts across multiple time data sets. The features of land-use land-cover change detection that have occurred, such as detecting change nature, measuring the aerial extent of the

change, and identifying the pattern of change are vital for monitoring natural resources. The efficiency of the land-use land-cover change detection techniques depends on several factors such as classification schemes, the spatial and spectral resolution of remote sensing data, ground reference data, and effective implementation of the result.

Remotely sensed imagery is critical for showing land use land cover change detection because it has the high ability to provide spatial and temporal information on a given area. To realize the difference in state of LULC the post-classification comparison change detection techniques were used since it is widely used and simple to understand. This approach also gives detailed 'from-to' information that can be efficiently extracted. The statistics of this variation will be computed by comparing values of the area of one data set with the corresponding value of the second data set in the common area in each period.

4.3.1. Land-use land-cover changes between 1990 to 2000 in Muger catchment

Table 4.4: Land-use land-covers change between 1990 and 2000

Land use land cover class	1990		2000		Area Change	
	Area(km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area(%)
Forest	261.13	3.19	266.47	3.25	5.34	0.06
Wood land	1044.83	12.76	1048.43	12.80	3.6	0.04
Shrub land	1210.02	14.78	851.09	10.39	-358.93	-4.39
Crop land	4665.05	56.99	4666.26	56.98	1.21	-0.01
Grass land	899.60	10.99	1253.83	15.31	354.23	4.32
Bare land	91.62	1.12	88.57	1.08	-3.05	-0.04
Settlement	14.30	0.17	14.32	0.17	0.02	0

As realized from Table 4.4 from the year 1990 to 2000 the forest, woodland, and grassland increased by 0.06%, 0.04%, and 4.32% respectively. Also, between this period the shrubland, cropland, and bareland were decreased by 4.39%, 0.10% and 0.04% respectively. The settlement does not show more change between this periods.

4.3.2. Land-use land-cover changes between 2000 to 2010 in Muger catchment

Table 4.5: Land-use land-cover change between 2000 and 2010

Land use land cover class	2000		2010		Area Change	
	Area (km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area(%)
Forest	266.47	3.25	181.42	2.22	-85.05	-1.03
Wood land	1048.43	12.80	573.70	7.01	-474.73	-5.79
Shrub land	851.09	10.39	667.86	8.16	-183.23	-2.23
Crop land	4665.05	56.98	5954.83	72.73	1289.78	15.75
Grass land	1253.83	15.31	605.50	7.40	-648.33	-7.91
Bare land	88.57	1.08	185.28	2.26	96.71	1.18
Settlement	14.32	0.17	19.16	0.23	4.84	0.06

Between the years 2000 and 2010, the cropland, bareland and settlement was increased by 15.75%, 1.18% , and 0.06% respectively as shown by Table 4.5. The forest, woodland, shrubland, and grassland were decreased by 1.03%, 5.79%, 2.23% and 7.91% respectively which is resulted due to the conversion of it to the cropland and settlement.

4.3.3. Land-use land-cover change between 2010 to 2021 in Muger Catchment

Table 4.6: Land-use land-cover change between 2010 and 2021

Land-use land-cover class	2010		2021		Area Change	
	Area (km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area(%)
Forest	181.42	2.22	175.68	2.15	-5.74	-0.07
Wood land	573.70	7.01	563.70	6.88	-10	-0.13
Shrub land	667.86	8.16	662.86	8.10	-5	-0.06
Crop land	5954.83	72.73	6003.96	73.33	49.13	0.6
Grass land	605.50	7.40	581.50	7.10	-24	-0.3
Bare land	185.28	2.26	175.28	2.14	-10	-0.12
Settlement	19.16	0.23	24.77	0.30	5.61	0.07

Also, as shown by Table 4.6 between the years 2010 and 2021 the cropland was increased by 0.6% and the settlement is by 0.07% in the catchment. The other LULC classes such as forest, woodland, shrubland, grassland, and bareland were decreased by 0.07%, 0.13%, 0.06% , 0.3%, and 0.12% respectively.

4.3.4. Land-use land-cover change between 1990 to 2021 in Muger catchment

Table 4.7: Land-use land-cover change between 1990 and 2021

Land use land cover class	1990		2021		Area Change	
	Area (km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area(%)
Forest	261.13	3.19	175.68	2.15	-85.45	-1.04
Wood land	1044.83	12.76	563.70	6.88	-481.13	-5.88
Shrub land	1210.02	14.78	662.86	8.10	-547.16	-6.68
Crop land	4666.26	56.99	6003.96	73.33	1337.7	16.34
Grass land	899.60	10.99	581.50	7.10	-318.1	-3.89
Bare land	91.62	1.12	175.28	2.14	83.66	1.02
Settlement	14.30	0.17	24.77	0.30	10.47	0.13

Also as realized from Table 4.7 from the years 1990 to 2021 the cropland, bareland, and settlement was increased by 16.34%, 1.02%, and 0.13% whereas the forest, woodland, shrubland, and grassland were decreased by 1.04%, 5.88%, 6.68%, and 3.89% respectively in the catchment.

Relative to the other periods the cropland is increasing at a large rate between this period. It shows more variation within this period. This increment is mainly due to the continuous expansion of the cultivation over the area which is the basic one for the life of human beings. It is increasing at the expense of shrub, grass, and bare land over the area continuously within Muger catchment relative to the others. The settlement is also increasing in small amounts from time to time over the area.

4.4.Sensitivity analysis, calibration, and validation

4.4.1. Sensitivity analysis

The sensitivity analysis was performed for Muger catchment to determine the most sensitive parameter which is important to improve the result of simulation. It also helps to realize the character of the hydrologic system and evaluation of the acceptability of the SWAT model in a good manner. To conduct this study different parameters were selected with absolute minimum

and maximum ranges. Generally, Table 4.8 shows the most influential parameters types and their detail description as shown below.

Table 4.8: Types, rank and description of parameters for sensitivity

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

4.4.2. Calibration and validation

The calibration was conducted based on the sensitive parameters selected from the sensitivity analysis which is influential on the simulation result. The first two years flow data were used as a warm-up period which is about 10% of the whole data. Then the calibration was conducted for the identified stream flow parameter of the SWAT by using the monthly flow data of Muger, Sibilu, and Aleltu river stations between the years 1995 and 2004 whereas the validation was performed by using the observed data between the years 2005 and 2009 without making further adjustments for the calibrated parameters.

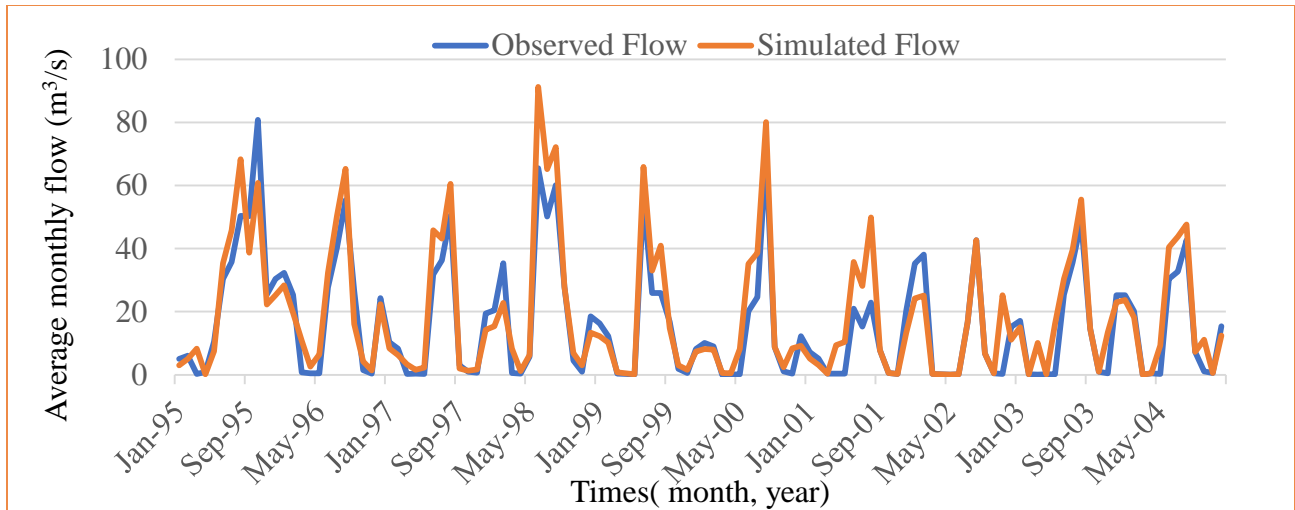


Figure 4.4: Observed and Simulated flow at Aleltu for the calibration period (1995 - 2004)

As shown from Figure 4.4 for Aleltu station the model was calibrated using the monthly stream flow data and the result shows that the coefficient of determination (R^2) of 0.81 and Nash Sutcliffe value (NSE) of 0.86, respectively which shows a good agreement between the observation and simulation.

