



HAWASSA UNIVERSITY

INSTITUTE OF TECHNOLOGY

EVALUATION OF THE IMPACTS OF CLIMATE CHANGE ON SEDIMENT YIELD FROM  
THE KATAR WATERSHED, CENTRAL RIFT-VALLEY BASIN, ETHIOPIA

MSC. THESIS

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THE KATAR WATERSHED, CENTRAL RIFT-VALLEY BASIN, ETHIOPIA

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## **DECLARATION**

I, Gelila Samuel declare that this thesis is my own work with the exception of such quotations or references which have been attributed to their authors or sources, and this thesis has not been previously submitted to this or any other university for a degree award.

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## **LISTS OF ACRONYMS AND ABBRIVATIONS**

Arc GIS- Software for Geographic Information Systems

AR4- Fourth Assessment report

AR5- Fifth Assessment Report

CMIP5- Coupled Model Inter comparison Project phase five

CORDEX- Coordinated Regional Climate down scaling Experiment CV Coefficient of Variation DEM  
Digital Elevation Model

FAO- Food and Agricultural Organization

GCMs- Global circulation Models

HadGEM2-ES- Hadley Global Environment Model 2 - Earth System IPCC Intergovernmental panel on  
climate change

IPCC- Intergovernmental Panel on Climate Change

MoWIE- Ministry of Water, Irrigation and Electricity

NMA- National Metrology Agency

RCM- Regional climate modeling

RCP- Representative Concentration Pathways

SWAT- Soil and Water Assessment Tool

SWAT-CUP- Soil and Water Assessment Tool- Calibration and Uncertainty Programs

SUFI-2-Sequential Uncertainty Fitting version-2

USGS- United States Geological Survey

WCRP-World Climate Research Program

## ABSTRACT

*Climate change is one of the issues that, the world facing today including Ethiopia and it is anticipated that climate change will impact sediment yield in watersheds. The purpose of this study was to investigate the impacts of climate change on sediment yield from the Katar watershed in the Eastern Lake Ziway Basin, Ethiopia. Here, used the coordinated regional climate downscaling experiment (CORDEX)-Africa data outputs of Hadley Global Environment Model 2-Earth System (HadGEM2-ES) under representative concentration pathway (RCP) scenarios (RCP4.5). The analysis was performed in two future projection of 2030's and 2060's under the reference of baseline period of 1987-2017 with their RCP correction. After assessment of missing, quality and consistency of data; bias, the coefficient of variation and correlation were used to evaluate the systematic error of precipitation amount, the degree of precipitation variability and bias-corrected before serving as input to the impact analysis A Soil and Water Assessment Tool (SWAT) model was constructed to simulate the hydrological and the sedimentological responses to climate change. The model performance was calibrated and validated using the coefficient of determination ( $R^2$ ) and Nash–Sutcliffe efficiency (NSE). The results of the calibration and the validation of the sediment yield  $R^2$  and NSE were 0.65 and 0.61, and 0.66 and 0.65, respectively. Climate change output from this research shows that the watershed will get warmer in the future. Both minimum and maximum temperature of the catchment have an increasing trend by 1.04 0C for 2030's and 2.04 0C for 2060's for minimum temperature and 0.90 0C for 2030's and 1.56 0C for 2060's for maximum temperature. Also, average annual rainfall shows increase by 4.8% for 2030's and 1.6 % for 2060's. The results of downscaled precipitation and temperature increased in both future period under RCP4.5 scenario. These climate variable increments were expected to result in intensifications in the mean annual sediment yield of 41.1% and 8.9% for RCP4.5 by the 2030s and the 2060s, respectively. The average annual sediment yield were 398 ton/km<sup>2</sup> and 307 ton/km<sup>2</sup> for the 2030's and 2060's, respectively. From this study, the results show that the sediment yield of the watershed is likely to increase under climate change scenarios. This will help water resources managers make informed decisions regarding the planning, management, and mitigation of the river basins.*

**Keywords:** Katar watershed; climate change; CORDEX-Africa; SWAT; RCP; sediment yield

# 1. INTRODUCTION

## 1.1. Background

The impact of climate change is a key topic in the Environmental discussion on both global and local scale (Houghton DD, 2002). Intergovernmental Panel on Climate Change (IPCC) description confirms that climate is changing in ways that can't be accounted for by natural variability and more changes have been expected for the coming decades (IPCC, 2007). The report (IPCC, 2013) in Earth near-surface air temperature and changes in precipitation patterns are noticeable features of climate change; these two factors impact almost all other hydrological processes. Considering all regions of the world are expected to experience a net negative impact due to climate change, quantifying hydrological impacts will be valuable in understanding and predicting sediment yield and discharge processes. Understanding the potential future changes in sediment load also should be seen as an important requirement for river basin management.

Climate change has several impacts on the environment in addition to the disruption of water resources. Erosion and sediment transport processes are sensitive to changes in climate and land cover and a wide range of human activities because of their close links to land cover, land use, and the hydrology of a river basin) (Houghton DD, 2002). Increased heavy rainfall as a result of climate change can cause soil erosion, crop damage and waterlogging. The suspended sediment response to climate change generally followed the patterns of simulated changes in streamflow (Rodríguez-Blanco, 2016).

Climate change will affect all nations, but the impact will be higher on low-income countries, such as Ethiopia, which have limited capacity to cope with the effects of a changing climate (Deressa T. , 2009). Changes in climate are also expected to have noticeable effects on the soil since rainfall and runoff are the factors controlling soil erosion and sediment transport. It is likely to affect sediment yield because of its effect on precipitation extremes. The intensity of rainfall, streamflow, and temperature are some of the parameters that influence the movement of sediment in the basin (Arekhi, 2008) .

Changes in sediment yields due to climate change in the future can have great implications for planned reservoirs and related sediment management. Increased sediment loads can intensify many problems linked to accelerated loss of Lake volume through sedimentation and siltation of river

channels and water distribution systems, and associated loss of conveyance capacity and increased turbidity of river water (Walling, 2008). Although decreasing sediment loads will frequently bring obvious benefits in terms of reduced sedimentation and siltation, it is important to recognize that there can also be negative impacts associated with reduced nutrient inputs to lakes, wetlands, floodplains, delta, and coastal areas, resulting in major ecosystem disturbances (Kummu M. & Varis O., 2007).

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).

In addition, the Central Ethiopian Rift Valley is characterized by a chain of lakes varying in size, hydrological and hydrogeological settings. The water levels of some of these lakes showed dramatic changes in the last few decades (Alemayehu T., Ayenew T., 2006). The sedimentation of lakes is a major challenge within the central rift valley (Meshesha, 2011). The previous study showed that the life expectancy of the lakes is likely to increase under climate change scenarios due to the increase of sediment yield to the lakes (Takele, 2018).

Recently, most researches indicate the cumulative effect of climate change that enhances soil degradation and loss associated with erosion resulting from over-exploitation of forests and vegetation covers. Central Ethiopian Rift Valley tributaries are characterized by a high concentration of suspended load (Schütt B. & Thiemann S., 2002).

It is in these regard , it is extremely important to conduct a research on the impacts of climate change on sediment yield so that people and society can foresee and respond the tentative future challenges either by mitigating the worst condition that likely to happen in future or at least be well prepared and resilient to face the possible challenges. In this study, the hydro-climatic data of CORDEX-Africa RCMs downscaled from different GCMs from CMIP5 simulation under different RCPs scenario (RCP4.5) is used for the catchment. Then the data is used as an input to the hydrological model (SWAT2012) to simulate the effect of climate change on the sediment yield and analyses the future sediment availability in the region.

## **1.2. Statement of the Problem**

Climate change affects hydro-climatic variables that in turn affect the sedimentation of the lakes. It is likely to affect sediment yield because of its effect on precipitation extremes (Cousino, 2015).

Despite the fact that the impact of different climate change scenarios is forecast at a global scale, the exact type and magnitude of the impact at a small watershed scale remains untouched in most parts of the world. Hence, identifying local impact of climate change at a watershed level is quite important. This gives an opportunity to identify the degree of vulnerability of local water resources and plan appropriate adaptation measures that must be taken ahead of time. Moreover, this will give enough room to consider possible future risks in all phases of water resource development projects (Zeray, 2006). However, such potential effects on sediment yield have received comparatively little attention.

Generally, climate change has a great influence on water resources are under this circumstance. Hence identifying the impact of climate change on the water resources and suggesting adaptation measures to deal effectively with associated problem is highly important.

Several studies have been conducted mainly on the Rift Valley Lakes; however, the hydrological behavior of the lakes is very much dependent on what happens in their catchment. Since the Lake sediments can be originated from the lake itself or externally from the surrounding watershed, so estimation of the sediment yield from catchments is required for the studies of sedimentation in Lakes.

In addition, understanding the change of catchment around the lakes is critical for watershed management. However, none of studies addressed the climate change impacts on sediment yield in the Katar watershed. Therefore, evaluation of sediment yield in light of future climate change is very important for sustainable planning and management of the water resources.

### **1.3. Objective of The Study**

#### **1.3.1. General Objective**

The main objective of this study is to estimate the potential impact of climate change on sediment yield in the Katar watershed.

#### **1.3.2. Specific Objective**

In order to achieve the general objective of the study, the following specific objectives are set for the study:

- ❖ To assess future climate change of Katar Watershed under RCP4.5 climate scenario.
- ❖ To assess the future sediment yield variation of Katar watershed compared with base periods using SWAT Model.
- ❖ To evaluate the impact of climate change on sediment yield.

### **1.4. Research Questions**

The research questions addressed in this study are:

- ❖ What are the temporal climate change trends of Precipitation and Temperature over the selected Katar catchment?
- ❖ What is the future variation of sediment yield under climate scenario?
- ❖ How to evaluate the sediment yield in changing climate for future periods?

### **1.5. Significance of the Study**

The purpose of this study was to investigate sediment yield contribution to the lake under changing climatic conditions. Evaluating the impact of climate change on sediment yield will help water resources managers make informed decisions regarding the planning, management, and mitigation of the river basins. It also increases understanding of future implications of potential climate change impacts on sedimentation of Katar watershed for effective management.

### **1.6. Scope of the Study**

The study focuses on the investigation of sediment yield due to climate change on the Katar watershed using SWAT model for predicting the sediment yield and also RCM under CORDEX-Africa with emission scenario of RCP4.5 were used to generate future for climatic variability. This study is restricted for effect of climate change on different Scenarios towards integrating climate change on sediment yield. This research considers only RCP 4.5 scenario's because of 4.5 emission scenario is the middle one it gives the middle result compare to others emission scenario and for the developing country the middle emission scenario have more power full than the higher and lower one. In this study the impact of climate change was assessed for the meteorological terms of Precipitation and Temperature the other climate variables such as Relative Humidity, Solar Radiation and Wind speed were assumed to remain the same in the future. The soil and land use/land cover assumed to be constant for future projection.

### **1.7. Overview of the Thesis**

This thesis contains five chapters: Chapter one discusses the background information, problem statement, general and specific objectives, and limitations of the study. It brings to focus the problems experienced in this region in light of the changing environment and climate. Chapter two summarizes literature regarding the subject of climate changes in terms of global, continental and regional aspect, Major previous studies conducted in the Katar watershed, hydrologic modeling for use in impact assessment and recent climate change scenarios data are also mentioned. Chapter three describes the various data used in the study, their sources, the methods used for data quality control and also a step-by-step methodology adopted in the research is presented. Chapter four presents the outcome of model application to assess the impact of climate change. Chapter five is finally, presents conclusions and recommendations based on the results and data used for this study. Additionally, references and Appendixes are attached at the end.

## **2. LITERATURE REVIEW**

### **2.1. Analysis of Climate Change**

#### **2.1.1. Global climate change**

Climate change defines as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and persist for an extended period typically a decade or even longer either due to anthropogenic or natural forcing (IPCC, 2013).

Most of the regions in the world have experienced decreased snowfall events where winter temperatures have increased. Almost the entire globe has been experiencing surface warming and the evidence for this warming comes from multiple climate system indicators from atmosphere to the oceans such as change in temperature of oceans, atmosphere and surface, change in glacier, snow cover, sea ice, sea level and water vapor (Hartmann, et al., 2013).

The warming in Africa is likely to be somewhat larger than the global, annual mean warming throughout the continent and in all seasons, with drier subtropical regions (especially arid zones) warming more than the moister tropics. Annual rainfall is very likely to decrease in much of North Africa and Northern Sahara, while winter rainfall will very likely decrease in much of Southern Africa. There will likely be an increase in annual mean rainfall in tropical and East Africa (coumou, et al., 2015).

#### **2.1.2. Climate Change of Ethiopia**

Ethiopia is a country in which the economy largely depends on rain-fed agriculture, which is highly vulnerable to the impacts of climate change, mainly changes in precipitation patterns. Precipitation pattern and character in Ethiopia are predominantly controlled by the oscillation of the Inter-tropical Convergence Zone (Deressa T. H., 2011)& (Cheung, 2008).

Ethiopia has become warmer over the past century and human induced climate change will bring further warming over the next century at unprecedented rates. It is likely that this warming will be associated with greater increase in rainfall higher evaporation (Ethiopia's Climate Resilient Green Economy Strategy, 2011). The climate change risk is high vulnerability derives in large measure from the country's heavy dependence on rain-fed, subsistence agriculture (FAO, 1995).

### **2.1.3. Impact of Climate Change**

Climate variability and change are expected to change hydrologic conditions and result in various impacts on global water resource systems. Likely impact may be on hydrological processes such as evapo-transpiration, temperature, streamflow volume, soil moisture, timing and magnitude of runoff, and frequency and severity of floods, all these will lead to changes in environmental variables (Nijssen B., O'Donnell G., 2001)

A warmer climate will accelerate the hydrological cycle, altering rainfall and the magnitude and timing of runoff. Changes in climate are also expected to have noticeable effects on the soil since rainfall and runoff are the factors controlling soil erosion and sediment transport within landscapes. The changes in flow characteristics resulting from climate change depend on individual catchment characteristics (Hamlet A. & Lettenmaier D., 2007).

Climate change impacts a basin's inflow supply in various ways. It may alter seasonal temperature and precipitation, shift the timing of streamflow runoff, and reduce the ability of existing supplies to meet water needs. The only means available to quantify the non-linear climate response is by using numerical models of the climate system based on well-established physical, chemical, and biological principles, possibly combined with empirical and statistical methods. These are designed mainly for studying climate processes and natural climate variability, and for projecting the response of the climate to human-induced forcing (Baede., A, 2001).

## **2.2. Overview of Sediment Yield**

### **2.2.1. General**

Sediment yield is the net result of soil erosion and processes of sediment accumulation, so it depends on variables that control water and sediment discharge to reservoirs (Duru., 2015) Sedimentation in catchment outlets such as reservoirs, lakes, ponds, and dams are perhaps the most problematic outcome of soil erosion (Van Rompaey A. & Krasa J., 2001).

The sediment load of a river is sensitive to both, climate change and a wide range of human activities within its drainage basin. These factors could influence sediment mobilization and transfer through actions like clearing of land, agricultural development, mineral extraction, urbanization and infrastructure development, dam and reservoir construction, and soil conservation and sediment control programs (Walling., 2008).

Erosion and sediment transport processes are sensitive to changes in climate and land cover and a wide range of human activities because of their close links to land cover, land use, and the hydrology of a river basin. Soil erosion can cause a variety of problems that affect both land and water resources where the erosion occurs and where subsequent deposition occurs respectively (Walling, 2009).

In Ethiopia watersheds, erosion, sediment transport, and sedimentation are critical problems. The current level of degradation leading to erosion, and sedimentation are causing considerable loss of soil. As a consequence, the soil becoming shallow and the storage of water become decline (Bezawit.A, 2011)

### **2.2.2. Factors Affect Sediment Yield**

Soil loss from a watershed can be estimated based on an understanding of the underlying hydrological process, climatic condition, landforms and soil factors. Erosion rates depend on the rainfall intensity and the total amount of precipitation (Bezawit.A, 2011).

Several factors influence soil erosion; which include climate, soil, topography, and vegetation and management practices. A number of studies have indicated the impact of climate change on soil erosion and hydrology. The basic energy input required to drive erosion processes is provided by rainfall and runoff and intensity of rainfall has a significant impact on soil erosion rates (Nearing, Pruski, & O'Neal, 2004).

The effect of climatic factors such as precipitation, temperature, and wind on sediment yields varies in different parts of the country. In addition, the important factors affecting sediment yields in the watershed are: sizes of drainage area, topography, soils, cover conditions, and degree of channelization (Robinson, 1977).

### **2.3. Review the Impact of Climate Change on Sedimentation**

Climate change is expected to have adverse impacts on socio-economic development globally; the degree of the impact will vary across nations. The IPCC findings indicate that developing countries, such as Ethiopia, will be more vulnerable to climate change. It may have far-reaching implications to Ethiopia for various reasons, mainly as its economy largely depends on agriculture. A large part of the country is arid and semiarid, and is highly prone to desertification and drought. Climate change and its impacts are, therefore, a cause for concern to Ethiopia. Hence, assessing

vulnerability to climate change and preparing adaptation options as part of the entire program is very crucial for the country (NMSA, 2001).

The correlation between climate change and sedimentation is a great issue of worldwide as it has influence on management action on water resources by affecting the hydrology a certain watershed and different studies have been done related to this issue such as;

The investigation of sediment yield contribution to Lake Ziway volume change under changing climatic conditions in Central Rift Valley Basin, analyzed that future average annual sediment yield is in decreasing pattern as compared to historical period this is due to the decrease in stream flow the future period. The reduction of stream flow related with the decrease in precipitation amount and the increase of maximum and minimum temperature in future scenario period, according to the projected climate data output (Takele, 2018).

The study on the Nam Ou Basin located in Northern Laos have been assessed the future changes in sediment flux attributable to climate change and finalized the future sediment yield from the Nam Ou Basin is likely to increase with climate change, which strongly suggests the need for basin-wide sediment management strategies to reduce the negative impact of this change (Shrestha, et al., 2012).

The basin-level impact of climate change on sediment yield in Upper Gilgel Abay catchment, Blue Nile Basin, Ethiopia, has been revealed that sediment yield was related to a change in climate variables and thus to streamflow. The study shows that the increase of climate variable in future period and this makes the increase of mean annual sediment yield in future time due the increase in streamflow (Adem, 2015).

#### **2.4. Previous Studies on Katar Catchment**

A number of studies have been done in the past, concerning different research topics such as land cover change on hydrology, the interaction of groundwater and surface water and others. Among the previous studies have been revised below in order to have indication about the research area.

The study in 2015 show that, changing of forest land and grassland to agricultural land and urban area has altered rainfall-runoff relationship and resulted in increased wet season surface flow and reduction of dry season water flow. The research recommended that the land-use/land-cover

change should be controlled in the watershed and some measures should be taken for the stabilization of the land cover change to sustain the contribution of groundwater in dry season and ecological bio-diversity within the basin (Damtew, 2015).

In the study of groundwater-surface water interaction and analysis of recent change in hydrologic environment of Lake Ziway catchment, the hydrograph of Katar River at Abura is smooth, showing less response to daily precipitation, higher runoff after immediate end of wet season but declining at faster rate. Furthermore, the five years moving average of the precipitation in the catchment shows that there is decrease in rainfall by about 30mm every five years and trends in potential evapotranspiration indicate rise on land surface from 1995 to 2004 (Alemu D., 2006).

In this research, since anthropogenic climate change poses critical challenges globally and regionally it is very critical to use, up-to-date climate scenario data, to improve our understanding of the potential impacts and implications of climate change. Therefore, in order to see the impact of climate change in detail Hydro-climatic data from CORDEX-Africa RCMs based on different RCPs scenarios (RCP4.5 and RCP8.5) were used in the analysis.

## **2.5. Climate Model**

GCMs, provide quantitative estimates of future climate change that are valid at the global and continental scale and over long periods. Although GCMs are valuable predictive tools, they cannot account for fine-scale heterogeneity of climate variability and change due to their coarse resolution. Various methods have been developed to bridge the gap between what GCMs can deliver and what society/businesses/stakeholders require decision making. It is possible to model these interactions and establish relationships between present-day local climate and atmospheric conditions through the downscaling process (Trzaska S. & Schnarr E., 2014).

Regional Climate Models (RCMs) are developed based on the same representations of atmospheric dynamical and physical processes as GCMs. They have higher spatial resolution in the order of 1050km that can cover a sub-global domain. As a result of the higher spatial domain, RCMs provide a better description of climatically effects, land-sea surface contrast and land-surface characteristics (Christensen, 2007). There are many different RCMs currently available, for various regions, developed at different modeling centers of the world More recently, a new project called

CORDEX (Coordinated Regional Climate Downscaling Experiment) has been initiated by the world climate research program simulations at 50km resolution for multiple regions.

An RCM is similar to a GCM but has higher resolution and additional regional information, which enables it to better represent local landscape and possibly local atmospheric processes. The dataset is the starting point of different regional downscaling initiatives on the generation of regional climate change scenarios, which are being coordinated worldwide for the first time within the framework of the Coordinated Regional Climate Downscaling Experiment. The purpose of CORDEX-Africa is to promote international downscaling coordination and facilitate easier analysis by scientists and end-user communities at the local level of regional climate changes (Trzaska S. & Schnarr E., 2014).

