IMPACT OF CLIMATE CHANGE ON THE GROUNDWATER HYDROLOGY OF LAKE ZIWAY WATERSHED, ETHIOPIA

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A THESIS SUBMITTED TO
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This is to certify that the thesis entitled " ***Impact of Climate Change on the Groundwater Hydrology of Lake Ziway Watershed, Ethiopia***" is submitted in partial fulfillment of the requirements for the Degree of Master of Science with a specialization in Water Resources Engineering and Management, the Graduate Program of Department of Water Resource and Irrigation Engineering, and it has been carried out by Mieraf Abebe Donka (ID No. PGWREMW/ 0015/11) under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Mieraf Abebe Donka have read and evaluated his/her thesis entitled " ***Impact of Climate Change on the Groundwater Hydrology of Lake Ziway Watershed, Ethiopia***", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters in "Water Resource Engineering and Management"

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DECLARATION

I, Mieraf Abebe, declare that this research report entitled " ***Impact of Climate Change on the Groundwater Hydrology of Lake Ziway Watershed, Ethiopia*** " is my original work and all sources of materials were used for this thesis have been appropriately acknowledged. I declare that this thesis is not submitted to any other University for an award of any academic Degree, Diploma, and Certificate.

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Date: May, 2022

DEDICATION

This research paper is dedicated to my mother Alemitu Bekele whom I lost last year during the start of this thesis.

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ABBREVIATIONS AND ACRONYMS

AWBM	Australian Water Balance Model
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRV	The central Rift valley
EBM	Energy balance model
EMIC	Earth models of intermediate complexity
FAO	Food and Agriculture Organization of the United Nations
GCMs	General Circulation Models
HBV	Hydrologiska Byråns Vattenbalansavdelning
HRU	Hydrologic Response Unit
IPCC	Inter-Governmental panel on climate change
LULC	Land Use Land Covers Change
MoWIE	Ministry of Water Irrigation and Energy
MoWR	Ministry of Water resource
NMAE	National Meteorology Agency of Ethiopia
RCA4	Rossby Centre regional Atmospheric model change number four
RCMs	Regional Climate Models
RCP	Representative Concentration Pathway
SLURP	Semi distributed Land Use-based Runoff Processes
SUFI	Sequential Uncertainty Fitting
SRES	Special Report on Emissions Scenarios
SWAT	Soil and Water Assessment Tool
SWAT -CUP	Soil and Water Assessment Tool – Calibration and Uncertainty Program

UNEP	United Nations Environment Programme
WMO	World Metrology Organization
WCRP	World Climate Research Program

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Climate change poses uncertainties to the supply and management of water resources. The relationship between the changing climate variables and groundwater is more complicated and poorly understood. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process.

The impact may be worse for developing countries like Ethiopia because of their economies are strongly dependent on basic forms of natural resources.

This thesis presents the likely impact of climate change on groundwater hydrology of Lake ziway watershed located in the Rift Valley basin of Ethiopia, The RCP scenarios of types 4.5, and 8.5 were used for the climate projection from the CORDEX Africa domain from CMIP5. The RCM of RCA4 was used to generate future possible local meteorological variables in the study area. These data were used as input to the Soil and Water Assessment Tool (SWAT) model to simulate the corresponding future streamflow Variability in the Ziway watershed. SWAT-CUP, a program for calibration and uncertainty was utilized for uncertainty analysis. The two projected time periods for this study were the 2040s, and 2070s.

In the Lake Ziway watershed, there exists a climate change in the study period of 1989-2019. Since, there is a significant change from the base period to the projected time periods, therefore there would exist a climate change impact for the projected time periods under both scenarios in the Lake Ziway watershed. Therefore, climate change shows a significant decreasing impact on the groundwater flow of Lake Ziway watershed, which in turn affects the level of Lake Ziway significantly.

Keywords: Climate change; Ziway watershed; Groundwater; CORDEX; RCA4; RCM; RCP; SWAT; SWAT-CUP;

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Climate change has been a burning issue among global scientific community since last two decades because of its potential serious impacts on human, society and environment. The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report has shown an increase of 0.85° C in the global mean temperature since 1880 until 2012 (IPCC 2013a),

These changes in global temperature have been accompanied by changes in climate in different ways (Feng et al. 2014). Many regions have experienced changes in precipitation leading to frequent occurrence of floods (Min et al. 2008, 2011) and droughts (Dai 2011, 2012). These changes in climate system will have a strong impact on local and regional hydrological regimes in many regions of the world (Dibike and Coulibaly 2005, Hu et al. 2013).

The impact may be worse for developing countries like Ethiopia because of their economies are strongly dependent on basic forms of natural resources mainly on agriculture and their economic structure is less flexible to adjust to such drastic changes (NMSA, 2001).

Watersheds serve as semi-closed systems for water whose single source is precipitation so that they provide a convenient logical unit for hydrologic analyses (Hwang et al., 2015). The physical processes of precipitation, evapotranspiration (ET), overland flow, infiltration, recharge or hydrology, and groundwater flow and their interactions in the atmosphere, land surface and sub-surfaces are involved in water movement dynamics and distribution from one system to the other within the hydrologic cycle (Delfs et al., 2013; Niu et al., 2014). Thus, watersheds are balanced by all of the sinks in the system − stream flow at the watershed outlet, ET, and anthropogenic water consumption for urban and agricultural purposes (Frey et al., 2013; Condon and Maxwell, 2014; De Schepper et al., 2015).

Lake Ziway and its watershed play a significant role in supporting the livelihoods of approximately 2 million people (CSA, 2013).The watershed also inhabits 1.9 million livestock (Tsegaye et al., 2012). The lake is a source of drinking and domestic water for nearby towns, water for open and closed farm irrigation, and fish supply to huge market centers in the country. A large number of anglers, both in cooperatives and individually, depend on this lake for their livelihoods, including women and children involved in processing and selling the fish. According to Vuik (2008), Lake Ziway and its watershed support unique ecological and hydrological characteristics in addition to its economic and livelihood values.

However, Lake Ziway is currently under heavy pressures associated with the increasing population (Jansen et al., 2007), climate change (Zeray et al., 2006) as well as the intensification of agricultural development activities in the watershed. Thus, water abstraction from the lake Feeder Rivers for irrigation farming (Ayenew, 2004; Scholten, 2007) and land cover change in the upstream areas of the watershed (Hengsdijk and Jansen, 2006) have been affecting the lake hydrology. In recent years, the rivers flowing into Lake Ziway are being diverted into farmlands for irrigation. Such multiple problems have the potential for damaging the hydrological and ecological integrity of Lake Ziway.

Climate change particular the shifts in precipitation and temperature can also exert a profound impact on hydrological conditions and spatial-temporal patterns of water resources (Sorribas *et al*., 2016; Sunde *et al*., 2017).

Developing countries like Ethiopia where agriculture serves as the backbone of the economy and ensure the wellbeing of the people, the adverse effects of land use and land cover changes are diverse. On the other hand, many of the world's countries already struggle under existing water stress from pressures such as irrigation demands, industrial pollution, and water-borne sewerage. These pressures will be significantly exacerbated by climate change, which for many regions will result in reduced Percipitation and increasing temperatures further reducing the availability of water for drinking, household use, agriculture and industry (Melese, 2016).

The study conducted by Melese (2016) concluded that the climatic impact on the water regime might also make worse other environmental and social effects of water management. For instance, reduced river runoff can concentrate the effects of pollutants or exacerbate the spread of water-borne disease. Climate fluctuations can also affect the use of agricultural land associated with irrigation systems.

Ziway-Shalla sub-basin is one of the major sub basins in Rift valley lakes Basin and it is geographically located between 7º–8º30’N latitude; 38º07’–39º30’E longitude. The sub-basin is shared administratively between two Regional States, Oromia National Regional State and Southern Nations, Nationalities and Peoples Regional State. Ziway-Shalla sub-basin consists of major lakes and their tributary rivers. It covers an area of 14,477 km^2.

The climate in Ziway-Shalla sub basin varies markedly with altitude. Pronounced gradients of Precipitation and temperature exist between the high plateaus, in the eastern and western portions of the CRV (Central Rift Valley) and the valley in the central portion of the CRV. The area is characterized by warm, wet summers (with most of the precipitation occurring from July to September) and dry, cold and windy winters.

Upon this backdrop, a study was necessary to assess the current status of Lake Ziway and its watershed from hydrological point of view using a mix of methods and tools. Accordingly, this study has been conducted using SWAT (Soil and Water Assessment Tool) model with the aim to quantify and compare feeder rivers hydrology, and the groundwater hydrology of Lake Ziway watershed. In this respect, this article is timely to understand the current state of Lake Ziway watershed and the groundwater hydrology.

1.2. Statement of the Problem

Due to increase in population and drastic climate change, the capacity of the readily available water to satisfy the demand is in jeopardy. In Lake Ziway catchment, the impact is more pronounced in the downstream areas where there is poor groundwater abstraction for different purposes like flower farms and other industries.

The Katar watershed, which is the major contributor of runoff for Lake Ziway is a very important area in connection with its water resources.

The Ethiopian Rift Valley Lakes basin especially Ziway-Shalla sub-basin is facing a growing number of challenges related to the water resources. The agricultural area has increased considerably, Water abstraction is often being done without the basic understanding of the complex hydrological and hydrogeological system. As a result, Lake levels are falling due to diminished water quantity

The water resources of the Ziway-Shalla Sub basin are already overused and the situation is unsustainable. Any further abstractions from Lake Ziway or its feeding rivers will likely be disastrous. Therefore, there is the need for the basin to formulate strategies to manage water resources in the basin. This can be done after quantification of the basin climate change (rain fall and temperature). Therefore, this study quantifies basin temperature and Precipitation volume using SWAT model and Mann-Kendall Statistical test to assess the effect of climate change on groundwater hydrology of the Lake Ziway watershed.

1.3. Objective

1.3.1. General Objective

The main objective of this study is to analyze the impact of climate change on groundwater hydrology of Lake Ziway watershed Using SWAT Model and Mann-Kendall Statistical test for the past 30 years (1989-2019)

1.3.2 Specific Objective

- To establish trends of temperature and precipitation in Lake Ziway watershed for the past 30 years,
- To analyze the trends of temperature and precipitation for the future period,
- To analyze the impact of climatic change on the baseflow of Lake Ziway watershed.

1.4. Research Question

- How the temperature and precipitation changed over the past 30 years?
- How future temperature and precipitation changes with respect to the base period?
- How the groundwater hydrology changed with change in temperature and precipitation?

1.5. Significance of the Study

This study provides awareness into groundwater responses to climate changes in Lake Ziway watershed in the past. So with this research completed we will have a clear knowledge about the effect of climate change on the Lake Ziway watershed. And in turn which is very important for the government bodies to control and impose laws on the use of the water resource especially the groundwater. Moreover, it may help in the development of adaptive measures in response to climate change; it may reduce unnecessary losses from the water cycle.

1.6. Scope of the study

The scope of this study is focused on the catchment characters and climate parameters analysis. The catchment characteristics studies are Climate change and groundwater hydrological value. Whereas the climate changes parameters used are temperature and precipitation, and the change trends over the study region. The climate change and its effect on groundwater hydrology will be examined spatially and in time scale. The study will be in regard of the climate response of temperature and precipitation trends over the study region and study period. The study period has been chosen from 1989 to 2019. maximum, minimum and average temperature will be studied.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Definitions and Concepts

Climate change is a long-term continuous change (increase or decrease) to average weather conditions (e.g., average temperature) or the range of weather (e.g., more frequent and severe extreme storms). Climate change is slow and gradual, and unlike year-to-year variability, is very difficult to perceive without scientific records. Climate change occurs because of changes to Earth's environment, like changes in its orbit around the sun or human modification of the atmosphere (US global change, 2009).

It should be noted that climate evolution in recent decades is a combination of human-induced climate change (e.g., increased greenhouse gas emissions) and naturally induced climate change caused by internal forcing. Hydrologists tend to use the terminology ‘climate change' to reflect both human-induced climate change and naturally induced climate change, and then quantify the effects on hydrological processes.

2.1.1. Definitions

Climate is the long-term average of weather, typically averaged over a period of 30 years. Some of the meteorological variables that are commonly measured are temperature, humidity, atmospheric pressure, wind, and precipitation. In a broader sense, climate is the state of the components of the climate system, which includes the ocean and ice on Earth. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents.

Climate change is the long-term alteration of temperature and typical weather patterns in a place. Climate change could refer to a particular location or the planet as a whole. Climate change may cause weather patterns to be less predictable. These unexpected weather patterns can make it difficult to maintain and grow crops in regions that rely on farming because expected temperature and Precipitation levels can no longer be relied on.

Climate change has also been connected with other damaging weather events such as more frequent and more intense hurricanes, floods, downpours, and winter storms.

Groundwater is the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from the surface; it may discharge from the surface naturally at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. The study of the distribution and movement of groundwater is hydrogeology, also called groundwater hydrology.

Watershed is described as an area of land that contains a common set of streams and rivers that all drain into a single larger body of water, such as a larger river, a lake or an ocean.

Climate and Hydrology: The Precipitation pattern is largely influenced by the annual oscillation of the Inter-Tropical Convergence Zone. The ‘Kiremt’ which is the rainy season (June, July, August and September) represents 50-70% of the average yearly total Precipitation.

The main rainy season accounts for 60% of the total annual Precipitation. Minor rain events, originating from moist south-easterly winds, occur between March and May. Due to their nature, these Precipitation events are more pronounced in the highlands.

Precipitation in Ethiopia is erratic and subject to large special variability, which is largely determined by altitude. Areas above 2500m may receive 1400-1800mm/year, mid altitude regions (600-2500) may receive 1000-1400mm/year, and costal low lands generally receive less than 200mm/year. (Halcrow & Parteners Ltd)

Lake Ziway catchment is located in mid-altitude regions; mean annual Precipitation varies from 700mm-800mm in the valley (weather stations at Ziway town, Admi tulu, Ogelcho) to 1150mm on the plateau (weather stations at Asella and Butajira)

2.2. Climate Scenarios

2.2.1. Definition of Climate scenarios

Nebojša Nakićenović et al., (2000) defined scenarios as images of the future, or alternative futures that are neither prediction nor forecasts but an alternative image of how the future might unfold. As Linda O. Mearns et al., (2001) put it: "climate scenario refers to a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change". A climate scenario is different from climate projection in that climate projection refers to a description of the response of the climate system to a scenario of greenhouse gas and aerosol emissions, as simulated by a climate model. The climate scenario is different from the climate change scenario. The latter is an interim step towards building climate scenario when combined with the description of the current climate as represented by climate observation. The Purpose of the climate scenario is to assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The goal of working with scenarios is not to predict the future, but to better understand uncertainties to reach decisions that are robust under a wide range of possible futures(Richard Moss et al., 2010).