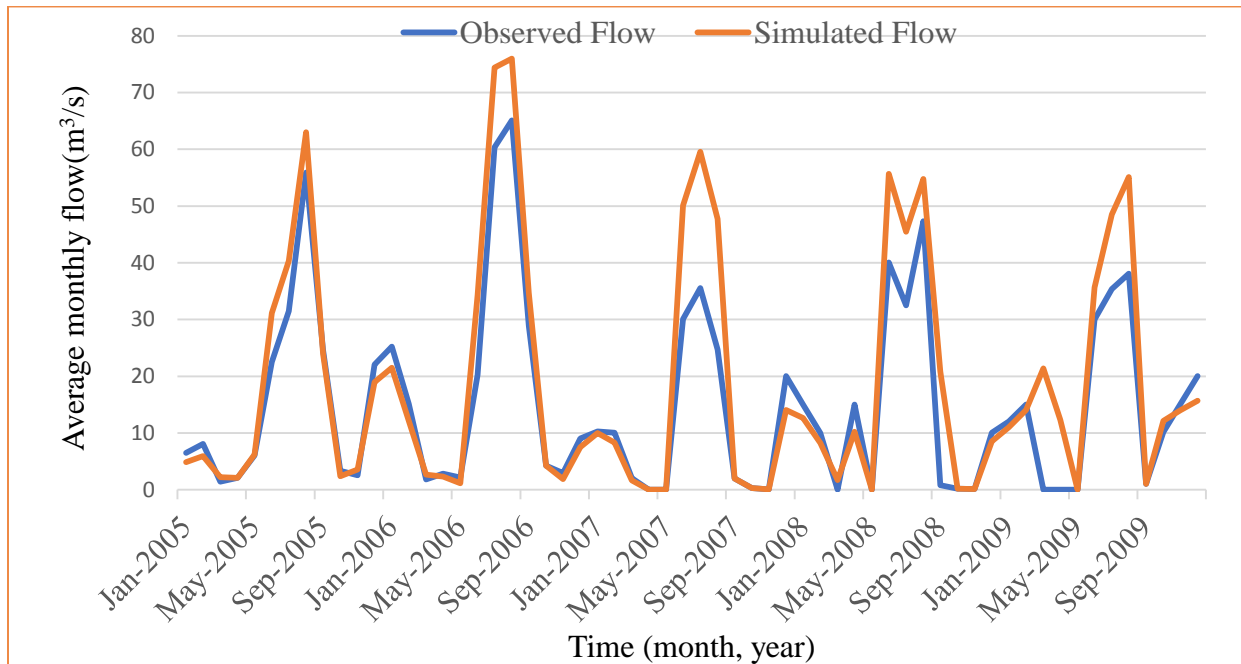


Figure 4.5: Observed and Simulated flow at Aleltu for the validation period (2005 - 2009)

Also as shown by Figure 4.5 for Aleltu station the validation result shows a coefficient of determination (R^2) of 0.89 and Nash Sutcliffe value (NSE) of 0.73, respectively which shows a good agreement between the observation and simulation.

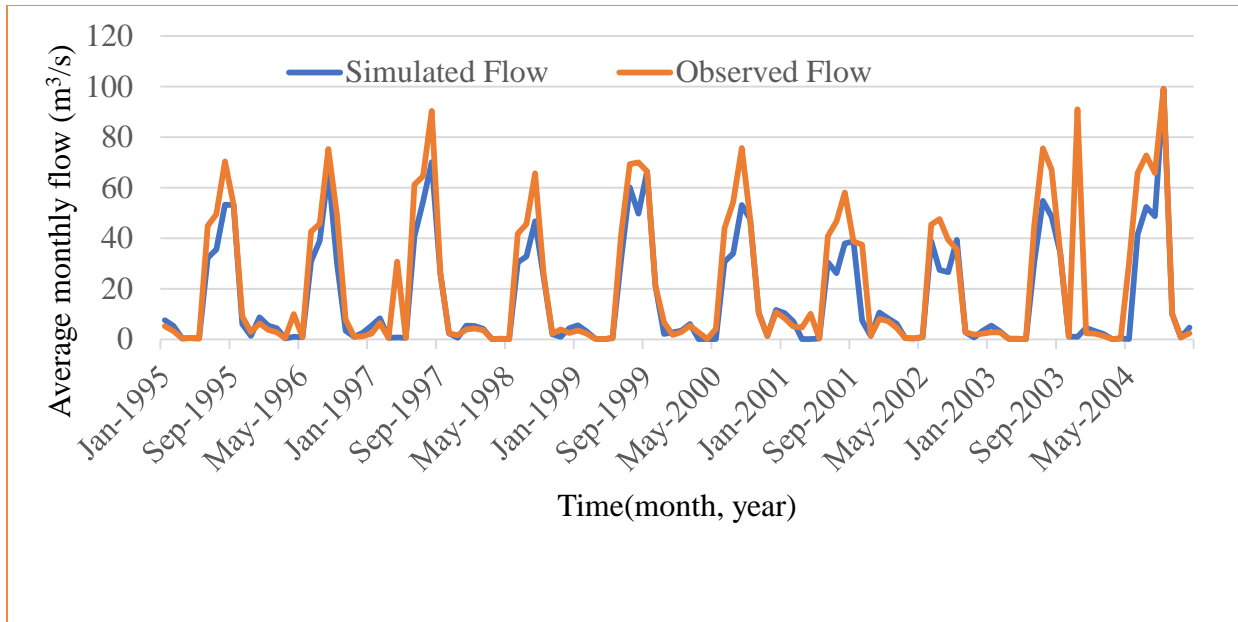


Figure 4.6: Observed and Simulated flow at Muger for the calibration period (1995 - 2004)

For Muger station the calibration result shows that the coefficient of determination (R^2) of 0.63 and Nash Sutcliffe value (NSE) of 0.84, respectively which also shows a good agreement between the observation and simulation.

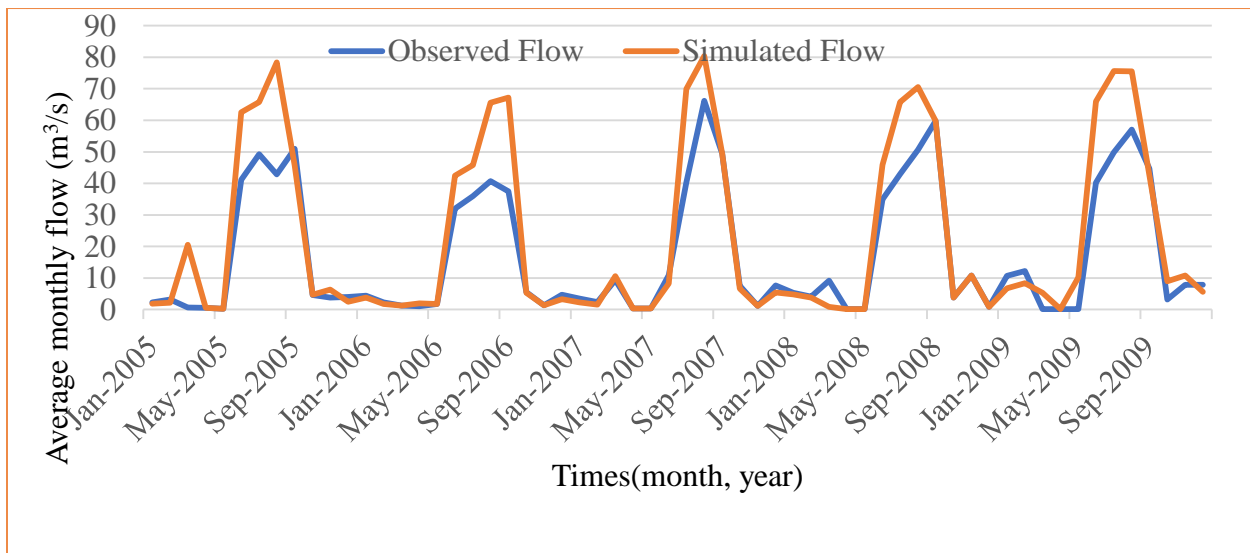


Figure 4.7: Observed and Simulated flow at Muger for validation period (2005 - 2009)