World climate Research program (WCRP) has initiated Global Coordinated Regional Downscaling Experiment (CORDEX: <http://wcrp-cordex.ipsl.jussieu.fr/>) with the intention of producing an ensemble of high-resolution climate change projections by downscaling GCM simulations from Coupled Model Inter-comparison Project Phase 5 (CMIP5) data archive. Africa was selected as the first target region. CORDEX-Africa RCMs generate an ensemble of high resolution historical and future climate projections at regional scale by downscaling different GCMs forced by RCPs based on the Coupled Intercomparison Project Phase 5 (CMIP5).

A number of widely used limited area modeling systems have been adapted to develop climate application. According to study by (Philber, 2016) on performance of RCMs from the CORDEX to simulate minimum air temperature (Tmin), maximum air temperature (Tmax) and rainfall from four RCMs over Tanzania by using bias, root mean square error and correlation, the RCMs capture the annual cycle of Tmin, Tmax and rainfall well. However, underestimate and overestimate the amount of rainfall in March, April and May and October, November and December respectively. Most RCMs reproduce inter-annual variations of Tmax, Tmin and rainfall.

In this study, results of CORDEX-Africa ensemble RCMs simulations for the historical (1951–2005) and future (2006–2100) climate projections downscaled from different GCMs under RCP4.5 used.

## **2.6. Climate Scenarios**

Over time, different scenarios have been used in climate research from SA92 used in IPCC first assessment report to Special Report on Emissions and Scenarios (SRES) used in third and fourth assessment report. And recently, the new scenarios called Representative Concentration Pathways were developed and used for preparing fifth assessment report (AR5) of IPCC released in 2015.

There are no universal ways to select suitable climate model for climate projections (Gleckler, 2008) and (Räisänen, 2009). Moreover, the coarse resolution of most current climate models certainly dictates caution in their application on smaller scales in heterogeneous regions such as along coastlines or rugged topography. The four criteria for selection of which GCMs/RCMs outputs to use for an impact study have been suggested are;

**Vintage**-In general, recent model simulations are likely (though by no means certain) to be more reliable than those of an earlier vintage. They are based on recent knowledge, incorporate more processes and feedbacks and are usually of a higher spatial resolution than earlier models.

**Resolution**-As climate models have evolved and computing power has increased, there has been a tendency towards increased resolution. Some of the early GCMs operated on a horizontal resolution of some 1000 km with between 2 and 10 levels in the vertical. More recent models are run at nearer 250 km spatial resolution with perhaps 20 vertical levels. However, although higher resolution models contain more spatial detail this does not necessarily guarantee a superior model performance.

**Validity** - A more persuasive criterion for model selection is to adopt the GCMs that simulate the present-day climate most faithfully, on the premise that these GCMs would also yield the most reliable representation of future climate. The approach involves comparing GCM simulations that represent present-day conditions with the observed climates. The modeled and observed data are projected to the same grid, and statistical methods employed to compare mean values, variability and climatic patterns.

### **2.6.1. Representative Concentration Path way (RCP)**

Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and other pollutants and with our understanding of the

effect of increased atmospheric concentrations of these gases on global climate. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in 2100. RCP is the latest generation of scenarios that provide input to climate models in climate research. RCPs are time and space dependent trajectories of concentrations and emission of greenhouse gases and pollutants resulting from human activities, including changes in land use (Vuuren, 2011).

Developing the new RCP scenarios were as a result of SRES scenarios do not consider current climate policy, whereas latest developments in climate models require detailed information on emissions scenarios through the collaboration of various disciplines. The RCPs supersede the old emission scenarios (SRES) in order to be coherent with new data, new world environment, and new models. The new scenarios are thus intended to connect work on climate change, impacts and adaptation, and mitigation (IPCC, 2013).

The criteria to select climate scenarios which are useful for impact researchers and policy makers i.e. consistency with global projections, physical plausibility, applicability in impact assessments and representative (Smith & Hulme, 1998). There are four RCPs defined by their level of the total radiative forcing pathway in the year 2100, and they were named as RCP2.6, RCP4.5, RCP6 and RCP8.5 which based on the radiative forcing target levels of 2.6, 4.5, 6 and 8.5 Watt/m<sup>2</sup>, respectively.

### **RCPs primary characteristics and their development:**

**RCP8.5 (high emission scenario):** was developed by Integrated Assessment Framework by the International Institute for Applied System Analysis (IIASA) using MESSAGE model. The important assumptions in this pathway are continuous increase in global population reaching 12 billion by 2100, slow income growth with modest rates of technological progress, long-term high energy demand, moving towards coal intensive technologies and high emission in the absence of climate change policies. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Vuuren, 2011).

**RCP6 (stabilization scenario):** was developed by the Asia-Pacific Integrated Model (AIM) modeling team at the National Institute for Environmental Studies (NIES) in Japan. In this

scenario, the GHG emissions will be the highest in 2060 and then decline thereafter. The primary assumptions of this RCP are increase in energy demand, shift from coal based to gas based production technologies, increase in use of non-fossil fuel energy type and increase in population and economic growth in urban area, expansion of cropland and forest area, and decrease in grassland (Meinshausen, et al., 2011).

**RCP4.5 (stabilization scenario):** was developed by the GCAM modeling team at the Pacific Northwest National Laboratory 's Joint Global Change Research Institute (JGCRI) in the United States. The major assumptions of this scenario are the global population reaches a maximum of 9 billion by 2065 and then declines to 8.7 billion in 2100, declines in energy consumption, increase in fossil fuel consumption, substantial increase in renewable energy and nuclear energy use, and large increase in forest area as a mitigation strategy (Clarke, et al., 2007).

**RCP2.6 (mitigation scenario):** was developed by the IMAGE modeling team of the PBL Netherlands Environmental Assessment Agency. The important assumption in this scenario is that new energy efficient technologies can be rapidly transferred to all over the world and implement immediately (van Vuuren., 2011).

Note; IA Model = Integrated Assessment model; MEASSAGE= Model for Energy Supply strategy Alternatives and their General Environmental Impact; International Institutes for applied Systems, Austria; AIM = Asia-pacific Integrated Model, National Institute for Environmental studies, Japan; GCAM= Global change Assessment Model, Pacific North West National Laboratory, USA (Previously referred to as MiniCAM); IMAGE= Integrated Model to Assess the Global Environment; Netherlands Environmental assessment Agency.

Developing counters like Ethiopia was under middle/ intermediate emissions scenarios. Hence, for this study the intermediate emission scenarios RCP 4.5 were selected to analyze how driving forces may influence future emission outcomes and to evaluate the associated impacts of future climate change.

### **2.6.2. Comparisons of SRES and RCP Climate Scenarios**

RCPs represent pathways of radiative forcing, not linked with exclusive socio-economic assumption in contrary to Special Report on Emission Scenarios (SRES). Any single radiative forcing pathway can result from a diverse range of socio-economic and technological development

scenarios. The SRES scenarios do not assume any policy to control climate change, unlike the RCP scenarios (IPCC, 2013).

The differences in temperature responses are consistent with the differences in radiative forcing estimates. The temperature increases with the RCP4.5 and SRES B1 scenarios are close and the temperature increase is larger with RCP8.5 than with SRES A2. The spread of projected global mean temperature for the RCP scenarios is considerably larger (at both the high and low response ends) than for the three SRES scenarios used in CMIP3 (B1, A1B and A2) as a direct consequence of the larger range of radiative forcing across the RCP scenarios compared to that across the three SRES scenarios (IPCC, 2013).

Unlike SRES, RCPs start with pathways of radioactive forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition), not with detailed socioeconomic narratives or scenarios (Vuuren, 2011).

Among the research that done previously will discuss below to compare the model according to the output provided by the study: -

The study done in Anjeni Watershed Blue Nile Basin uses GCM to project and quantify the relative change of climate variables between current and future periods. One of the global circulation models, HadCM3, was used for this study because the model is widely applied in many climate changes studies. The outputs of HadCM3 coupled atmosphere-ocean GCM model for the SRES, A2 and B2 emission scenarios were used to produce future scenarios. These outputs were downscaled to the watershed scale through the application of the SDSM model (Yakob., 2009).

The SRES depend on the historical data this forces the future climate pattern to only those roughly similar to historic and also the model requires sufficient amount of observational data that may be unavailable for many areas.

In research assessment of climate change on sediment yield in the Central Rift Valley Basin, the model used five RCMs in CORDEX-Africa were considered for assessing climate change. The climate variables (precipitation, minimum and maximum temperatures) in RCMs were bias-corrected against observed data. Two emission scenarios, the Representative Concentration Pathways, RCP4.5, and RCP8.5, were considered for the future scenario period (Takele, 2018).

RCMs have advantages because of not constrained by historical record and the model based on consistent, physical mechanism. The output from CORDEX-Africa with emission scenario not requires further downscaling since it downscaled for the region rather the data is bias corrected.

## **2.6. Bias Correction**

Using downscaled regional climate data for impact assessment without any bias correction may lead to considerable deviation when a hydrologic model is forced with a biased RCM. Hence, a bias correction method was applied for each daily precipitation and temperature dataset derived from CORDEX-Africa to minimize the systematic statistical deviation of climate input data from observational one before using them for any modeling and future climate change projection. Bias correction methods are assumed to be stationary, i.e. the correction algorithm and its parameterization for current climate conditions are assumed to be valid for future conditions as well.. (Teutschbein C., 2013).

The correction method used in the study was the power transformation. The method uses the exponential form  $aX^b$  that is used to adjust the statistical variance standard deviation and coefficient of variation of precipitation time series. The temperature was bias corrected by variance scaling method.

## **2.7. Performance Evaluation of Selected Climate Model**

The ability of RCMs to simulate climate conditions at a particular location can be evaluated using a variety of techniques (Flato, 2013). However, no individual evaluation technique or performance measure is considered superior; rather, it is combined use of many techniques and measures that provides a comprehensive overview of model performance. The outputs from RCMs are evaluated against observations using some of the statistical measures recommended by the World Meteorological Organization (WMO) as reported in (Gardon, 2000). These statistics include bias, coefficient of variation and Pearson correlation coefficient.

## **2.8. Hydrological Modeling**

A hydrological model involves the application of mathematical equations to model the physical response of a watershed to meteorological events in a catchment area. Effective watershed management and ecological restoration require a thorough understanding of hydrologic processes

in the watersheds. Spatial and temporal variations in soils, vegetation and land use practices make a hydrologic cycle a complex system, therefore, mathematical models and geospatial analyses tools are needed for studying hydrologic processes and hydrologic responses to land use and climatic changes.

A wide range of soil erosion models has been developed in the past few decades, each differing in terms of complexity, accuracy, inputs and outputs, approaches and their spatial and temporal scales. Generally, based on the physical processes simulated by the model, approaches to generate the data and data dependence, different kinds of models can be categorized into four widely-used models including:

**Empirical models:** area simulation of natural processes, mostly based on statistical observations, and relies on developed regression relationships. The computational processes of empirical models are simple, and their data requirements are less than those that are required for conceptual and physically-based models. The difficulty with using empirical models is the inability to be accurately used outside of the geographical area where their relationships were derived. Empirical models also may utilize unrealistic assumptions about the physics of the catchment system and, therefore, ignore the heterogeneity of some catchment inputs such as rainfall and soil types.

**Conceptual models:** are basically combinations of empirical and physically-based models and developed on the basis of spatially-lumped forms of water and the sediment continuity equation. These models usually unify general descriptions of catchment processes without specifying the process of interactions that would require very detailed catchment information. The value of each parameter in conceptual models is obtained through calibration against observed data, such as stream discharge and sediment concentration measurements.

**Physically-based models:** are generally based on the concept of the conservation of mass, momentum equations and energy as governing equations describing streamflow or overland flow, and conservation of mass equation for sediment. Basically, the parameters of physically-based models are independently measurable. Most of the developed physically-based soil erosion models that are being used worldwide to predict erosion and sediment yield are not 100% physically-based because mathematical expressions describing each individual process are developed based on the empirical/conceptual approaches.

**Hybrid models:** are mixtures of dynamic and empirical soil erosion evaluation techniques. The structure of hybrid models is usually physical or conceptual at the core, while the configuration of the model in the spatial and temporal scales is based on statistical observations and relies on developed regression relationships.

### **2.8.1. Hydrological Model Selection Criteria**

There are various criteria which can be used for choosing proper hydrological model for a specific problem. These criteria are always driven from research problems, since every project has its own specific requirements and needs. Furthermore, the spatial and temporal scales, suitability, accuracy, and validity of a model in catchment conditions, model assumptions, and data requirements should be considered by the user (Mohammad H. & Assefa M., 2018)

In this study spatially distributed model was used to assess the climate change impact on the sediment yield. The choice of these models depended on their moderate input data requirement (uses readily available inputs), ability to simulate the major hydrological processes and its availability (freely available). Moreover, the model was widely used in the basin for hydrological model studies and confirmed that SWAT model has been widely applied to the different sizes of the watersheds and its application all over the water resources, including the effect of climate and soil erosion (Neitsch, 2005).

The SWAT model was applied for predicting sediment yield in different area of Ethiopia, such as the study in fincha watershed which examines the applicability of the SWAT model in a watershed with a high sediment runoff modulus. The result of the model calibration and validation showed a reliable estimate of monthly sediment yield, which mean the predicted and observed sediment yield matched well. The study showed that the model is capable of predicting sediment yield (Ayana, 2012).

### **2.8.2. Soil and Water Analysis Tool (SWAT)**

Soil and Water Assessment Tool hydrological model is a watershed scale model developed by Dr. Jeff Arnold for United States Department of Agriculture (USDA) in Agriculture Research Service (ARS). It is a physically-based, conceptual, and computationally efficient model that operates on a daily time step at basin scale (Arnold J. , 2000).The model operations involve the division of a

watershed into sub-basins by overlaying land-use, soil map, and Digital elevation DEM, then further sub-divided into lumped units called hydrologic response units (HRUs). HRUs are defined as homogenous spatial units characterize by common climate, land use, geomorphology and hydrological properties.

The model requires comprehensive input data and currently being applied for climate change studies worldwide with reported success and some of them are listed here:

(Shrestha, et al., 2012) used the Soil and Water Assessment Tool (SWAT) model in the Nam Ou Basin in northern Laos to predict the impact of climate change on sediment yield and reported changes in an annual sediment yield. It was concluded that SWAT model simulated well historical and future sediment yield and changes in climate change.

(Adem, 2015) Studied the climate impact assessment on sediment yield was done by Soil and Water Assessment Tool (SWAT) hydrological model. SWAT model performance in simulating daily sediment yield for the study area was satisfactory. (Adeoguni, Sule, & Salami, 2015) Studied an evaluation of the SWAT model in simulating sediment yield in the watershed of Lake Jebbain Nigeria revealed satisfactory performance for streamflow and sediment yield predictions in the watershed. (Luke, Richard, & Kirk, 2015) Analyzed the effect of climate change on watershed yield by SWAT model and the model simulated well. Therefore, SWAT model is well for application of climate impact assessment on sediment.

### **3. MATERIAL AND METHODS**

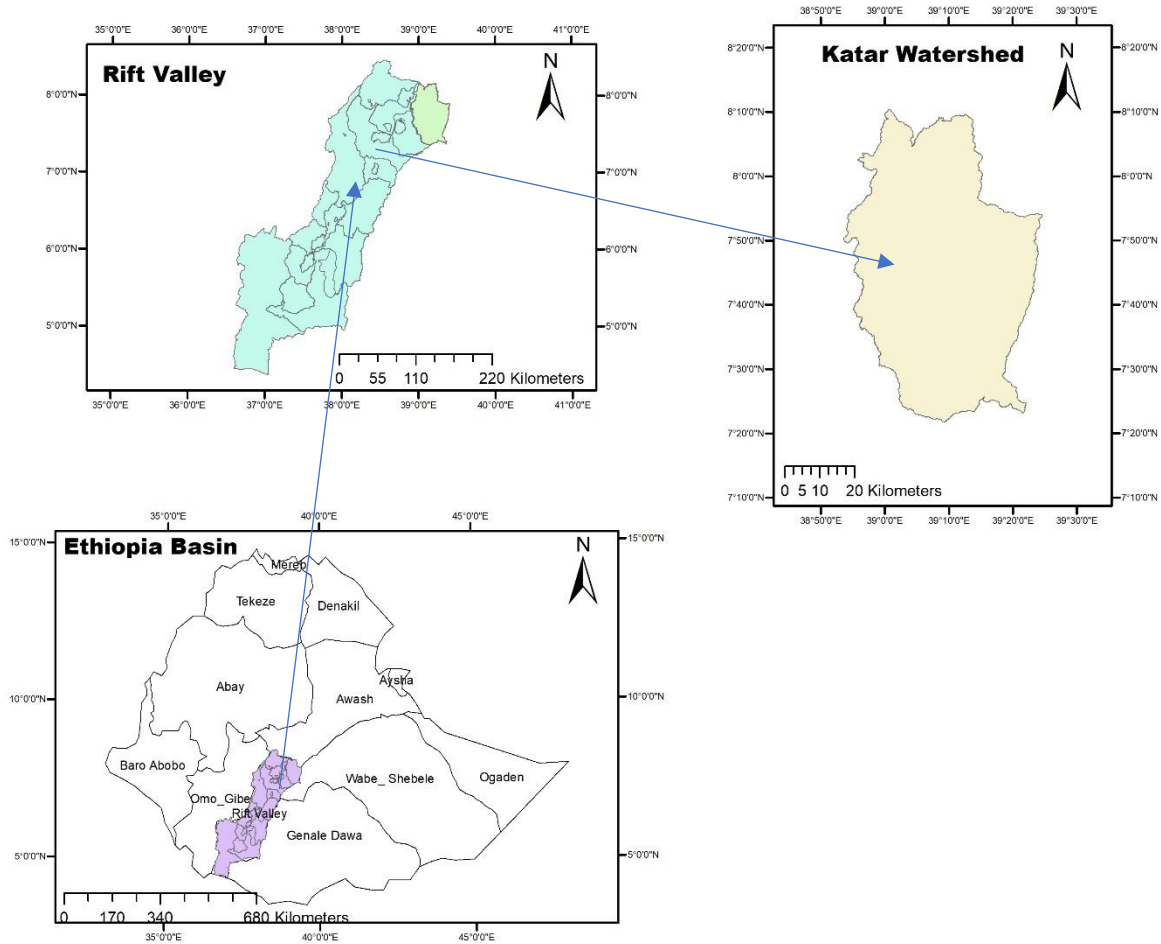
#### **3.1. Description of the Study Area**

##### **3.1.1. General**

The Central Rift Valley Basin contains four major lakes, namely: Ziway, Shala, Abiyata and Langano. It also has perineal rivers, namely: Meki, Katar, Bulbula and Harakalo. Bulbula and Harakalo rivers connect lake Abiyata to Ziway and Langano lakes respectively but these lakes have different characteristics. Among the lakes, Lake Shala is the deepest and closed lake, and is highly alkaline so this makes the water not suitable for irrigation purpose. In general, from the existing lakes only Ziway Lake is a fresh water lake. The catchment of lake Ziway covers about 7300 km<sup>2</sup> area and the surface area of the lake is 440 km<sup>2</sup>. The Katar and Meki rivers are major rivers that contribute annual streamflow and sediment to the Lake.

##### **3.1.2. Location**

The study area, Katar River catchment is sub catchment of Ethiopian Central Rift Valley Basin. This watershed is located in the Oromia Regional State of Ethiopia and northern part of Central Rift Valley catchment in the part of the Ziway Shala basin. In terms of geographic coordinate system, the watershed lies between 7°21'34'' to 8°9'55'' North latitudes and 38°53'57'' to 39°24'46'' East longitudes. The Katar River and its tributaries start from the eastern parts of mountains Chilalo, Galema and Kakka of Arsi Zone and drains to Lake Ziway. Topographically, the Katar catchment shows variation with altitude ranging from around 1637m near Abura (at gauging Station) to about 4213m above mean sea level on the high volcanic ridges along the eastern watershed. The watershed area is about 3304 km<sup>2</sup> up to the outlet.



**Figure 3-1: Location of Katar Watershed**

### 3.1.3. Topography

The topographic features of Katar catchment vary between the outlet (near Lake Ziway) and on the high volcanic ridges along the eastern watershed with altitude range from 1646 up to 4171 masl. The gradient of the river is generally steep throughout its course to Lake Ziway, and it is often increase up to 50m below ground surface.

