EVALUATION OF CLIMATE AND LAND USE LAND COVER CHANGE IMPACTS ON STREAM FLOW OF GUDER CATCHMENT, IN THE UPPER BLUE NILE BASIN IN ETHIOPIA

Bekam Bekele Gulti

A Thesis Submitted to the Department of Water Resources Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resource Engineering (Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

Adama

October, 2020

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Subject: **Thesis Submission**

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This is to certify that the thesis/dissertation entitled "**Evaluation of Climate and Land Use Land Cover Change Impacts on Streamflow of Guder Catchment in the Upper Blue Nile Basin**" submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering (Irrigation Engineering) the Graduate Program of the department of Water Resource Engineering and has been carried out by Bekam Bekam Gulti (ID. No: PGR/18035/11) under our supervision and guidance.

Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

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Co- Advisor	Signature	Date

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LIST OF ACRONOMYS AND ABBREVIATIONS

AGNPS	Agricultural Non-Point Source Pollution Model
AIM	Asia-Pacific Integrated Model
ANSWERS	Areal Non-Point Source Watershed Environment Simulation
AR5	Assessment Report Five
AWBM	Available Water Balance Model
BCEOM	French Engineering Consultants
CORDEX	Coordinated Regional Downscaling Experiment
CMhyd	Climate model for Hydrologic Modelling
CMIP5	Coupled Model Inter-Comparison Project Phase 5
CN	Curve Number
CNRM	Centre National de Recherches Météorologiques
CSA	Central Statistical Agency
CRCM5	Canadian Regional Climate Model Phase 5
DDSM	Dynamical downscaling Model
DMC	Double Mass Curve
CV	Coefficient of Variation
DEM	Digital Elevation Model
ECRGE	Ethiopian Climate Change Resilience Green Economy
GCMs	Global Circulation Mode
GHGs	Green House Gas
HRU	Hydrologic Response Unit
IIASA	International Institute for Applied System Analysis
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
JGCRI	Joint Global Change Research Institute
HRU	Hydraulic Response Unit
HSPF	Hydrological Simulation Program Fortran
HWSD	Harmonized World Soil Database Viewer V1.2
LH-OAT	Latin Hypercube One-factor-At-a-Time
MESSAGE	Model Energy Supply Strategy Alternatives and General Environmental
MK	Mann-kendel Test
MOA	Ministry of Agriculture
MOFED	Ministry of Finance and Economic Development
MOWIE	Ministry of Water Irrigation and Electricity
MPI-M	Max-Planck-Institute
NMS	National Meteorological Services
PLOAD	Pollutant Load Application
PET	Potential Evapotranspiration

RCMs	Regional Climate Model
RCP	Representative Concentration Pathways
RCA_4	Rossbey Center Regional Climate Model
RMSE	Root Mean Square
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SIMHYD	Simplified Hydrology Model
SDSM	Statically Downscaling Model
SRES	Special Report on Emission Scenarios
SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil Water Assessment Tool Calibration and Uncertainty Program
UBNRB	Upper Blue Nile River Basin
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Program
UNDESA	United Nations Department of Economic and Social Affairs
USDA	United States Department of Agriculture
USGS	United States Geology Survey
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WCRP	World Climate Research Program
WEPP	Water Erosion Prediction Project
WMO	World Meteorological Organization
WXGEN	Weather Generator Model

ABSTRACT

Changes in watershed hydrology are mainly driven by changes in land use and climate. This study Evaluate Climate and LULC change impacts on Streamflow in the Guder catchment in Upper Blue Nile Basin. Specifically, dynamical downscaled rainfall simulations were evaluated for selected three RCMs output and one ensemble was undertaken by—RCA4. A suite of performance measures such as Bias, RMSE, correlation coefficient and coefficient of variability of basin averaged annual rainfall amount was used to assess performance of climate models output from CORDEX Africa. Calibration and Validation of the study area was done by using SWAT CUP SUFI 2 and three main performance measurement criteria such as R^2, NSE and Bias. Short term and RCP 4.5 scenarios was used to evaluate stream flow on CC and LULC. The performance Evaluation of the GCMs model shows that, CCNMR model performed -0.82, 0.26 and 23 in terms of bias, CV and RMSE, in terms of correlation Ensemble perform best which 00.7. Performance evaluation of RCM output show that, CCNMR simulates rainfall over most stations better than other RCMs irrespective of the driving GCM. Statistical agreement between simulated and observed flow data during the calibration periods resulted in a high agreement using R^2, NSE and BIAS with the result of 0.84, 0.83 and 8.3% respectively. The finding of climate scenario show that, the maximum increment and decreasing precipitation in January and December was change 5e % and (-23%) respectively. Tmax and Tmin showed an increment of annual average temperature of by 1.4 ^{0}C and 0.32 ^{0}C with 2040's scenarios respectively. Due to this climate change, 38 % of streamflow was increased in the month of August and the peak flow was reduced from 38% to 4% in the month of August to September. At the same time, the response of streamflow due LULC reveal that, the annual change in stream flow was decreased by -13.5%. The streamflow in mean wet season, small rain season and dry season due to LULC was -14%, -11% and -6% respectively. Finally, the total increases in mean annual streamflow due to future climate change were 27% while the total decrease change in annual streamflow due to Land use Land cover in mean was (-12%). The predicted changes in streamflow will have implications for water supply, flood control and stormwater management. Therefore, a comprehensive strategy of low impact developments, smart growth, and open space is critical to handle future changes to watershed systems.