2.2.2. Types of climate scenarios from 1990-present

When the IPCC published its first report in 1990, there were four scenarios used concerning the emission of GHG and concentration of Co_2 in the atmosphere. These are 2030 high emission, 2060 low emission, control policy, and Accelerated policy scenarios(D. Tirpak & P. Vellinga, 1990). In 1992 the IPCC again modified all the first scenarios and formulated six scenarios (IS92a-f). This is due to the foundation of new data that were not available when publishing the first Report. These data include revision of population size forecasting by the World Bank and the United Nations, Publication of IPCC Energy and industry sub-group scenario of greenhouse gas emission to 2025, and Political events and economic changes across the globe(J.T.Houghton et al., 1992). In 1995 emission scenarios that were amended in the year 1992 were evaluated. This is because of the change in understanding of driving forces of emission such as the carbon intensity of energy supply and the income gap between developed and developing countries, and sulfur emissions. And hence in the following year, a new set of scenarios were presented by the IPCC. These scenarios are generally named SRES scenarios, which have a scenario group clustered with a scenario family which was established by different storylines. In 2001 the IPCC finally published the stabilized SRES scenarios making a lot of modifications in the years in between. These modifications include the use of different factors such as socio-economic change, land use and land cover, environmental change, climate change, and sea-level rise change. After nearly a decade, due to the need to include newly emerged economic data, technologies, and observation of environmental factors new scenario development was required. Not only this but also the information need for the end-users including the policymakers for a higher resolution of spatial and temporal improved representation of extreme events and scientific advances in the scientific community played a great role in bringing a new generation of scenarios called the Representative Concentration Pathways (RCPs).

2.2.3. Representative Concentration Pathways (RCPs)

The need for a new "Representative Concentration Pathways" is evident for the reasons mentioned above. These pathways are selected from works of literature based on different criteria. These are Range, Number, separation and shape, Robustness, Comprehensiveness, and near-term resolution. Four RCPs were defined in terms of radiative forcing level and pathway shape from the works of literature to meet the required criteria(Richard Moss et al., 2008).

2.2.3.1 Uses and limitations of RCPs

The intended Uses of RCP as described by Richard Moss et al. (2008) are they can be used as an input for climate models and facilitate pattern scaling of climate model outcomes. In addition to these, they are useful in exploring the range of socioeconomic conditions consistent with a given concentration pathway and the climate implications of spatial forcing patterns. Whereas the limitation of RCPs is they should not be considered forecasts or absolute bounds and policy-prescriptive. The socio-economic scenarios underlying each RCP should not be considered unique and cannot be treated as a set with an overarching internal logic. There are uncertainties in the translation of emissions profiles to concentrations and radiative forcing.

2.2.3.2. RCP 8.5

Riahi et al. (2011) signified RCP 8.5 as a scenario with high greenhouse gas emissions. This means that it assumes The RCP8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions in absence of climate change policies. Since there is no policy intervention the adaptation required will be attained at a high cost. Energy generation will be with the help of coal-fired power and the transportation system is using fossil fuels with a rise in temperature of 3.7^0C and a large increase in extreme weather by the end of the 21st century relative to 1986-2005.

2.2.3.3. RCP 6.0

According to (Masui et al., 2011) RCP 6.0 is a climate intervention and stabilization scenario of long-term, global emissions of greenhouse gases (GHGs), short-lived species, and land-use/land-cover change which stabilizes radiative forcing at 6.0 Wm-2 in the year 2100 without exceeding that value in prior years. Assumes Using Both Renewable and Coal-Fired energy generation System with a moderate increase in temperature by 2.2^0C and a moderate increase in extreme weather by the end of 21st century relative to 1986-2005. Since there is a policy intervention the adaptation required will be attained medium level cost when compared to RCP 4.5,8.5 and 2.6.

2.2.3.4. RCP 4.5

Representative Concentration Pathway (RCP) 4.5 is a stabilization scenario of long-term, global emissions of greenhouse gases, short-lived species, and land-use-landcover which stabilizes radiative forcing at 4.5 Watts per meter squared (W/ m^2, approximately 650 ppm CO2-equivalent) in the year 2100 without ever exceeding that value(Thomson et al., 2011). This differs from RCP 6.0 in that the energy generation is purely renewable and avoids coal-fired Power and is assumed to have a rise in temperature of 1.8^0C.

2.2.3.5. RCP 2.6

The RCP 2.6 emission and concentration pathway is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C. These scenarios form the low end of the scenario literature in terms of emissions and radiative forcing(van Vuuren et al., 2011). Assumes about 70% of the emission is curbed and the cost Assumes Coal-Fired energy generation System with a low increase in temperature by 1.0^0C and a small increase in extreme weather by the end of 21st century relative to 1986-2005(Pachauri & Mayer, 2015). Since there is high-level a policy intervention the adaptation required will be attained low-level cost when compared to RCP 4.5,8.5 and 2.6.

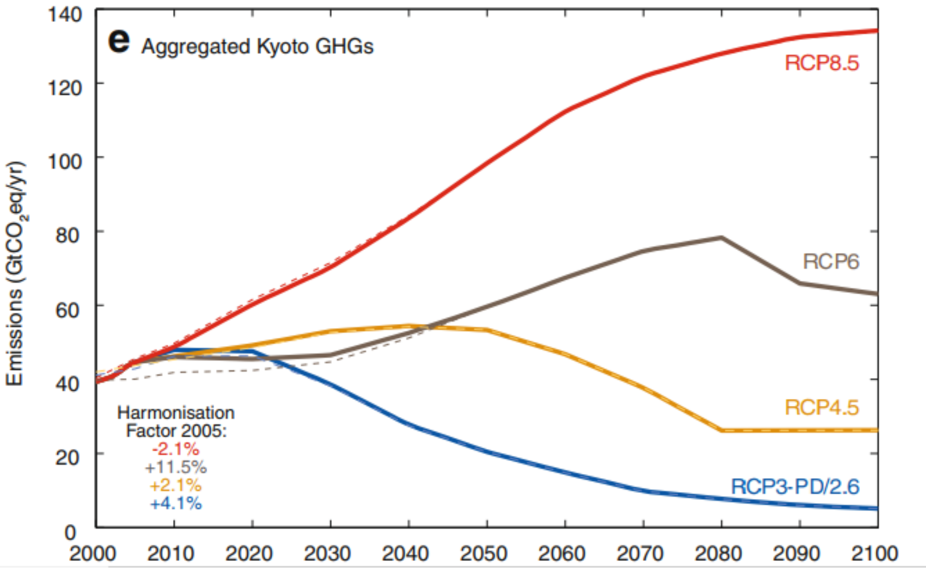

Figure 2.1 Harmonized emission under the four RCP scenarios (Meinshausen et al., 2011)

2.3. Climate Models

2.3.1. Definition of climate models.

Stocker (2011) states that the climate system consists of five different parts. These are the Atmosphere, Hydrosphere, Cryosphere, land surface, and Biosphere. Climate models are nothing but the mathematical representations of the components of the climate system in Particular or ensemble form. Climate models are the primary tools available for investigating the response of the climate system to various forcing, for making climate predictions on seasonal to decadal time scales, and for making projections of future climate over the coming century and beyond(Flato, G. et al., 2013).

Through time with the advancement of computer technology the climate models are improved and integrated to get a better understanding of the climate system.

2.3.2. Types of climate model

Based on complexity climate models are grouped into four. These are the Energy balance model (EBM), Earth models of intermediate complexity (EMIC), and Global Circulation Models (GCM). Energy balance models do not include any explicit spatial dimension, providing only globally averaged values for the computed variables. Thus, they are called Zero dimensional models. Differing from EBMs EMIC always includes the representation of earth Geography, which means they give more detailed information than the EBMs and make them two-dimensional. Whereas GCMs give the most precise and complex description of the climate system. When compared to the other two GCMs need a more power full computer system because of the additional complex variables that it includes(Hugues Goosse, 2015).

2.3.3. Global Circulation Models (GCMs)

GCMs are the finest in the block of models. They provide reasonably global, hemispherical, or continental climate information and can be used to know the present climate and project the future climate based on different scenarios(Sylwia Trzaska & Emilie Schnarr, 2008). The spatial resolution of GCM is between 100-500 km grid by a height of 1km(Auffhammer et al., 2011; Kendon et al., 2010).

Although GCMs are the most important in representing the climate system globally they don’t do well for small spatial scales. Not only this but they are also Inadequate in representing Interactions Among Variables and they need a huge amount of Computer Power(Saini et al., 2015; the United

States General Accounting Office, 1995). To avoid such problems new methods were set on a path-what is now called Downscaling.

2.3.4 Downscaling of GCMs

Downscaling GCMs follows two methods namely dynamical and statistical downscaling. The first way of downscaling is now referred to as the regional climate model (RCMs). These models involve regionalizing GCM outputs into specific areas on the earth's surface by combining the primitive equations associated with continuity, momentum and thermodynamic, processes with surface characteristics of the region of interest. It takes a large amount of computing time to attain fine resolution. Whereas the latter one involves a relationship between larger scale and local scale variables and unlike dynamical downscaling this one needs short computing time computer power. In addition to that, it can be used in a spatial level of stations (Le Roux et al., 2018; Lee & Singh, 2018).

2.3.5. Coordinated Regional Climate Downscaling Experiment (CORDEX)

As cited in Evans (2011) Giorgi, Jones, and Asrar (2009) defines CORDEX as a World Climate Research Program (WCRP) backed framework to produce ensembles of regional climate projections for all continents globally. CORDEX will bring together regional-scale climate projections produced using both statistical and dynamical techniques. It also provides an opportunity for generating high-resolution regional climate projections, which can be used for the assessment of the future impacts of climate change at regional scales. CORDEX essentially has the twofold purpose to provide a framework to evaluate and benchmark model performance (model evaluation framework), and design a set of experiments to produce climate projections for use in impact and adaptation studies (climate projection framework). The spatial resolution provided from these projects of the first phase is 50km, but nowadays this resolution increased much higher getting up to 10km or less(Lee & Singh, 2018).

2.4. Impacts of Climate Change on Hydrology

Climate change is perceived to have been driven by global warming, in turn, is resulting in the changes in the temporal and spatial distribution of precipitation patterns (IPCC, 2014). Global climate change is one major factor that directly affects hydrological processes (Zhang et al., 2016) and global warming is identified as an important issue regarding climate change during the coming century (Chien et al., 2013).

Potential impacts of changes in climate (e.g. precipitation and temperature) may cause variations in hydrological processes including evapotranspiration, surface runoff, timing and magnitude of streamflow, and flood events (Neupane and Kumar, 2015). Temperature variation and wind speed affect evaporation and transpiration sub-processes, which influence surface and sub-surface water budgets (Hu et al., 2015).

2.4.1. General Implications of Changing Climate on Hydrology

Changes in the earth's climate can have multiple significant implications for hydrologic regimes. Increased concentrations of greenhouse gas will cause much of the solar radiation to be trapped inside the earth, hence elevating its temperature (Trenberth, 1998). Rising global temperatures will lead to changes in the characteristics of the hydrologic cycle influencing the spatiotemporal characteristics of precipitation and Precipitation, runoff, and potential evapotranspiration (IPCC, 2007). For example, the intensification of the hydrologic cycle that has been observed can lead to a decrease in precipitation in sub-tropical areas, which then increases the probability of drought (Dai et al., 1998; Huntington, 2006).

On the other hand, increased annual precipitation in the tropics and at high latitudes will lead to an increasing probability of floods (Huntington, 2006). The melting of glaciers and rising sea levels because of climate change can threaten freshwater supplies (Jackson et al., 2001). These overall changes are likely to have a strong influence on the environment, including water resources availability and accessibility, and therefore pose challenges in water resources planning and management.

2.4.2. Impact of Climate Change on the Groundwater

Although the most noticeable impacts of climate change could be fluctuations in surface water levels and quality, the greatest concern of water managers and government is the potential decrease and quality of groundwater supplies, as it is the main available potable water supply source for human consumption and irrigation of agriculture produce worldwide. Because groundwater aquifers are recharged mainly by precipitation or through interaction with surface water bodies, the direct influence of climate change on precipitation and surface water ultimately affects groundwater systems.

It is important to consider the potential impacts of climate change on groundwater systems. As part of the hydrologic cycle, it can be anticipated that groundwater systems will be affected by changes in recharge (which encompasses changes in precipitation and evapotranspiration), potentially by changes in the nature of the interactions between the groundwater and surface water systems, and changes in use related to irrigation. The Central Ethiopian Rift-Valley, where Lake Ziway catchment is located, has been a center of study in many disciplines. For instance, geology, volcano-tectonics, hydrogeology, hydrology and water resource potential assessment which directly or indirectly related to the current study.

The following recent studies were done in the study area which are related with the effect of climate change on the hydrology. A study conducted by Mulugeta et al, (2015), study the water level fluctuations of eight Ethiopian Rift Valley lakes were analyzed for their hydrological stability in terms of water level dynamics and their controlling factors. Long-term water balances and morphological nature of the lakes were used as bases for the analyses. Pettit's homogeneity test and Mann–Kendall trend analysis were applied to test temporal variations of the lake levels. This study aims to investigate the hydrological nature of Main Ethiopian Rift Valley lakes by assessing their long-term water balances; their morphological characteristics; and analyzing their time series data of water level records. Assuming the fundamental similarity of all lakes, the study adopted four different approaches to estimate the natural responses of the lakes. The study is also having a wider sense which is looking after the rift valley lakes hydrological nature by which it assumes for their similarities. Where as we know hydrological response for catchments vary by single parameters from place to place for example temperature. The result of study conducted by Mulugeta et al,(2015), showed that most the Ethiopian Rift Valley lakes experienced unstable water level fluctuations due to climate variability. Although the lakes are in the same climate zone, they do not show similar hydrological behavior in all cases. This is on one hand caused by neo-tectonic activities (e.g., Lake Beseka) or by excessive water abstraction (Lake Abiyata), which may mask other processes. The analyses and syntheses of this study showed that long-term monotonic changes provide limited information in explaining the dynamics of lake levels.

Research thesis conducted by Selam Legesse, (2016), studies the groundwater and surface water interaction in the area have been analyzed using groundwater table contour method. The analysis result shows that Meki River in volcano-lacustrine deposit of rift floor and Katar River in Upper and Central Wonji Fault Belt are loosing reaches. In the rest of the catchment areas, the rivers and streams are gaining reaches. This facts are important in identifying the reaches which are continuously recharged by the groundwater. These reaches are favorable for abstraction because their potential is continuously being recharged. On the other hand for the loosing reaches this information helps us to avoid over abstraction. Direct groundwater recharge of the catchment was estimated using soil moisture budgeting method. It is a common observation that, management of water resources has focused on surface water or groundwater as if they were different entities. Groundwater and surface water are interdependent that is why as development of land and water resource increases, it is apparent that development of either of these resources affects the quality and quantity of the other. Nearly all surface water features (streams, lakes, reservoirs, wetlands and estuaries) interact with groundwater. These interactions take many forms. In many situations, surface water bodies gain water and solute groundwater systems and in others the surface water body is the source of groundwater recharge and causes in groundwater quality. The result of study conducted by Selam Legesse, (2016), showed that withdrawal of water from streams can deplete groundwater or conversely, pumping of groundwater can deplete water in streams, lakes, or wetlands... thus, effective land and water management requires a clear understanding of the linkage between groundwater and surface water as it applies to any given hydrologic setting.