From Figure 4.7 for Muger station the validation result shows the coefficient of determination (R^2) of 0.84 and Nash Sutcliffe value (NSE) of 0.63, respectively which also shows a good agreement.

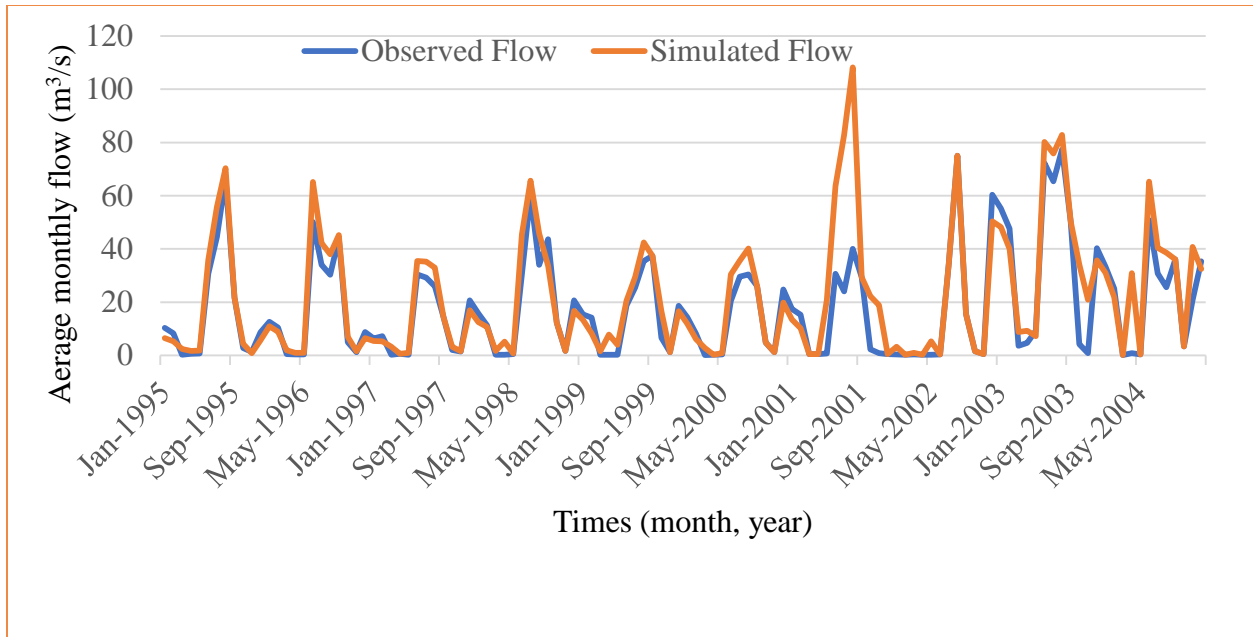


Figure 4.8: Observed and Simulated flow at Sibilu for the calibration period (1995 - 2004)

The calibration result shows that the coefficient of determination (R^2) of 0.79 and Nash Sutcliff value (NSE) of 0.66, respectively for Sibilu station which shows a good agreement between the observation and simulation.

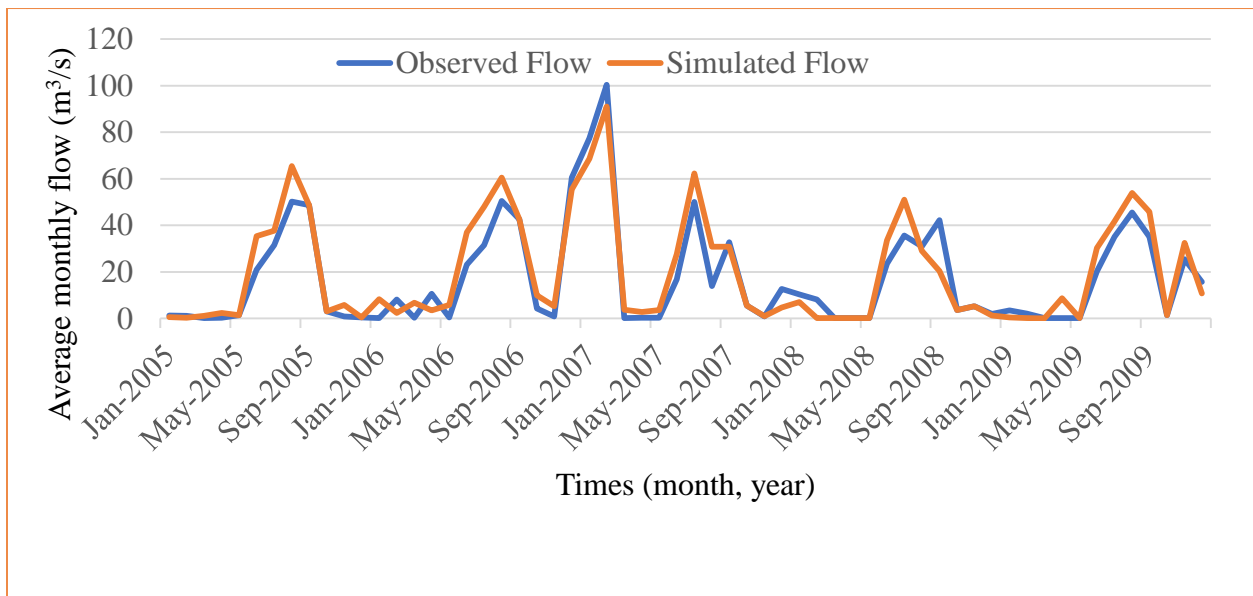


Figure 4.9: Observed and Simulated flow at Sibilu for the validation period (2005 - 2009)

Also as shown by Figure 4.9 for Muger station the validation result shows the coefficient of determination (R^2) of 0.89 and Nash Sutcliffe value (NSE) of 0.87, respectively which shows a good agreement between the observation and simulation.

4.5. Hydrological Response to LULC Change

LULC change is an important characteristic in the runoff process that affects infiltration, erosion, and evapotranspiration. Understanding the effects historic land-use changes have on hydrology is required to understand the future impacts of land-use and land-cover on hydrological regimes at the catchment level. The main aim of the study was to model the historic land-use land-cover change and to assess its impacts on the hydrological process that it has on the Muger catchment. Therefore, surface runoff, and groundwater flow were the most important catchment processes, and the evaluation was done depending on these processes.

These processes can be affected by changing LULC from time to time. To assess these effects of the historic LULC change on the hydrology, the SWAT model was calibrated and validated and the model was re-run to estimate the change of flow due to LULC changes. The effect of LULC modification on the hydrology were evaluated by comparing the simulation flow. To test the influence of land-use land-cover modification on hydrological process , the SWAT was re-run based on monthly basis by changing land-use land-cover map and keeping the other inputs held constant. A comparison of the surface runoff and ground water flow were generated by using the LULC map of 1990, 2000, 2010, and 2021 respectively.