Keyword; Climate change, Land use/Land cover, Mann-Kendall, SWAT, RCM, and Steamflow.

1. INTRODUCTION

1.1. Back Ground

Climate and land use and land cover (LULC) change are considered the main two drivers affecting water quantity in watersheds and waterways (Kharel *et al*. 2016). Due to this, effective planning and management of water resources require better understanding of climate and land use/land cover change effects on watershed hydrology (Singh *et al*., 2014); which is critical in supporting ecosystem services and food security (Millennium Ecosystem Assessment, 2005).

Over the last century, climate observations at regional and global scales revealed the more frequent extreme events characterized by changes in temperature and precipitation with direct impacts on local and regional water resources (IPCC, 2013). The concentration increased to over 400 ppm in 2015 and it is expected to reach 463–623 ppm by 2060 and 470–1099 ppm by 2100. With continuation of the above emissions trajectory, the global mean surface temperatures would likely increase by 2.0^{o}C by mid-century and 3.7^{o}C by the end of the 21st century (IPCC, 2014). Fortunately, this global climate changes especially on the Nile Basin are gain particular concern due to their geopolitical and socioeconomic implications (Niang *et al.,* 2014).

Upper Blue Nile are expected to have a lower streamflow by the end of the 21st century because of declining precipitation and increasing use of water for irrigation and hydropower (Mccartney *et al*., 2012). Fikru *et al*, (2018) studied impact of climate change on water resource on Guder catchment of upper Blue Nile Basin in Ethiopia using SWAT Hydrological model. SDMS was used to project climate variable at local scale from coupled model inter-comparison project 3 (CMIP3) data set and found that an increments of mean annual and seasonal in flow volume for both A2a and B2a emission scenario in three benchmark period in the future.

In addition to climate change issues, changes in land use have also been a major driving factor of hydrologic alterations (Zhang *et al*., 2016). Numerous studies have investigated hydrological impacts of land use change at watershed scales (Dwarakish and Ganasri, 2015). Some of the study are; increased transpiration (Hardanto *et al*., 2017), increased evapotranspiration (Meijide *et al*., 2017), decreased infiltration (Tarigan *et al*., 2016), reduced minimum discharge (Merten *et al*., 2016) and water quality (Babel *et al.,* 2011). All these changes potentially increase streamflow fluctuation in a river basin. For example, Schilling *et al.* (2008) found that average annual ET decreased with increasing corn acreage in the Raccoon River watershed in Iowa.

The effect of changes in forest and other land use patterns on the flow regime needs monitoring, especially in areas such as the Upper Blue Nile basin, where streamflow during the dry season is an important factor for food security and the development potential of the region (Yihun *et al*., 2018). The recent study done by Moges *et al*, (2018) reveal that LU/LC change increased the wet season flow by 14.5% while decreasing by 9.65% in dry season. In wet season the flow increased by 4.5% while decreased by 3.3% in dry season because of change in climate and seasonal variability. The study showed the increase in streamflows can be directly attributed to the expansion of cultivated lands at a cost of the forested vegetation.

Watershed modeling remains an important tool in simulating processes to predict/or forecast storm water flows due to the impact of climate change and Land cover change (Dudula & Randhir, 2016). However, the complexities of watershed processes make it difficult to predict storm water quality. Hydrologic models such as ANSWERS (Beasley *et al*., 1980), AGNPS (Young *et al*. 1987), WEPP (Flanagan & Nearing, 1995), PLOAD (Shen *et al*.. 2011), EuroSEM (Morgan *et al.,* 1998), Hydrological Simulation Program Fortran (HSPF;Bicknell *et al*., 1993), RUSLE (Renard *et al.,* 1997) and SWAT (Santhi *et al*.2006) are often used in combination with geographic information systems (GIS) for discharge simulations and sediment and nutrient transport studies. Recently, integration of SWAT with land use simulation models become a new method for hydrological assessment of future and hypothetical land-use and land cover scenarios (Zhang *et al,* 2012).