A study conducted by Hayal Desta et al, (2017), the result showed that most of the surface runoff and baseflow (shallow groundwater recharge) which contributes to the river discharge in Lake Ziway watershed are generated in the high-elevation areas. A decrease of surface and base flow and an increase of ET are observed in Lake Ziway sub-watersheds including the lake itself. This will lead in a long-term to the undesired effects on the lake. The increased irrigation development works in the watershed are one of the major drivers to reduce the flow of Katar and Meki Rivers. This can, in turn, affect the hydrology of Lake Ziway by making it shallower and increasing ET as has been observed in this study, along with increasing air temperature in these times of climate change. The study concludes that a more detailed study should be conducted to assess the influences of human pressures and climate changes on land and water resources in Lake Ziway watershed. Nonetheless, all concerned public institutions, private companies, and local communities in the watershed should be warned about the consequences that may follow on future generations because of the actions people take today without committing themselves to protect the watershed from further degradations. Otherwise, Lake Ziway will face severe problems in future and might become the second to go next to Lake Haramaya (Alemaya).

A study conducted by Abraham et al., (2018), predicted future runoff conditions under changing climate using multi model outputs from Coupled Model Intercomparison Project Phase 5 (CMIP5) over Lake Ziway Catchment. From the study, a reduction in Precipitation has brought larger effects on runoff reduction than evapotranspiration components. Due to future reduction of River flow on the region optimal allocations for water use purposes at all levels of water resource development projects are crucial for future water planning and management. The study basically concerned in studying the hydrological responses of the Lake Ziway catchment that is basically the surface water due the change in climate and used the model HBV for his study. The result of study by Abraham et al., (2018), revealed that the maximum and minimum temperature increased under RCP 8.5 and RCP 4.5 scenarios. However, precipitation showed a decreasing trend.

2.4.3. Summary of Literature Reviews on the study area

In the Article work *Mulugeta, et al, (2015)* aims to investigate the hydrological nature of Main Ethiopian Rift Valley lakes by assessing their long-term water balances; their morphological characteristics; and analyzing their time series data of water level records. The study mainly focused on investigating level of lakes in the rift valley in which results revealed that most the Ethiopian Rift Valley lakes experienced unstable water level fluctuations due to climate variability. Although the lakes are in the same climate zone, they do not show similar hydrological behavior in all cases. The study tries to show the level of water change in the studied lakes due to several reasons not specifically climate change even though the climate change variabilities have impact on it and additionally the groundwater flow of the watershed is not studied in the research.

In the thesis study by *Selam Legesse, (2016),* the Groundwater and surface water interaction in the area have been analyzed and as a result, withdrawal of water from streams can deplete ground water or conversely, pumping of ground water can deplete water in streams, lakes, or wetlands. The study shows that the interaction between ground water and surface water and explained in the impact by land use land cover whereas the climatic influence is not studied and future scenarios are not predicted.

In this article the study by Hayal Desta et al, (2017), results showed that a decrease of surface and base flow and an increase of ET are observed in Lake Ziway sub-watersheds including the lake itself. This will lead in a long-term to the undesired effects on the lake. The increased irrigation development works in the watershed are one of the major drivers to reduce the flow of Katar and Meki Rivers. Concludes that a more detailed study should be conducted to assess the influences of human pressures and climate changes on land and water resources in Lake Ziway watershed in which the present thesis study is one which focuses on climate change impact on the groundwater flow.

In the journal study *Abraham, et al. (2018)* future runoff conditions under changing climate using multi model outputs from Coupled Model Intercomparison Project Phase 5 (CMIP5) over Lake

Ziway Catchment basically concerned in studying the hydrological responses of the Lake Ziway catchment in which there is a significant change on the River flow due to climate change in the projected scenarios where affects the livelihood. The study is focused on the surface flow whereas the groundwater flow is not studied.

The current study focuses on the impact of climate change on the groundwater hydrology of Lake Ziway. The climate change trend is analyzed and also future climate change scenarios have been projected and estimating the effect on the groundwater using the medium to high emission scenarios (RCP4.5 and RCP8.5) and analyze the trend of climate change in precipitation and temperature which is useful information for Policymakers and the general public to manage the resource on a sustainable basis.

2.5. Hydrological Modeling

Devia, et al (2015) state that Hydrological models are models that are mainly used for predicting system behavior and understanding various hydrological processes. This hydrological process includes precipitation, runoff, evaporation. Bizuneh et al. (2021) also states that hydrological models are a mathematical depiction of physical processes of the hydrological cycle in diverse physical environments within particular watersheds

2.5.1. Types of hydrological models

On their review on hydrological models Jajarmizad et al., (2012) showed that there are different classifications of hydrological models based on different criteria that are all aimed to make the models simple to understand and operate yet these hydrological models are not so different in their concept except for their setting up and installment procedures. Based on the laws and assumptions to represent the real hydrologic system models are classified as Empirical and theoretical. Empirical models are the representation of certain data with no predictive capacity if the conditions are changed whereas theoretical models are models that are helpful in prediction under changed circumstances (Woolhiser, 1973). Based on the simulation capacity of a subbasin at different scales models can be divided into three. These are lumped, distributed and semi-distributed models. The lumped model assumes the complete subbasin as a homogeneous unit, fully distributed models are employed to calculate values for time-dependent variables at specific grid locations in a hydrological system. Semi distributed models lie in between the two having the disadvantage of lumped models(Jajarmizad et al., 2012).

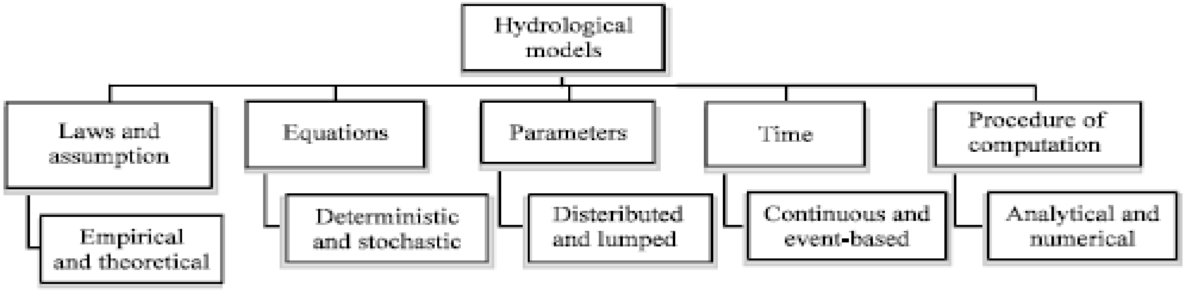

Figure 2.2. classification of Hydrological models based on criteria

2.5.2. Hydrological models used in climate change impact assessment

Concerning the hydrologic response, the models used by researchers are of various kinds. The models employed by researchers are HBV(Shaka, 2008), (Gebre, 2015 Flint & Torregrosa, 2020), SWAT (Fontaine et al., 2001; Abera, 2011; SLURP (Ahn et al., 2011); Andargachew, 2017; Zuo et al., 2015; Flint & Torregrosa, 2020). From this the frequently used model recently is SWAT.

2.5.3. Comparison of SWAT model with other models

Bizuneh et al. (2021) performed a comparative analysis of SWAT and HBV response to streamflow estimation in the upper Blue Nile Basin and found out that based on the statistics response evaluation index SWAT model responses were better than the HBV model in all watersheds. Though the SWAT model showed less appropriate performance when compared to two conceptual models i.e. TANK and AWBM, it can be used for spatial and climatic data-driven impact assessment of change due to climate and land use in the basin(R. K. Jaiswal et al., 2020). Emma Brännström (2019) stated that SWAT is more intuitive and demands less computer power, is easier to use and model for a novice user when compared to MIKE SHE.

2.6. Estimation of mean areal meteorological data

The three most frequently used methods for estimating MAR(Mean Areal Precipitation) data were the Arithmetic mean method, the Thiessen polygon method, and the Isoheytal method(Shaw & Lynn, 1972). Different researchers compared these methods and found out different results related to their topography. Balany, (2011) used the above three methods in Indonesia and found out that no method is consistently superior. Whereas Barbalho et al., (2014) found out in the semi-arid areas of Brazil that the Thiessen polygon method was superior compared to other methods. Eruola, A. O et al., (2015) employed the above three methods in a tropical and wet climate of southwestern Nigeria and found out that both Isoheytal and Thiessen Polygon methods are superior when compared to the Arithmetic mean method. Kang et al., (2019) made a comparison of both methods and find out that for a mountainous area Isoheytal method is more suitable for it considers the locations of the rainfall stations and the orographic effect and because there are no errors with altitude. The Isoheytal method is similar to that of the Thiessen method in terms of Using the area as a weighting factor, but the difference comes in when the Isoheytal method uses the area weight to the average precipitation between Isohyets and does not directly weigh the observed precipitation.

2.7. Uncertainties in climate projection

K. C. Abbaspour, (2015) states that the uncertainties in climate projection are due to four major reasons. These are model uncertainties due to (a) simplification in the conceptual model (b) processes that are occurring in the watershed but not included in the model (c) processes that are not occurring in the watershed but are included in the model and (d) processes unknown to the modeler and not included in the model either. In addition to this, he also states uncertainties due to inputs. Uncertainties in the combined use of hydrological model and climate model into traditional uncertainty and climate prediction uncertainty. The traditional uncertainty arises from hydrological models due to uncertainties in the model inputs, model structure and model parameters and the climate prediction uncertainties arise due to due to the model uncertainty, scenario uncertainty and internal variability (Gaur et al., 2021). Due to the inherent nature of uncertainties, it is possible to find uncertainties in combined use of both climate and hydrological models.

2.8. Mann-Kendall Statistical test

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. The MK test can be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test, that is, the MK test is a non-parametric (distribution-free) test. This test is the result of the development of the nonparametric trend test first proposed by Mann (1945). This test was further studied by Kendall (1975) and improved by Hirsch et al (1982, 1984) who allowed to take into account a seasonality.

The assumptions of MK test is when no trend is present, the measurements (observations or data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time. The observations obtained over time are representative of the true conditions at sampling times. The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time. Mann-Kendall Statistical test software will be used to analyze the trend for the change in temperature and precipitation for the entire study period using the data from the meteorological stations.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Lake Ziway is located about 160 kms south of the capital city Addis Ababa, in Ethiopia. Lake Ziway catchment falls in between 7°15’N to 8°30’N Latitude and 38°15’E to 39°30’E Longitude covering a total area of about 6991 km. Lake Ziway Catchment is found in the Central Ethiopian Rift valley basin. It starts from the highlands of the Eastern Gurage Zone from which the Meki River is originating, passes through the central parts of the East Shoa Zone where Lake Ziway is located, and ends up in the Western Highlands of the Arsi Zone from which the Katar River is originating. Lake Ziway has an open water area of 442 km2 and elevation of 1636 m.a.s.l. with maximum and mean depth of 8.9m and 2.5m respectively.