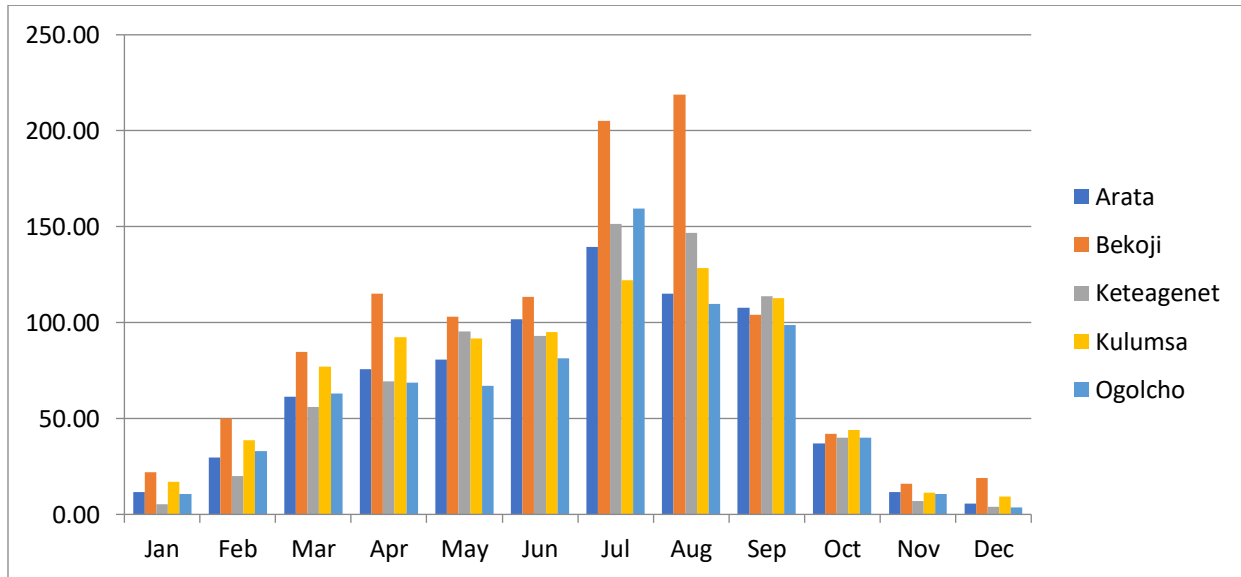
### 3.1.4. Climate

The traditional climate classification of the country which is based on altitude and temperature shows the presence of five climatic zones namely: Wurch (cold climate at more than 3000m altitude), Dega (temperate like climate ;highland with 2500-3000 m altitude), WoinaDega ( warm 1500-2500m altitude), Kola (hot and arid type, less than 1500 m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001). According to this classification, the study area falls in Wurch, Dega and WoinaDega climate zone. The movement of the Inter-Tropical Convergence

Zone (ITCZ) throughout the year mainly determines the climate pattern of the Katar River Basin. There are three seasons in the Katar River Basin based on the movement of ITCZ, the amount of precipitation timing. The three seasons namely wet summers (Kiremt), which is the main rainy season (June-September), dry period (Bega), which is the dry season (October-February) and warm period (Belg), and the small rainy season (March-May). Therefore, the precipitation was categorized under bi-modal pattern.

**Rainfall**

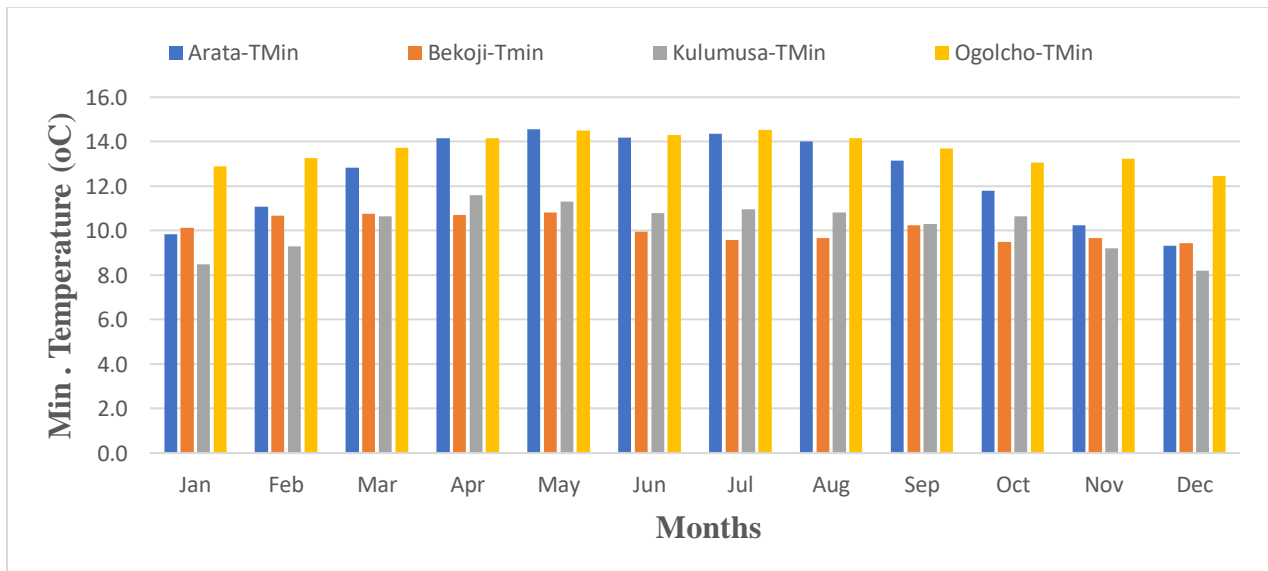
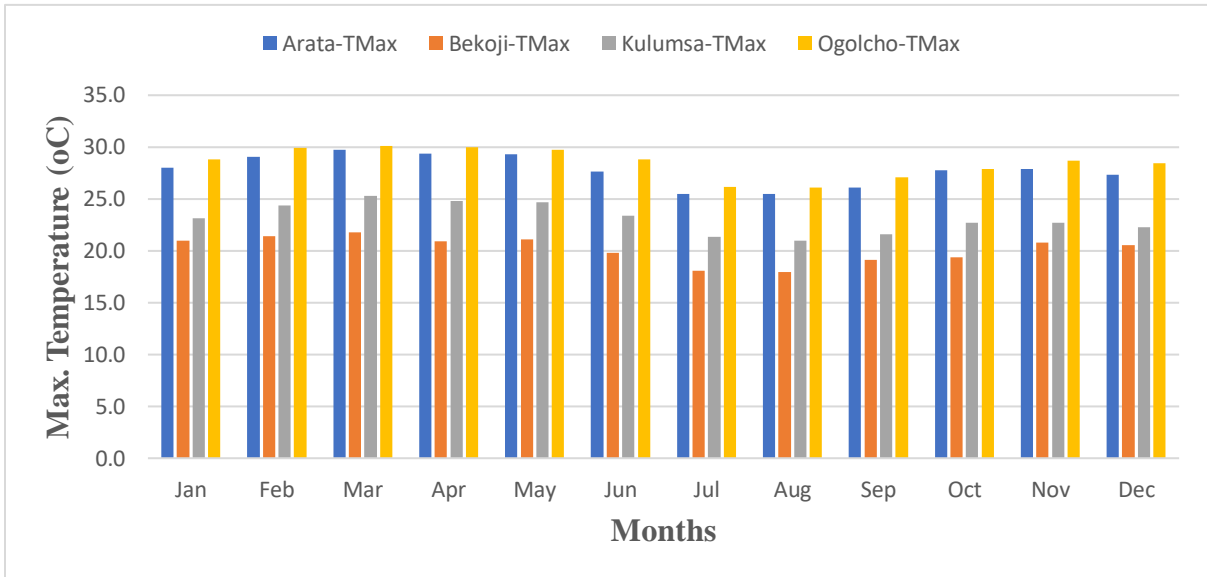
The rainfall distribution in the Katar River Catchment varies from higher altitudes in the mountainous regions to the low land areas. The monthly rainfall distributions of the study area indicate that July, August and September are the wettest months of the year. Five rainfall stations used in the study area which are collected from NMSA for a period of 31 years (1987-2017) show a mean annual rainfall amount range between 745mm in Ogolcho and 1093mm in Bekoji.



**Figure 3-2: Average Monthly Rainfall of Different station in Katar watershed (1987-2017)**

**Temperature**

According to the data of the four stations, the mean annual maximum temperature of the study area varies from 21°C to 30.1°C: while the mean minimum temperature varies from 8.2°C to 14.6°C.



**Figure 3-3: Mean Monthly Maximum and Minimum Temperature for the stations found in the study area (1987-2017)**

### 3.1.5. Land Use

The land cover for Katar watershed is mainly characterized by dominantly cultivated, grass land, shrub land, and forest according to the Ministry of Water, Irrigation and Electricity land cover classification. The main crops produced in this scheme are onion, cabbage, potato, sugarcane, carrot etc. Crops like teff, maize and bean are also cultivated during the rainy season. Land

degradation, soil erosion and reduction of soil fertility are seen inside the basin due to cultivation of marginal lands and lack of land use management system (MOWR, 2010).

### **3.1.6. Soil**

According to the Ministry of Water Irrigation and Electricity the major dominant soil types in the Katar watershed are Vertosols, Nitsols, Andosols, Cambisols, Fluvisols and Luvisols Mentioned in Characterization. Based on the classification the following soil types are considered to be the major dominant soil in the study area. Pellic Vertisols covers about 49.44 %, Chromic Luvisols 9.57%, Eutric Cambisols 0.42%, Eutric Nitsols 2.98%, Eutric fluvisols 0.16%, Vitric Andosols 2%, Mollic Andosols 8.68%, VerticCambisols 10.08% and Orthic Luviols 15.97%.

### **3.2. General Methodology**

The general methodology of this study is depending on the data which are collected from different organization and also site observation. In order to achieve the objectives of the study all the necessary data were collected from meteorological stations, hydrological stations, and respective organizations and prepared DEM for the study area.

Meteorological data of Abura gauging station like daily precipitation, maximum and minimum temperature, sunshine hours, relative humidity and wind speed was collected from NAMA. Hydrological data including streamflow were collected from MoWIE of Hydrology Department. Daily stream flow data and sediment data at Abura gauging station is used for calibration and validation of SWAT model for this study at the outlet.

Regionally down scaled climate change data also provided from Coordinated Regional Downscaling Experiment. The data derived from HadGEM2-ES Global climate model outputs that are dynamically down scaled by the CORDEX-Africa program using regional model for the representative concentration pathway scenario - RCP 4.5 projection scenario.

Arc GIS 10.3 was used to analyze spatial data including preparing base maps and other maps that serve as inputs to the other models used in this study. The study required different materials and models to arrive at the stated objectives. In this study one basic hydrological modelling system is used to meet all objectives.

### 3.3. Data collection

The data used for this research were varied in types and sources. Daily climate variables of (Rainfall, temperature, Relative humidity, Wind speed and Sunshine hour) were sourced from National Meteorological Service Agency of Ethiopia (NMSA) while Daily discharge and sediment of Katar River at Abura gauging Station were obtained from Ministry of Water, Irrigation and Electricity (MoWIE).

Regional Climate Model data from Coordinated Regional Downscaling Experiment (CORDEX) were downloaded from the download node (<https://esgf-data.dkrz.de/search/cordex-dkrz>). The climate model data includes simulated historical and projected temperature and precipitation data for 1951-2005 and 2006-2100 respectively under RCP4.5 scenario.

**Table 3-1: Input Data used for this study**

S.NO	Metrological Data		
1	Data type	Time Step	Data Sources
	Rainfall	1987-2017	NMSA
	Temperature		
	Wind Speed		
	Sun Shine Hour		
	Relative Humidity		
2	Hydrological Data		
	Stream flow data	1987-2007	MOWIE
	Sediment data		MOWIE
3	Spatial Data		
	Soil		MOWIE
	Land Cover		Ethio-GIS
4	Climate Scenarios Data		
	CORDEX-RCP Climate Data	2021-2050(2030's) 2051-2080(2060's)	CORDEX-Africa

### 3.3.1. Metrological Data

The Metrological data collected for the study area was from 7 stations was collected from National Meteorological Service Agency (NMSA). The number of meteorological variables collected varies from station to station. Some stations contain all climate variables of: precipitation, maximum and minimum temperature, Humidity sunshine hours and wind Speed but other stations may only have climate variables of rain fall and Temperatures Data. SWAT requires daily meteorological data that either can read from a measured data set or generated by a weather generator model. Data of daily precipitation, maximum and minimum temperature, sunshine hours, relative humidity and wind speed collected for five meteorological stations within and around the watershed based on the quality and the availability of long year recorded data. The stations namely; Arata, Ketera Genet, Kulumsa, Bekoji and Ogolcho. The location of the stations and the detail of the data collected presented in the figure and table.

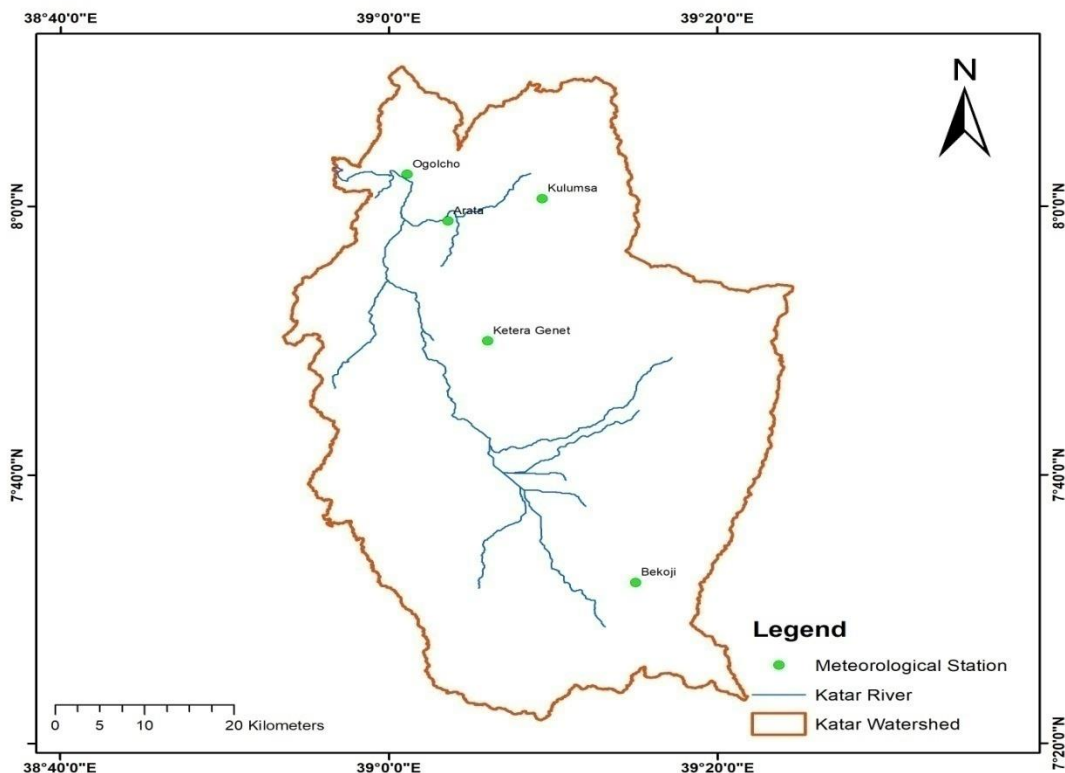


Figure 3-4: Meteorological Station in Katar Watershed

The observed data for a period of 30 years (1987–2017) were used for this study. The table show all meteorological stations used for the study and the data available in the stations.

**Table 3-2: Available Data of Meteorological station around study Area**

Stations	Latitude (°C)	Longitude (°C)	Rainfall	Max temp	Min temp	Sunshine hours	Relative Humidity
Arata	7.98	39.06	Yes	Yes	Yes	No	No
Bekoji	7.53	39.25	Yes	Yes	Yes	NO	No
Keteragenet	7.83	39.10	Yes	No	No	No	No
Kulumsa	8.01	39.16	Yes	Yes	Yes	Yes	Yes
Ogolcho	8.04	39.02	Yes	Yes	Yes	No	No

### 3.3.2. Hydrological Data

#### I. Stream Flow Data

Daily flow data for Katar River for a period of 21 years from 1987-2007 recorded at ABURA gauging station was collected from Ministry of Water Irrigation & Energy (MoWIE). The missing discharge data was filled using linear regression. SWAT CUP used this data values for sensitivity analysis, calibration and validation of the model by comparing the observed values and simulated flow data.

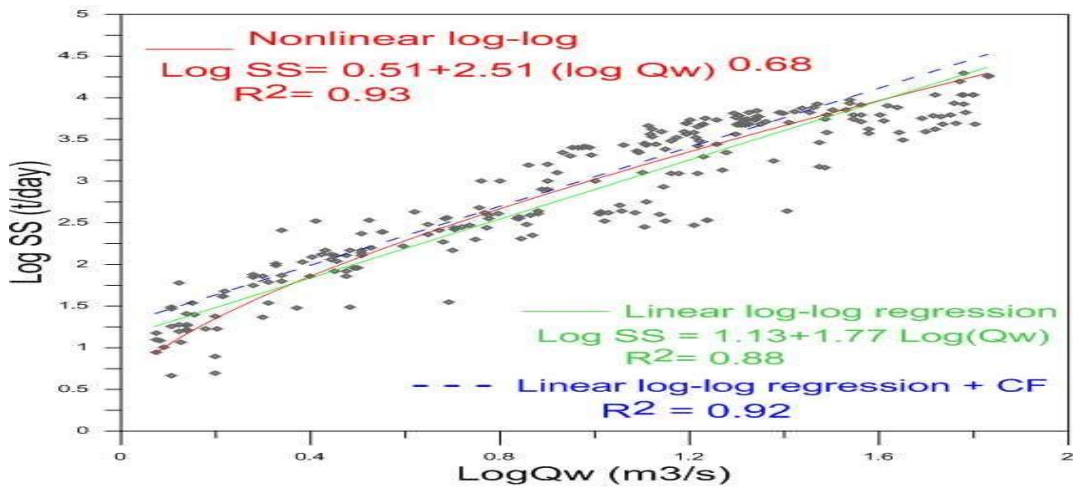
#### II. Sediment Data

Few measurements of sediment data were collected from Ministry of Water Irrigation & Electricity (MOWIE) with the corresponding streamflow data at Abura gauging station. Due to the scarcity of continuous sediment data, the sediment rating curve was necessary to develop the relationship between daily streamflow and sediment data measured at the outlet of the Katar watershed. It displayed the rate of sediment transport as a function of streamflow (Julian, 2010) and equated as

$$\log Q_s = a + b * \log(Q_w) \dots\dots\dots 3-1$$

Where,  $Q_s$  is suspended sediment(ton/day),  $Q$  is streamflow(m<sup>3</sup>/s), and  $a$  and  $b$  are regression coefficient and exponent, respectively.

Sediment rating curve expresses the average relation between discharge and suspended sediment concentration for a certain location. For this research the curve developed by Aga et al.,(2019) were used. The rating curve was developed with al linear log–log regression, normal linear log–log regression with correction factor, and non-linear least squares regression methods were established and the most appropriate sediment rating curve was selected based on goodness-of-fit.



**Figure 3-5: Sediment rating curve of the Katar River at the Abura gauging station (Source: (Alemu O. Aga et al., 2019))**

The goodness-of-fit of the rating curves were evaluated by using coefficient of determination ( $R^2$ ), Nash–Sutcliffe efficiency (NSE), root mean square error (RMSE) observations standard deviation ratio (RSR) and percent bias (PBIAS).