1.2 Statement of the Problem

In the past, only a few studies explicitly acknowledged the combined effect of LULCC and climate change in different parts of the World (Tu, 2009; Qi, *et al*., 2009 and Asner *et al*., 2010). However, it is becoming one among the utmost prevalent areas of research (Pan et al., 2017; Hamad *et al*., 2018 and Mekonen *et al.,* 2017). These studies suggest that the hydrological responses of catchments to LULCC vary with the climate and physical characteristics of the catchments. Further, Qi *et al*. (2009) showed that future hydrological changes and LULCC are expected to be site-specific, and that climate variability is an important factor for controlling the basin hydrological process. Combalicer and Im., (2012) showed that climate variability leads to a direct impact on hydrology on a watershed.However, the response of future climate conditions may vary depending on the LULCC.

As the principal supplier to the Nile flow, the Guder catchment response to environmental change LULC and climate change is vital for the Nile River flow in general, and the catchments in particular. Moreover, combined study of climate change and LULC can provide information about watersheds that will be useful for making decisions regarding the development and management of water and land resources (Randhir and Tsvetkova, 2011). This reveals that, separate studies of LULC or climate changes do not completely answer the questions as to the resulting influences on streamflow.

An adequate amount of research has been conducted on the potential impacts of LULC change on stream (Rientjes *et al*., 2011; Tekleab *et al.,* 2014; Welde and Gebremariam, 2017). Similarly some research is done on future climate change on stream flow (Fikru *et al*., 2018; Beyene *et al.,* 2010;Taye *et al*., 2011; Hadgu *et al., 2015*; Haile and Rientjes, 2015; Gebremedhin *et al.*,2017;Gizaw *et al.,* 2017). Having separate studies of LULC or climate changes does not completely answer the questions as to the resulting influences on streamflow. It is, therefore, crucial to consider both climate change and LULC dynamics and to evaluate their relative influence to stream flow change.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of the study was to investigate response of streamflow under changing climate and LULC in Guder catchment of Upper Blue Nile Basin in Ethiopia.

1.3.2. Specific objectives

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

i. Determine future Temperature and Precipitation scenario for the study area using dynamically downscaled climate model.
ii. Quantify impact of future climate change on Streamflow.
iii. Quantify the impact of future LULC on Streamflow.
iv. Evaluation of combined impact of CC and LULC on stream flow.

1.4. Research Questions

i. How future characteristics of temperature and precipitation that downscaled dynamically look like over the study catchment?
ii. How future streamflow of Guder catchment responding under changing LULC?
iii. How future streamflow of Guder catchment responding under changing climate?
iv. How to evaluate combined implication of changing both climate and LULC on future streamflow of Guder catchment?

1.5. Significance of the Study

The result of this study is expected to be used as background information on the short-term stream flow and its temporal trend for water resource planning and irrigation water management in Guder catchment. Furthermore, the study was estimating of Temperature and Rainfall, which is essential for design, operation and management of irrigation projects and they are prerequisites parameters for optimal water resources management especially in rain-fed agricultural areas prone to water deficits. Moreover, the study will also help for policy makers as a tool for decision making on irrigation developmental projects in the catchment. The results of this study have significances for water resource management and land use planning in the Guder catchment and for other regions encountering identical pressures from climate change and LULC dynamics. Generally, such local studies are desirable to increase understanding of economical, societal, and environment implications of land use change in the face of a changing climate.

1.6. Scope and Limitation of the Study

The domain of the study is Guder catchment, the central highlands of Ethiopia highlands. For this study, the scope has been limited with respective to the stated objectives above. Thus, Performance Evaluation of GCMs driving model; projecting climate variable (Temperature and Precipitation); quantifying impact of future climate change, LULC and combine of both on stream flow of Guder catchment. The dynamically downscaled regional climate data from the CCNMR output of CORDEX-Africa downscaled by RCA-4 model with recently developed RCPs 4.5scenarios were used to indicate future projections in one time frames: 2021-2040 represented as near-term with respect to the baseline period from 1987-2006.
LULC scenario was done based of SWAT land use updating extension. The SWAT model also applied to simulate future stream flow the basin for this specific study.

The followings are the limitations the study:

- 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.
- In addition, the Physiographic terms such as land cover assumed to conserve for the future. However, in real world the above variables are changing.
- Small meteorological stations are available in the basin, and this shows an indication of the data scarcity for the basin and this can cause a alter level of performance by a hydrological model during the calibration and validation processes.
- The climate variables used in this study are results of CORDEX-Africa ensemble RCMs simulations scaled by downscaling different GCM models under different RCPs with a spatial resolution of 50km, which is a little bit coarse

1.7. Organization of the Thesis

Chapter 1: Introduction; This chapter 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 2: Literature review; This chapter summarizes literature regarding the subject of climate changes in terms of global, continental and regional aspect, Major previous studies conducted in the Upper Blue Nile Basin ,hydrologic modeling for use in impact assessment and recent climate change scenarios data are also mentioned.