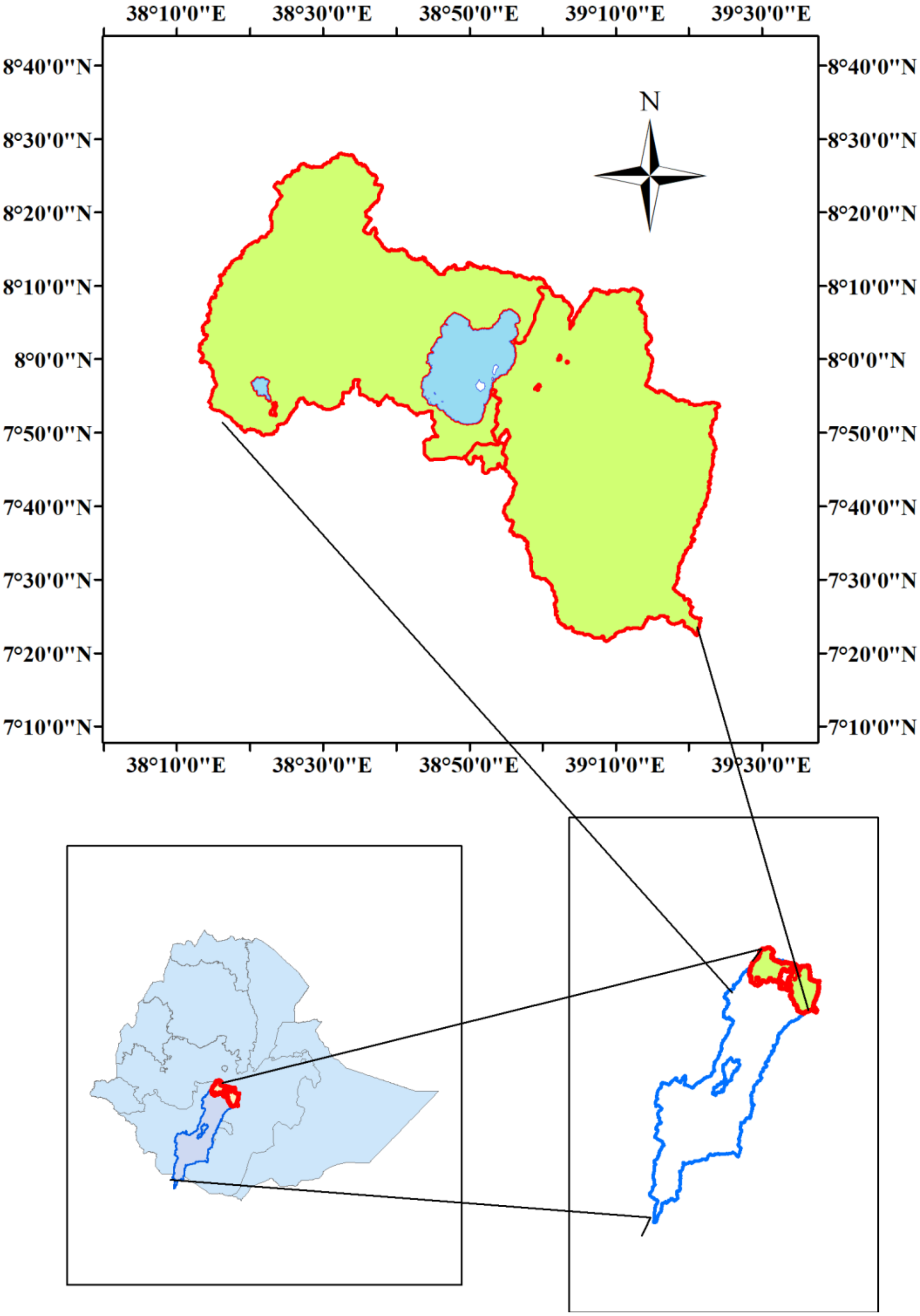

Figure 3.1. Location of Lake Ziway Watershed

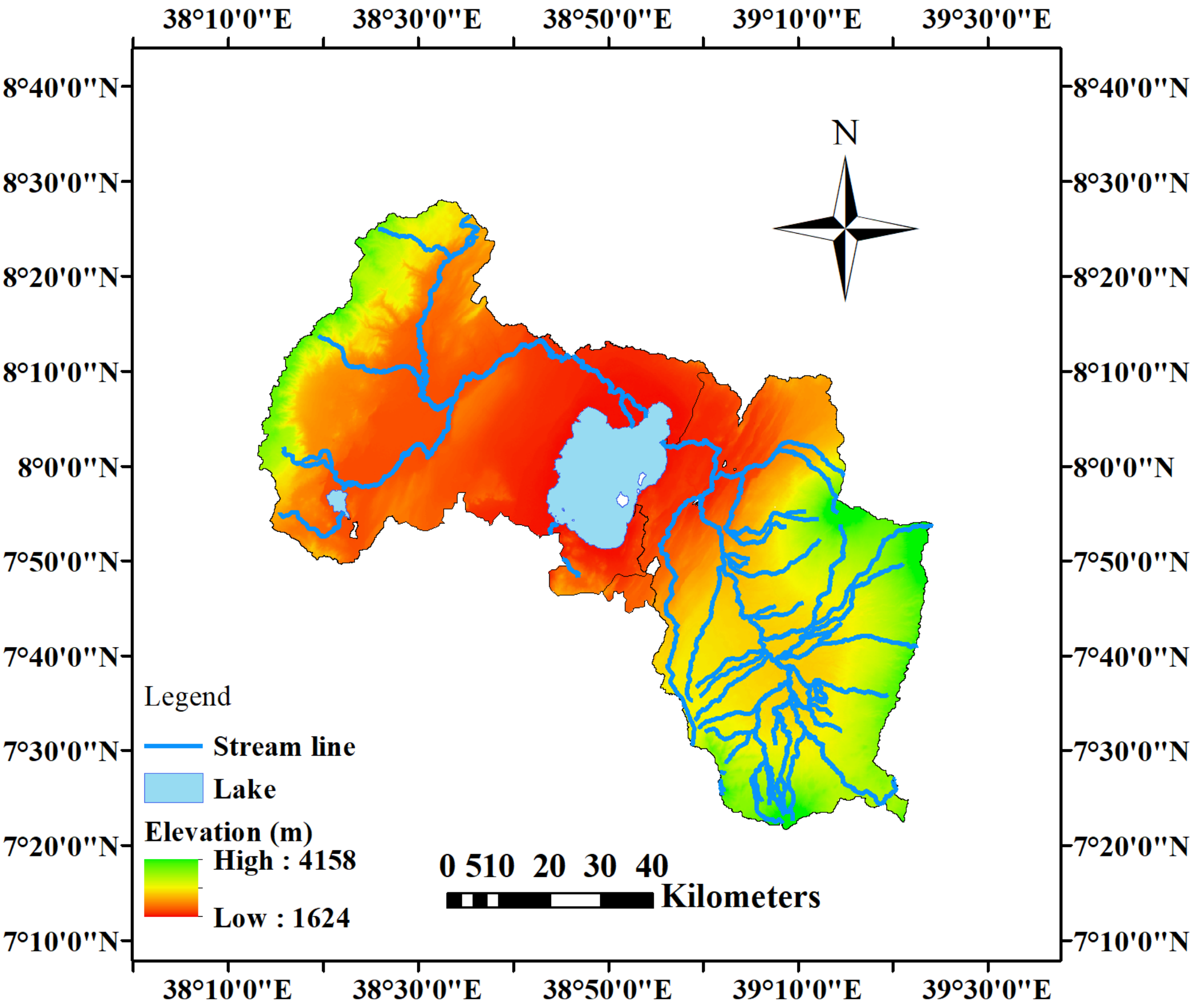

Figure 3.2 Topographical map of Lake Ziway Watershed

3.1.2. Climate

As stated in Tadesse (2016), According Makin M.J. et al (1975), climate of the study area consists of three ecological zones: humid to dry humid lands, dry sub-humid or semi-arid lands and semiarid or arid lands. Accordingly, highland areas west of Butajira and east of Asela are categorized under humid to dry sub-humid land. The areas east of Butajira around Lake Abay and a strip of land between Lake Ziway and Asela are dry sub-humid lands. The rest of the area which is around the lake is in semiarid or arid zone. The average annual precipitation of the area varies spatially from about 620mm in lowland to over 1200mm at extreme highland areas. The mean daily temperature also varies between 13.5^{o}C and 21.8 ^{o}C in different physiographic areas

3.1.3. Land use/ land cover

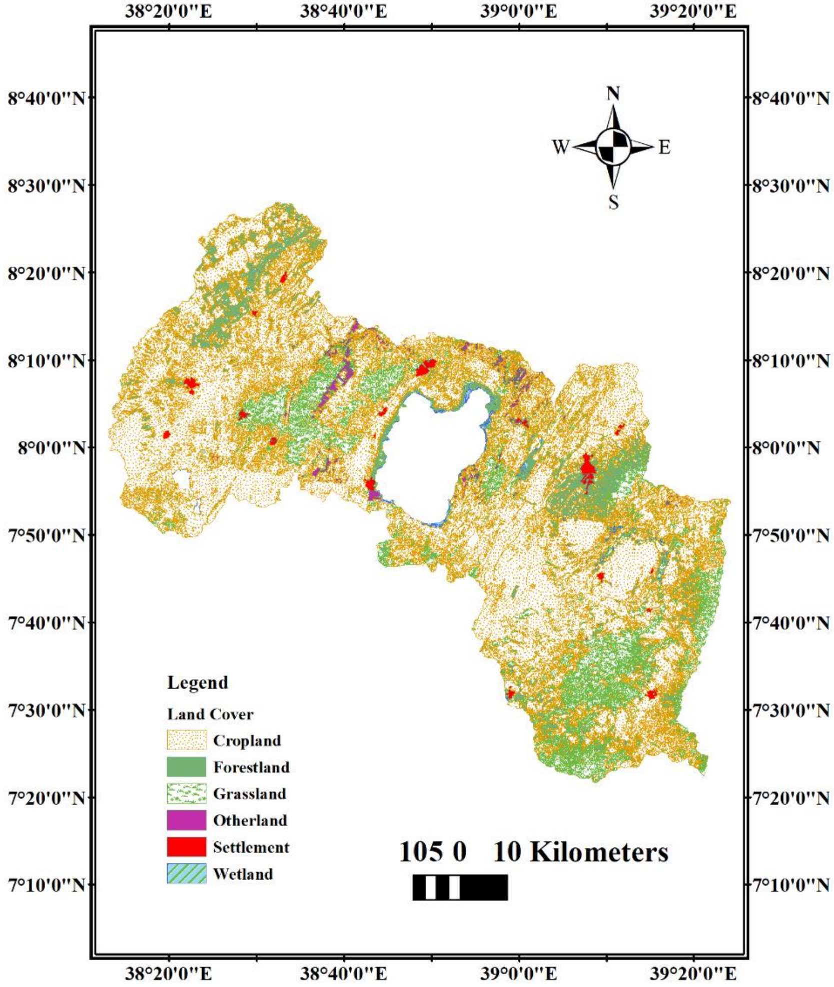

Figure 3.3 Land use/Landover map of Ziway Watershed

3.1.4. Soil

According to their texture, FAO classifies the soil types in the subbasin into three groups. These are the clay, loam, and clay-loam. Of all these three, loam soil comprises the largest portion, and Eutric Nitosol being the dominant loam soil type.

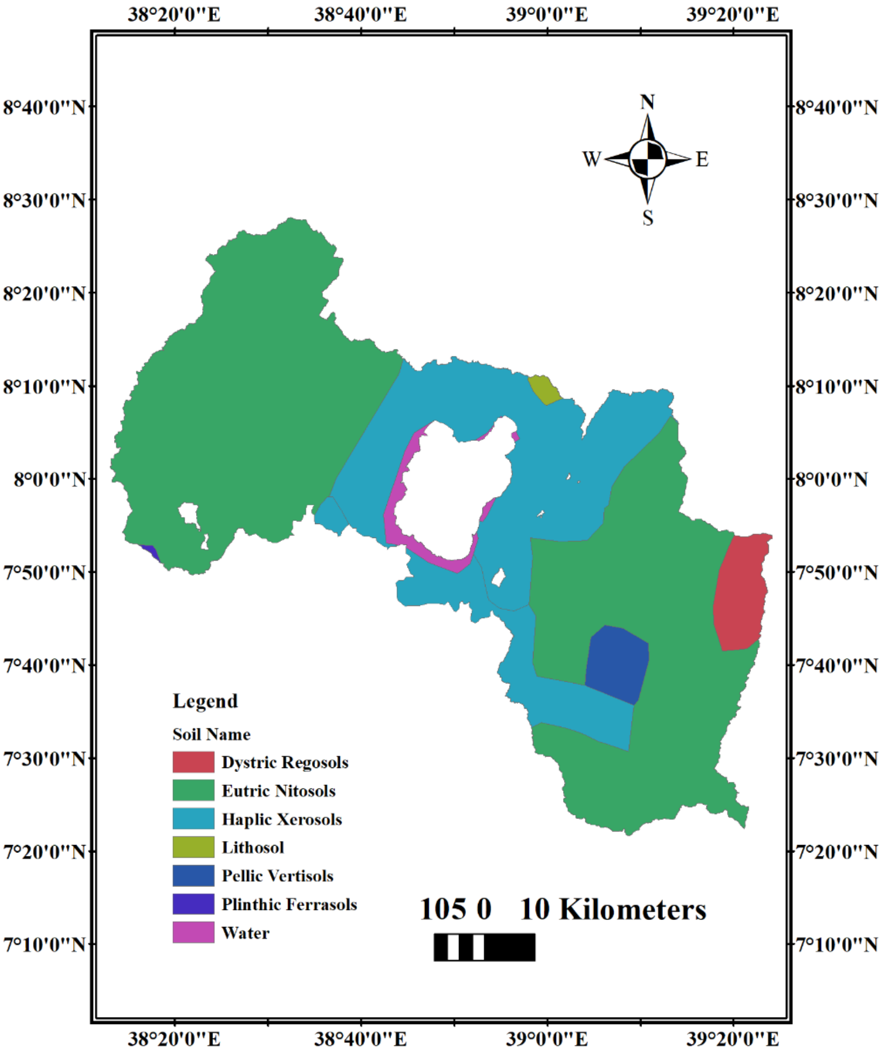

Figure 3.4 Soil map of Lake Ziway Watershed

3.1.5. Hydrology

The Lake Ziway Watershed is drained by two major rivers running from the east and west into Lake Ziway. Lake Ziway is fed by Meki River from west and Katar River from east and drained by Bulbula River.

3.2. Data types and analysis

3.2.1. Data types and sources

In order to meet the first objective which is to assess the existence of climate change in lake Ziway Watershed the meteorological data were collected from CORDEX- AFRICA, NMAE. The list is summarized in table below. In order to meet the third objective other than meteorological data hydrological, spatial and climate scenario data were used as an essential input in SWAT model.

3.2.1.1. Meteorological data

The principal metrological data needed for SWAT Model are daily precipitation(mm), daily maximum and minimum temperature(^{0}C), wind speed(m/sec), Relative humidity (%), and Sunshine duration(hr.) and were collected from the Ethiopian National Meteorology Agency as shown in Table 3-1 from six different stations that are stationed inside the watershed.

Table 3-1 Summary of selected Meteorological stations within the study area

SN	Station	Latitude	Longitude	Elevation	Available data
1	Adamitulu	7.9	38.7	1630	Precipitation, min & max Temp, wind speed, Relative humidity, sunshine hour
2	Assela	8.0	39.1	2413	Precipitation, min & max Temp
3	Butajra Police Station	8.2	38.4	2000	Precipitation, min & max Temp
4	Meki	8.2	38.8	1662	Precipitation
5	Ogolcho	8.0	39.0	1682	Precipitation, min & max Temp
6	Ziway	7.9	38.7	1640	Precipitation, min & max Temp, wind speed, Relative humidity, sunshine hour

This data was used as an input of the SWAT precipitation-runoff model to simulate the hydrological conditions of the study area of the Watershed.

3.2.1.2. Hydrological data

Daily or monthly streamflow data is required for SWAT simulated results for calibration and validation. This data was obtained from the Ministry of Water, Irrigation and Energy, Hydrology and Water Quality Directorate, and Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo). Based on the data availability Meki and Katar station were used for the year 1994-2011 and 1995-2010. These years determined the data that must be used for SWAT model Calibration.

Table 3-2 Streamflow gauging stations of Lake Ziway Watershed

No.	***Station***	***Parameter***	***Time step***
1	*Meki*	*Streamflow*	*1994-2011*
2	*Katar*	*Streamflow*	*1995-2010*

3.2.1.3. Spatial Data

A soil data map for the Ziway subbasin was obtained from the Ministry of Water, Irrigation and Energy for the year 2006. Digital Elevation Model (DEM) was obtained from https://search.asf.alaska.edu which is 20m by 20m resolution size. Land cover/ land use data were obtained from MoWIE.

3.2.1.4. Climate scenario data

The climate scenario data for this study was obtained from CORDEX-AFRICA, from the RCA4 (Rossby Centre regional Atmospheric model change number four), which downscaled the GCM

MIROC5 (Model for Interdisciplinary Research on Climate Version Five) These data include daily values of precipitation, the daily value of the minimum and maximum temperature for RCP 2.6, RCP 4.5, and RCP 8.5.

Table 3-3 Data types and their source

S.No	***Datatype***	***Time step***	***Source***
I	***Metrological data***		
1	*Precipitation*	*1989-2018*	*NMAE*
2	*Temperature*		
3	*Sunshine duration*		
4	*Relative Humidity*		
5	*Wind speed*		
II	***Hydrological data***		
1	*Streamflow*	*1989-2018*	*MoWIE*
III	***Spatial data***		
1	*Soil*	*2006*	*FAO*
2	*Land use/ land cover*	*2006*	*MoWIE*
3	*DEM*		https://search.asf.alaska.edu
IV	***Climate data***		
1	*Precipitation*	*2041-2100*	*CORDEX-AFRICA*
2	*Temperature*	*2041-2100*	*CORDEX-AFRICA*

3.2.2. Data Analysis

3.2.2.1. Data Preparation

K. Subramanya (2008) strongly advises that it is necessary to check any data for continuity and consistency before using the records of a station. Inconsistencies and non-homogeneities in the hydrological and meteorological time series could be identified by incorporating statistical tests that detect trends and change points. Inconsistency which reflects systematic errors during recording and the non-homogeneity that arises from either natural or manmade changes to the gauging environment are both important for adequate time series analysis(Wijesekera & Perera, 2012).

Estimation of missing hydrological data

Sattari, Rezazadeh-Joudi, and Kusiak (2017) list some methods to estimate missing precipitation data including Arithmetic mean, Multiple linear regression, and NIPALS. From these methods, Multiple linear regression was suggested to be used for subbasins with higher elevation differences. this method is also supported by other publications (Hasanpour Kashani & Dinpashoh, 2012).

Sattari, Rezazadeh-Joudi, and Kusiak (2017) defined Multiple linear regression as a statistical method for estimating the relationship between a dependent variable and two or more independent or predictor variables. Which can be given by the following equation.

$$v_0 = a_0 + \sum_{i=1}^{n} (a_i v_i)$$

Where V_0----, a_i, $a_1 \ldots a_n$ are the regression coefficients.