Table 4.9: Surface runoff and ground water flow using LULC map of 1990, 2000, 2010, and 2021

Hydrological process item	1990	2000	2010	2021	Change between 1990 and 2021
Mean annual Surface runoff(mm)	124.35	145.23	169.45	193.21	+68.86
Mean annual ground water flow(mm)	95.23	78.63	64.52	43.27	-51.96

Table 4.9 shows that the mean annual surface runoff for the year 1990 is 124.35mm and for 2021 is 193.21mm which is increased by 68.86mm between this period due the change of land-use land-cover within the catchment. Also the ground water flow in the year 1990 is 95.23mm and for the year 2021 is 43.27mm which is decreased by 51.96mm between this period. This occur due to the expansion of crop land and settlement within the catchment from time to time

continuously. Also from this simulation output, we get the change in the streamflow between the wettest and driest months which indicates the seasonal effects of the land-use land-cover change on the streamflow. The streamflow for the wettest months (June, July, and August) is increased and for the driest month is (December, January, February) is decreased due to the change in land use land covers within the Muger catchment.

4.6. Discussion

Modeling the LULC change and assessement of it's impacts on hydrology between the years 1990 and 2021 were conducted for Muger catchment. The land-use land-cover map preparation and change detection were performed by using the Landsat imagery of the years 1990, 2000, 2010, and 2021 which were acquired in the dry season from the USGS. The acquired Landsat imagery were classified into 7 classes using the maximum likelihood classification techniques after performing the necessary preprocessing activity. The seven classified LULC class types are forest, woodland, shrubland, cropland, grassland ,bareland and settlement. After the LULC classification the accuracy assessement were done using the error matrix which determines the producer's accuracy, user's accuracy, overall accuracy, and kappa cofficients. The overall accuracy of 90.98% and kappa cofficients of 0.87 were achieved for the classified LULC map of 2021 which shows a good agreement between the classified and the ground collected LULC types. According to Achenafi et al., (2019) a value of kappa cofficients greater than 0.8 were shows almost a perfect agreement. Also a value of kappa greater than 0.8 showing a strong agreement; between 0.4 and 0.8 shows a moderate agreement and below 0.4 shows a poor agreement Fikirte (2017). Therefore, the overall accuracy for this study is within acceptable range and kappa value shows a good agreement.

The forest, woodland, and grassland increased from 3.19 to 3.25%, 12.76 to 12.80%, and 10.99 to 15.31% whereas the shrubland, cropland, and bareland were decreased from 14.78 to 10.39%, 56.99 to 56.98% and 1.12 to 1.08% respectively from the year 1990 to 2000. The settlement does not show change between this periods. But , between the years 2000 and 2010, the cropland, bareland and settlement was increased from 56.98 to 72.73%, 1.08 to 2.26% , and 0.17 to 0.23% whereas the forest, woodland, shrubland, and grassland were decreased from 3.25 to 2.22%, 12.80 to 7.01%, 10.39 to 8.16% and 15.31 to 7.40% respectively. Also, the cropland and settlement was increased from 72.73 to 73.33, and 0.23 to 0.30% from 2010 to 2021 in the

catchment respectively. However, between this period the other LULC classes such as forest, woodland, shrubland, grassland, and bareland were decreased from 2.22 to 2.15%, 7.01 to 6.88%, 8.16 to 8.10% , 7.40 to 7.10%, and 2.26 to 2.14% respectively.

Generally, from the years 1990 to 2021 the crop land and settlement is gradually increasing whereas the forest, woodland, shrubland, grassland and bareland is decreasing which is consistent with the findings of Ayele et al., (2019), but the magnitude of change are different. Also, according to the study conducted by Fikirte et al., (2017) on Libokemkem the continuous decrease in forest land , shrub land and grass land were observed throughout the study period. But, the agricultural land and settlement shows an increment within the study period which also consistency within this study except the rate of change. Also, Tessema et al., (2020)suggested that the agricultural land and settlement is increasing at the expense of forest, shrub land, and grass land but the rate of change is different from the rate of LULC change of this study.

Sensitivity analysis were conducted to select the most influential parameter and identifies 10 parameters have a significant influence on the flow of the catchment. The calibration result shows a good agreement between the measured and simulated monthly flows with the NSE of 0.81 and R^2 of 0.86 for the Aleltu river; NSE of 0.63 and R^2 of 0.84 for Muger river and NSE of 0.66 and R^2 of 0.79 of Sibilu river. Also, the validation result shows NSE of 0.73 and R^2 of 0.89 for the Aleltu river; NSE of 0.66 and R^2 of 0.88 for Muger river and NSE of 0.87 and R^2 of 0.89 for Sibilu river. A study conducted by Metaferia (2018) shows that NSE of 0.89 and R^2 of 0.93 for calibration whereas NSE of 0.95 and R^2 of 0.98 which shows a good agreement between both the simulated and observed flow. Similarly, a study conducted by Asmare (2020) on Borkena watershed shows that NSE of 0.79 and R^2 of 0.81 for calibration period and NSE of 0.74 and R^2 of 0.75 for validation period. Therefore, the NSE and R^2 value shows a good agreement between the simulated flow and observed flow for the Muger Catchment both for the calibration and validation periods.

The mean annual surface runoff from the years 1990 to 2021 is increased by 68.86mm and the mean annual ground water flow were decreased by 51.96mm due to the change in land-use land-cover from time to time in Muger catchment. A lot of studies was conducted on the different parts of Ethiopia to assess the impacts of the land-use land-cover change on the hydrology. For instance, a study conducted by Belihu et al., (2020) in upper Gidabo watershed of rift valley lake

basin demonstrates that the change of land-use land-cover increases the surface runoff and evapo-transpiration. It shows the wet season flow increase whereas the dry season flow decreases over the area. Also, a study conducted by Gashaw et al., (2018) on Andassa watershed of blue Nile basin shows that the change in land-use land-cover increases a wet season flow, and surface runoff and whereas decreases the dry season flow, and ground water flow.

Similarly, a study conducted on Gummara watershed by Teklay et al., (2019) shows that the expansion of agricultural land and reduction of the forest cover increases the average annual surface runoff and decreases ground water flow. As a general, within this study the expansion of crop land and settlement and reduction of forest, woodland, shrubland, grassland and bareland resulted in the increase of surface runoff and decrease of ground water recharge. It resulted also into the increase of wet season flow and decrease of dry season flow within Muger Catchment.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The change in land-use land-cover facilitates socio-economic advancement for the society. Even though, as this change is continuously increasing from time to time it exerted pressure on the natural environment such as climate variability, soil degradation, and hydrological cycle variation. This study deals on modeling land-use land-cover changes and assessment of its impacts on hydrology in Muger catchment using GIS and remote sensing techniques by the SWAT hydrological model. After performing the land use land cover change analysis following its recommended preprocessing activity, the assessment of its impacts on the different hydrological processes within the catchment was analyzed using the SWAT hydrological model. The spatial data and temporal data were integrated with a hydrological model to assess the impacts of land use and land cover changes on the Muger catchment. To conduct this analysis the land use and land cover change for the past 31 years(1990- 2021) were quantified.

Before conducting the assessment of the impacts of LULC change on the hydrology of Muger catchment; LULC Classification, change detection, accuracy assessment, and SWAT input data preparation were performed. After that sensitivity analysis, calibration, validation, and evaluation of the model performance were conducted. Finally, assessments of the impacts of the land use land cover change on the hydrology were carried out for the Muger catchment.

The results of LULC change of the Muger catchment show that the cropland and settlement continuously increase from time to time whereas the forest, woodland, shrubland, grassland, and bareland show a reduction at a certain rate over the past four decades. The dominant expansion of cropland at the expense of reduction of forest, woodland, shrubland, grassland, and bareland was observed in the Muger catchment. Also, a settlement is increasing from time to time but at a small rate relative to the cropland. The expansion of cropland was lead to the deforestation of forest and shrubland that exist within the Muger catchment in a rapid manner. This might be due to the population demand for cultivated lands were increased.