**Table 3-3: Developed rating curves (source: (Alemu O. Aga et al., 2019))**

Rating curve methods	Abura station	
Linear log-log Regression $\text{Log (SS)} = a + b * \text{log (Q}_w\text{)}$	$R^2$	0.88
	NSE	0.85
	RSR	0.38
	PBIAS	0.74
Linear log-log Regression + CF	CF	0.15

$\text{Log (SS)} = a + b \cdot \log(Q_w) + CF$	R <sup>2</sup>	0.92
	NSE	0.83
	RSR	0.41
	PBIAS	-4.23
Non-Linear log-log Regression $\text{Log (SS)} = a + b \cdot (\log Q_w)^c$	R <sup>2</sup>	0.93
	NSE	0.87
	RSR	0.36
	PBIAS	-0.61

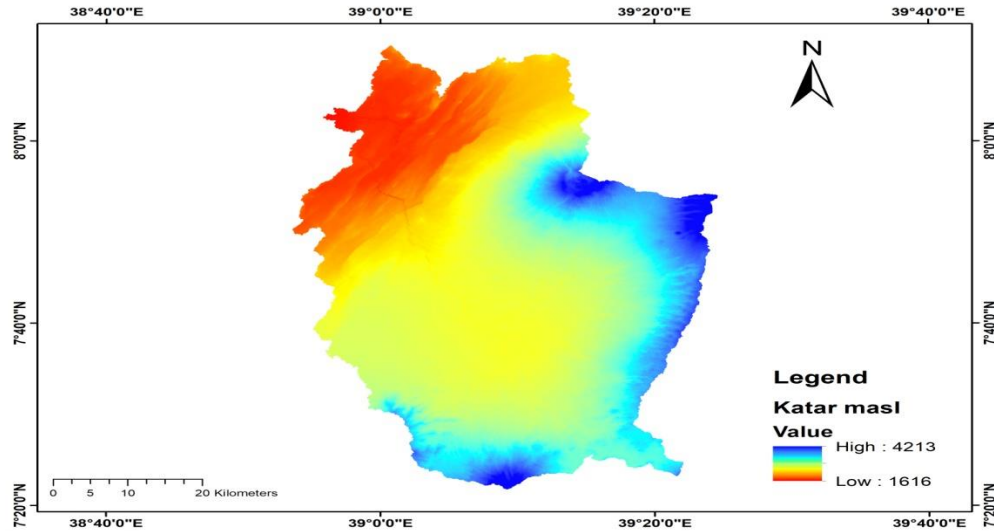
According to the result the most appropriate method compared with their magnitudes, for all statistical parameters developed, the non-linear method is better than the others.

$$\log(ss) = 0.51 + 2.51(\log Q_w)^{0.68} \dots\dots\dots 3-2(\text{source (Alemu O. Aga et al., 2019)})$$

### 3.3.3. Spatial data

#### Digital Elevation Model (DEM)

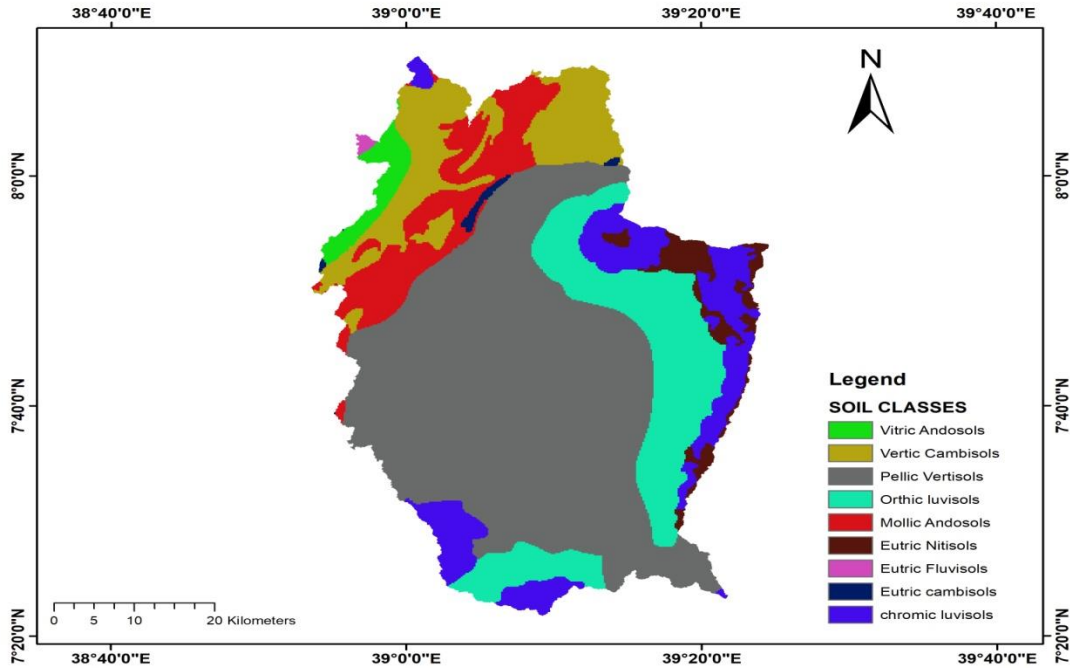
The Digital Elevation Model (DEM) is digital representation of a topographic surface which describes the elevation of any point in a given area at a specific spatial resolution. DEM are used to delineate the watershed in to a number of sub watershed or sub basins and used to analyze the drainage pattern of the watershed also it is the basic input of SWAT hydrologic model. The raw DEM was processed & projected using ARCGIS10.3 with a resolution of 30\*30m.



**Figure 3-6: Digital Elevation Model for Katar Watershed**

#### **Soil Data**

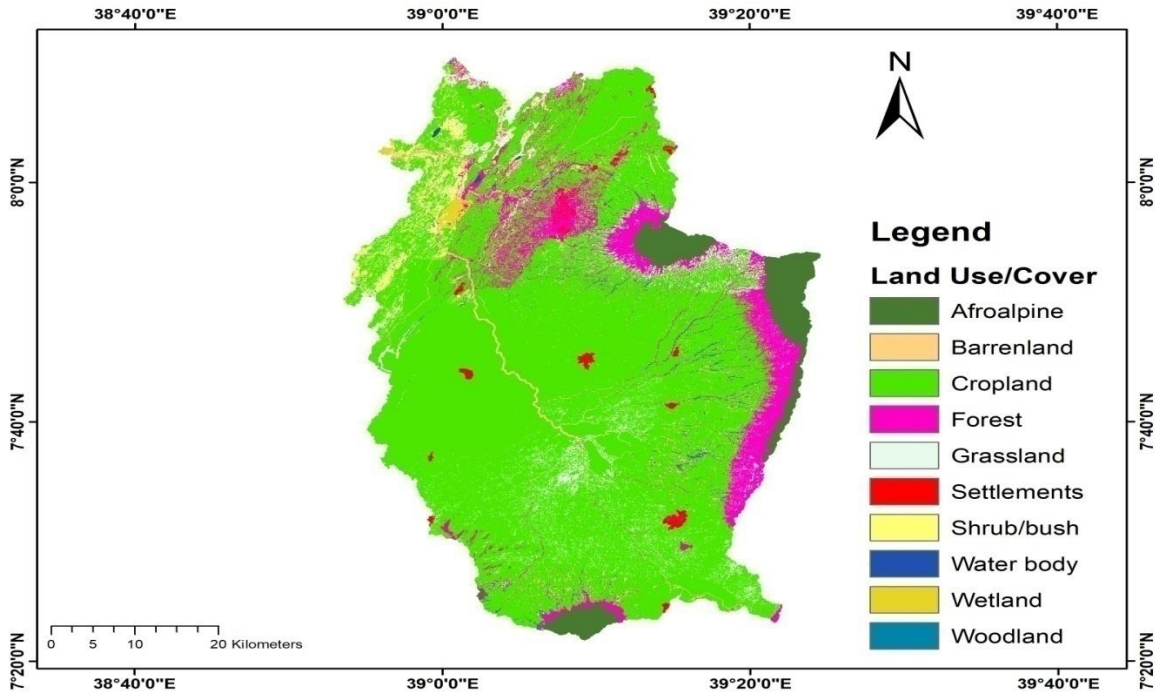
SWAT model basically needs the soil data to define HRUs which concerning catchment's soil physical and chemical properties. The soil map of the study area obtained from Ministry of Water, Irrigation and electricity GIS department. Based on the data acquired, the soil map of the watershed was developed by overlying the soil map shape file during HRU definitions. Using this shape file, soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers were extracted for each Major Soils types.



**Figure 3-7: Soil Map of Katar Watershed**

#### Land Use / Land cover Data

Land use / Land cover are the spatial input data required by SWAT model. The LULC data combined with the soil cover data generates the hydrologic characteristics of the basin or for the study area, which in turn determines the excess amounts of precipitation, recharge to the ground. The LULC data combined with the soil cover data generates the hydrologic characteristics of the basin or for the study area, which in turn determines the excess amounts of precipitation, recharge to the groundwater system and the storage in the soil layers. The land use map (2016) of the study area 30m\*30m resolution obtained from Ethio-GIS. Katar land use data were prepared as per requirement of SWAT model and reclassified using SWAT2012 land use database.



**Figure 3-8: Land use and Land Cover Map of Katar Watershed**

### 3.3.4. CORDEX-RCP Climate Data

Down scaled rainfall and temperature (minimum and maximum) projected climate data for historical (1951–2005) and future (2006–2100) period have been obtained from CORDEX-Africa database and is available at a spatial resolution of (approximately 50 km × 50 km). CORDEX is a program sponsored by World Climate Research Program (WCRP) for using the latest generation of regional climate models (RCMs). CORDEX data projections are presented showing possible future regional climate change scenarios on several domains of the worldwide including East Africa.

In this study, down scaled CORDEX-Africa precipitation and temperature for historical (1951–2005) and future (2006–2100) climate projections for RCP 4.5 scenarios period were obtained from International Water Management Institute (IWMI). The climate data contains daily values of Precipitation, Maximum and Minimum Temperature but the other climate variables were assumed to be constant for the future time period. The data is dynamically down scaled from regional climate model by changing GCMs into RCMs under representative pathway (RCP4.5).

Outputs from GCM for the 1986–2005 (baseline), 2021–2050 (2030's) and 2051–2080 (2060's) used to generate climate change scenarios. The 2030's and 2060's correspond to short-term and

long-term future, respectively. Climate scenarios information was then transferred to the hydrological model for analysis of the effect of climate change on sediment yield.

### 3.4. Data Analysis

#### 3.4.1. Filling Missing for Rainfall

Some stations may have short breaks in the records because of absence of the observer or because of instrumental failures further the personal to take readings are either too few or unreliable this problem to many developing countries. Before the observation data for both climate and discharge were used for analysis, data quality control was carried out to get rid of errors in the result. This is because consistency of data is an indispensable perquisite in any analysis. Inadequate climate and discharge data results in unrealistic output. There are methods to fill in missing data: these are arithmetic mean method, normal ratio method and inverse distance weighing method.

In this study Arithmetic mean method and Normal ratio method were used. Arithmetic mean method used when the normal annual rainfall of the missing station is within 10% of the normal annual rainfall of the surrounding stations (Subramanya, 2008). The general formula for computing missing precipitation by Normal ratio method is:

$$P_x = (P_1 + P_2 + \dots + P_n) * \frac{1}{n} \dots\dots\dots 3-3$$

Where  $P_x$  is missing precipitation for the station

$P_1, P_2, \dots, P_n$  are precipitations of index stations

$n$  is the number of index stations

The general formula for computing missing precipitation by Arithmetic mean method is:

$$P_x = \frac{N_x}{n} \left( \frac{P_1}{N_1} + \frac{P_2}{N_2} \dots + \frac{P_n}{N_n} \right) \dots\dots\dots 3-4$$

Where  $P_1, P_2, \dots, P_n$  are the rainfall data of index stations

$N_1, N_2, \dots, N_n$  the normal annual rainfall of index stations

$P_x$  and  $N_x$  the corresponding values for the missing station  $x$  in question and

$n$  is the number of stations surrounding the station  $x$

**Table 3-4: Percent of missing precipitation in study area**

SN	Stations	% of missing
1	Arata	5.57
2	Bekoji	22
3	Keteragenet	18.5
4	Kulumsa	8.72
5	Ogolcho	9.36

**3.4.2. Checking Homogeneity and Consistency of Data**

**a. Homogeneity of data**

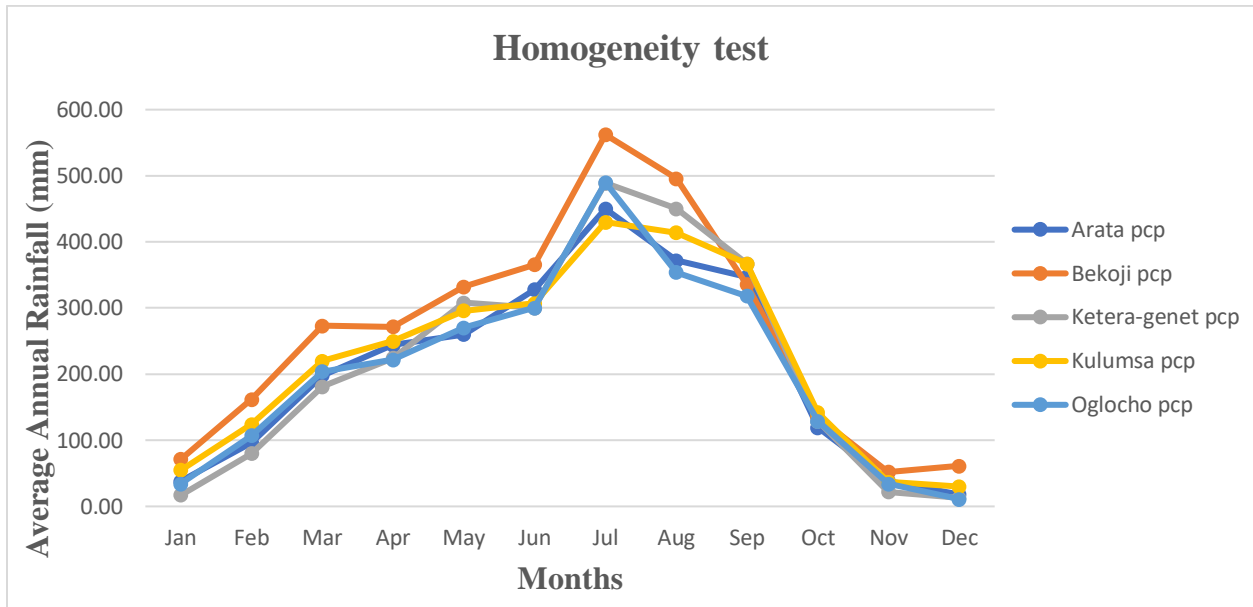
Homogeneity analysis was used to separate a change in the statistical properties of the time series data which was caused by either natural or man-made like alterations to land use and relocation of the observation gauging station. A time series of observational data is relatively consistent and homogeneous if the periodic data are proportional to an appropriate simultaneous period. One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall records. In this method the recorded precipitation data is plotted to compare the stations with each other. Graphical comparison of the rainfall data was done by plotting the time series of monthly rainfall data. Non-dimensional values of the monthly precipitation of each station can be computed by the following equation (3-4) (Mucuen, 1998).

$$PI = \frac{Pi}{P} * 100 \dots\dots\dots 3-5$$

Where: -PI = Non dimensional value of PP for month i

P= over years averaged monthly precipitation for the station i

Pi = the over years average yearly precipitation of the stationi

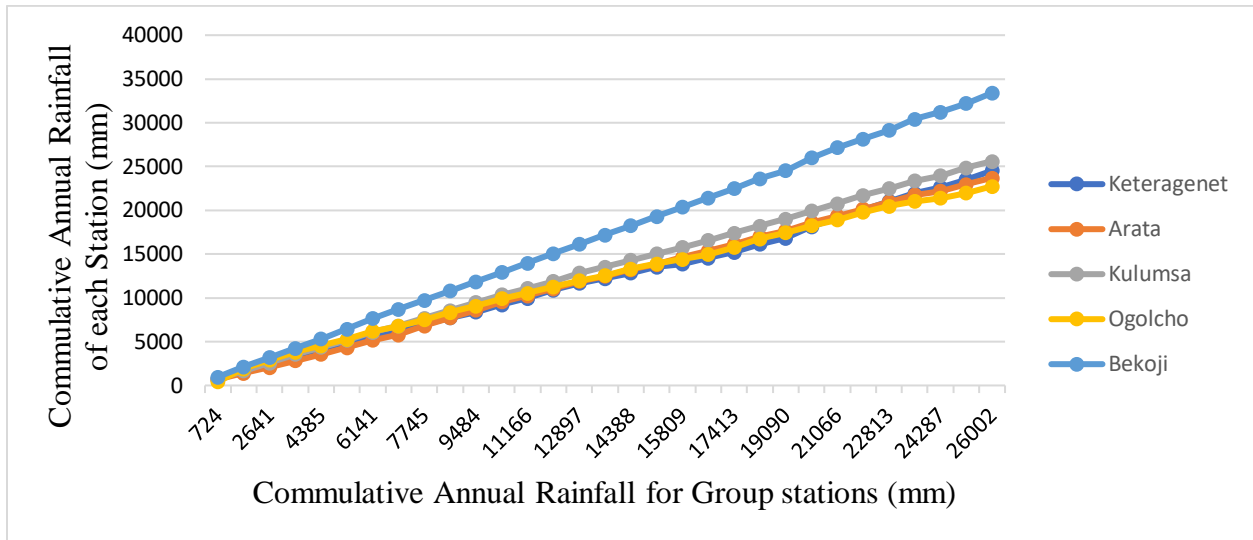


**Figure 3-9: Homogeneity tests for rainfall stations**

**b. Consistency of data**

The most common method of checking for inconsistency of recorded data is Double Mass Curve analysis (DMC). To assess the data consistency the Double Mass Curve analysis has been used for the period of 1987-2017. Cumulated values of a given station are plotted against accumulated values of the average value of other stations, over the same period of time through the double mass curve in homogeneities in the time series (in particular jumps) can be investigated, if for a change in observer record, in rain-gauge type, etc. This is indicated in double mass plot, showing an inflection point in the straight line (Mucuen, 1998).

Rainfall data reported from meteorological stations may not be always consistent due to changing the location of gauging station or other difficulty in the area. This difficulty affects the quality of data which have influence on the result. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of rainfall record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time the significant change took place. The selected stations show similar periodic pattern of records (Figure 3-10) and stations used in this study have not undergone a significant change during the base line period (1987-2017) of the study.



**Figure 3-10: Consistency test graph for all the stations**

### 3.4.3. Areal Precipitation

The most common methods used for areal parameter estimation are station-average method, arithmetic mean, grid point, Thiessen polygon method and Isohyetal method. In order to achieve accurate estimation of the spatial distribution of rainfall the Thiessen polygon method was considered because this method is the most important in engineering praxis especially in engineering hydrology. The method weighs each gauge in direct proportion to the area it represents of the total basin without consideration of topography or other basin physical characteristics. Station weights are scalar factors used to transform point precipitation observed at this rainfall gauging stations into an associated mean precipitation over an area that the station data are assumed to represent (Subramanya, 2008).

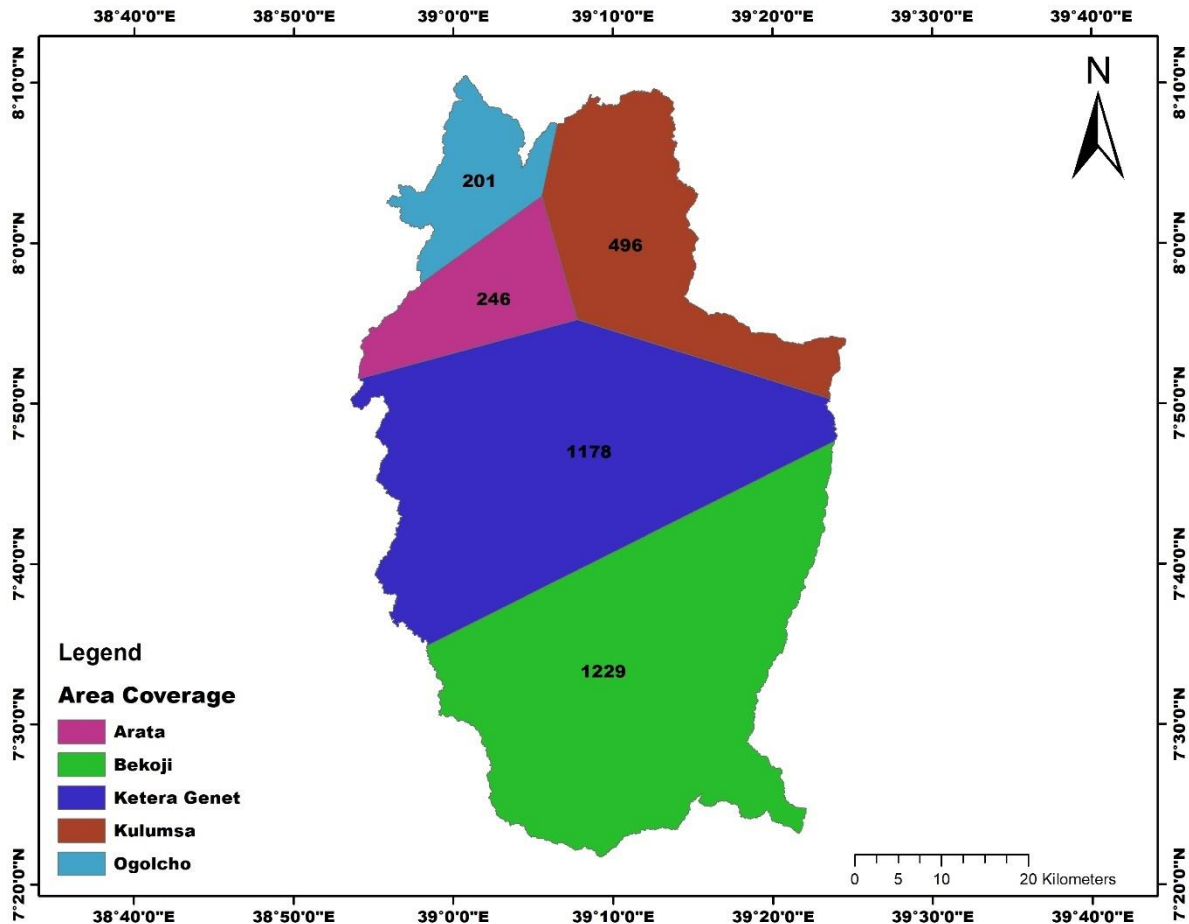
$$P_x = \frac{\sum_{i=1}^n A_i P_i}{A} \dots\dots\dots 3-6$$