Testing for Consistency and Homogeneity

The consistency of time series data is analyzed based on the theory that a plot of two cumulative quantities that are measured for the same period should be a straight line and their proportionality remains unchanged which is represented by the slope. To check the consistency of data, a double mass curve was used to correct rain gauge data for the stations.

Estimation of mean areal data

Mean precipitation using the Isoheytal method can be determined by the following Equation.

$$P_m = \frac{\left(A_1P_{1m} + A_2P_{2m} + \ldots + A_nP_{nm}\right)}{A_1 + A_2 + \ldots + A_n} = \frac{\sum_{i=1}^{n} A_iP_{im}}{\sum_{i=1}^{n} A_i}$$

Where P_m is the average precipitation in the watershed, P_{im} is the average precipitation in the area between two adjacent isohyets, n is the number of area sections divided by the isohyets, and $A_1 \cdots A_n$ are the areas divided by the isohyets.

For the study area at hand as specified in the image below though the Isoheytal method is preferred for its accommodation for altitude yet the station distribution fails the method by not covering all the inter Isoheytal areas. Although the station density is not as ideal as it gates (i.e. 100-250 sq.Km per station), it is as acceptable as per the standard of WMO as stated in K. Subramanya, (2008)(i.e. 25-1000 sq. Km per station) for all stations except for Assela and Butajira meteorological station which pass slightly the bar, hence Thiessen polygon method is selected, which is determined by the following formula.

$$P_m = \left(\frac{A_1}{A}\right)P_1 + \left(\frac{A_2}{A}\right)P_2 + \left(\frac{A_3}{A}\right)P_3 + \ldots + \left(\frac{A_n}{A}\right)P_n = \sum_{n=1}^{i} \left(\frac{A_n}{A}\right)P_n$$

Where $\left(\frac{A_n}{A}\right)$ is the weighted area.

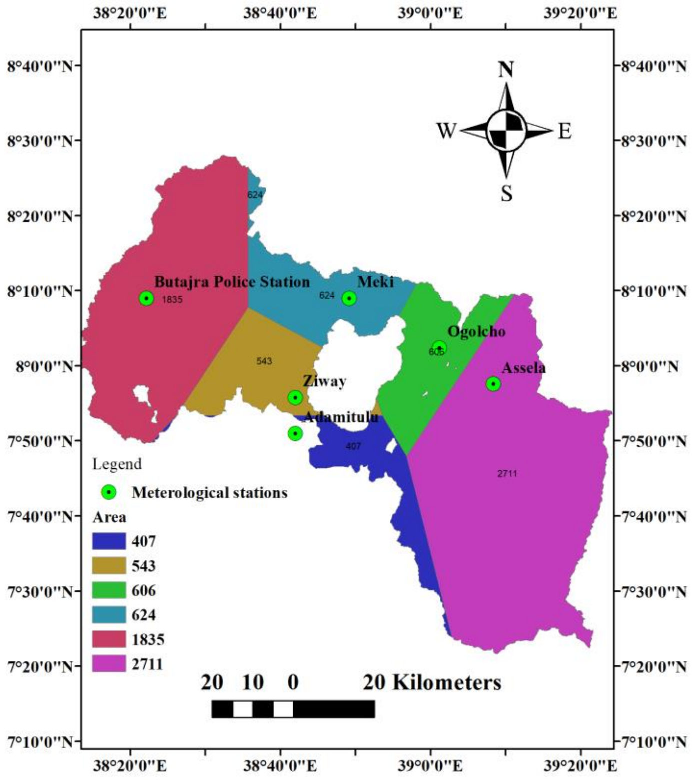

Figure 3.5 Area partition by Thiessen Polygon

3.2.2.2. Bias correction for climate data

Though Shrestha et al., (2017) state that there is no significant difference in the output of linear scaling and Quantile mapping, Luo et al., (2018) made a comparison on the methods of Bias correction such as Linear scaling, Daily translation, local intensity scaling, Daily Bias correction, Power transformation, Distribution mapping and Empirical Quantile mapping for Precipitation and Linear scaling, Daily translation, variance scaling, Distribution mapping and Empirical Quantile mapping for temperature and finding out that while linear scaling did show a poor result, Distribution mapping and Empirical Quantile mapping showed good result for precipitation. For the case of temperature, all methods showed a good result except for linear scaling. This is also supported by others (Willkofer et al., 2018). According to Soriano et al, (2019) for bias correction of the climate data, two methods are efficient. To correct the bias in temperature simple seasonal bias correction method is efficient, whereas to correct the bias in the Precipitation Quantile mapping correction method is efficient. Gupta et al., (2019) Used a developed climate data bias corrector tool that functions based on the Quantile mapping method in India. Furthermore, Ayugi et al., (2020) suggested that using Quantile mapping on outputs from RCA4 is an important intermediate step to improve climate data before performing any regional impact analysis. The two-methods function is based on the following equation respectively.

$$Ti,j,corr = Ti,j + \Delta Ti,j,$$

where *Ti,j* is the mean temperature in month *j* for the climate model i', Δ*T* is the difference between the mean temperature of the climate model *i* and the observations in month *j*, and *Ti,j,corr* is the corrected temperature in month *j* for the climate model *i*.

$$\bar{x}_{ms.corr} = \left\{ \begin{array}{l} F_{oh}^{-1}(F_{mh}(x_{ms})), x_{ms}{}^{3}\ x_{th} \\ 0, x_{ms} < x_{th} \end{array} \right\}$$

Where x is precipitation, $\bar{x}_{ms.corr}$ is bias-corrected model-simulated data; to categories between the wet and the dry threshold Value x_{th} is used (a day with Precipitation greater than 1mm is assumed to be a wet day); F is CDF, whereas F^{-1} is its inverse. (o= observed, m=model, h= historical period, s= simulation period. Here the simulated Period can either be a historical or future period (Gupta et al., 2019).

A base or reference period of 30 years (1989-2018) was selected to be historical and for simulation of future impacted flow in SWAT model and the future climate data was divided into 30 years of 2041-2070 (Mid) and 2071-2100 (Far).

3.3. Methods Used

In order to meet the first and second objective comparison of future and base period values of the variables was done using Mann-Kendall Statistical test and t-test respectively to determine the significant value, for an alpha value of 5%. For this alpha value if the P-value is greater than the test showed that there is no significant change between the two compared samples whereas if it is less than the alpha value then the test showed that there is a significant change in the two samples with 95% certainty and hence reject the null hypothesis (Ho) which states that there is no significant change between the two samples. To meet the third objective SWAT model was selected and used by fitting it with real world using SWAT-CUP SUFI-2 algorithm.

3.3.1. SWAT model setup for the study area

SWAT is a watershed scale, physically based, a semi-distributed hydrological model developed to predict the impact of land management practices on hydrologic and water Quality Response of complex watersheds with heterogeneous soils and land use conditions(P. W. Gassman et al., 2007). With all its drawbacks Arc SWAT has proven to be one of the best hydrological models in studying Impact assessment(Abu-Zreig & Hani, 2021; Bizuneh et al., 2021; Tan et al., 2019). The procedure to assess the impact of climate change will be discussed as follows.

- ✓ The first step will be to load the Digital Elevation Model in the ARCSWAT version-2012 interface.

- ✓ The stream network will be generated by the use of a threshold area that defines the origin of a stream. The smaller the number, the more detailed the stream network generated by the interface.
- ✓ The locations of the river gauging location for watershed delineation will be added manually as sub-basin outlets. This is to ensure that the model calibration will be done at the exact location. Once the entire watershed outlet is selected, the sub-basins will be delineated and their parameters will be calculated.
- ✓ Next, the land-use and soil maps will be loaded. The lookup table for each map will also be loaded for the interface to know which codes or names to assign to the different categories.
- ✓ Then slope classification will be done by assigning a multiple slope option. Once the land use, soil map, and slope will be loaded and reclassified, an overlay will be done, resulting in land use, soil, and slope distribution within the sub-basins.
- ✓ The HRUs will then be created by applying combination of land use, soil, and slope.
- ✓ Then, the climate data defined in the user weather generator for metrological stations will be loaded.
- ✓ At the final step, the SWAT input files are built and the model is set to run.

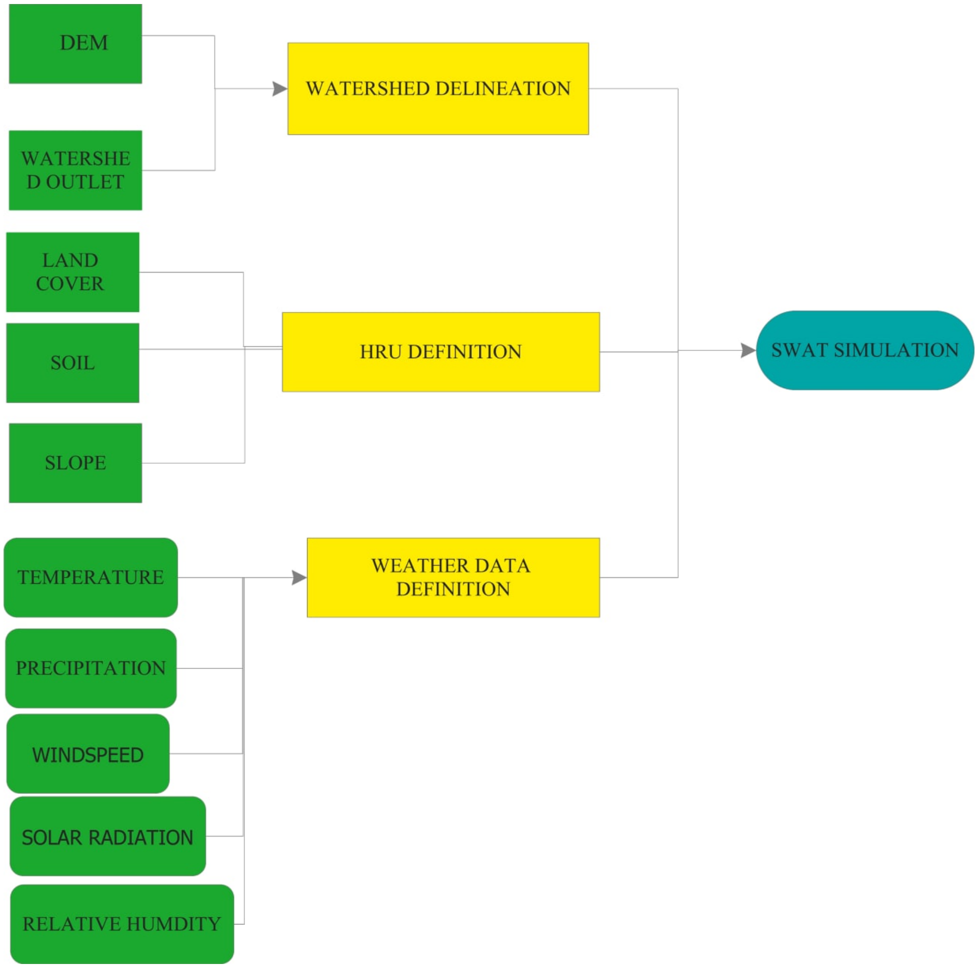

Figure 3.6 SWAT Simulation Process

3.3.2. Model Simulation, calibration, and validation

3.3.2.1 Sensitivity analysis

The ability of a hydrological model to produce satisfactory predictions are necessarily correlated to adequate sensitivity analysis and model calibration (Moreira et al., 2018; Song et al., 2015). Sensitivity Analysis is a measure of the effect of change of one parameter on another(Mohammed, 2018). Sensitivity analysis will be undertaken by using a built-in tool in SWAT-CUP. 13 Sensitive parameters were selected for the task by comparing carefully parameters from different works of literature (for instance (Mechal et al., 2015, 2017; Zeiger & Hubbart, 2017) with the default SWAT-CUP given parameters.

3.3.2.3. Calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. The term calibration refers to a procedure where the difference between model simulation and observation is minimized(K. Abbaspour et al., 2017). The ArcSWAT for ArcGIS 10 interface for SWAT 2012 is used in this study to set up the model to simulate the flow at the outlet. Calibration is achieved by SWAT calibration and uncertainty programs SWAT-CUP using Sequential Uncertainty Fitting version-2 (SUFI-2) algorithm with 4000 iterations and manual calibration

Measured flow data of the Meki and Katar Rivers is collected from 1994 to 2011 and 1995 to 2010 respectively. Data from 1994 to 2004 and 1995 to 2003 is used for calibration from the Meki and Katar stations respectively.

3.3.2.4. Validation

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals(J. G. Arnold et al., 2012). After finding the best parameter during the calibration period these best parameters ranges were then applied to validate the streamflow from 2004 to 2011 and 2005 to 2010 for Meki and Katar stations. The statistical criteria (R^2 and NSE) that will be used during the calibration procedure were also checked here to make sure that the simulated volume is still within the accuracy limits.

3.3.2.5. Model performance evaluation

The Performance evaluation parameters that will be used to check the performance of the SWAT model are the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Percent Bias (PBIAS). Below are given the formula to find the performance indicators of R^2, NSE and PBIAS.

$$R^2 = \left[\frac{\Sigma_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\Sigma_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{\Sigma_{i=1}^{i}(P_i-\bar{P})^2}}\right] \qquad NSE = 1-\left[\frac{\Sigma_{i=1}^{n}(O_i-P_i)^2}{\Sigma_{i=1}^{n}(O_i-\bar{O})^2}\right] \qquad PBIAS = \frac{\Sigma_{i=1}^{n}(O_i-P_i)}{\Sigma_{i=1}^{n}O_i} * 100$$

Where O_i and P_i are the observed and simulated flow data, $\bar{O}$ and $\bar{P}$ are mean of the observed simulated flow data respectively.

According to D. N. Moriasi et al. (2015), the performance evaluation for watershed in monthly bases are expressed below as shown in Table 3-4.

Table 3-4 Performance evaluation criteria for recommended statistical performance measures for watershed for monthly scale

Measure	***Very good***	***Good***	***Satisfactory***	***Not Satisfactory***
R^2	$R^2 \geq 0.85$	$0.85 < R^2 \leq 0.75$	$0.75 < R^2 \leq 0.6$	$R^2 \leq 0.6$
NSE	$NSE \geq 0.8$	$0.8 < NSE \leq 0.70$	$0.7 < NSE \leq 0.5$	$NSE \leq 0.5$
PBIAS	$PBIAS \leq \pm 5$	$\pm 5 \leq PBIAS < \pm 10$	$\pm 10 \leq PBIAS < \pm 15$	$PBIAS \geq \pm 15$

3.3.3. Impact of Climate Change on Groundwater

After finalizing the calibration and validation process for the observed climate data the model will run for the historical period (1994-2011 and 1995-2010) and the data derived from an ensemble of downscaled climate data based on the Coordinated Regional climate Downscaling Experiment over African domain (CORDEX-Africa) under Representative Concentration Pathways of RCP4.5 and RCP8.5 climate scenarios. The input climate data (daily precipitation, minimum and maximum temperature) under each RCP scenario were used for future simulation. The impact of climate change was analyzed taking the historical simulated flow from (1997-2006) as the baseline against which the future flow will compare for two future periods of 30 years: early mid-21st (2041-2070), and late 21st (2071-2100).