Chapter 3: Materials and Methodology; It describes the various data used in the study, their sources, the methods used for data quality control step-by-step methodology adopted in the research is presented.

Chapter 4: Result and Discussion; this chapter presents the output of model application to assess the impact of climate change. It gives a detailed account Trend analysis, performance evaluation regional downscaling model, climate projection, land cover change scenario and finally determination of streamflow.

Chapter 5: The last chapter includes conclusion and Recommendation; this chapter summarizes the contribution of this research with conclusion and recommendation.

2. LITERATURE REVIEW

2.1. General Circulation Model (GCM)

GCMs are suitable tools for the assessment of climate variability and change. Current GCMs have spatial resolution about 100–250 km and have the potential to simulate the main characteristics of general circulation at the range of this scale (Shongwe, 2009). Although GCMs can satisfactorily simulate the atmospheric general circulation at the continental scale, they are not necessarily capable of capturing the detailed processes associated with regional–local climate variability and changes that are required for regional and national climate change assessments (Rummukainen *et al*., 2010).

Simulations of general circulation models (GCM) are generally used for the assessment of climate change. However, the GCM simulated climate is associated with large uncertainties due to model structure, parameterization, assumption, calibration processes and so on (Yatagai *et al*., 2012). Therefore, not all the GCMs can be directly used to project the future climate in certain regions.

The coarse resolution prohibits global models from providing an accurate description of extreme events with respect to the regional and local impacts of climate variability and change (Giorgi *et al*., 2009). Hence, downscaling of the climate from the coarse resolution GCMs to regional scale for the computation of the local details to obtain the relevant temporal and spatial scales pertinent for climate change studies is required.

2.2. Downscaling Method

Climate downscaling techniques are used to bridge the spatial and temporal resolution gaps between what climate modelers are currently able to provide and what impact assessors require (Wilby, 2007). There is a significant gap between the large spatial resolution GCMs and regional and local watershed processes. This scale mismatch causes a considerable problem for the assessment of climate change impact using hydrological models. Hence, significant attention should be given to the development of downscaling methodologies for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs).

There are two main approaches available for the downscaling of large spatial resolution GCM outputs to a finer spatial resolution- Dynamical downscaling (DDSM) and Statistical downscaling (SDSM). DDSM and SDSM approaches have their own advantage and disadvantage, but there is no consensus that one approach is superior in terms of reproducing the observed variability of local climate (Mearns *et al,* 1999).

2.2.1. Statical downscaling approach

Based on particular statistical relationships between the coarse GCMs and fine observed data, statistical downscaling is a straightforward means of obtaining high-resolution climate projections (Wilby *et al*, 2004). Statistical downscaling may be used whenever impacts models require small-scale data, provide suitable observed data are available to derive the statistical relationships and covers all kind of locations. The output obtained is generally small scale information on future climate or climate change (maps, data, etc.), the key input being appropriate observed data to calibrate and validate the statistical model(s) and GCM data for future climate to drive the model(s) (Wilby *et al,* 1998).

Reviews of downscaling methods are widely available (Probst *et al.,* 1987), Maraun *et al* (2010). Taking the relationship with RCMs into consideration, (Maraun *et al* 2010) divided statistical downscaling approaches into prefect prognosis (PP), model output statistics (MOS) and weather generators. In PP, the statistical downscaling relationships are established by observations. Geostatistical approach (Jha *et al*., 2012) has recently been developed that has an added feature of its application in remote sensing. Although statistical downscaling can be a computationally efficient alterative to dynamic downscaling, the validity of statistical downscaling is based on an assumption that the empirical relationship identified for the current climate will hold for future climate scenarios (Wilby *et al*, 2004). There are evidence which unfold dynamical downscaling is superior to statistical downscaling techniques to simulate rainfall of regions with diverse topography (Fowler *et al*., 2007).

2.2.2. Dynamical downscaling approach

Dynamical downscaling is usually based on the use of regional climate models (RCMs), which generate finer resolution output based on atmospheric physics over a region using GCM fields as boundary conditions (Hewitson, Crane *et al.,* 1996 ; Giorgi *et al* 199. The physical consistency between GCMs and RCMs is controlled by the agreement of their large-scale circulations (Von Storch *et al* 2000). The individual choice of domain size controls the divergence between the RCMs and their driving GCMs (Jones *et al* 1997). Because of the higher spatial resolution output, RCMs provide a better description of topographic phenomena such as orographic effects (Christensen et al 2007).