Where,  $P_x$ = Areal average rainfall

$P_i$  = Rainfall measured at station  $i$ ,

$A_i$ = Area of sub-region of  $i$  station and

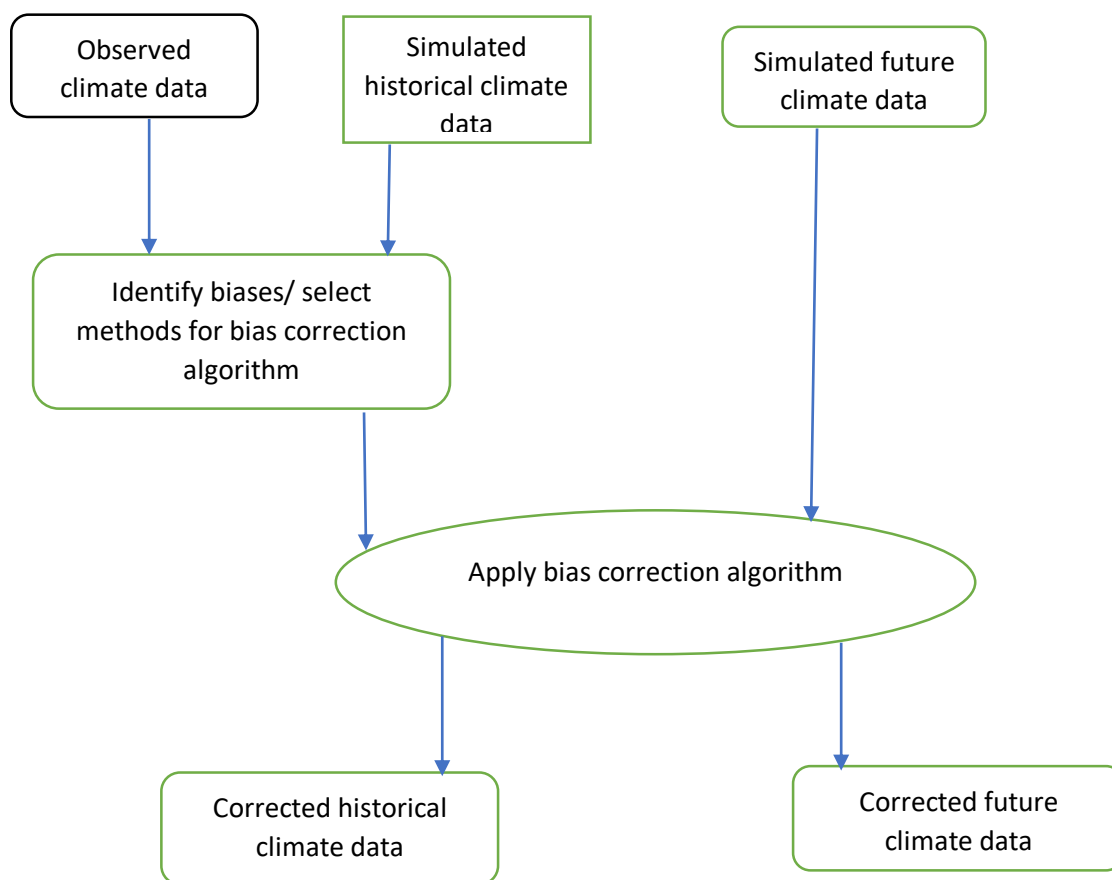
$A$  = total area of sub-basin



**Figure 3-11: Areal coverage of each Stations**

#### 3.4.4. Bias Correction for CORDEX Climate Data

Bias correction procedures are used to minimize the discrepancy between observed and simulated climate variables on a daily time step so that hydrological simulations driven by corrected simulated climate data match simulations using observed climate data and employ a transformation algorithm for adjusting RCM output. The underlying idea is the identification of possible biases between observed and simulated climate variables, which is the basis for correcting both control and scenario RCM runs. Bias correction methods are assumed to be stationary, i.e., the correction algorithm and its parameterization for current climate conditions are also valid for future conditions. For this particular study, CMhyd (Climate Model data for hydrologic modeling) software program was used to both extract climate model variables from ASCII file and correct biases of selected climate variables.



**Figure 3-12: Bias correction frame work**

For bias correction of adjusting RCM simulations were used, Power transformation method (PT) for precipitation that perfectly match the monthly average of corrected values with observed ones and Variance scaling (VS) to correct temperature. First the correction for climate date was made for Historical period with that of the Observed data for the period of (1987-2017) then the correction applied for future time under each climate scenarios.

### **Power Transformation for precipitation**

Power transformation is a nonlinear method which corrects both mean and variance of precipitation (Min Luo, 2018). In this study the RCM data of precipitation was bias corrected by using Power Transformation Method because it corrects the mean, variance and coefficient of variation (CV), leads to a better copy of observed precipitation. The precipitation is usually varied spatially and highly nonlinear in nature. The equation used for Power transformation method is:

$$P^* = a * P^b \dots\dots\dots 3-7$$

Where, P\* is corrected precipitation, P is simulated precipitation. The parameters a and b are estimated by equalizing the coefficient of variation (CV) of the corrected simulations Pb and CV of the observed values, both from the calibration/optimization period. Parameter b was first determined iteratively by ensuring that the CV of the corrected precipitation matched that of the observed. Then parameter a, which depends on the value of b, was determined by matching the means of the corrected and observed precipitation.

**Variance Scaling for Temperature**

The PT method is an effective method to correct both the mean and variance of precipitation, but it cannot be used to correct temperature time series, as temperature is known to be approximately normally distributed. The VARI method was developed to correct both the mean and variance of normally distributed variables such as temperature (Min Luo, 2018). Temperature is normally corrected using the VARI method with:

$$T_{corr} = T_{mean\ obs} + \left(\frac{\delta T_{obs}}{\delta T_{rcm}}\right) * (T_{rcm} - T_{mean\ rcm}) \dots\dots\dots 3-8$$

Where T<sub>corr</sub>: the corrected daily temperature, T<sub>rcm</sub>: the uncorrected daily temperature from RCM model and T<sub>obs</sub>: the observed daily temperature while T<sub>meanobs</sub> is mean observed temperature and T<sub>mean<sub>rcm</sub></sub> is mean simulated temperature.

**3.4.5. Model Performance Evaluation of Climate**

The evaluation of the climate model’s accuracy is required for assessment of climate change impact. For this reason, in this study, the model’s performance was evaluated using statistical measures such as Bias, Coefficient variability (CV) and Correlation (CC). The large bias indicates that the observed rainfall amount largely deviates from RCP rainfall amount also the negative bias indicates under estimation while the positive indicates overestimation. The correlation used to evaluate the linear relationship between the observed and simulation rainfall amount. Calculated coefficient variability evaluates how well the rainfall variability well captured (Haile, 2015).

$$Bias = \left(\frac{Rmrcm - Rmobs}{Rmobs}\right) * 100 \dots\dots\dots 3-9$$

$$CV = \left( \frac{\delta R}{Rm} \right) * 100 \dots\dots\dots 3-10$$

$$CC = \frac{\sum_{i=1}^N (Robs - Rmobs)(Rrcm - Rmrcm)}{\sqrt{\sum_{i=1}^N (Robs - Rmobs)^2 (Rrcm - Rmrcm)^2}} \dots\dots\dots 3-11$$

### 3.5. Model Selection

Selecting the best and appropriate model is an essential part in any research work. There are various criteria to choosing the correct hydrological model for specific problem. These criteria are always research dependent, since every research has its own specific requirements and needs. One commonly accepted approach to estimate the effects of climate change in reservoirs or water resources is with watershed or hydrological simulation models. The criteria of Cunderlik and Simonovic (2007) used for selecting the hydrological model such as required output of the model, availability of input data, prices and availability of the model, the model structure. Considering the listed criteria and limitations of each models like, SWAT from HEC-HMS, HEC-HMS more inclines to concepts plus it is lumped type of model but SWAT is not lumped because SWAT works at level of Hydraulic Response Unit but HECHMS works at the level of Sub Basin.

In countries like Ethiopia, especially there is a shortage of long-term observational data series to use sophisticated models; SWAT is a useful tool to model watersheds that do not have any monitoring data because it is less demanding on input data (Arnold J. , 1998). The model SWAT is public domain; readily and freely available.

### 3.6. Basic Equations and Concepts of SWAT

A hydrological model Soil and Water Assessment tool (SWAT) was selected as the best modeling tool owing to many reasons. First and for most it is a public domain model and it is used for free. Secondly in countries like Ethiopia, there is a shortage of long-term observational data series to use sophisticated models; however, SWAT is computationally efficient and requires minimum data. Besides, several researchers have used SWAT model in Ethiopia. The methodological steps which were carried out in SWAT model were described in the following section.

#### 3.6.1. Watershed Delineation

The watershed delineation is primary made on the sub-basin level, and is determined based on the relative spatial location of each sub-basin, the direction of hydrologic flow and the natural divisions of stream networks determined by elevation. The watershed delineation carries out

advanced GIS functions to aid the user in segmenting watersheds into several hydrologically connected sub-watersheds for use in watershed modeling with SWAT.

The initial stream network and sub basin outlets were defined based on a drainage area threshold (DEM- based). After creating initial stream networks and sub basin outlets were defined, the final stream network and outlet configuration used for modeling were refined by outlets.

### **3.6.2. Determination of Hydrologic Response Units (HRU's)**

After watershed delineation of Katar watershed was completed, the Hydrologic Response Units (HRU) were defined in Arc SWAT by overlaying soils, land use and slope classes and divides each sub-basin into hydrologic response units, with specific combinations. The layer produced by this process is crucial to the ultimate analysis performed by the SWAT model, because it determines the land, soil and slope category assigned to each HRU. This category determines how land will respond to precipitation, runoff, infiltration and other hydrologic processes during the simulation. Each sub-basin can then have one or more major HRUs defined within it.

The required land cover and soil data is accompanied by preparing a look-up table with attribute information for each specific land cover and soil type, and provides these tables for each layer. The last layer needed for the HRU Analysis setup is slope, which is determined from the DEM supplied during watershed delineation. Once each layer is loaded, they must be overlaid to determine the HRU features. For every unique combination of slope, land use and soil class than a HRU will be created, although within the study area there can be multiple HRUs with the same combination (ARCSWAT user manual interference for SWAT2009).

### **3.6.3. Weather Generator Data Preparation**

Long periods of daily weather data are required for hydrological model simulation. But in most of developing countries such data are either incomplete or records may not have sufficient length. Weather generators solve this problem by generating data having the same statistical properties as the actual ones.

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. SWAT has a built-in weather generator called WGEN that used to fill the gaps, filled with identifier 99. But in this research the missing climate variables data was

filled manually using suitable statistical approach. Using four stations the SWAT model generates representative weather variables for Katar watershed.

### 3.6.4. Hydrologic Water Balance

Water balance is the driving force behind everything that happens in the watershed. In SWAT simulation of hydrology of the watershed can be separated in to two major divisions. The first division is the land phase of hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings in to the main channel in each sub basin. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation and detailed description of all equation used for sediment yield and Runoff estimation are found SWAT input /output documentation (Neitsch, 2005). The hydrologic cycle simulated by SWAT is based on the following water balance equation:

$$Swt = Swo + \sum_{i=1}^t (R - Qsurf - ET - Qperc - Qr) \dots\dots\dots 3-12$$

where Swt is the final soil water content (mm), Swo is the initial soil water content on day i (mm), t is time (days), R is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), ET is the amount of evapotranspiration on day i (mm), Qperc is the amount of percolation on day i (mm), and Qr is the amount of groundwater flow on day i (mm).

### 3.6.5. Surface Runoff and Peak Runoff Rate

Surface runoff is computed based on the Soil Conservation Service (SCS) curve number method, also can be computed based on the Green and Ampt method. The SCS curve number is a function of the soil’s permeability, land use and antecedent moisture conditions (SCS, 1972) whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity (Green and Ampt, 1911).SWAT uses the daily and hourly time steps to calculate surface runoff. For daily time steps, SWAT uses an empirical SCS curve number (CN) method and for hourly time steps SWAT uses the Green and Ampt equation. For these research work SCS curve number method has been selected for the simulation of surface runoff in SWAT since it requires the readily available daily data (Arnold J. , 2000).

The SCS curve number equation is:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \dots\dots\dots 3-13$$

Where:  $Q_{surf}$  is the accumulated runoff of rainfall excess (mmH<sub>2</sub>O),  $R_{day}$  is the rainfall depth for the day (mmH<sub>2</sub>O),  $I_a$  is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mmH<sub>2</sub>O),  $S$  is the retention parameter (mm).

The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 \left( \frac{1000}{CN} - 10 \right) \dots\dots\dots 3-14$$

Where: CN is the curve number for the day.

The initial abstraction,  $I_a$ , is commonly approximated as  $0.2S$  and Equation become:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \dots\dots\dots 3-15$$

Runoff will only occur when  $R_{day} > I_a$ .

The peak discharge or the peak surface runoff rate is the maximum volume of flow rate passing a particular location during a storm event. SWAT calculates the peak runoff rate with a modified rational method it assumed that a rainfall of intensity  $I$  begins at time  $t=0$  and continuous indefinitely, the rate of runoff will increase until the time of concentration  $t_c$  and mathematically expressed as:

$$q_{peak} = \frac{0.475 * Q_{surf} * Area}{3.6 * t_{conc}} \dots\dots\dots 3-16$$

Where:  $q_{peak}$  is the peak runoff rate (m<sup>3</sup>/s),  $Q_{surf}$  is the fraction of daily rainfall that occurs during the time of concentration,  $I$  is the surface runoff (mm), Area is the sub-basin area in (km<sup>2</sup>), and  $t_c$  is the time of concentration (hr.), and 3.6 is the conversion factor.

### 3.6.6. Sediment Component

Erosion and sediment yield caused by rainfall and runoff are estimated through SWAT for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE). In each HRU sediment yield was estimated using a modified universal soil loss equation (MUSLE) (Arnold J. W., 1995). The modified universal soil loss equation:

$$Sed = 11.8 * (Q_{surf} * q_{peak} * A_{hru})^2 * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \dots\dots\dots 3-17$$

where Sed is the sediment yield (metric ton day<sup>-1</sup>), Qsurf is the surface runoff volume (mm ha<sup>-1</sup>), qpeak is the peak runoff rate in m<sup>3</sup> s<sup>-1</sup>, Ahru is the area of HRU in ha, K<sub>USLE</sub> is the soil erodibility factor, C<sub>USLE</sub> is the cover and management factor, P<sub>USLE</sub> is the support practice factor, LS is topographic factor, and CFRG is the course fragment factor.

### 3.6.7. Routing

The routing phase is the second division of hydrological cycle which can be defined as the movement of water, sediments etc, through the channel network of the watershed to the outlet. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. Both are variations of the kinematic wave model. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model.

The sediment-routing model that simulates sediment transport in the channel network consists of two components operating simultaneously, deposition and degradation. The amounts of deposition and degradation are based on the maximum concentration of sediment in the reach and the concentration of sediment in the reach at the beginning of the time step (Arnold J. W., 1995).

The amount of sediment degradation in the channel can be calculated:

$$Sed_{deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \dots \dots \dots 3-18$$

The net amount of sediment deposited in the reach segment is calculated:

$$Sed_{dep} = (Conc_{sed,ch,i} - Conc_{mx}) * V_{ch} \dots \dots \dots 3-19$$

Where: Sed<sub>deg</sub> is the amount of sediment re-entrained in the reach segment (metric tons), Conc<sub>sed,ch,i</sub> is the amount of initial sediment concentration in the reach (kg/l or ton/m<sup>3</sup>), Conc<sub>sed,ch,mx</sub> is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m<sup>3</sup>), K<sub>ch</sub> is the channel erodibility factor (cm/hr/pa), C<sub>ch</sub> is the channel cover factor and V<sub>ch</sub> is the volume of water in the reach segment (m<sup>3</sup>), Sed<sub>dep</sub> is the amount of sediment deposited in the reach (metric tons).

The final amount of sediment in the reach was determined by:

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} * Sed_{deg} \dots \dots \dots 3-20$$

where  $Sed_{ch}$  is the amount of suspended sediment in the reach (metric tons days<sup>-1</sup>),  $Sed_{ch,i}$  is the amount of suspended sediment in the reach at the beginning of the time period (metric tons days<sup>-1</sup>)  $Sed_{dep}$  is the amount of sediment deposited in the reach segment (metric tons days<sup>-1</sup>) and  $Sed_{deg}$  is the amount of sediment re-entrained in the reach segment (metric tons days<sup>-1</sup>).

The amount of sediment transported out of the reach was calculated as:

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V_{ch}} \dots\dots\dots 3-21$$

where  $Sed_{out}$  is the amount of sediment transported out of the reach (metric tons days<sup>-1</sup>),  $V_{out}$  is the volume of out flow during the time step (m<sup>3</sup>), and  $V_{ch}$  is the volume of water in the reach segment(m<sup>3</sup>).

### **3.7. Data set for SWAT Model**

#### **3.7.1. Model Input**

The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on meteorological and river discharge also used for prediction of stream flow and calibration purposes.

#### **A. Digital Elevation Mode**

Digital elevation model used by the SWAT model to delineate watershed to analyze the drainage pattern of the watershed, slope, stream length, width of channel within the watershed. The DEM used is in this study obtained from the MOWIE with a resolution of 30\*30m. The DEM was processed using ARC GIS 10.3 with ARCSWAT 2012 version.

#### **B. Soil Data**

Soil data is the major input data for the SWAT model. Accordingly, there were nine soil types found in the study area. It requires different soil textural and physio-chemical properties such as available water content, soil texture, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type.

#### **C. Land Use and Land Cover**

Land use data influences highly the properties of the watersheds. The SWAT model has predefined four letter codes for each land use category. These codes were used to link the land use map to

SWAT land use data bases of the study area. These codes were used to link or associate the land use map of the study area to SWAT land use databases. Hence, while preparing the lockup-table, the land use types made compatible with the input needs of the model.

### **3.7.2. SWAT Model Setup**

The SWAT model was set up using the data prepared described in above section and the (ARCSWAT, 2012) interface. The general step followed to set up the model is described as follows.

The first step was to load the Digital Elevation Model in the ARCSWAT version-2012 interface. The stream network was generated by use of a threshold area that defines the origin of a stream. The locations of the river gauging location for watershed delineation were added manually as sub-basin outlets (Abura Gauging Station) this was to ensure that the model calibration was done at the exact location. Once the entire watershed outlet is selected, the sub-basins are delineated and their parameters are calculated. Next, the land use and soil maps are loaded. Then slope classification is done by assigning a multiple slope option. Once the land use, soil map and slope have been loaded and reclassified, an overlay is done, resulting in land use, soil and slope distribution within the sub-basins. The HRUs were then created by applying Dominant land use, soil and slope. Then, the climate data defined in the user weather generator for metrological stations is loaded. At the final step, the SWAT input files are built and the model is set to run.

### **3.7.3. Sensitivity Analysis**

Sensitivity analysis is a method of minimizing the number of parameters to be used in the calibration step by making use of the most sensitive parameters largely controlling the behavior of the simulated process. It is also a measure of the effect of change of one parameter on another. Sensitivity analysis was undertaken by using a built-in tool in SWAT-CUP. To improve simulation result and understand the behavior of hydrological system in the catchment, sensitivity analyses were conducted for the selected parameters.

In general, identifying sensitive parameters prior to model calibration helps to allow the possible reduction in the number of parameters that must be calibrated thereby reducing the computational time required for model calibration. Once the sensitivity analysis is done calibration can be performed for limited number of influential parameters.

#### **3.7.4. SWAT Calibration and Validation**

The SWAT model generally have a large number of parameters which are not directly measurable and must therefore be estimated through model calibration, i.e. by fitting the simulated outputs of the model to the observed outputs of the watershed by adjusting the model parameters. A measure of the fit between the simulated and observed outputs is called calibration.

The Arc SWAT for ArcGIS 10.3 interface for SWAT 2012 is used in this study to set up the model to simulate the discharge and sediment yield at the outlet of the Abura Gauging station. Calibration is achieved by SWAT calibration and uncertainty programs SWAT-CUP using Sequential Uncertainty Fitting version-2 (SUFI-2) algorithm that finds out the most favorable model parameters within the uncertainty ranges of 95% after incorporating the possible parameters ranges.

Measured discharge and sediment data of the Katar River are collected from 1987 to 2007. Data from 1990 to 2000 is used for calibration and data from 2001 to 2007 is used for validation including three years as a warm up period (1987–1989) in order to minimize the influence of initial conditions such as soil water content.

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model should be tested against an independent set of measured data without further adjustments this testing of a model with an independent set of data set is commonly referred to as model validation (Santhi, 2001).

The model was validated using datasets from 2001 to 2007 at the location of study. The statistical criteria ( $R^2$  and ENS) used during the calibration procedure were also checked here to make sure that the simulated volume is still within the accuracy limits.

#### **3.7.5. SWAT Model Performance**

The Performance evaluation parameters used to check the performance of SWAT model are: the coefficient of determination ( $R^2$ ) and Nash-Sutcliffe efficiency (ENS). The coefficient of determination ( $R^2$ ) describes the proportion of the variance between simulated and measured data.  $R^2$  ranges from 0 to 1, with higher values indicating less error variance and typically values greater than 0.6 are considered acceptable. Nash-Sutcliffe efficiency (ENS) displays how fine the

observed plot fits the simulated plot which ranges from  $-\infty$  to 1 with higher values indicating a less error and typically, values greater than 0.5 are considered acceptable (Santhi, 2001).