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Trends of Temperature and Precipitation in Lake Ziway Watershed

4.1.1. The existence of climate change in Lake Ziway Watershed

A Manni-Kendell test was done for the 30-year data from NMAE (1989-2018) for the variables maximum and minimum temperature and precipitation and the following results were found as shown in the table and Figures below. Since the P-values are less than the alpha value of 0.05 this implies that the null hypothesis should be rejected, which specifies that there is no significant change in Precipitation and Maximum Temperature for upward trend and Minimum Temperature for downward trend in the time periods tested and hence the change in Precipitation and Maximum Temperature show an upward trend and Minimum Temperature shows a downward trend. As it is shown in the table though the Z-value shows a positive value, that means an increasing or upward trend the slope value(B-value) shows a negative value. This is due to the equation used to develop the trend which is a linear model. This implies that the trend is not necessarily associated with the linear model and that the trend can be expressed by other models to show that it is increasing.

Table 4-1 comparison of climate variables between a reference and observed time period

Variable		**Precipitation**	**TMPmax**	**TMPmin**
Z-value		5.33	10.315	-10.35
B-value		-0.000045	0.000053	-0.000043
P-value	Upward Trend	0.000	0.000	1
	Downward Trend	1	1	0.000

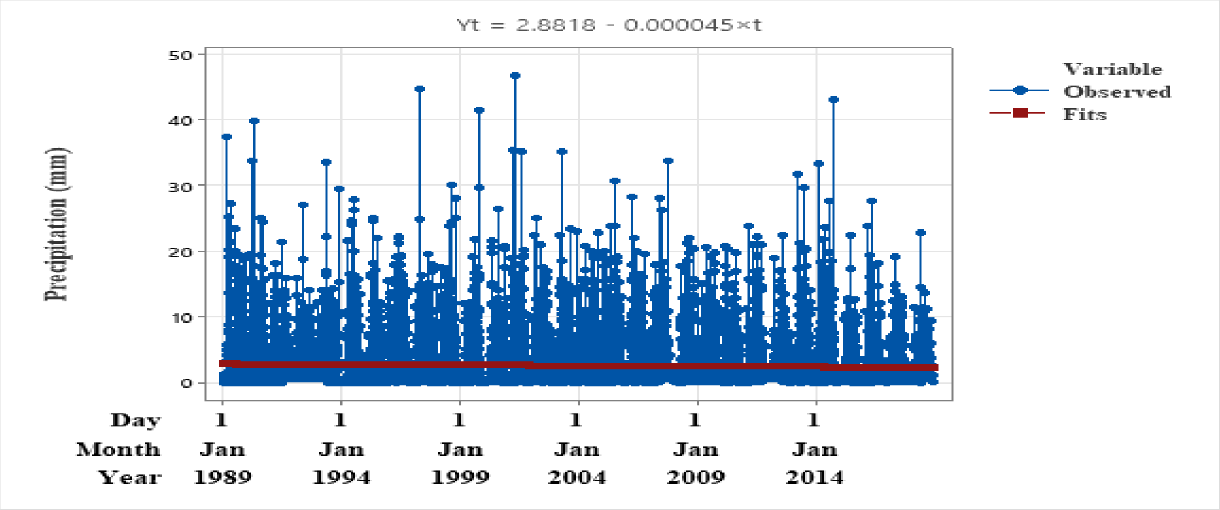

Figure 4.1 Trend analysis plot for Precipitation

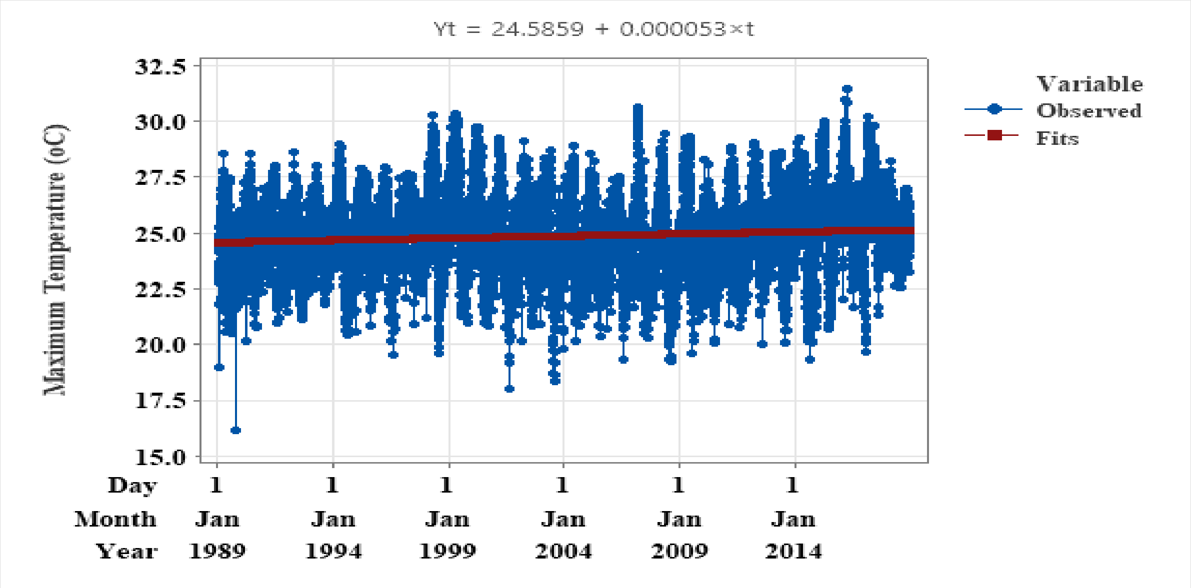

Figure 4.2 Trend analysis plot for Maximum Temperature

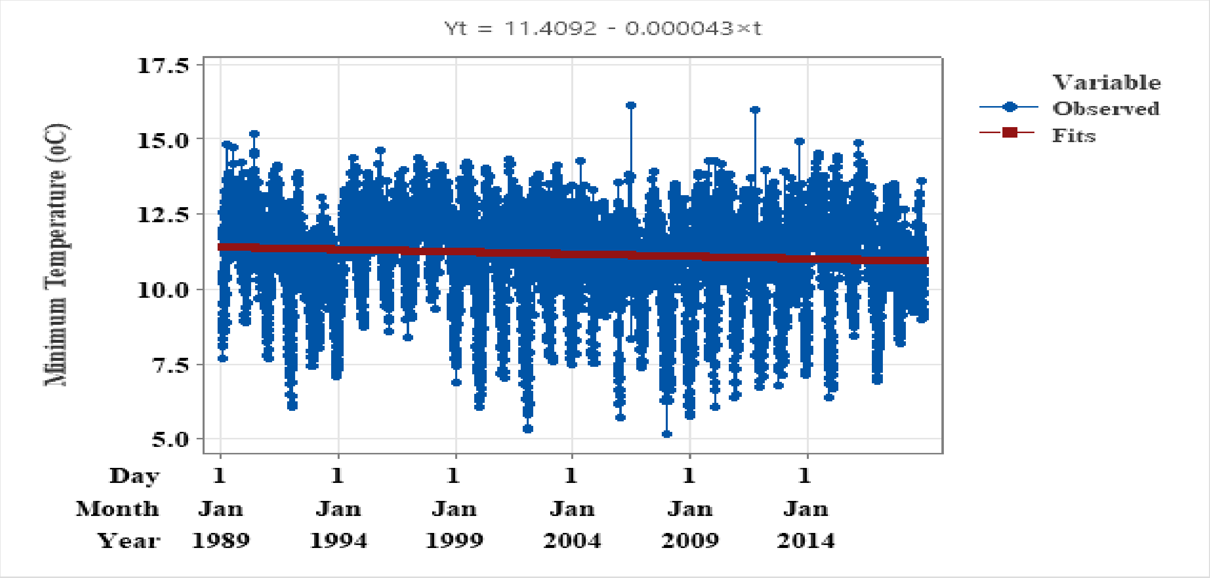

Figure 4.3 Trend analysis plot for Minimum Temperature

4.1.2. Base period, Historical and Future RCM data comparison for Precipitation and Temperature

a) Historical RCM data Bias correction

The statistical T-test performed on the daily bias-corrected Precipitation and Maximum and Minimum Temperature data for the study area and the observed Precipitation and Maximum and Minimum Temperature data showed that the null hypothesis should be accepted since the P-Value is greater than the alpha value for 95 % certainty which states that there is no significant change between the observed and bias corrected variables.

Table 4-2 Bias correction of Historical data

Variable	Comparison	Mean Differences	t-value	P-value
Precipitation	Observed - Historical (RCM)	-0.00006	-0.001	0.999
Tmax	Observed - Historical (RCM)	-0.00095	-0.041	0.968
Tmin	Observed - Historical (RCM)	-0.00092	-0.049	0.961

As it is shown in the above table there is no significant difference between the historical (RCM) and the observed Precipitation and temperature. The mean difference is also very small. Due to the above sufficient reason the historical data was used to bias correct the future climate data in order to use it for future SWAT flow simulation.

b) Future climate data comparison with the base period

The statistical T-test performed on the future daily bias-corrected Precipitation and Maximum and Minimum Temperature data for the study area and the observed Precipitation and Maximum and Minimum Temperature data showed that the null hypothesis should be rejected since the P-Value is less than the alpha value for 95 % certainty which states that there is significant change between the observed and bias corrected variables. Precipitation and maximum Temperature show a negative change whereas minimum temperature shows a positive change for mid and far time periods for RCP 4.5 and in the case of RCP 8.5 Precipitation show a negative change whereas maximum Temperature shows a positive change but the change in 2040s is insignificant, and minimum Temperature shows a positive change for mid and far time periods. From the three parameters minimum Temperature shows the maximum change with a t-value of 225.662. The maximum mean difference for precipitation is in RCP 4.5 with -1.72053 in 2070s and the minimum mean difference for precipitation is in RCP 4.5 with -1.23954 in 2040s , The maximum mean difference for Tmax is in RCP 8.5 with 1.43785 in 2070s and the minimum mean difference for Tmax is in RCP 4.5 with -0.23622 in

2070s whereas the maximum mean difference for Tmin is in RCP 8.5 with 4.93033 in 2070s and the minimum mean difference for Tmin is in RCP 4.5 with 2.50841 in 2040s

Table 4-3 Comparison of RCP 4.5 with the Base period

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 4.5	**Precipitation**	Observed - 2040s	-1.23954	-22.864	0.000
	Tmax	Observed - 2040s	-0.56576	-22.635	0.000
	Tmin	Observed - 2040s	2.50841	120.742	0.000

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 4.5	**Precipitation**	Observed - 2070s	-1.72053	-37.487	0.000
	Tmax	Observed - 2070s	-0.23622	-9.379	0.000
	Tmin	Observed - 2070s	2.88643	139.048	0.000

Table 4-4 Comparison of RCP 8.5 with the Base period

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 8.5	**Precipitation**	Observed - 2040s	-1.66186	-35.377	0.000
	Tmax	Observed - 2040s	0.02537	0.979	0.327
	Tmin	Observed - 2040s	3.25489	154.226	0.000

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 8.5	**Precipitation**	Observed - 2070s	-1.59435	-33.164	0.000
	Tmax	Observed - 2070s	1.43785	54.673	0.000
	Tmin	Observed - 2070s	4.93033	225.662	0.000

4.2. Impact of climate change on groundwater hydrology

The groundwater flow of a subbasin is dependent on many factors of which climate parameters are the major ones. From the climate Parameters, precipitation and temperature can be listed among the influential (Fan & He, 2015). Hence some changes are observed in the groundwater flow simulated at Meki and Katar gaugging station. These changes are analyzed discussed below as follows starting from the SWAT Hydrological model results.

4.2.1. SWAT Hydrological Model Results

4.2.1.1. Watershed delineation

Using ArcSWAT, the Lake Ziway – Meki and Katar watersheds are delineated using DEM data. From the topographic report, a total area of 2046.88 km^2 with 1 watershed and 3166.4 km^2 with 3 watersheds were generated by taking an outlet near Lake Ziway.

4.2.1.2. Determination of Hydrologic Response Unit

The Meki and Katar watershed delineation was followed by the determination of 36 HRUs depending on distinct soil, land use land cover, and slope types regardless of their spatial Positioning. Figures 4-4 and 4-5 below show the delineated of the subbasin and defined HRU and Table 4-5 shows the topographic report of the subbasin.