Moreover, the finer dynamical processes in RCMs produce more realistic mesoscale circulation patterns (Buonomo *et al* 2007). However, RCMs are not expected to capture the observed spatial precipitation extremes at a fine cell scale (Fowler *et al.,* 2007). Many studies (Rauscher *et al.,* 2010) have found that the skill improvement of RCM depends not only on the RCM resolution but also on the region and the season. Although RCMs may give feedback to their driving GCMs, many dynamic downscaling approaches are based on a one-way nesting approach and have no feedback from the RCM to the driving GCM (Maraun et al., 2010).

The primary advantage of RCMs is their ability to model atmospheric processes and land cover changes explicitly. Regional climate models (RCMs) dynamically downscale GCM output to scales more suited to end-users and are useful tor understanding local climates in regions that have complex topography and they account for land surface heterogeneity. In addition, RCMs act as a zooming device to deliver climate information on regional to local scale (Akinsanola *et al*., 2015).

Generally, dynamical downscaling is computationally expensive. At present, many collaboration projects are generating climate simulation from dynamical downscaling for model inter-comparisons and impact assessments. These projects include the Coordinated Regional Climate Downscaling Experiment (CORDEX) that produces dynamical downscaled climate simulation for all continents. CORDEX (Coordinated Regional Climate Downscaling Experiment) under the auspices of the World Climate Research Program (WCRP) is an initiative to downscale different GCM outputs that participated in the Coupled Model Inter-comparison Project Phase 5 (CMIP5) data archive (Taylor *et al*., 2012) on 25Km and 50Km grid spacing for 14 regions of the Globe.

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). Different studies evaluated the performance of climate models representing the climate of the Upper Blue Nile Basin using various techniques (Gebrekidan *et al.,* 2018). From their result, they recommend using GCMs downscaled using RCA-4 RCMs and stations based statistical bias correction to manage elevation-based biases of RCMs in the Upper Blue Nile Basin. In line with this recommendation, RCA-4 was used in this study to evaluate the performance of GCM output in Guder catchment.

2.3. Evaluation of General Circulation Model Simulations of Rainfall

Accurate and reliable simulation of the climate over the African continent by means of GCMs and RCMs is a major challenge partly due to the complexity and the diversity of processes to be represented (Laprise *et al*., 2013). Evaluation studies on RCM simulation results over the major river basins of Africa only are few. Kim *et al*. (2014) reported that five out of ten models of CORDEX-Africa (http://cordex.dmi.dk/joomla/)somewhat captured the magnitude of inter-annual rainfall variability across the continent. In the same study, the models overestimated spatial variability of annual mean rainfall over the Ethiopian highlands. Findings in (Endris *et al*. 2013) for the Ethiopian highlands indicate that simulation results of ten models of CORDEX-Africa captured the shape of the monthly rainfall distribution and the annual rainfall anomaly but overestimated the mean monthly rainfall amount.

Laprise *et al. (*2013) evaluated the fifth-generation Canadian Regional Climate Model (CRCM5) over the CORDEX Africa domain. The boundary condition data set was obtained from simulations of the MPI-ESM-LR Global Climate Models (GCMs) of the Max-Planck-Institute fϋr Meteorologie (http://www.mpimet.mpg.de/ en/home.html) and the Canadian Centre for Climate Modeling and Analysis (http://www.cccma.ec.gc.ca/), respectively.

Based on the above gap, CORDEX-Africa RCM results was evaluated for historical rainfall over the Guder catchment. The evaluation for annual time scales was carried out to select the best model so that it can be used as input for the next objective of this study. It can also improve the understanding of reliability of dynamically downscaled simulations of three GCMs that were part of the Coupled Model Intercomparison Project Phase 5 (CMIP5). The downscaling was accomplished by the recent version of the Rossby Centre using the Regional Climate Model—RCA4 (http://www.smhi.se/en/) (Alemseged and Tom, 2015).

2.4. Climate Scenario

In climate change research, scenarios become an important element as they allow researchers to understand the long-term consequences (Van Vuuren *et al.,*2011) and describe plausible pathways of climatic condition and other aspects of future. Scenarios have been used by decision makers and planners to analyze the situations where outcomes are uncertain. Climate scenarios are plausible representations of future climate conditions (temperature, precipitation and other climatological phenomena). In climate change research, they have become an important element as they allow researchers to understand the long-term consequences (van Vuuren *et al.,* 2011) and describe plausible pathways of Climatic condition and other aspects of future (Moss *et al.,* 2010).