$R^2$  and NSE calculated as follows respectively:

$$R^2 = \frac{[\sum_{i=1}^n (q_{si} - q_{s \text{ mean}})(q_{oi} - q_{o \text{ mean}})]^2}{\sum_{i=1}^n (q_{si} - q_{s \text{ mean}})^2 * \sum_{i=1}^n (q_{oi} - q_{o \text{ mean}})^2} \dots\dots\dots 3-22$$

$$ENS = \frac{[\sum_{i=1}^n (q_{oi} - q_{si})]^2}{\sum_{i=1}^n (q_{si} - q_{s \text{ mean}})^2 * \sum_{i=1}^n (q_{oi} - q_{o \text{ mean}})^2} \dots\dots\dots 3-23$$

Where:  $q_{si}$  is the simulated stream flow

$q_{oi}$  is the measured stream flow

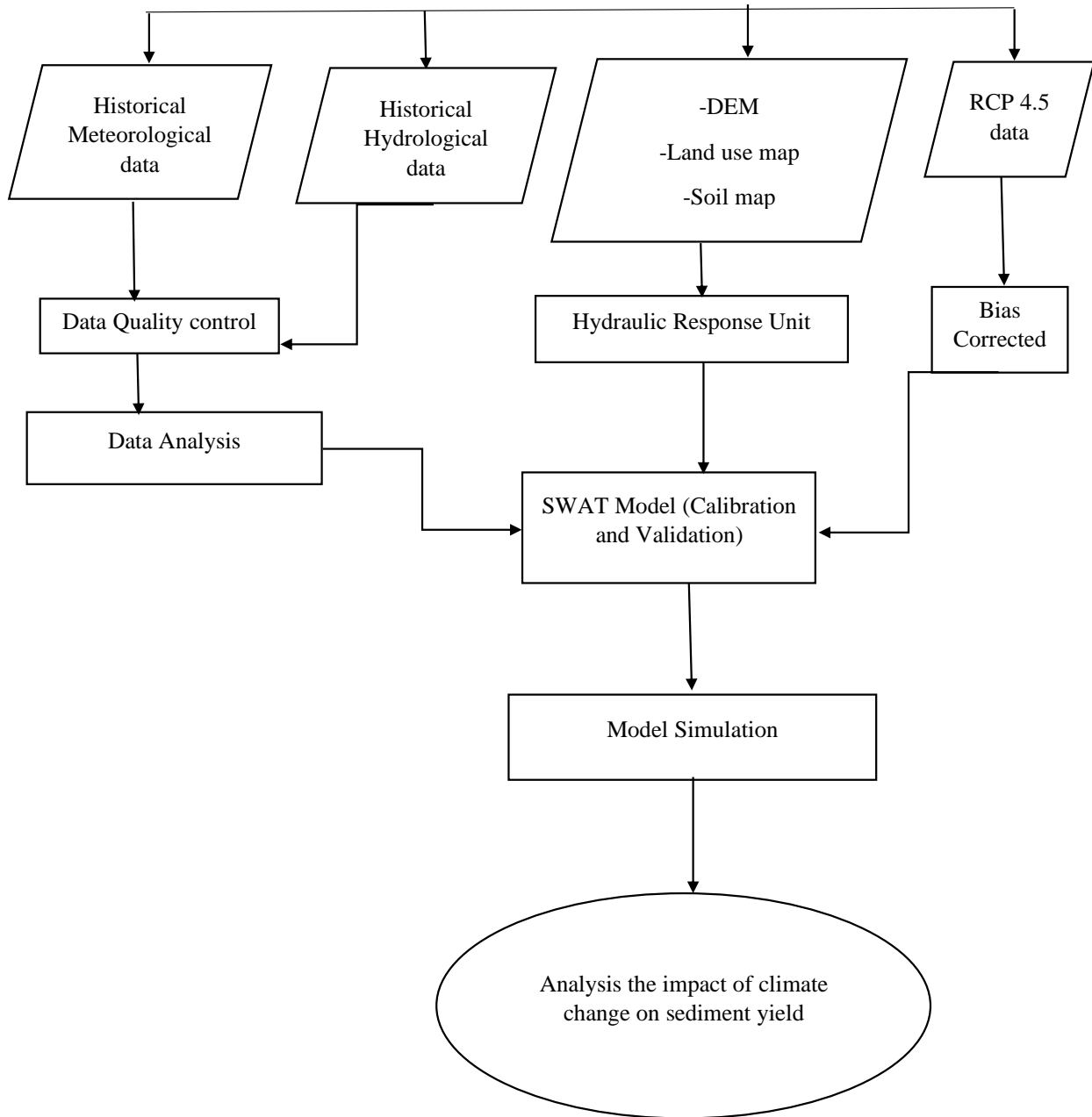
$q_{s \text{ mean}}$  is the average simulated stream flow

$q_{o \text{ mean}}$  is the average measured stream flow

### 3.8. Impact of Climate Change on Sediment yield

The impact of climate change was analyzed taking the historical simulated sediment yield from (1987-2007) as the baseline against which the future sediment yield is compared for future periods of 2030's and 2060's. The input climate data (daily rainfall, minimum and maximum temperature) under each RCP scenarios were used for future simulation.

In simulating the future sediment yield other climate variables such as wind speed, solar radiation, and relative humidity were assumed to be constant throughout the future simulation periods. Even though it is definite that in the future land use changes will also take place, this was also assumed to be constant as the objective of this study is only to get indicative results with respect to the change in the climate variables (Rainfall and Temperature) keeping all other factors constant.



**Figure 3-13: Methodological Frame Work**

## 4. RESULTS AND DISCUSSION

### 4.1. Performance Evaluations of RCP simulation Data

Any climate data can be needed to evaluate its performance when it was dynamically or statically down scaled from climate data set and use in different hydrological models. For this reason, in this study, the data was evaluated using statistical measures such as bias, Coefficient of Variation (CV), and correlation based on rainfall. Observed mean annual precipitation as well as bias-corrected and bias-uncorrected historical RCPs framed for the Katar watershed was 851.59, 855.45, and 1273.66 mm, respectively. The result showed overestimation in model simulation but after bias corrected the mean annual precipitation of the observed and the model showed good relationship. The results indicates the degree of rainfall coefficient variability ( $CV = 3.49\%$ ) for observed and bias-corrected RCP data ( $CV = 4.65\%$ ) but the bias for bias-corrected RCP data was overestimation and the value of correlation ( $CC=0.57$ ) for bias-corrected model simulation data was an approximately good linear relationship between observed simulated precipitation data.

Generally, although it is possible to use the climate model outputs (precipitation, maximum and minimum temperature) before bias correction was applied, it is better to use after bias correction for future projection of stream flow over the study area. Applying bias correction to climate model outputs highly reduces the differences and improves the climate model performance in reproducing recorded data.

**Table 4-1: Performance Evaluation of Observed and Historical RCP Data sets in Katar Watershed (1987-2017)**

	Mean Annual Precipitation (mm)	CV (%)	Bias (%)	Correlation
Observed	851.59	3.49		
Bias-corrected RCP	855.45	4.65	1.74	0.57
Un-corrected RCP	1273.66	2.93	32.38	0.36

## 4.2. Statistical Results of RCP Climate Projections

### 4.2.1. Base Period Analysis for Precipitation and Temperature

In this study 0.50 \*0.50 grid resolution of bias corrected RCP 4.5 emission scenario for Katar Watershed used for analysis. Period from 1987-2017 taken as a baseline and two future climate projection considered for impacts study for 2030`s (2021-2050) and 2060`s (2051-2080). Scenarios generated for the base period averaged to a monthly, seasonal and annual time steps for the comparison with the observed, RCP bias corrected and RCP bias uncorrected.

#### I. Precipitation

The monthly average bias corrected RCP and observed precipitation for the study area shows variation with some months. In February, March, May, August, October and November months the precipitation underestimated when compared to the observed while September, December including, January, April, June and July months the precipitation overestimated. The precipitation of observed and un-corrected RCP data showed much difference which indicates that using down scaled RCP scenarios output directly without doing bias correction may lead to huge uncertainty of hydrological analysis.

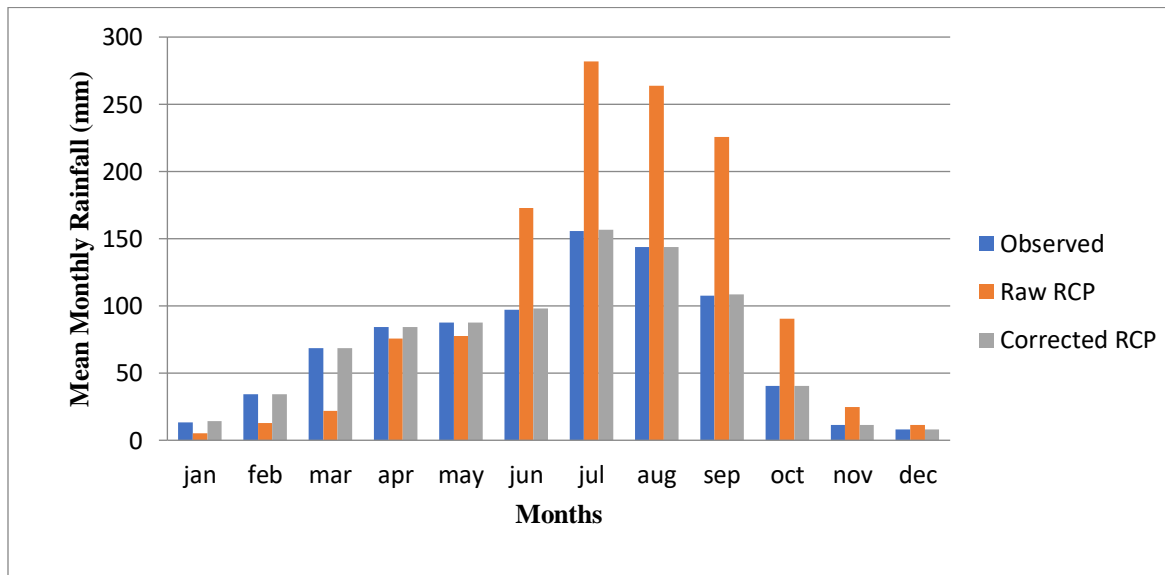
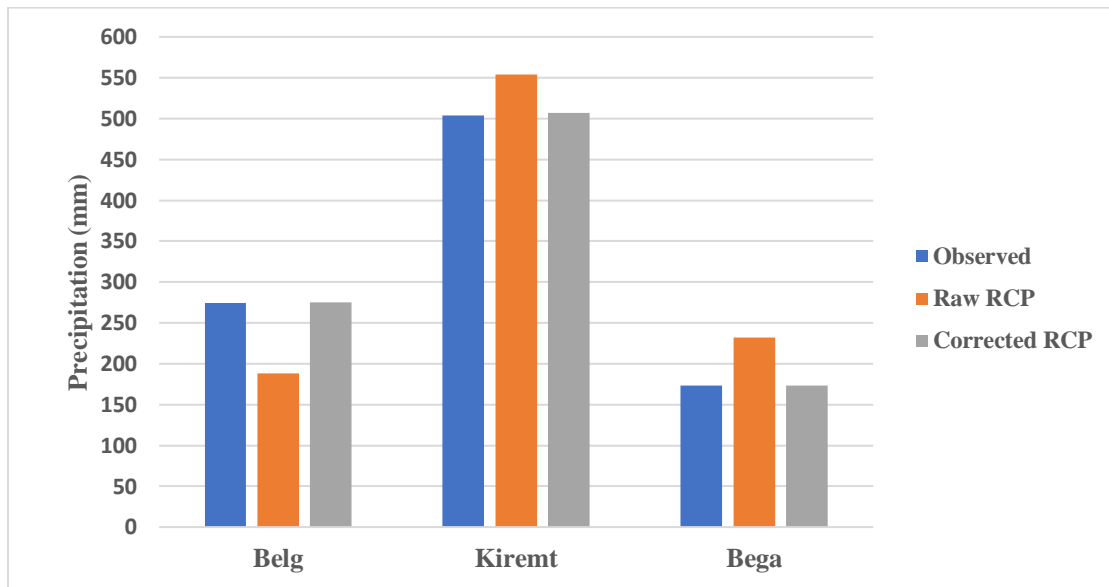


Figure 4-1: Observed and Historical RCP Mean Monthly precipitation

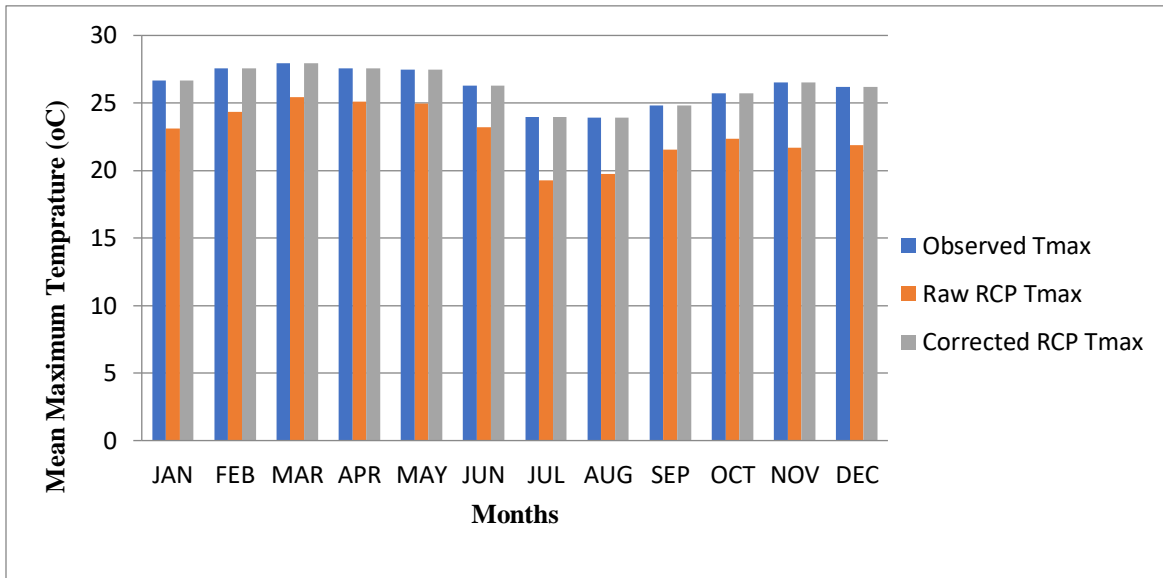
The analysis of seasonal distribution of total precipitation is carried out considering the main seasons namely; Kiremt (June, July, August and September) is overestimated; Bega (October, November, December and January dry season) is slightly overestimated and Belg (February, March, April and May) small rainy season is underestimated. Average precipitation to a monthly, seasonal and annual, which shows significant difference from bias uncorrected mean monthly when compared with mean monthly observed data. This result indicates that using the RCP4.5 output without doing bias correction may lead to huge uncertainty of hydrological analysis.



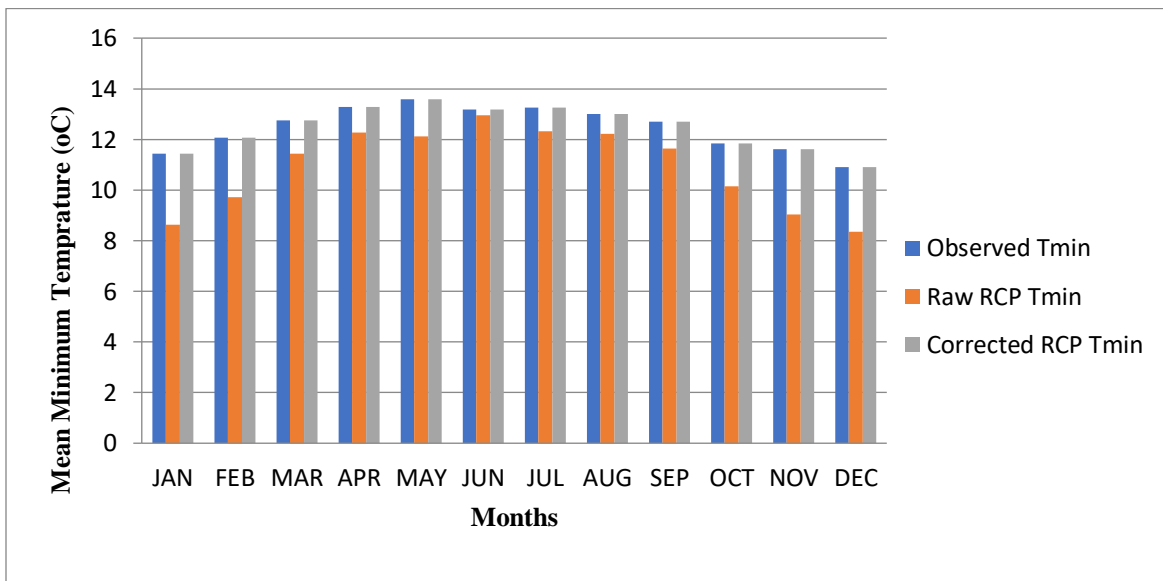
**Figure 4-2: Mean Seasonal Rainfall Distribution**

## II. Temperature

Bias corrected mean monthly maximum and minimum temperature showed good relation with observed temperature for historical period. For maximum temperature September, November and March shows slightly overestimated but during other months the maximum temperature slightly underestimated compared to the observed temperature. On the other hand, the Bias corrected mean monthly minimum temperature shows slightly overestimation during January, February, May, June and December months when compared to the observed while the remaining months slightly underestimated. This result indicated bias correction is very important before any assessment.



**Figure 4-3: Mean Monthly Maximum Temperature for historical period**



**Figure 4-4: Mean Monthly Minimum Temperature for base period**

#### 4.2.2. Projected Future Climate Variables Generated from RCP Scenario

The future scenarios were developed for the future time series of: 2021-2050 and 2051-2080. The future climate projection (2021– 2080) carried out with down scaled and bias corrected RCP precipitation and temperature, and future calculated data used to generate the future sediment yield of the river. The period from 1987-2017 was taken as a base period for comparison. The future climate pattern includes precipitation and temperature (minimum and maximum) was analyzed under RCP 4.5 scenario's for Katar watershed.

## **I. Precipitation**

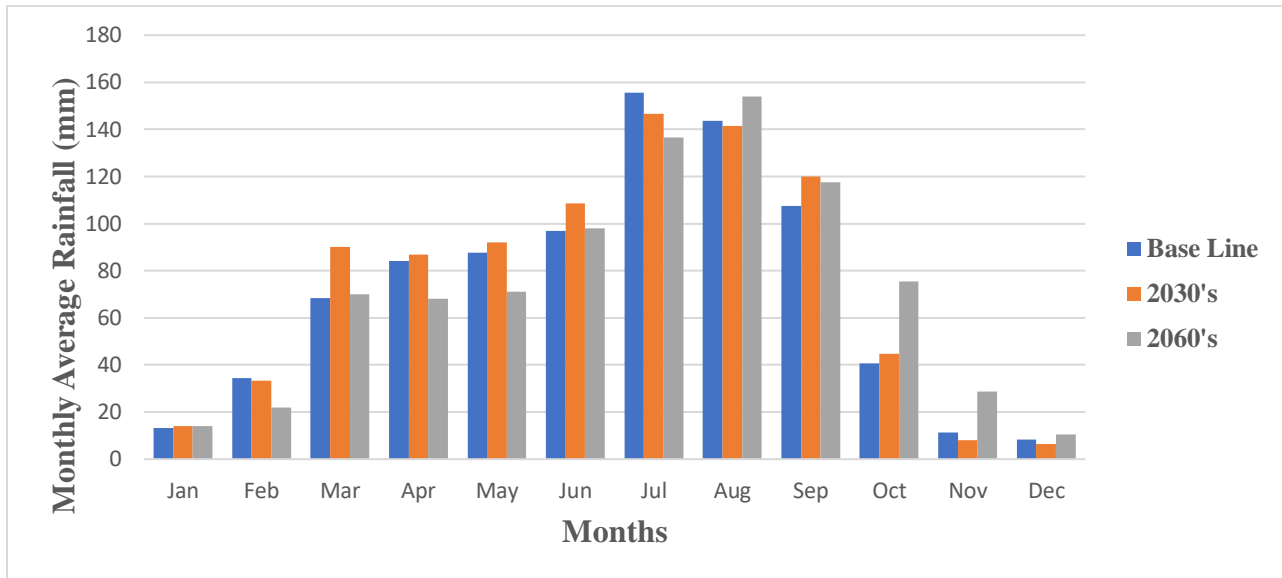
The precipitation obtained from RCP grid data for each meteorological stations used in the study area were bias corrected before using it in SWAT hydrological model in such a way precipitation for the study area is calculated for RCP climate data under each future time series and finally a comparison is made with respect to the base period.