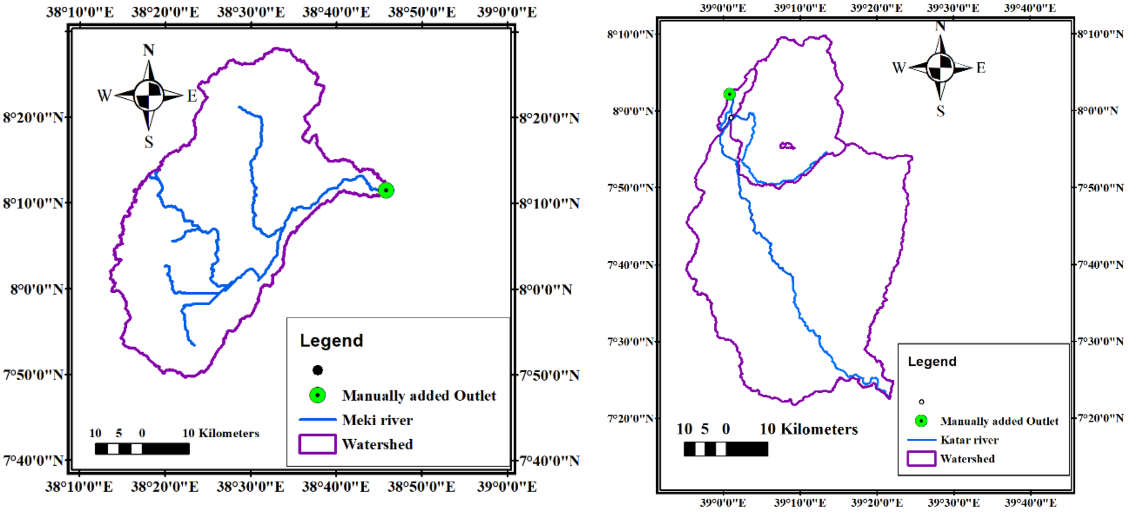

Figure 4.4 Meki (left) and Katar (right) delineated watersheds

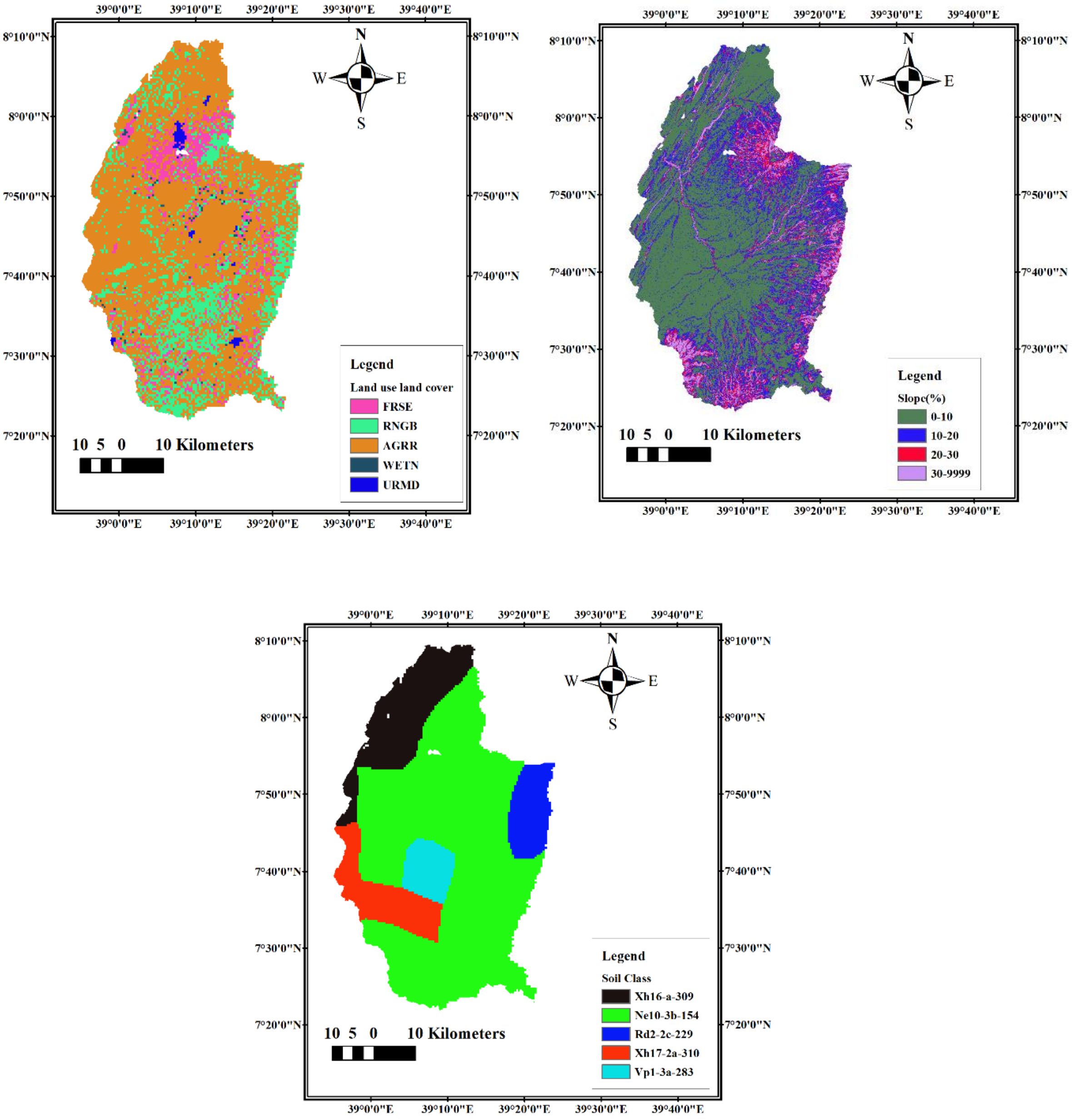

Figure 4.5 HRU defined for the study area using; Slope (Top right), Land Use Land Cover (Top left), and Soil type (Bottom middle) for Katar Watershed

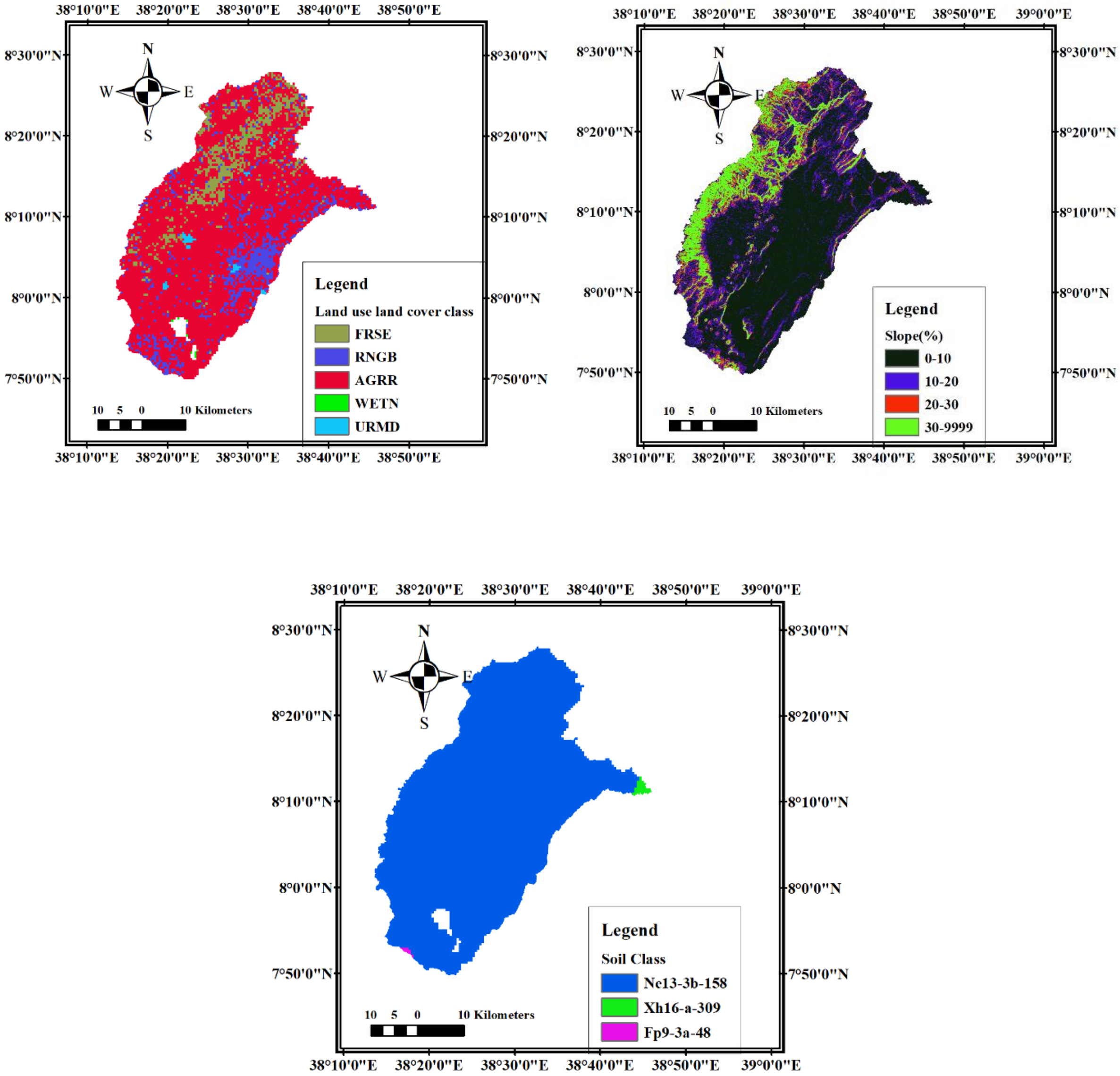

Figure 4.6 HRU defined for the study area using; Slope (Top right), Land Use Land Cover (Top left), and Soil type (Bottom middle) for Meki Watershed

Table 4-5 Topographic report of the watersheds

S.No	***Name***	***Elevation (m)***			***Area (km^2)***	***Number of HRU***	***Number of subbasin***
		Max.	*Min.*	*Mean*			
1.	*Meki watershed*	*3664*	*1670*	*1976.76*	*2046.88*	*36*	*1*
2.	*Katar Watershed*	*4144*	*1663*	*2637.29*	*3166.4*	*127*	*3*

4.2.1.3. Performance evaluation of SWAT Hydrologic Model

Sensitivity analysis

For sensitivity analysis, 27 parameters were considered out of which 13 were found to be relatively more sensitive. The t-stat offers a measure of sensitivity, the largest absolute value represents higher sensitivity and p-value determined the significance of sensitivity a value close to zero has more significance. Table 4-5 shows the sensitivity parameters in their Adjusted value. GW_DELAY.gw is the least important parameter because of the very high p-value and very low t-value. CN2.mgt is the most important influencing parameter on Streamflow with a very low p-value and very high t-value.

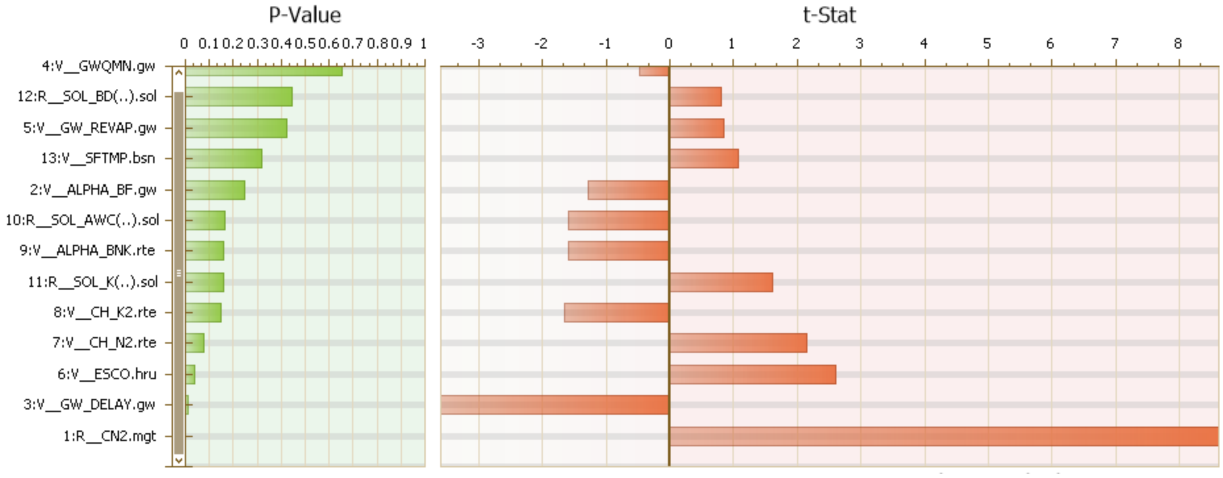

Figure 4.7 Meki watershed analysis of sensitive parameters

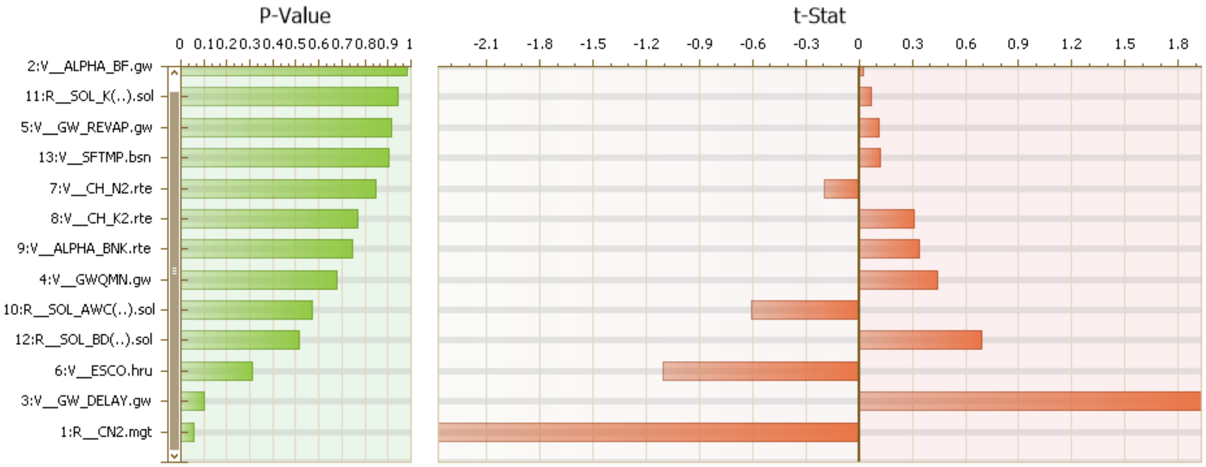

Figure 4.8 Katar watershed analysis of sensitive parameters

Flow Calibration and Validation

After the completion of sensitivity analysis flow calibration was performed using observed flow gauged at the outlet of the Meki and Katar watershed for a period of 10 years from January 1994 to December 2005 and validated from January 2005 to December 2011 all-in monthly basis.

Table 4-6 Initial and final adjusted Parameter Values for Meki watershed

SN	Parameter_Name	Fitted_Value	Min_value	Max_value
1	R__CN2.mgt	0.036757	-0.052762	0.272762
2	V__ALPHA_BF.gw	-0.191221	-0.255848	0.605848
3	V__GW_DELAY.gw	276.311218	164.744827	462.255188
4	V__GWQMN.gw	1.080753	-0.50971	1.20971
5	V__GW_REVAP.gw	0.281323	0.093444	0.296556
6	V__ESCO.hru	0.742677	0.718569	0.911431
7	V__CH_N2.rte	0.007016	-0.008952	0.203952
8	V__CH_K2.rte	21.258202	1.321731	89.928268
9	V__ALPHA_BNK.rte	0.056487	-0.331755	0.581755
10	R__SOL_AWC(..).sol	0.281630	-0.037174	0.327174
11	R__SOL_K(..).sol	-0.200526	-1.326317	0.126317

SN	Parameter_Name	Fitted_Value	Min_value	Max_value
12	R__SOL_BD(..).sol	0.387066	-0.040392	0.965392
13	V__SFTMP.bsn	-2.400343	-4.536696	2.036696

Table 4-7 Initial and final adjusted Parameter Values for Katar watershed

SN	Parameter_Name	Fitted_Value	Min_value	Max_value
1	R__CN2.mgt	0.245152	0.234512	0.421572
2	V__ALPHA_BF.gw	-0.000233	-0.000517	0.000517
3	V__GW_DELAY.gw	-0.330954	-0.389358	0.389358
4	V__GWQMN.gw	0.001128	-0.001187	0.001187
5	V__GW_REVAP.gw	-0.000075	-0.000137	0.000137
6	V__ESCO.hru	0.000146	-0.000224	0.000224
7	V__CH_N2.rte	-0.000124	-0.000191	0.000191
8	V__CH_K2.rte	-0.078968	-0.092903	0.092903
9	V__ALPHA_BNK.rte	-0.000107	-0.000427	0.000427
10	R__SOL_AWC(..).sol	-0.030126	-0.031712	0.031712
11	R__SOL_K(..).sol	0.007727	-0.030908	0.030908
12	R__SOL_BD(..).sol	0.01219	-0.034828	0.034828
13	V__SFTMP.bsn	-0.000276	-0.005515	0.005515

Monthly Calibration and Validation Result

Table 4-8 and Table 4-9 shows model performance parameters (R^2, NSE, and PBIAS) calculated using the observed and simulated discharge for calibration (1994-2004) and validation (2005–2011) period at Meki and Katar gauging station for Monthly bases. Accordingly, the results fulfilled the requirements suggested by *Santhi et al. (2001)* and (D. N. Moriasi et al., 2015) for $R^2 > 0.6$.