Climate scenario can be produced using a variety of approaches including: incremental techniques where particular climatic (or related) elements are increased by plausible amounts; spatial and temporal analogues in which recorded climate regimes that may resemble the future climate are used as example future conditions;

Other techniques, such as extrapolation and expert judgment and techniques that use a variety of physical climate and Earth system models including regional climate models (Mearns *et al.*, 2001). All of these techniques continue to play a useful role in development of scenarios, with the appropriate choice of method depending on the intended use of the scenario (Carter *et al*., 2007), but most major advances are expected with model-based approaches. There is a notable increase in interest in regional-scale climate scenarios and projection methods, especially for impact and adaptation assessment.

Over time, different scenarios have been used in climate research from SA92 used in IPCCs first assessment report to Special Report on Emissions and Scenarios (SRES) used in third and fourth assessment report. Recently, the new scenarios called Representative Concentration Pathways were developed and used for preparing fifth assessment report (AR5) of IPCC released in 2015(IPCC, 2014).

2.4.1 Representative concentration path way (RCP)

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. 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. The RCPs were developed by combined efforts of the researchers from different disciplines involved in climate research (Van Vuuren *et al*., 2011).

Four pathways RCP2.6, RCP4.5, RCP6 and RCP8.5 were developed. They were named based on the radiative forcing target levels of 2.6, 4.5, 6 and 8.5 Watt/m2, by the end of 21st century. Estimation of radiative forcing is based on the forcing of green house gas (GHGs) and other agents.

All these four pathways were considered to be the representative of all the literature pertinent to change in climate and each RCPs defines a specific emissions trajectory and subsequent radiative forcing (Wayne, 2013).

2.4.1.1 RCP 2.6 (mitigation scenario)

In order to achieve this, emission and CO_2 would need to be reduced by more than 100 % by 2100. This can be achieved by replacing use of fossil fuel by renewable energy, nuclear power, increased use of bioenergy and use of carbon capture and storage (CCS). 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, *et al*. 2011).

2.4.1.2 RCP4.5 (stabilization scenario)

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, CO2 emissions only slightly before the decline commence around 2040, Decreasing use of croplands and grasslands due to yield increases and dietary changes. In addition, Strong reforestation programs as a mitigation strategy (Smith and Wigley, 2006) baseline conditions (i.e. 1981–2000 periods) with NCDC weather data.

2.4.1.3 RCP6 (stabilization scenario)

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 (Moss *et al.* 2011).

2.4.1.4 RCP8.5 (high emission scenario)

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 (Riahi *et al*. 2011).

Table 2.1 Description of the four Representative concentration pathways (RCPs)

RCP	Description	Publication-IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370ppm CO2) by 2100	(Riah*et al.* 2011)-MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850ppm CO^2eq) at stabilization after 2100	(Fujino*et al.* 2006; Hijioka et al. 2008)-AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650ppm CO^2eq) at stabilization after 2100	(Clarke *et al.* 2007; Smith and Wgley 2006)- GCAM
RCP2.6	Peak in radiative forcing at ~3W/m^2 (~490ppm CO2) before 2100 and the decline (the selected pathway declines to 2.6 W/m^2 by 2100)	(Van Vuurent*et al*., 2007a; Van Vuurent *et al*. 2006)-IMAGE

Source; (BJORNS. 2013)

2.4.2. Comparisons of SRES and RCP climate scenarios

The four RCP scenarios used in CMIP5 lead to radiative forcing values that range from 2.6 to 8.5 W m–2 at 2100, a wider range than that of the three SRES scenarios used in CMIP3 (IPCC, 2013). The SRES scenarios do not assume any policy to control climate change, unlike the RCP 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 (Van Vuuren *et.al*.,2011)

2.5. Impact of Climate change on Temperature and Precipitation

2.5.1. Global climate change impact on temperature and precipitation

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 (Hargreaves and Samani, 2115). There is a total increase of $0.78^{0}C$ in global temperature from the second half of the 19 century to the 1^{st} decade of 20^{th} century (IPCC, 2013c) While the number of cold days and cold nights have decreased, the number of warm days and nights have increased globally. Due to these changes in temperature and precipitation, glaciers have continued to shrink globally, and arctic sea ice and spring snow cover have decreased remarkably in Northern Hemisphere (IPCC, 2013c).

2.5.2. Climate change impact on temperature and precipitation on Africa

Africa has been identified as one of the parts of the world most vulnerable to the impacts of climate change (IPCC, 2014). Evaluation of Climate Change impact on Hydrology (A case of Upper Abay Basin Using RCP Climate Data) African countries are more affected by climate change because of their reliance on agriculture as well as their lower financial, technical, and institutional capacity to adapt (Rose, 2017). The African continent is expected to be the most affected by climate change, land degradation, and desertification (Hummel, 2015).