The sensitive parameter was identified by performing the sensitivity analysis of the SWAT model. The SWAT model calibration and validation showed that simulated and observed

streamflow portrays a good agreement. The result showed NSE of 0.81 and R^2 of 0.86 for the Aleltu river; NSE of 0.63 and R^2 of 0.84 for Muger river and NSE of 0.66 and R^2 0.79 of Sibilu river. Also, the validation result shows a good agreement between the measured and simulated flow with the NSE 0.73 of and R^2 of 0.89 for the Aleltu river; NSE of 0.66 and R^2 of 0.88 for Muger river and NSE of 0.87 and R^2 of 0.89 for Sibilu river.

The dynamic nature of the land use land cover has a great influence on the hydrological processes within the catchment in a different way. The expansion of cropland and settlement and reduction of forest, woodland, shrubland, grassland, and bareland resulted in the increase of surface runoff and decrease of ground water recharge for Muger catchment. Also, it shows the increase of wet season flow and decrease of wet season flows.

5.2. Recommendation

- ❖ The shortage of evenly distributed metrological and rain gauge station were observed within the study area. Therefore, it is highly recommended that establish the evenly distributed gauging station for better access to both hydrological and metrological data.
- ❖ The study only considered land-use land-cover change effects by assuming all other variables constant. But the change in climate, soil management, and other activities may also have a great impact on the hydrology of the catchment. Therefore, a further study that may conduct on this area should have to take the consideration of these parameters in a good manner.
- ❖ To conduct a very accurate land-use land-cover classification and change detection using the higher resolution satellite imagery is recommended which increases the quality of the work.

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Appendices

Appendix A: Locations of river gauging stations

ID	River name	East(X)	North(Y)
112002	Mugher	470713	1027938
112012	Aleltu	465227	1033470
112014	Sibilu	472539	1020567

Appendix B: Streamflow data for Mugher, Aleltu and Sibilu river gauge station respectively

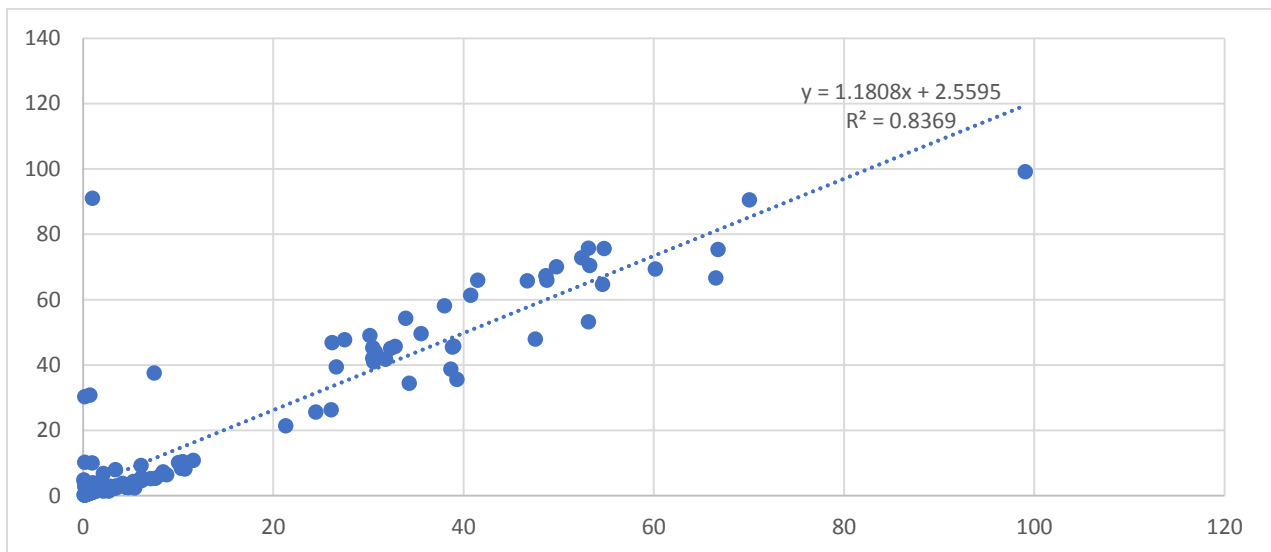
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	10.245	20.325	0.375	0.496	0.431	4.985	52.536	102.359	53.136	9.156	2.976	0.804
1996	0.756	0.857	0.477	9.979	0.882	2.654	35.754	94.324	28.987	7.869	1.002	0.717
1997	0.456	0.496	0.613	30.74	0.691	1.321	54.624	120.423	26.176	2.443	1.653	0.939
1998	0.292	0.662	0.153	0.292	0.171	1.975	32.839	69.657	25.498	2.326	3.921	0.586
1999	2.534	0.244	0.212	0.185	0.534	1.833	66.186	49.777	66.528	21.316	6.758	0.766
2000	2.963	5.463	2.742	0.134	4.188	3.986	33.933	153.657	47.854	10.325	1.461	10.785
2001	0.348	0.126	4.748	10.177	0.359	60.567	26.207	138.011	38.693	37.486	1.452	0.709
2002	0.426	0.189	0.474	0.348	0.873	8.84	7.665	9.35	35.552	2.831	1.972	0.491
2003	0.439	10.745	0.292	0.276	0.186	0.483	54.779	118.657	34.312	1.159	90.999	70.538
2004	0.333	0.147	0.205	0.377	30.203	41.506	102.457	133.776	99.07	10.056	0.769	80.45
2005	1.879	0.196	20.567	0.571	0.248	1.144	49.248	42.808	45.687	4.687	6.352	3.425
2006	0.349	0.256	1.289	1.986	1.722	1.948	88.962	95.627	67.503	5.314	1.354	0.674
2007	0.145	0.319	10.562	0.348	0.376	10.914	69.987	110.365	49.425	6.653	1.162	11.352
2008	10.335	0.128	0.789	0.121	0.134	2.942	92.969	30.587	59.83	3.821	10.803	0.877
2009	6.692	0.218	5.324	0.124	10.165	5.986	29.894	80.542	42.567	8.976	10.742	20.635