### **Annual Distribution**

Accordingly, for RCP4.5 scenario the mean annual precipitations were projected to increase by 4.8% and 1.6% for the 2030s and the 2060s, respectively. The bias correction annual pattern carried out based on observed data shows that the total annual rainfall significantly an increase by 40.90 mm for 2030's and by 14.01 mm for 2060's respectively when compared to the base period. This is in line with the observed records at Arata, Bekoji, Ketera-genet, Kulumsa and Oglocho meteorological stations. Generally, as the result clearly indicates that, for both future periods under RCP 4.5 scenarios mean annual precipitation expected to increase over the study area

### **Monthly Distribution**

The result showed decreased patterns in February, July, August, November and December, whereas in January, March, April, May, June, September and October showed an increase in precipitation patterns in the 2030's compared with base period. Besides, the results showed an increase in January, March, June and from August-December, while in February, April, May and July the precipitation indicated a decreased pattern in the 2060's future period. Generally, as the result clearly indicates that, for both future periods under RCP 4.5 scenario mean annual precipitation expected to increase over the study area. Supporting the present study's findings, Intergovernmental Panel on Climate Change (IPCC) reported an increase of precipitation in rainy seasons with heavy precipitation events over the world. The global precipitation pattern is expected to increase up to 20% (IPCC, 2013) also (UNFCC., 2007) assessed regional impacts and vulnerabilities to climate change in four regions including Africa and the results showed that annual mean rainfall increases in East Africa due to climate change.



**Figure 4-5: Mean Monthly Precipitation for Katar Watershed**

### Seasonal distribution

The analysis of seasonal distribution of rainfall carried out considering the main seasons namely; Kiremt, Bega and Belg. The characteristics of seasonal rainfall pattern in the three seasons are presented in table 4-2. The bias correction shows that for period 2030's and 2060's there is a change in 10.05 % and -15.80 % in Belg season, respectively in the Katar watershed. In Bega, in the case of 2060's period which rainfall increase by 20.47 % and a decrease of 0.05 % in the period 2030's. Similarly, in the case of Kiremt season in the period of 2060's which the rainfall quantity increased by 0.47 % and by 2.65 % in period 2030's.

**Table 4-2: Seasonal change of rainfall between historical and 2030's and 2060's**

	Seasonal Change (%)		
	Belg	Kiremt	Bega
2030's	10.05	2.65	-0.05
2060's	-15.80	0.47	20.47

## II. Temperature

In this study, the predicted temperatures in all months showed an increase in RCP scenario. Changes in monthly maximum temperatures ranged from 0.03 °C to 1.24 °C with an average annual of 0.68 °C by the 2030s and from 1.37 °C to 3.14 °C with an average annual of 1.89 °C by the 2060s. The results also indicated that all the values of monthly minimum temperature increased from 0.62 °C to 1.29 °C by the 2030s and from 1.54 °C to 2.46 °C by the 2060s under RCP4.5 with average annuals of 0.99 °C and 2.03 °C, respectively, compared to the baseline period.

Supporting the present study's findings, the conducted by (Takele, 2018) on climate change impact on loss of volume of Lake Ziway watershed also reported an increase in predicted average monthly maximum temperature up to 1.61 °C and minimum temperature up to 1.91 °C under RCP4.5 in the period from 2041-2070. The study conducted by (Lijalem, 2017) also showed an increase in average monthly maximum temperature up to 3.6 °C and minimum temperature up to 4.2 °C under a special report on emission scenarios (SRES) in the period from 2001-2099. Overall, these findings were in line with previous studies in Central Rift Valley Basin.

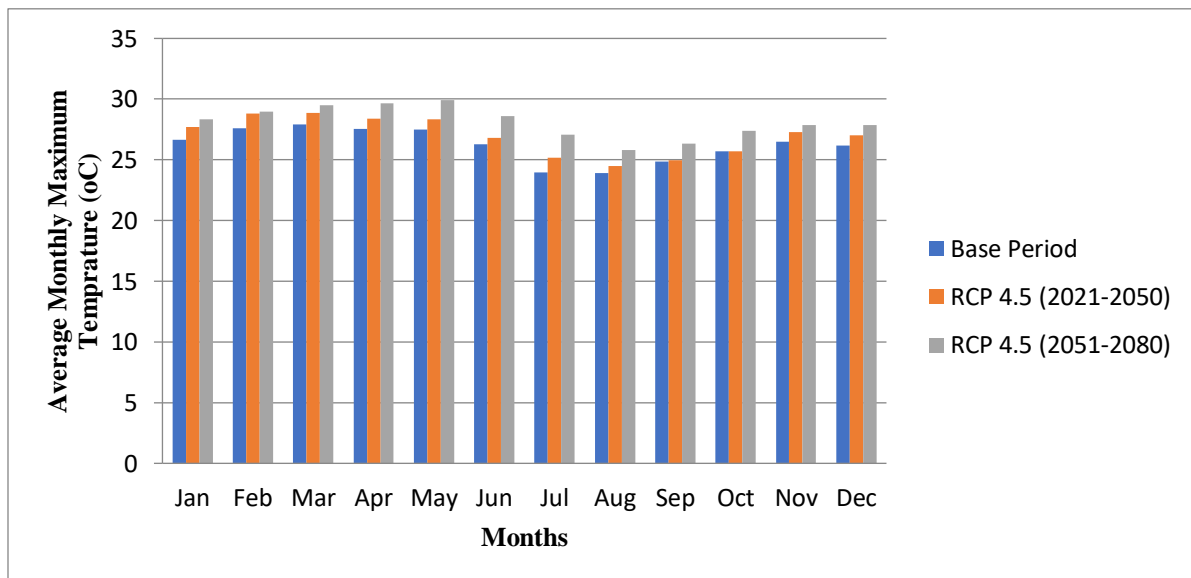
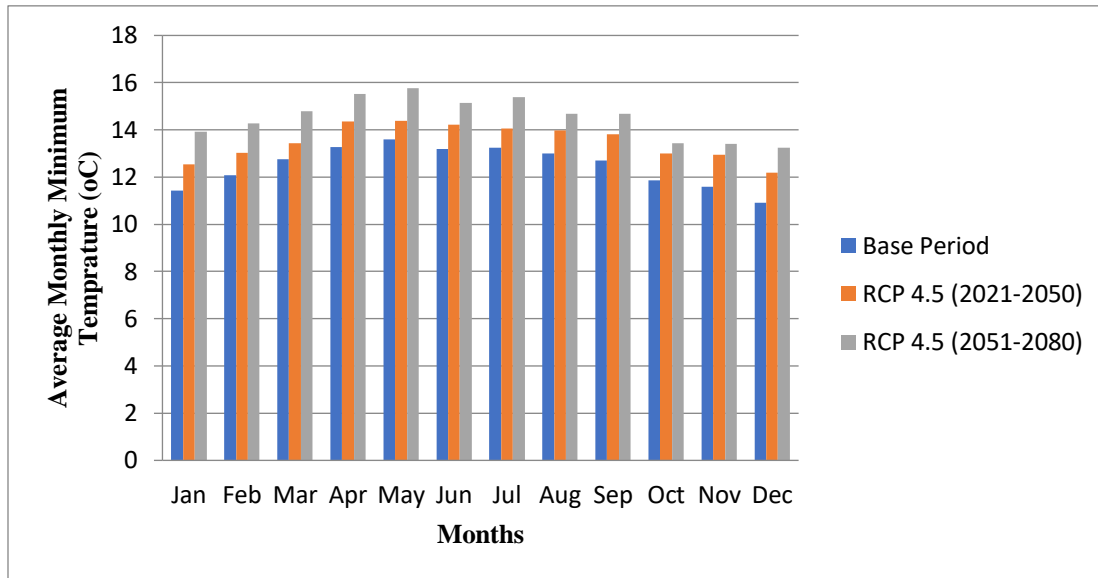


Figure 4-6: Mean Monthly Bias Corrected Maximum Temperature



**Figure 4-7: Average Monthly Bias Corrected Minimum Temperature**

### 4.3. Swat Model Result

Using Arc-SWAT, Katar basin was delineated using Digital Elevation Model data. From the topographic report a total area of 3304 km<sup>2</sup> with 21 sub basins were generated by taking an outlet at Abura gauging station located in Katar river. The catchment delineation was followed by the determination of HRUs using land use, soil and slope map of Katar watershed by setting a threshold value of 15, 15 and 10%. From the 21 sub basins 153 hydrological response units were further generated depending on domination land, soil and slope type by considering the effect of formulation in the final water balance results and for making the HRU formulation in manageable amount.

#### 4.3.1. Sensitivity Analysis of Streamflow

Before running the calibration, sensitivity was carried out to save time during calibration. The sensitivity analysis was done for flow and sediment separately since some parameters are sensitive to both or only sensitive to either flow or sediment. Identifying sensitive parameters enable to focus only on those parameters which highly affect the model output during calibration.

The parameter identification was done by using the monthly flow data from 1990 to 2000. Thirteen of the most sensitive parameters were selected for streamflow simulation of Katar watershed with their fitted value ranked in table 4-3.

**Table 4-3: Result of the sensitivity analysis parameters of Streamflow in Katar watershed**

Rank	parameter	Descriptions	Min	Max	Fitted value
3	CN-2.mgt	Effective hydraulic conductivity of the main channel	35	98	44.19
4	SOL_K.sol	Saturated hydraulic conductivity	0	2000	15.26
12	HRU_SLP.hru	Average slope steepness	0	60	42.93
1	CH_K2.rte	Effective hydraulic conductivity in main channel (mm/hr)	5	130	84.10
5	GW_REVAP.gw	Ground water revap coefficient	0	0.2	0.08
13	SOL_AWC.sol	Available water content of soil	-0.2	0.4	-0.019
6	GWQMN.gw	Threshold depth of water in shallow aquifer for return flow to occur	0	5000	2672.14
11	SURLAG.bsn	Surface runoff lag coefficient	0.05	24	12.83
9	ESCO.hru	Soil evaporation compensation factor	0.01	1	0.45
10	GW_DELAY.gw	Ground water delay (days)	0	500	331.16
2	ALPHA_BF.gw	Base flow alpha factor (days)	0	1	0.23
8	SOL_BD.sol	Moist bulk density	0	0.25	0.08
7	EPCO.hru	Plant evaporation compensation factor Soil depth (for each layer)	0	1	0.34

### 4.3.2. Streamflow Calibration and Validation

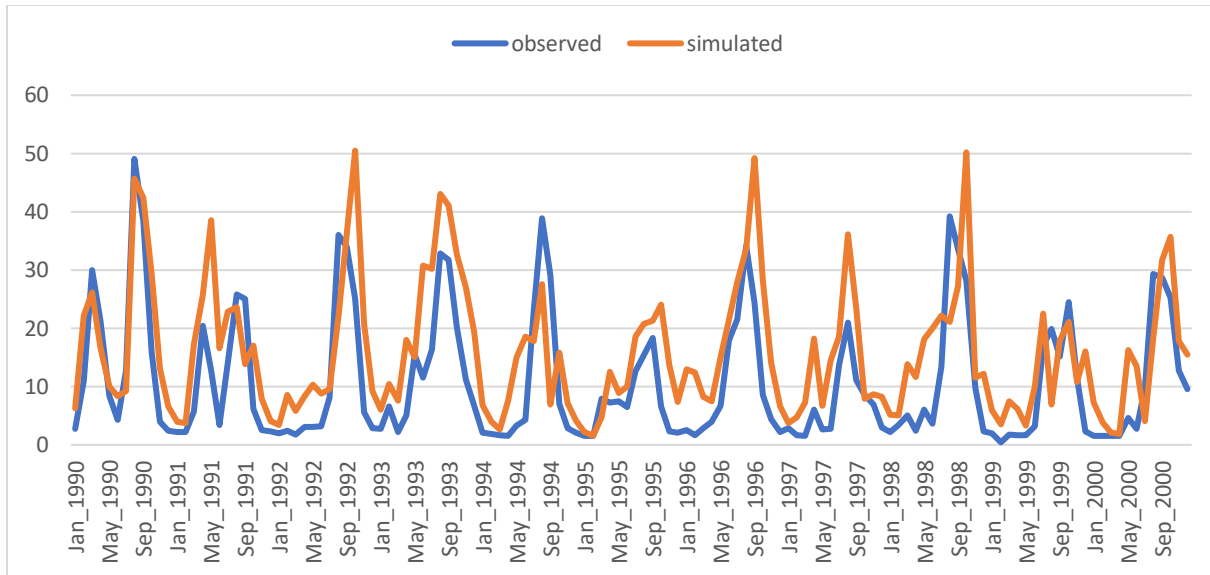
Streamflow calibration and validation was done by comparing the observed and the simulated flow value for 14-years period (1987-2007). The first three years (1987-1989) were considered as warm-up period, the 1990-2000 periods were used for the model calibration, and the 2001-2007 periods was used for the validation period.

The performance of the model was evaluated using  $R^2$  and NSE coefficient statistical measure in SWAT\_CUP. After calibration and validation, the streamflow simulation obtained acceptable result that revealed the simulated and observed streamflow was consistent. The result obtained fulfilled the requirements suggested by (Santhi, 2001) for  $R^2 > 0.6$  and  $ENS > 0.5$ . Simulated stream flow and observed stream flow for both calibration and Validation at Katar River compared graphically in Figure 4-7 and Figure 4-8, respectively.

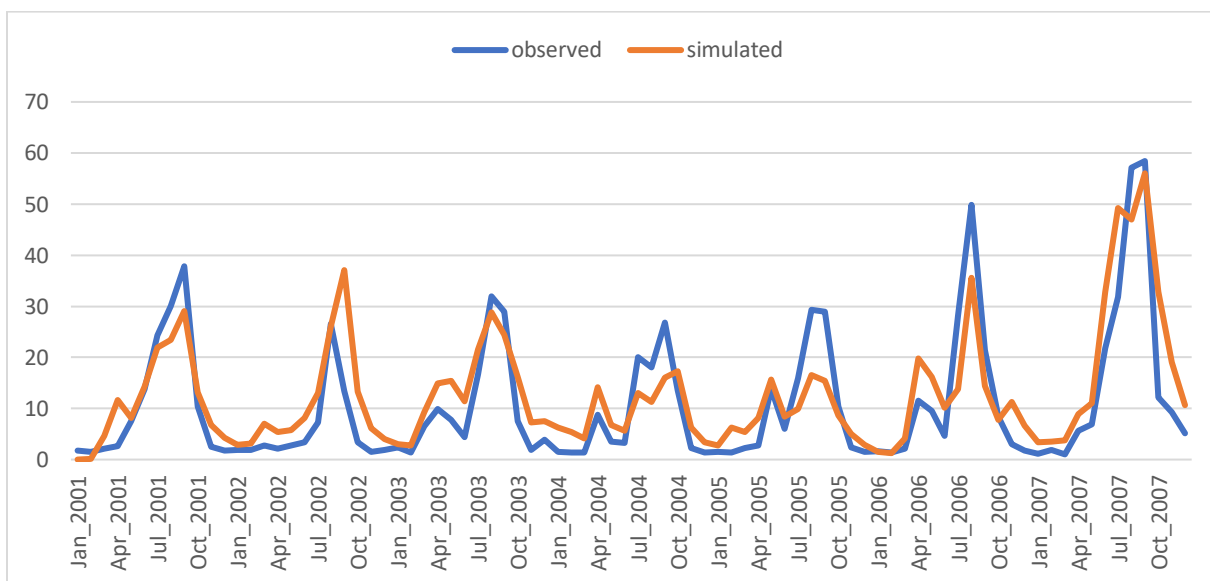
**Table 4-4: Objective function values for calibration and validation period (1987-2007).**

Variable	Calibration (1990-2000)	Validation (2001-2007)	NSE:Nash-Sutcliffe efficiency
$R^2$	0.76	0.71	
NSE	0.69	0.67	

Comparison between observed and simulated flows, for monthly calibration and validation are presented in figure 4.3. The shape of observed flow was well captured by the shapes of the simulated flow. Nevertheless, some high peaks were not matched well and low flows were over estimated by the model during the validation period. The under estimation might be due to the scarcity of climate gauging station in the study area, parameter selected for calibration and the data quality of some gauging station (Engidayehu, 2014). The results revealed that the variation pattern of simulated streamflow was generally consistent with that of the observed streamflow in the base periods. The result obtained by (Alemu O. , 2019) in the Rift Valley lake basin for katar watershed used the SWAT model to evaluate streamflow and sediment yield, and found with good performance of the model.



**Figure 4-8: Simulated stream flow and observed streamflow for calibration (1987-2000)**



**Figure 4-9: Simulated stream flow and observed stream flow for validation (2001-2007)**

### 4.3.3. Sediment Yield Calibration and Validation

To determine the magnitude of catchment sediment yield, initial sensitive sediment parameters were calibrated using the global sensitivity analysis procedure. Besides, six sensitive sediment parameters were identified. Those are USLE support practice factor (USLE\_P.mgt), Channel erodibility factor (CH\_COV1.rte), Channel Erodibility factor (CH\_ERODMO.rte), Exponential

factor for channel sediment routing (SPEX\_P.bsn), Linear factor for channel sediment routing (SPCON.bsn) and Channel Cover factor (CH COV2.rte).

**Table 4-5: Result of the sensitivity analysis parameters of Sediment yield in Katar watershed**

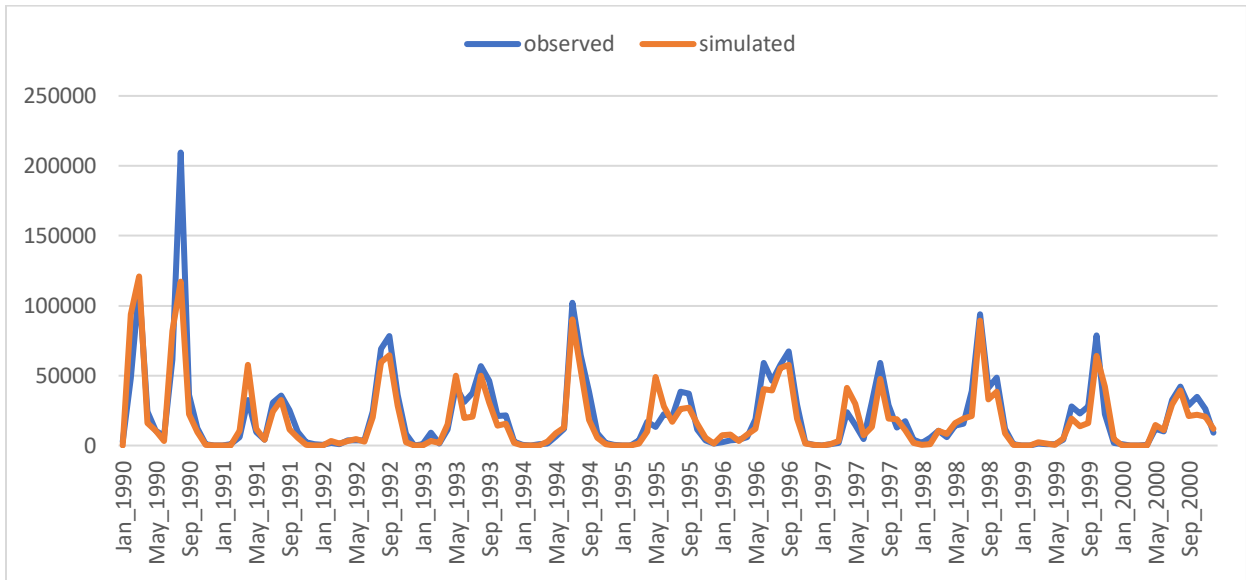
Parameter	Description	Fitted value	Min	Max	Rank
SPCON.bsn	Linear re-entrainment parameter for channel sediment routing	0.004	0.0001	0.01	2
SPEXP.bsn	Exponential re-entrainment parameter	1.14	1	1.5	6
USLE_P.mgt	USLE support practice factor	0.19	0	1	3
USLE_K.mgt	USLE equation soil erodibility	0.92	0	0.65	1
CH_COV1.rte	Channel erodibility factor	0.44	-0.05	0.6	7
CH_COV2.rte	Channel cover factor	0.15	-0.001	1	4
CH_ERODMO.rte	Channel Erodibility factor	0.32	0	1	5

The model also showed adequacy in predicting monthly sediment yield in Katar watershed using the most sensitive parameter value. The best simulation performances of sediment yield results using these fitted parameters and the value for monthly calibration and validation are shown in table 4-5. The result obtained fulfilled the requirements suggested by Santhi et al. (2001) for  $R^2 > 0.6$  and  $ENS > 0.5$ . In the presence study, the result of calibration and validation for the simulated and the observed value of both streamflow and sediment yield showed good relations with reasonable accuracy.