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 Sub-Saharan Africa is considered to be the most vulnerable to the impacts of climate change because of its high dependence on agriculture and natural resources, warmer baseline climates, low precipitation, and limited ability to adapt. Several studies have shown that surface water and groundwater evolutions over the past decades in Sub-Saharan Africa have been strongly affected by rainfall variations (Nhemachena, 2008).

2.5.3. Climate change impact on temperature and precipitation on Ethiopia

Several individual studies have been done to study the impacts of climate change on the water resources of Upper Blue Nile River basin. Taye *et al.* (2011) reviewed some of the research outputs and concluded that clear discrepancies were observed, particularly on the projection of precipitation. For instance, as the results obtained from Bewket and Conway (2007), Conway (2000) and Gebremicael *et al.* (2013) showed, there is no significant trend observed for rainfall, while non-significant increasing trends in annual and seasonal rainfall. For the future projection, expected changes in precipitation amount are unclear. For instance, Kim (2008) used the outputs of six GCMs for the projection of future precipitations and temperature, and the result suggested that the changes in mean annual precipitation from the six GCMs range from −11 to 44 % with a change of 11 % from the weighted average scenario in the 2050s. However, the changes in mean annual temperature range from 1.4 to 2.6^{0}C with a change of 2.3^{0}C from the weighted average scenario.

Likewise, Yates and Strzepek (1998a) used three GCMs and the result revealed that the changes in precipitation range from −5 to 30 % and the changes in temperature range from 2.2 to 3.5 ^{0} C. Yates and Strzepek (1998b) also used six GCMs and the result showed in the range from −9 to 55 % for precipitation while temperature increased from 2.2 to 3.7 ^{0}C. Another study done by Elshamy *et al*. (2009) used 17 GCMs and the result showed that changes in total annual precipitation range between −15 to 14 % but the ensemble mean of all models showed almost no change in the annual total rainfall, while all models predict the temperature to increase between 2 and 5 ^{o} C.

Gebre and Ludwig (2015) used five bias-corrected 50 km × 50 km spatial resolution GCMs for RCP4.5 and RCP8.5 scenarios to downscale the future climate change of four watersheds (Gilgel Abay, Gumara, Ribb and Megech) located in Tana subbasin for the time period of 2030s and 2050s respectively. The result suggested that the selected five GCMs disagree on the direction of future prediction of precipitation, but multimodal average monthly and seasonal precipitation may generally increase over the watershed.

2.6. Trend Analysis of Climatic Data

Climate change threatens to increase temperature and evapotranspiration; and hence, increasing the risks of heat waves associated with drought (Touré *et al*., 2017). Thus, the change in climate is expected to increase vulnerability in all eco-regions through the increased temperature and more erratic rainfall, which effect food security and economic growth. Some regional analysis was undertaken to understand the extreme climate and trends. However, the trend indices showed significant increases and decreases in seasonal and annual precipitation, for example, Asfaw *et al*., (2017) reported a decreased rainfall in annual, Belg, and Kiremt in the Woleka sub-basin of Ethiopia. On the other hand, Bewket, (2007) reported variations in daily rainfall with no consistent trends. Mekasha *et al*., (2014) also reported increasing warm extremes in temperature and increasing precipitation in different stations across Ethiopia.

Thus, extreme climate indices should be tested for future studies on the perception of climate Change with a wide coverage within the country. Therefore, it is essential to analyze the recent trends of climatic variables as these show the climate-related adaptation and mitigation strategies employed by different entities to improve the agrarian economy of the country at large. Furthermore, trend analysis of climatic variables is very important to understand the climate system of the country and become a vital research area for other researchers.

2.7. Hydrological and Land Resources Modelling

2.7.1. Hydrological Modelling

There is a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. Beven, (2001) suggested four criterions for selecting model structures as follow:

1. Consider models which are readily available and whose investment of time and money appeared worthwhile.

2. Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.

3. Prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes.

4. Make a list of the inputs required by the model and decide whether all the information required by the model can be provided within the time and cost constraints of the project. Thus, a semi distributed physically based hydrological model SWAT is selected for this particular study by considering the factors stated above.

2.7.1.2. Soil and Water Analysis Tool (SWAT)

SWAT is a physically based semi distributed hydrological model which is a process -based, basin scale and continuous time model developed in early 1990s by Agriculture Research Service of the United States Department of Agriculture (USDA) (Arnold, 2009). Due to its versatility and applicability to complex watersheds, researchers have identified the Soil and Water Assessment Tool (SWAT) as one of the most intricate, consistent, and computationally efficient models (Neitsch *et al,* 2009).

Getachew *et al.* (2017) study Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin. This finding indicates that the assessment of model performance in the quintile domain revealed that the SWAT model was better than the simple conceptual models.