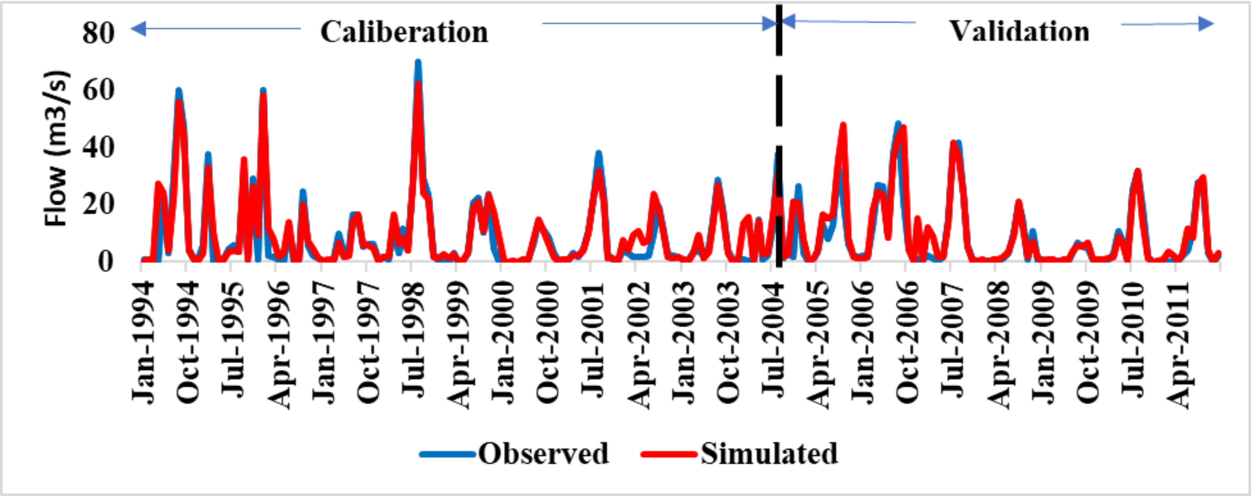

Figure 4.9 Monthly Calibration and validation at Meki gauging station

Table 4-8 Performance evaluation of SWAT model for calibration and validation at Meki station

Performance indicators	***Calibration (1994-2004)***	***Validation (2005-2011)***
NSE	*0.87*	*0.82*
R^2	*0.87*	*0.85*
PBIAS	*-0.89*	*0.67*

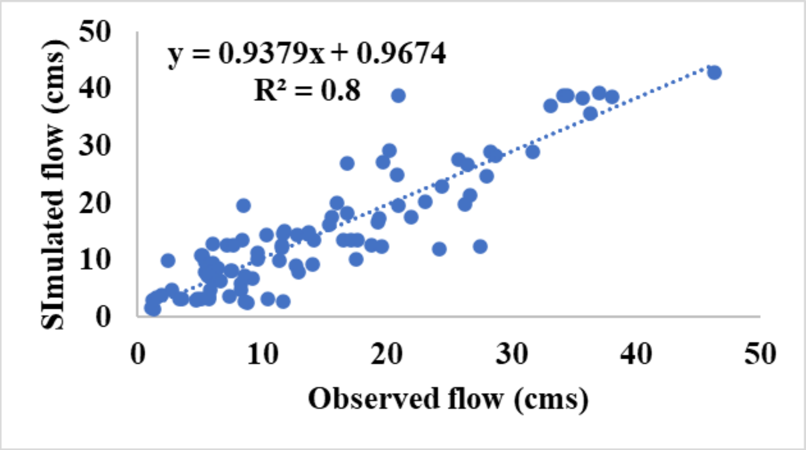

Figure 4.10 Regression line for Simulated vs Observed flow for Meki watershed (cms-Cubic Meter per Second)

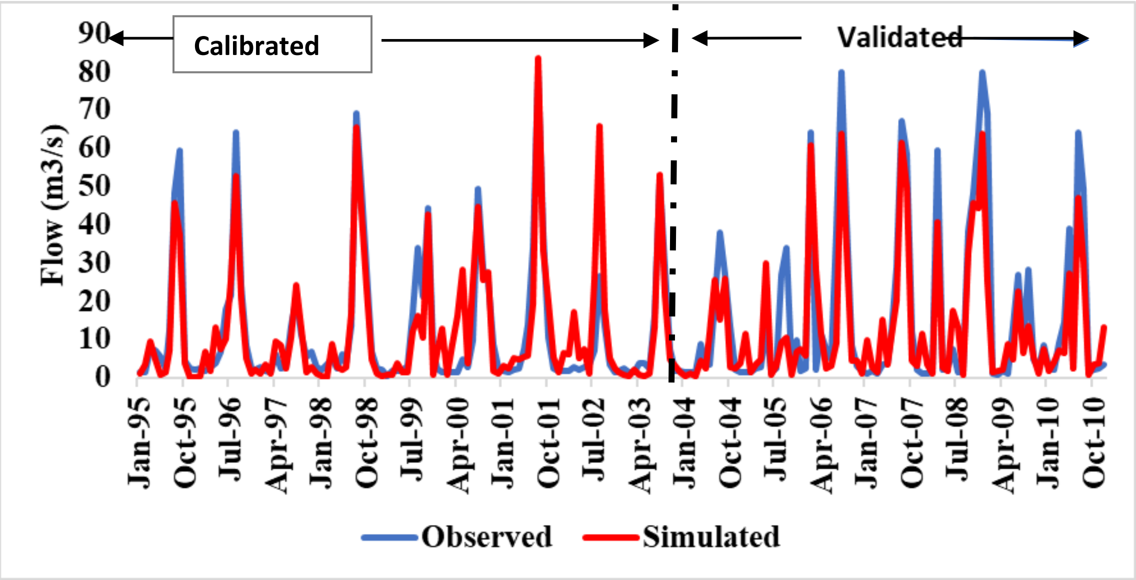

Figure 4.11 Monthly Calibration and validation at Katar gauging station

Table 4-9 Performance evaluation of SWAT model for calibration and validation at Katar station

Performance indicators	***Calibration (1995-2003)***	***Validation (2004-2010)***
NSE	*0.81*	*0.80*
R^2	*0.80*	*0.77*
PBIAS	*0.21*	*0.21*

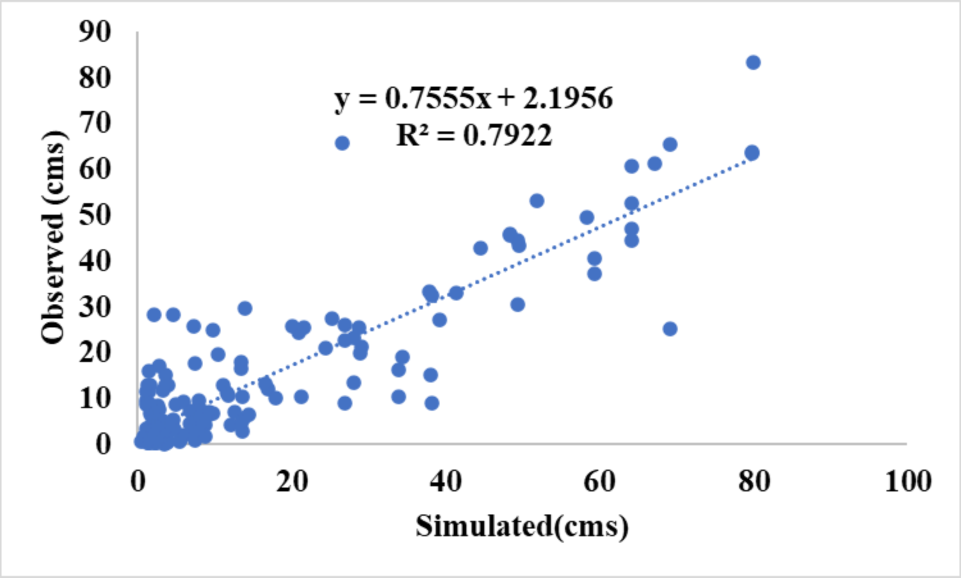

Figure 4.12 Regression line for Simulated vs Observed flow for Katar watershed (cms-Cubic Meter per Second)

D. N. Moriasi et al., (2015) suggested that when using R^2 as performance indicator the regression line should also be shown with the intercept to be near zero and the gradient to be near one. And as such is shown in the Figure 4.10 and Figure 4.12 above. In both cases, the NSE gives a value > 0.7, and R^2 >0.75, which meets previously listed criteria's (D. N. Moriasi et al., 2015) and give a good result for both Calibration and Validation time periods. The Percent Bias also shows a good result which is in range.

4.2.2. Impact of Climate Change on Baseflow

The impact of climate change was analyzed taking the 1989-2018 simulated river flow as the the baseline against which the future flows mid and far time periods were compared. As it is shown in the table below base flow has shown a significant change.

Table 4-10 Comparison of base flow of Katar Stream base period RCP 4.5 and RCP 8.5 in 2040s and 2070s

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 4.5	**Baseflow**	Base period - 2040s	-29.06061	-105.68	0.000
	Baseflow	Base period - 2070s	-28.06781	-98.711	0.000

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 8.5	**Baseflow**	Base period - 2040s	-26.52499	-94.089	0.000
	Baseflow	Base period - 2070s	-25.11302	-85.611	0.000

The mean difference shows a decrease in the base flow for both RCP4.5 and RCP8.5 in Katar stream flow in which the maximum t-value appears in RCP4.5 in the 2040s and minimum t-value appears in RCP 8.5 in 2070s.

Concerning Meki stream the base flow has a significant change and the mean difference shows a decrease in the base flow with both RCP4.5 and RCP8.5 in which the maximum t-value appears in RCP4.5 in the 2040s and minimum t-value appears in RCP 8.5 in 2040s.

Table 4-11 Comparison of base flow of Meki Stream base period RCP 4.5 and RCP 8.5 in 2040s and 2070s

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 4.5	**Baseflow**	Base period - 2040s	-23.05934	-63.53	0.000
	Baseflow	Base period - 2070s	-29.34284	-105.891	0.000

	Variable	Comparison	Mean Differences	t-value	P-value
RCP 8.5	**Baseflow**	Base period - 2040s	-28.61384	-106.058	0.000
	Baseflow	Base period - 2070s	-27.48513	-98.994	0.000

The maximum mean difference of the baseflow in katar stream RCP 4.5 with -29.06061 in 2040s and the minimum mean difference of the baseflow is in RCP 8.5 with -25.11302. And for Meki stream the maximum mean difference of the baseflow is in RCP 4.5 with -29.34284 in 2070s and the minimum mean difference of the baseflow is in RCP 4.5 with -23.05934.

4.2.3. Comparison of the result with previous studies

The results revealed that the maximum and minimum temperature increased under RCP 8.5 and RCP 4.5 scenarios. However, precipitation showed a decreasing trend similarly as it is shown in the study by Abraham et al., (2018). Accordingly, about the groundwater flow as it is concluded in the study by both Selam Legesse, (2016) and Hayal Desta et al, (2017), further study on climate change impact on groundwater should be studied, the present study is one that studies the impact of climate change on groundwater hydrology of Lake Ziway watershed. And results show that the groundwater decrement in both mid and far time periods were the base flow shows a decrement in both Katar and Meki streams when compared with base period base flow.

CHAPTER FIVE

5. SUMMARY AND CONCLUSION

5.1. Summary

Climate change has potential impacts on future hydrological and meteorological variables due to increased greenhouse emissions. In the present study, the future impact of climate change on hydrometeorological Parameters like precipitation and temperature of the Lake Ziway Watershed has been studied for the 2040s (2041-2070) and 2070s (2071-2100) using data derived from an ensemble of downscaled climate data based on the coordinated regional climate downscaling experiment over African domain (CORDEX-Africa) with coupled Model Intercomparison project Phase5 (CMIP5) simulations under representative concentration pathways viz. RCP4.5 and RCP8.5 climate scenarios.

The SWAT2012 hydrological model was used to simulate Streamflow in the basin to study impacts of climate change on future groundwater hydrology. The model was calibrated and validated for the periods of 1994–2004 and 2005–2011 and 1995-2003 and 2004-2010 respectively, at Meki and Katar gauging station located in the Lake Ziway Watershed. Three model performance indicators (Coefficient of determination; R^2, Nash and Sutcliff Efficiency; NSE and Percent Bias; PBIAS) used to check the performance of the model. The performance evaluation of the model confirmed that the statistical measure parameters for monthly simulation were good with values of $R^2 = 0.87$, NSE = 0.87 for calibration period and the corresponding value for validation period shows $R^2 = 0.85$, NSE = 0.82 for Meki and $R^2 = 0.8$, NSE = 0.81 for calibration period and the corresponding value for validation period shows $R^2 = 0.77$, NSE = 0.8 for Katar.

Bias-corrected CORDEX RCPs data for temperature and precipitation under RCP4.5 and RCP8.5 were fed into the SWAT model to simulate the Streamflow for future time periods. In this study, the simulated Streamflow data was divided into two future periods (Mid and far) and was compared with the baseline period (1989–2018). Statistical paired t-test was used to see the change and results are summarized below.

5.1.1. Manni-Kendal Test for Precipitation, maximum and minimum temperature for Base period (1989-2018)

The result for the comparison shows a significant increasing trend for precipitation and maximum temperature whereas a significant decreasing trend for minimum temperature. This by itself provides that there is a significant climate change, that would affect Lake Ziway Watershed in different fronts.

5.1.2. T-test for Future Precipitation, Maximum and Minimum Temperature Change

When compared to the base period the future Precipitation was projected to show decrement for all scenarios in both time periods. while maximum temperature shows an increment for RCP4.5 in both future time periods, it showed a non-significant change in 2040s and decrement in 2070s for RCP 8.5. minimum temperature show increment over the basin for all RCP scenarios. The maximum change is found in the projected minimum temperature in RCP 8.5 2070s.

respectively.

5.1.3. Baseflow Change

The result for projected baseflow change shows a decreasing trend under both RCP scenarios for all time periods, with a maximum t-value of 106.058 in 2040s for RCP 8.5. the minimum t-value of 63.53 is projected at RCP 4.5 2040s.

5.2. Conclusion

The main conclusions of the study are the following: -

I. In the Lake Ziway Watershed, there exists a climate change in the study period of 1989-2019.

II. When compared to the base period the projected Maximum temperature shows a decrement for RCP 4.5 in both time periods and a non-significant change in 2040s and a significant positive change and the projected future Precipitation shows a decrement in mid and far time periods for both scenarios and Minimum Temperature shows an increment which by itself turns out to show a maximum change from the three climate variables. Since, there is a significant change from the base period to the projected time periods, therefore there would exist a climate change impact for the projected time periods under both scenarios in the Lake Ziway Watershed.

III. According to the study, the results obtained for the change in future baseflow under different RCP climate scenarios show a decrement when compared to the base period. Therefore, climate change shows a significant decreasing impact on the baseflow of Lake Ziway Watershed, which in turn affects the level of Lake Ziway significantly.

Therefore, this research concluded that a change in climate variables of precipitation and Maximum and Minimum Temperature would significantly influence the groundwater flow (baseflow) of the basin to the lake negatively in Lake Ziway Watershed.

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