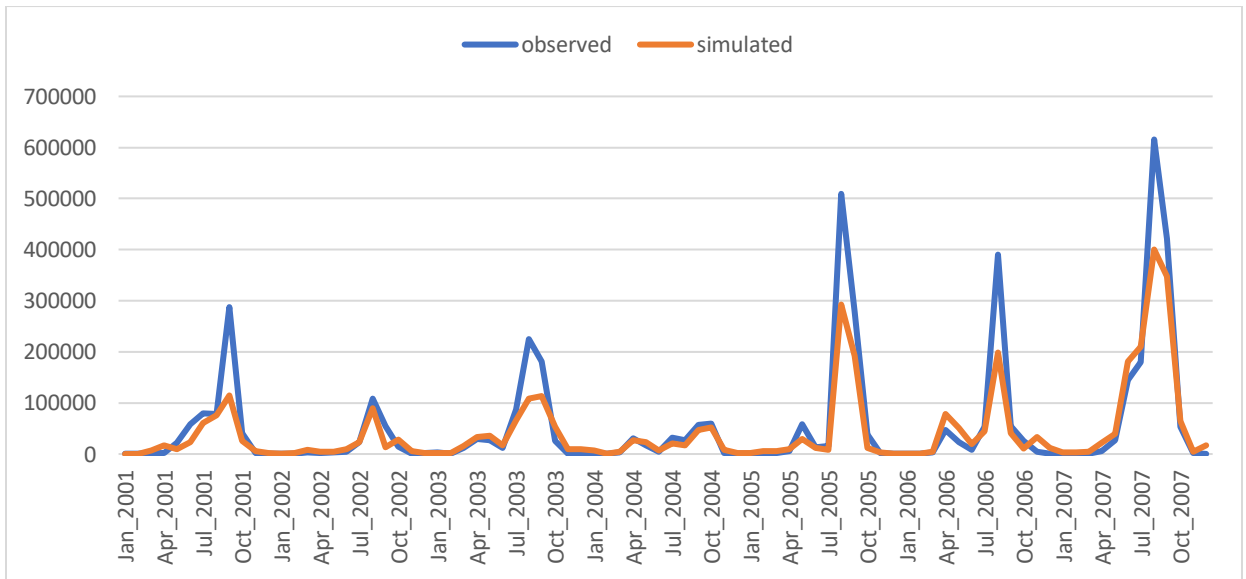
**Table 4-6: Objective function values for calibration and validation period (1987-2007).**

Variable	Calibration	Validation
$R^2$	0.72	0.67

NSE	0.68	0.65
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**Figure 4-10: Simulated sediment yield and observed sediment yield for calibration (1987-2000)**



**Figure 4-11: Simulated sediment yield and observed sediment yield for validation (2001-2007)**

The efficiency results of the SWAT model in this study showed similarity with other studies in different parts of the world in simulating sediment yield. According to (Takele, 2018), the model

performance for sediment yield estimation was in the satisfactory range with the value of  $R^2$  and NSE were 0.51 and 0.53, respectively for the calibration and for validation the value of  $R^2$  and NSE were 0.49 and 0.49, respectively for Katar watershed. A study by (Adem, 2015) in the Upper Gilgel Abay of the Blue Nile Basin in Ethiopia showed similar efficiency values of SWAT model calibration and validation for sediment yield estimation. (Ayana, 2012) examined the applicability of SWAT in estimating runoff and sediment yields in the Fincha watershed in Ethiopia. It was concluded that the SWAT model performed well in predicting flow and yield in a given watershed.

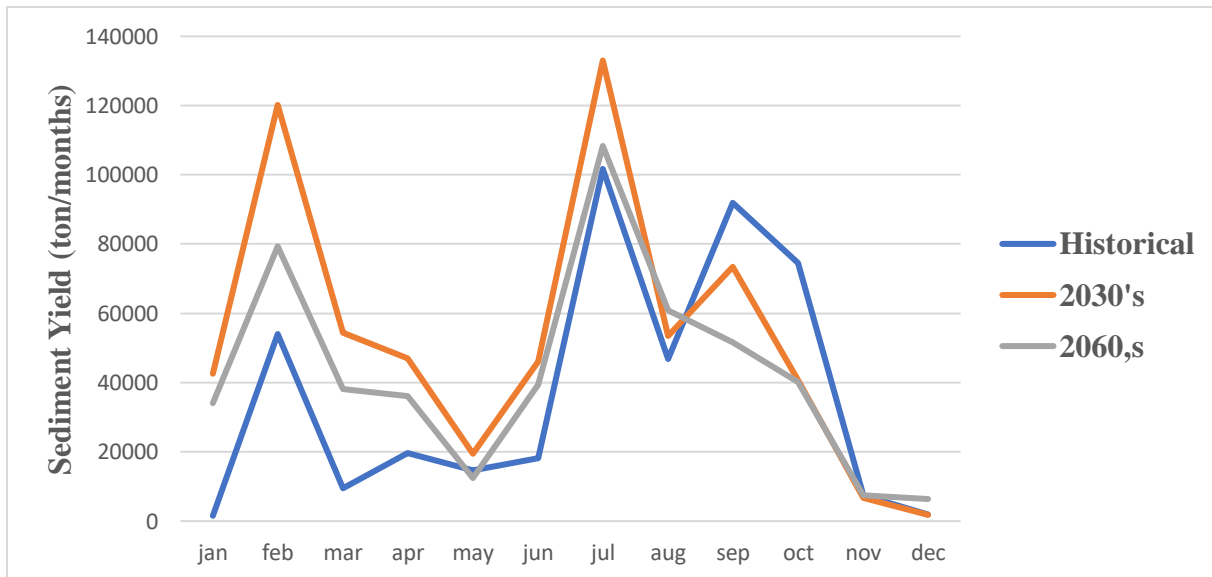
Overall, the calibration and validation of the both stream flows and sediment show that the model successfully simulated with measured data. When stream flow compared with sediment yield, the stream flow was well matched more.

#### **4.4. Future Sediment Yield Under RCP 4.5 Climate Scenarios**

After successful calibration and validation of SWAT hydrological model, bias corrected precipitation and temperature were used to simulate sediment for future two consecutive periods of 2030's and 2060's and then the simulated sediment was compared to baseline period (1987-2007) to evaluate the change. Mean annual sediment loads of observed and simulated values in the years were 2.94 ton/ha and 2.82 ton/ha, respectively in base period (1987-2007). This indicated the estimates of sediment load in the model were less than the observed values. This may have been due to limited observed sediment data, quality and constraint of weather data, streamflow, errors during data recording, and uneven distribution of gauging stations in the watershed. The finding of this study in the historical period showed underestimation of sediment yield as compared to values in a study conducted by Tekle et al. at the same area which estimated 3.24 ton/ha (Takele, 2018). Besides, the finding by (Feven, 2017) indicated that the annual sediment yield for katar watershed was 2.1 ton/ha for 1988-2008 historical period which showed overestimation of sediment yield of this study. This variation might be because of the study area experienced a great land use and land cover change for the last three decades and agricultural land was increased by 27.7% between 1986 and 2010, with annual rate of (15.5 km<sup>2</sup>/year), as indicated in the research conducted by (Damtew, 2015).

The future sediment yield to the Katar River is generated by using the downscaled climate variable as an input to the SWAT hydrological model. For comparison purpose the generated sediment is

compared with the (1987-2007) mean monthly observed sediment yield. During base periods, the rate of sediment yield ranged from with mean annual value of 294 t/km<sup>2</sup> while under RCP4.5 the mean values of sediment yield were 398 t/km<sup>2</sup> and 307 t/km<sup>2</sup> by the 2030's and the 2060's, respectively. The results indicated that precipitation and temperature with sediment yield had strong relationships. Moreover, the relationship between streamflow and sediment load at the outlet of the Katar watershed was strongly related. Both streamflow and sediment yield were predicted to increase under RCP scenarios for both future periods. Results indicated that for RCP4.5 the maximum and the minimum sediment loads of the watershed occurred in the sub-watersheds 12 and 19, respectively, in both time series data. This result plays a critical role for the detailed understanding and evaluation of the amount of sediment yield as well as for designing an appropriate management scenario at the watershed.



**Figure 4-12: Sediment yield in the Katar River in the future scenario as compared to the historical period.**

#### 4.5. Evaluation of the Impact of Climate Change on Sediment yield

The objective of the down scaling is to generate an estimate of meteorological variables corresponding to a given scenario of the future climate so that these meteorological variables will be used as a basis for hydrological impact assessment. Therefore, after calibrating the hydrological models with the historical record, the next step is the simulation of sediment yield in the catchment by using the down scaled precipitation and maximum and minimum temperature as input to SWAT

hydrological models. Based on this, hydrological impact of the Katar River is analyzed with respect to the period of 2030's (2021-2050) and 2030's (2051-2080) and the hydrological model is re-run for each case.

The simulation results of mean monthly sediment yield for two future periods and observed are summarized in Table 4-6. In January, February, June, July, October, and November, the simulated mean monthly sediment projected to increase under both periods. However, in April the projected sediment expected to decrease. For other of months sediment shows a little underestimation and overestimation compared to baseline period.

**Table 4-7: Mean monthly sediment (ton/months) compared with base period.**

Months	Mean monthly sediment (ton/months)			Change from base period	
	Obs	2030's	2060's	2030's	2060's
Jan	1552.63	42551.16	34116.75	26.41	20.97
Feb	4057.87	120154.07	79317.07	28.61	18.56
Mar	9437.61	54456.18	38116.32	4.77	3.04
Apr	19634.30	46993.87	16067.60	1.39	-0.18
May	14719.35	19548.75	2528.93	0.32	-0.83
Jun	18109.00	45999.04	39504.10	1.54	1.18
Jul	101704.9	133025.50	108342.96	0.31	0.07
Aug	466850.1	53555.13	60856.30	-0.89	-0.87
Sep	251941.5	73417.87	39421.32	-0.71	-0.84
Oct	74521.08	40658.52	40253.06	-0.45	-0.46
Nov	7521.12	6628.11	25379.59	-0.12	2.37
Dec	1934.11	1803.78	6383.25	-0.07	2.3

The highest sediment yield change during historical period is on July which is the month that mean monthly sediment peaks for both periods. The mean annual sediment yields were expected to increase by 35.4% and 4.4% for the 2030's and the 2060's, respectively, for RCP4.5. The mean annual streamflow was expected to increase by 38.1% and 1.3 % for RCP4.5 in the 2030's and 2060's, respectively. It might be due to the accompanied increment of future temperature, and varies in future precipitation. This indicated that the sediment yield was influenced by stream flow at the outlet of Katar watershed. This might be related to an increase in streamflow in the future scenario periods of 2030's and 2060's, which in turn was related to an increase in the precipitation amount. The projected climate data outputs from the ensemble mean of regional climate models (RCMs) in our study show that precipitation will increase with increase of the minimum and maximum temperature, as described in above section. Thus, the combined effects of an increase in precipitation and increase in temperature in the future period might cause a rise in streamflow. It has also been shown that there is a significant relationship between streamflow and sediment yield. It has been revealed in a study conducted by (Adem, 2015) in the Upper Gilgel Abay of the Blue Nile Basin in Ethiopia that sediment yield was related to a change in climate variables and thus to streamflow. The mean annual sediment yield increase follows the trend of the mean annual stream flow increase.

The projected climate data outputs show that precipitation will increase with the minimum and maximum temperature increase in the 2030's which associated with increase in streamflow and also sediment yield that indicated significant relationship between streamflow and sediment as well as precipitation and temperature. In addition, in 2060's the result implies that the increment in sediment yield which related with the increment in streamflow. Thus, implied that sediment yield at the outlet of the watershed was influenced by streamflow. In a similar study, average annual sediment loads generally increase in response to climate change by 47.7%, 44.5% and 35.9% for the A1F1, A2 and B1 scenarios, respectively in 2040–2069 (Azari, 2016). (Rodríguez-Blanco, 2016) also showed that suspended sediment is generally expected to decrease in 2031–2060 by 11%, and in 2069–2098 by 8%, as compared to the baseline period (1981–2010). This was mainly due to decreased streamflow in response to climate change. In general climate change results in an increase in sediment yield at the outlet of Katar river which is one of the major tributaries of Lake Ziway. The increase in sediment yield might have positive as well as negative implication on socio economic conditions of the sub basin.

## 5. CONCLUSIONS AND RECOMMENDATION

### 5.1. Conclusions

The study investigated the impacts of climate change on sediment yield from Katar watershed in the eastern part of Lake Ziway of the Central Rift Valley Basin. Regional climate models in CORDEX-Africa with RCP4.5 by the 2030's and by 2060's as compared to the baseline period of 1987-2017 were applied for this investigation.

Results indicated that mean annual precipitation as well as maximum and minimum temperatures would increase under RCP4.5. The projected annual precipitation would increase by 4.8 % and 1.6 % for 2030's and 2060's, respectively under RCP4.5 scenario. The projected climate variables were used in the SWAT model to estimate the sediment yield.

The SWAT hydrological model was used to simulate present and future changes in sediment yield and SWAT-CUP program was used for identify sensitive parameter, calibration and validation for sediment yield. The performance evaluation of the model confirmed that statistical measure parameter for monthly simulation were in satisfactory range with a value of  $R^2 = 0.71$  and  $NSE = 0.68$  for calibration period. The corresponding value for validation period shows  $R^2 = 0.67$  and  $NSE = 0.65$ . The analyses suggested that the SWAT model could be applied to simulate future changes in sediment yields due to climate change.

The model response to climate change indicated an increase in sediment during the future period in the 2030's and 2060's as compared to the historical period (1987–2007) under RCP4.5 emission scenario. The mean annual sediment yields of projected RCP4.5 in the 2030s and the 2060's were predicted to increase by 35.4 % and 4.4 %, respectively. The results show that future climate change will affect the sedimentation. The combined effects of increase in precipitation and temperature in the future periods cause the increment in streamflow. It has also been shown that there is a significant relationship between streamflow and sediment yield.

Moreover, the pattern of precipitation, temperature and streamflow was similar to sediment yield. This indicated that precipitation, temperature, streamflow and sediment load would operate in good relation with in the watershed. Finally, the result showed that the amount of sediment load would vary in the watershed due to the changes in precipitation and temperature in the 2030's and 2060's for RCP4.5.

## 5.2. Recommendation

Assessing the impact of climate change on sediment yield is critical for planning and implementing sediment management strategies in the basin and helpful to reduce the risk of climate impact. Based on the result of the study the following recommendations are derived.

- This study was based on the outcomes of RCP4.5 scenario but apply different RCP scenarios are recommended to make comparison between their results.
- Land use and soil variable were assumed constant in the future. Hence, further research is recommended to study the combined effect on sediment yield.
- Availability of hydrological data is very important while using any model analysis for current and future projections. However, Katar watershed stream flow gauging station has data scarcity. It affects the accuracy of the output results; therefore, it is recommended for future studies to use updated and recent data in order to get more reliable result and better accuracy.
- SWAT model calibrated using observed flow data at gauging station and the model prediction also depend on the input data. Therefore, in order to improve the model performance, the weather stations should be improved both in quality and quantity.
- The sediment data used for this study were generated from sediment rating curve developed from limited measured data. However, there will be a gap between the actual and derived sediment data; therefore, it is recommended for future studies the recording the data with accurate value should be necessary for better reliable result.
- As the SWAT model is capable of simulating the hydrological processes in a watershed, it can be further extended to similar watersheds in the country, particularly in the larger river Basin of Ethiopia, where quantifying the total volume of runoff and sediment yields generated from the basin is urgently required for better land and water resources planning and management purposes.

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## APPENDICES

### Appendix-A: Annual Rainfall for the selected stations

No	year	Arata	Bekoji	Ketera-genet	Kulumsa	Ogolcho
1	1987	690.1	967.1	755.8	775.5	432
2	1988	717	1161.4	909.4	874.4	1487.3
3	1989	670.9	1078	797.5	916.3	970.1
4	1990	747	1056.3	910.1	984	939.4
5	1991	749.9	1039.7	795.2	796.3	704.7
6	1992	741.2	1153.8	743.9	809.5	739.8
7	1993	841.7	1186.2	705.6	930.6	928.7
8	1994	638	1051.4	668.8	727	589.2
9	1995	1016.9	1030.9	703.8	866.9	727.7
10	1996	922.4	1063.5	728.9	877	816
11	1997	882.6	1083	660.2	911.6	747.2
12	1998	928.3	1057.2	826.3	874.5	824.5
13	1999	707.4	1058.7	754	746.6	633.1
14	2000	805.2	1065.6	933.1	797.5	719.7
15	2001	837	1066.1	788.4	938.9	703.7
16	2002	575.2	1061.9	546	708.4	583.3
17	2003	771.2	1063.1	610.5	758.6	775.7
18	2004	602.2	1064.3	686.4	728	572
19	2005	785.4	1063.3	333.4	743.3	527.5
20	2006	726.1	1063.8	710	805.7	540.6
21	2007	791.8	1063.3	665	835.9	820.1
22	2008	848.9	1063.6	891.3	807.6	960.3
23	2009	651.7	1120.3	706.5	789.4	689.8
24	2010	961.4	916.3	1327	917.8	816.2
25	2011	739.2	1469.8	969	849.7	659.2

26	2012	806.4	1170.9	930.2	961.2	877.9
27	2013	788.9	979.3	953.2	749.8	709.3
28	2014	806.5	1284.8	916.9	868.3	536.4
29	2015	439.6	821.1	721	613.6	365
30	2016	784.5	975.9	880.3	892	588.1
31	2017	735.7	1193.9	1002.1	753.5	765.3

### **Appendix-B: WGEN (Weather generator) parameters used by SWAT Model**

Symbol	Symbol definition
TMPMX	Average or mean daily maximum air temperature for month (0C)
TMPMN	Average or mean daily minimum air temperature for month (0C)
TMPSTDMX	Standard deviation for daily maximum air temperature in month (0C)
TMPSTDMN	Standard deviation for daily minimum air temperature in month (0C)
PCPMM	Average or mean total monthly precipitation (mm H2O)
PCPSTD	Standard deviation for daily for daily precipitation in month (mm H2O/day)
PCPSKW	Skew coefficient for daily precipitation in month
PR_W1	Probability of a wet day following a dry day in month
PR_W2	Probability of a wet day following a wet day in month
PCPD	Average number of days of precipitation in month
RAINHHMX	Average daily relative humidity in month
SOLARAV	Average daily solar radiation for month (MJ/m2)
DEWPT	Average daily dew point temperature in month (0C)
WNDVAV	Average daily wind speed in month (m/s)

**Appendix-C: Measured Mean Monthly Streamflow (m<sup>3</sup>/s) at Abura gauging station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	1.85	1.81	4.87	18.12	9.79	14.78	10.02	19.34	17.06	7.37	2.37	2.01
1988	1.85	2.12	2.02	2.30	2.52	2.73	22.99	99.43	34.52	20.31	5.17	2.69
1989	2.40	2.35	2.33	6.39	5.80	3.93	12.84	25.06	29.16	12.10	3.43	4.01
1990	2.71	10.95	20.02	21.31	5.30	4.31	12.70	59.06	38.43	15.91	3.93	2.39
1991	2.16	2.24	3.76	5.39	2.77	3.44	14.05	45.78	36.07	6.14	2.56	2.31
1992	2.02	2.46	1.76	3.04	3.07	3.23	8.18	65.98	53.99	25.08	4.56	2.83
1993	2.71	6.55	2.19	5.10	11.51	11.56	16.41	52.83	35.71	20.12	7.17	2.70
1994	2.14	1.92	1.64	1.56	3.29	4.27	22.93	68.87	49.09	7.02	2.81	2.04
1995	1.56	1.58	7.94	7.22	5.44	2.54	12.60	48.41	59.31	4.59	2.34	2.11
1996	2.48	1.69	2.86	3.93	6.74	17.94	21.50	64.12	24.36	8.54	2.44	2.16
1997	2.91	1.67	1.56	6.00	2.60	2.73	13.57	20.98	11.05	5.58	6.96	2.94
1998	2.19	3.45	5.01	2.38	5.99	3.66	13.40	69.19	49.60	28.11	6.76	2.36
1999	1.99	0.43	1.71	1.64	1.69	3.19	17.00	33.86	21.21	44.47	7.45	2.33
2000	1.58	1.58	1.56	1.49	4.67	2.74	9.73	49.31	28.69	25.27	8.7	2.5
2001	1.76	1.55	2.17	2.57	7.57	13.82	34.32	80.05	37.86	10.45	2.44	1.79
2002	1.84	1.90	2.77	2.08	2.80	3.43	7.29	26.57	13.45	3.33	1.48	1.92
2003	2.44	1.39	1.55	3.93	3.80	2.44	16.62	51.94	28.99	7.50	1.84	1.85
2004	1.47	1.34	1.35	8.71	3.52	3.32	20.03	38.03	26.83	13.57	2.22	1.41
2005	1.51	1.39	2.29	2.74	13.87	6.00	25.92	59.26	38.91	10.39	2.33	1.54
2006	1.64	1.40	2.15	11.56	7.50	4.70	38.20	79.89	41.37	8.34	3.01	1.79
2007	1.16	1.89	1.01	3.62	3.85	11.76	28.83	67.17	58.43	12.16	2.26	1.09

#### Appendix-D: Land Use/ Cover Classifications

Land use/ Land cover (LULC)	SWAT code	Area (km <sup>2</sup> )	Cover percentage (%)
Forest-Mixed	FRST	322.47	9.76
Woodland	FRSD	36.01	1.09
Shrub/ bush	RNGB	109.03	3.30
Cropland	AGRL	2429.43	73.53
Grassland	PAST	149.34	4.52
Barren land	BARR	73.68	2.23
Wet-land	WETL	9.25	0.28
Water	WATR	3.63	0.11
Afroalpine	FRSE	149.67	4.56
Urban	URMD	20.48	0.62
Total		3304	100

#### Appendix-E: Soil Classification

Soil type	Area (km <sup>2</sup> )	Cover percentage (%)
Pellic Vertisols	1633.50	49.44
Chromic Luvisols	316.19	9.57
Vitric Andosols	65.75	1.99
Mollic Andosols	286.79	8.68
Vertic Cambisols	356.83	10.80
Eutric Fluvisols	5.29	0.16
Orthic Luvisols	527.65	15.97
Eutric Cambisols	13.88	0.42
Eutric Nitsols	98.13	2.97
Total	3304	100