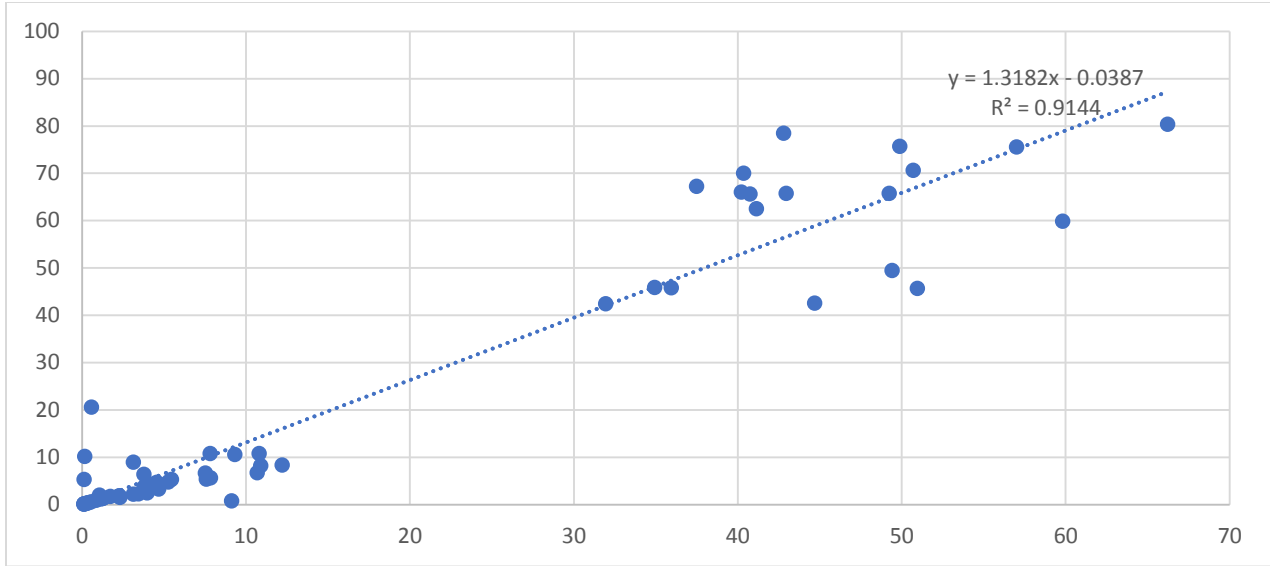
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0.083	0.099	0.252	0.874	0.51	0.37	13.779	73.365	10.252	10.789	25.46	30.351
1996	0.362	2.275	0.771	0.479	0.478	2.692	40.274	79.293	26.641	1.515	0.419	10
1997	0.39	0.26	0.258	0.344	0.258	1.788	56.236	50.521	2.961	0.978	0.684	0.467
1998	0.447	0.397	0.535	0.344	5.761	0.512	42.166	120.147	27.859	4.481	1.008	0.507
1999	0.307	0.198	0.386	0.23	0.097	0.714	36.98	130.965	16.764	1.872	0.558	0.185
2000	0.08	0.031	0.012	0.057	0.147	0.133	16.583	89.926	8.781	1.128	0.389	0.234
2001	0.158	0.118	0.349	0.365	0.366	0.915	0.1	39.87	7.737	0.624	0.318	0.212
2002	0.211	0.137	0.222	0.163	0.077	0.148	16.678	42.667	6.789	0.445	0.247	0.129
2003	0.108	0.128	0.064	0.199	0.134	0.378	39.602	58.5	14.53	0.974	0.47	0.259
2004	0.249	0.194	0.115	0.482	0.253	0.409	15.75	55.671	7.239	1.093	0.588	0.417
2005	1.56	1.105	1.436	2.088	6.029	2.542	31.466	57.92	24.669	3.326	2.542	2.082
2006	1.22	1.107	1.809	2.83	2.175	2.272	76.348	95.096	36.899	4.244	2.94	0.021
2007	0.31	10.066	2.029	0.043	0.034	0.087	0.563	4.716	2.016	0.311	0.106	0.06
2008	10.035	0.029	0.023	15.032	0.038	0.053	6.493	7.789	0.834	0.187	0.127	10.05
2009	12.046	15.039	0.026	0.027	0.024	0.03	0.405	8.093	1.044	10.166	15.067	20.052

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0.301	0.302	0.305	0.652	0.79	0.699	24.479	66.461	21.705	2.734	1.392	0.704
1996	2.68	0.475	0.504	0.421	0.378	5.206	64.101	10.324	44.18	4.966	1.231	0.802
1997	0.433	0.211	0.226	0.613	0.253	0.391	19.265	52.936	14.424	2.078	1.501	0.676
1998	0.725	0.269	0.289	0.267	0.491	2.42	7.386	4.035	43.613	12.316	1.681	0.702
1999	0.433	0.188	0.274	0.219	0.212	0.826	29.506	98.481	37.433	6.668	1.201	0.618
2000	0.369	0.181	0.116	0.223	0.373	0.482	19.563	101.463	26.05	4.827	1.228	0.802
2001	0.424	0.233	0.452	0.447	0.765	3.634	58.042	84.058	29.294	2.272	0.898	0.515
2002	0.435	0.213	0.334	0.293	0.248	0.433	34.457	75.095	15.524	1.581	0.526	0.398
2003	5.235	7.657	3.588	4.699	9.281	1.205	65.885	107.874	50.437	4.194	0.91	0.327
2004	0.276	0.149	0.104	0.9	0.326	0.889	30.829	95.568	36.071	3.359	20.806	35.423
2005	0.288	0.148	0.154	0.362	1.462	0.914	41.464	80.155	48.609	3.038	0.836	0.478
2006	0.204	0.188	0.281	0.614	0.423	1.145	71.443	80.448	42.602	4.27	0.884	0.546
2007	0.376	100.302	0.185	0.267	0.26	6.793	50.054	13.839	32.774	5.532	0.837	0.662
2008	0.262	0.159	0.14	0.173	0.184	3.535	65.615	10.982	42.259	3.643	5.192	2.01
2009	0.485	0.193	0.146	0.208	0.218	0.277	16.077	93.509	35.111	1.458	25.455	15.62

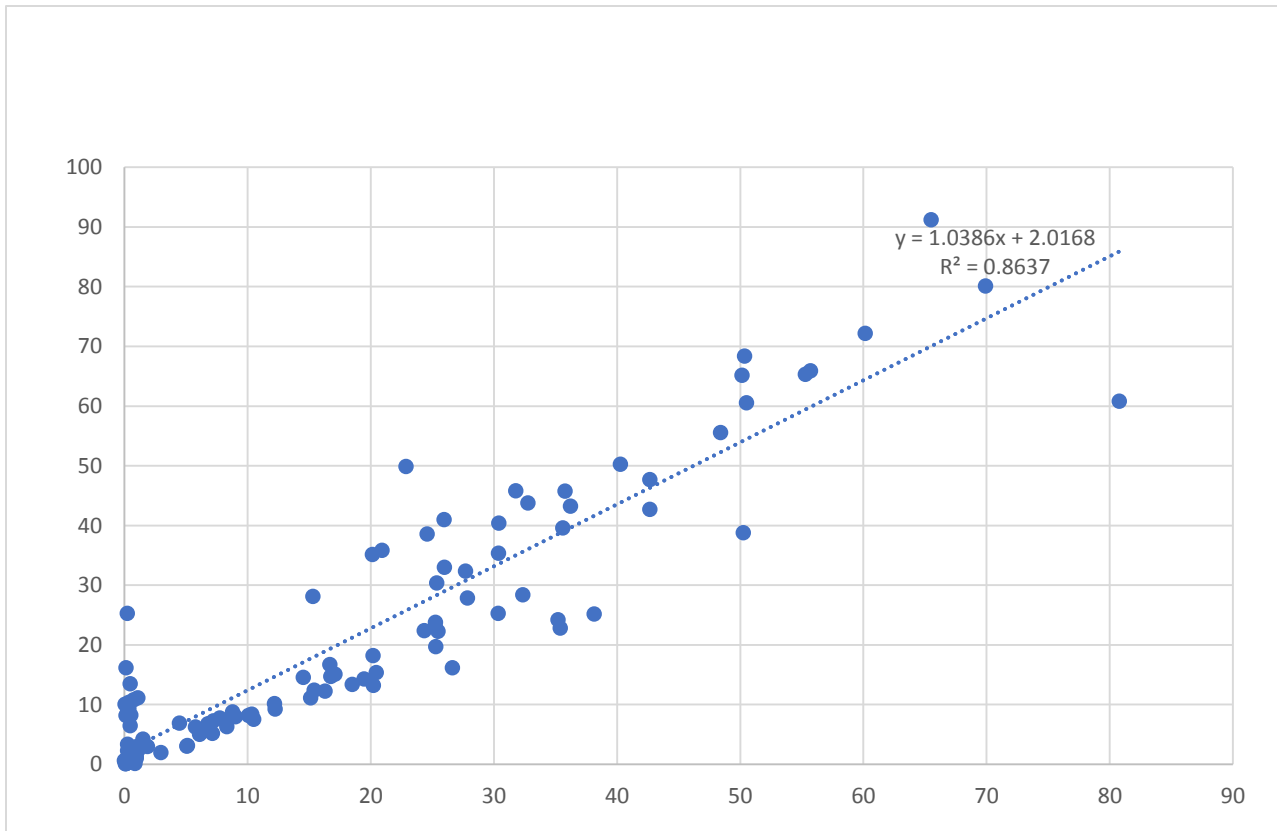
Appendix C: Graph showing the relationship between the observation and simulation value for calibration and validation period

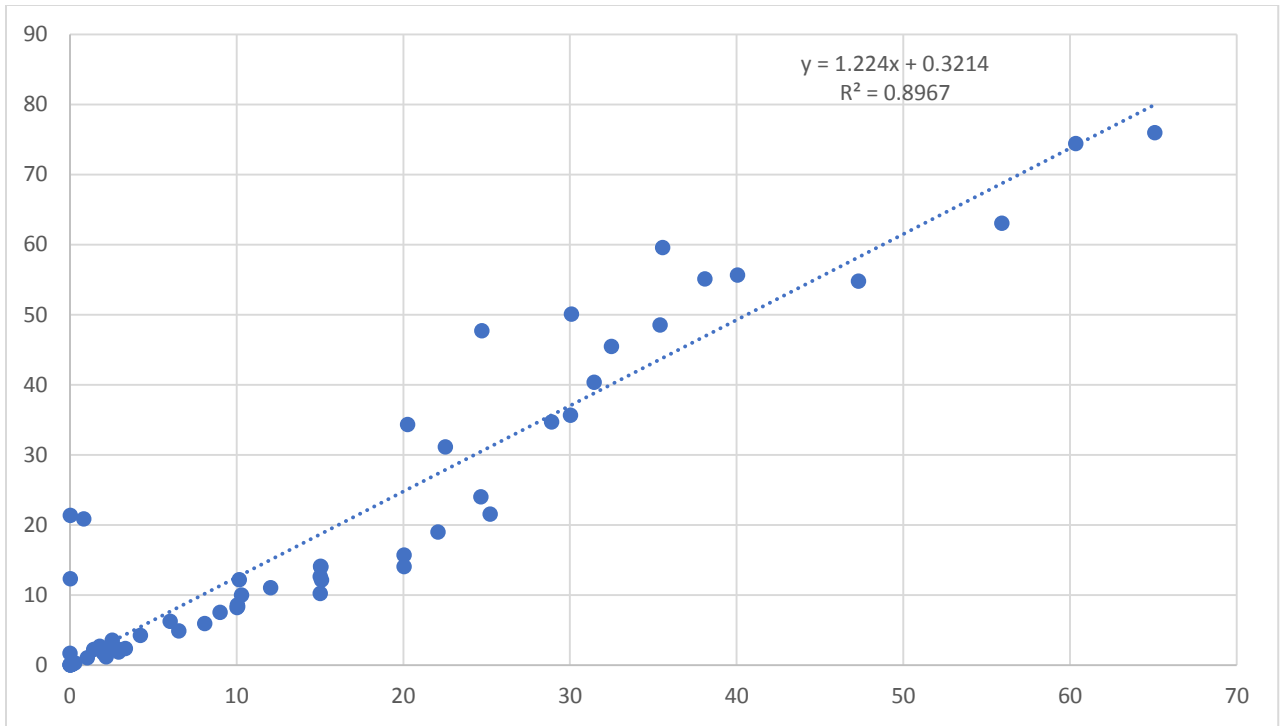
The graph shows R^2 value for calibration and validation for Muger River respectively



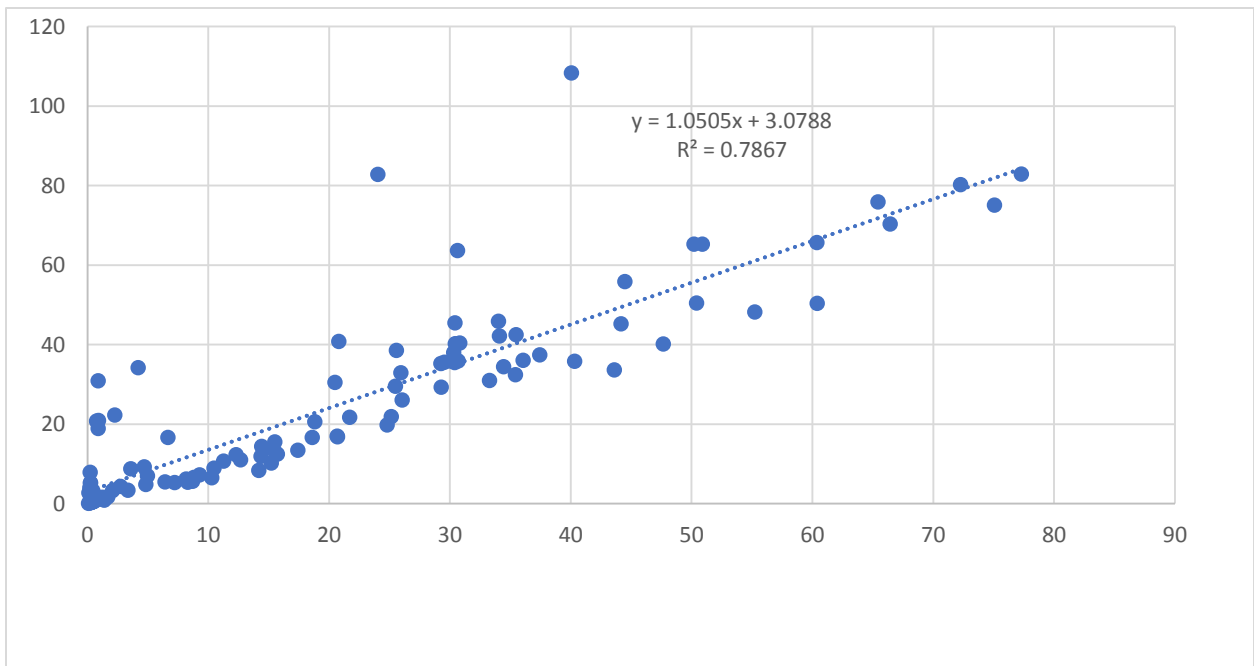


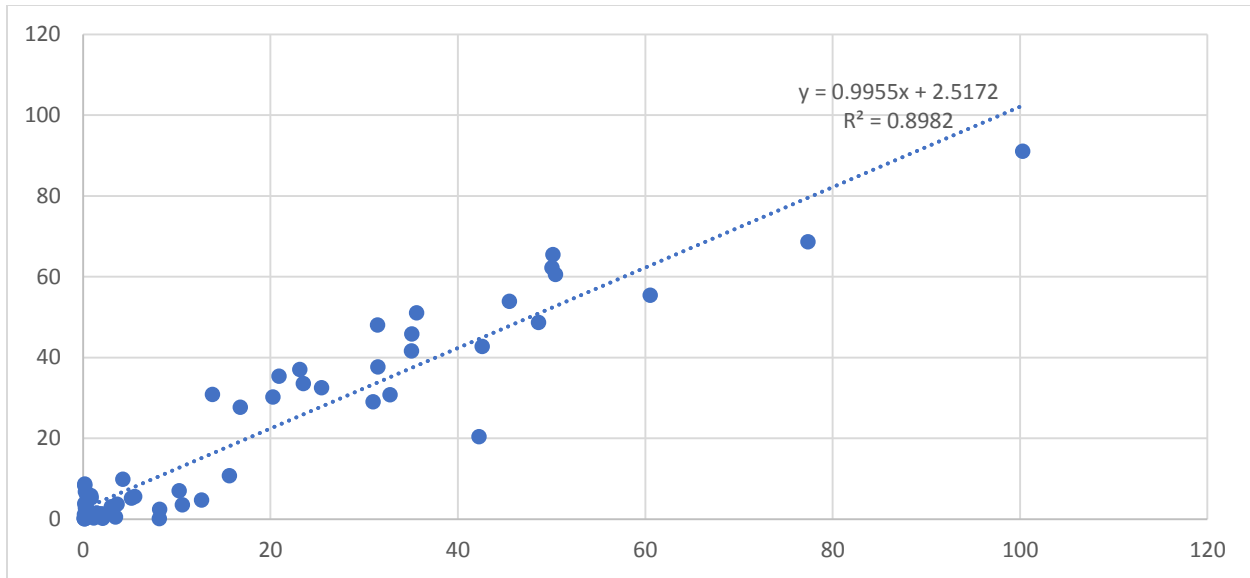
The graph shows R^2 value for calibration and validation for Aleltu River respectively





The graph shows R^2 value for calibration and validation Sibilu River respectively





Appendix C: Metrological location of the study area

Station	ID	Latitude	Longitude	Elevation
Derba	SHDERB13	9.4255	38.6508	2385
Suhulta	SHSULU23	9.18333	38.7333	2610
Muger	SHMUGE14	9.4585	38.3432	2553
Fiche	SHFICH11	9.7667	38.7333	2784

Appendix D: Monthly precipitation data of Sululta, Derba, and Muger respectively

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0.000	0.240	0.474	1.900	0.666	2.703	1.760	7.383	7.530	16.442	3.357	0.132
1996	0.000	0.000	0.281	0.000	0.594	1.783	1.813	2.147	9.413	9.358	1.627	1.777
1997	2.120	0.029	2.210	0.718	0.194	2.563	3.881	6.340	9.729	2.407	0.000	0.000
1998	0.781	0.461	0.919	0.533	1.513	6.313	12.926	14.290	4.893	2.539	0.197	0.000
1999	0.000	0.000	0.242	3.193	2.610	5.480	15.158	13.623	4.600	0.226	0.787	0.429
2000	0.116	0.018	5.297	1.510	3.461	5.563	10.868	6.948	2.643	0.165	0.000	0.000
2001	1.148	0.879	3.139	1.817	0.813	5.117	9.752	9.326	2.707	0.081	0.000	1.148
2002	0.132	0.500	1.055	2.900	0.210	5.430	11.787	11.068	4.657	0.065	0.000	0.287
2003	0.326	0.348	1.181	3.217	0.152	4.253	9.013	12.681	5.527	1.500	0.247	0.058
2004	0.310	0.125	1.074	2.463	0.577	1.390	8.313	8.071	5.177	0.784	0.457	0.000
2005	0.081	0.725	2.652	2.483	2.284	5.953	12.435	8.800	6.173	0.852	0.000	2.977
2006	0.455	1.245	0.207	1.332	1.233	3.600	8.140	9.168	12.006	4.017	0.184	0.157
2007	0.000	0.000	0.666	0.384	1.337	2.145	2.977	12.868	9.271	4.427	1.061	3.407
2008	0.000	0.784	0.168	0.440	4.217	11.661	0.365	4.211	1.832	1.990	3.777	8.927
2009	14.223	12.074	8.100	0.355	0.747	0.326	0.084	0.189	2.381	2.653	7.613	10.384
2010	12.113	6.027	0.026	0.453	0.000	0.000	0.000	1.197	5.877	2.987	4.137	15.542
2011	13.665	10.037	0.481	0.000	0.813	0.200	0.011	0.939	1.983	1.655	5.130	8.145
2012	10.981	4.850	1.077	0.457	0.016	0.000	0.900	1.484	2.193	2.613	2.013	8.423
2013	9.968	4.033	1.452	0.000	0.016	0.000	1.004	0.603	0.027	2.703	4.493	7.065
2014	7.703	3.270	0.174	0.487	0.084	0.500	0.686	1.290	3.223	3.406	10.494	5.710
2015	0.300	0.000	1.348	1.543	4.216	2.960	10.735	0.000	0.000	10.253	10.665	13.194

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.000	4.375	2.803	1.897	2.016	5.783	12.306	18.323	7.910	0.045	0.000	0.000
1991	1.345	3.539	2.910	0.153	1.800	9.887	8.926	15.487	3.973	0.148	0.467	0.197
1992	2.390	1.090	2.300	1.423	2.929	3.927	11.797	11.687	8.323	3.155	1.110	1.697
1993	0.000	2.729	0.923	7.786	4.603	8.770	19.584	19.155	9.873	1.897	0.247	0.119
1994	0.000	0.000	2.581	0.180	2.055	5.163	11.497	8.761	4.533	0.000	0.200	0.000
1995	0.000	1.161	2.029	4.560	2.555	0.983	10.239	6.352	4.833	0.000	1.323	1.158
1996	0.104	3.661	3.537	3.087	6.870	6.039	11.410	4.077	0.410	0.320	0.068	1.352
1997	0.000	2.597	1.160	1.206	2.700	10.203	6.323	2.403	2.439	0.977	0.148	0.574
1998	0.918	1.168	1.223	3.210	4.273	7.384	7.861	2.627	2.123	0.543	0.000	0.000
1999	0.000	0.871	0.333	0.845	5.857	10.603	4.590	1.443	1.945	0.000	0.210	0.000
2000	0.000	0.323	1.227	0.135	0.983	5.413	11.839	8.100	1.187	0.507	0.308	0.033
2001	0.507	3.090	9.400	11.242	5.452	2.560	0.065	0.193	0.435	1.387	0.239	1.681
2002	0.843	0.613	3.083	6.939	8.687	4.693	0.000	1.245	0.387	2.214	4.752	2.123
2003	0.000	3.293	9.026	11.332	4.060	0.000	0.067	0.355	0.671	0.745	0.732	2.487
2004	0.484	0.977	0.000	2.245	3.507	1.523	3.537	7.990	7.903	3.503	0.745	0.000
2005	0.103	0.094	0.661	4.190	2.097	2.729	2.110	12.400	12.581	4.953	0.361	0.000
2006	1.033	0.574	0.368	2.439	27.468	0.660	2.252	9.790	9.677	4.383	0.855	0.000
2007	0.000	0.000	0.000	0.000	1.380	0.935	2.807	9.481	9.306	2.540	0.581	2.767
2008	0.132	1.297	0.636	1.129	2.080	1.332	1.397	7.161	11.877	1.170	1.719	0.090
2009	0.413	0.581	0.743	0.761	2.287	2.239	4.643	12.174	4.974	3.453	0.080	0.393
2010	0.803	0.148	0.396	1.842	0.930	1.119	3.147	6.535	11.242	5.420	0.000	0.743
2011	0.000	1.097	2.393	0.194	3.250	9.484	7.503	5.490	0.000	0.153	0.023	0.087
2012	0.023	0.087	0.143	1.110	0.863	0.867	4.387	6.613	5.690	4.097	0.158	0.083
2013	0.000	0.077	0.646	1.945	3.853	4.361	2.963	7.890	8.687	2.983	0.465	0.000
2014	0.289	0.987	0.047	3.003	3.393	4.600	6.329	0.237	0.787	1.014	0.732	7.355
2015	3.273	0.000	1.757	1.700	0.603	10.316	2.463	0.103	3.877	6.523	6.219	8.877

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	1.296	0.689	3.623	1.133	0.787	4.410	5.019	7.742	3.953	0.000	0.000	0.690
2003	0.790	2.146	1.761	3.427	0.097	4.470	13.110	8.484	5.433	0.000	0.000	1.555
2004	0.503	0.428	0.926	2.960	1.490	6.390	10.994	13.242	6.877	0.106	0.133	0.065
2005	0.216	0.000	3.700	1.667	3.474	5.450	11.155	8.006	8.643	0.739	0.050	0.000
2006	0.000	0.120	0.525	3.474	5.603	3.139	9.457	14.100	11.368	5.077	0.619	0.607
2007	1.848	0.716	1.000	2.000	1.337	5.461	10.417	10.590	7.380	0.887	0.003	0.000
2008	0.023	0.155	0.000	0.937	5.323	8.913	17.345	11.168	5.857	1.342	4.400	0.042
2009	0.329	0.664	0.703	1.203	1.748	8.353	14.487	14.810	3.403	2.032	0.143	1.132
2010	1.071	1.626	1.793	5.590	7.393	12.703	11.735	4.677	0.529	1.237	1.468	0.606
2011	0.000	3.161	2.693	2.748	6.517	4.535	18.903	9.133	0.116	3.113	0.000	0.000
2012	9.150	1.653	0.367	0.000	4.353	8.665	8.487	6.360	1.606	2.427	1.600	0.000
2013	1.089	1.916	1.350	3.045	2.903	0.000	1.089	1.916	1.350	3.045	2.903	0.000
2014	0.461	0.726	0.283	5.083	5.250	9.780	10.450	2.617	0.000	0.987	0.968	0.000
2015	0.461	0.726	0.283	5.083	5.250	9.780	10.450	2.617	0.000	0.987	0.968	1.800

Appendix E: Classified land-use and land-cover map of 2021 and reference points