2.7.1.3. Hydrological component of SWAT

The simulation of the hydrology of a watershed is done in two separate divisions (Neitsch, 2005). The first is the land phase process of the hydrological cycle that controls the fluxes of water, sediment, nutrient and pesticide loadings to the main channel in each Catchment. Hydrological components which are simulated in this process include: precipitation, canopy storage, infiltration, Evapotranspiration, lateral flow, surface runoff and return flow.

In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation:

$$SW_t = SW_0 \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \ldots\ldots\ldots (1)$$

where, SW_t is the final soil water content (mm/day); SWo is the initial soil water content on day i (mm/day), t is the time (days), R day is the amount of precipitation on day i (mm/day); Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), Wseep is the amount of water entering the vadose zone from the soil profile onday i (mm), and Qgw is the amount of return flow on day i (mm).

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers the Soil Conservation Service (SCS), curve number equation and the Green &Ampt infiltration methods to estimate the surface runoff volume (Neitsch, 2005).

The 1972 SCS curve number equation (Equation 2) is used in SWAT model:

$$Q_{surf} = \frac{(P_{day} - 0.2s)^2}{(P_{day} + 0.8s)} \ldots\ldots\ldots (2)$$

where, Qsurf is the accumulated runoff or rainfall excess (mm),Rdayis the rainfall depth for the day(mm), S is the retention parameter (mm). Where CN is the moisture condition curve number, the retention parameter (S) is defined by Eq. (3)

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

Potential evapotranspiration (PET) was a concept originally introduced by Thornthwaite (1948) as part of a climate classification scheme. Roughly 62% of the precipitation that falls on the continents is evapotranspired (Neitsch, 2005). Three methods for estimating potential Evapotranspiration (PET) are provided in SWAT. These are Priestly-Taylor, Penman-Monteith and Hargreaves methods. These methods have different input data requirements. The penman-Monteith equation is:

$$\lambda E = \frac{\Delta(H_{net} - G) + \rho_{air} * C_p * [e_z^o - e_z]/r_a}{\Delta + r * (1 + \frac{r_c}{r_a})} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: λE is the latent heat flux density (MJ $m^{-2}d^{-1}$), E is the depth rate evaporation (mm d^{-1}), Δ is the slope of the saturation vapor pressure-temperature curve, de/dT (kPa °C^{-1}), is the net radiation (MJ $m^{-2}d^{-1}$), G is the heat flux density to the ground (MJ$m^{-2}d^{-1}$), ρ_{air} is the air density (kg m^{-3}) , H_{net} is the specific heat at constant pressure (MJ kg^{-1}°C^{-1}) , e_z^o is the saturation vapor pressure of air at height z (kpa), e_z is the water vapor pressure of air at height z (kPa) , C_p is the psychometric constant (kpa °C^{-1}), is the plant canopy resistance (sm^{-1}), and r is the diffusion resistance of the air layer (aerodynamic resistance) (s m^{-1}).

2.7.1.4. SWAT model uncertainty analysis.

Most important issue with calibration of watershed models is that of uncertainty in the predictions. Watershed models suffer from large model uncertainties. These can be divided into conceptual model uncertainty, input uncertainty, and parameter uncertainty.

1. Conceptual model uncertainty (or structural uncertainty)

2. Input uncertainty is because of errors in input data such as rainfall, and more importantly, extension of point data to large areas in distributed models.

3. Parameter uncertainty: Another uncertainty worth mentioning is that of “modeler uncertainty”. It has been shown before that the experience of modelers could make a big difference in model calibration. The packages like SWAT-CUP can help decrease modeler uncertainty by removing some probable sources of modeling and calibration errors. The combined effect, however, should always be quantified on model outputs (Abbaspour, 2008).

2.7.1.5. SWAT CUP model

There is intimate relationship between calibration and uncertainty, (Abbaspour *et al*., 2015). SWAT Calibration and Uncertainty Program (SWAT-CUP) is a program developed to provide calibration, validation and sensitivity analysis of SWAT models. Parameter sensitivity analysis helps focus the calibration, and uncertainty analysis is used to provide statistics for goodness-of-fit. The user interaction or manual component of the calibration forces the user to obtain a better understanding of the overall hydrologic processes and of parameter sensitivity. By integrating these tools in the calibration processes, SWAT-CUP provides a powerful approach to watershed calibration, (Abbaspour, 2008).

Sensitivity analysis is a technique used for assessing the effect of uncertainty on the system performance. It is also used to measure the effects of a change of parameter on the model (Gaaman *et al,* 2007). Sensitivity analysis was undertaken by using a built-in tool in SWAT2012 that uses Automated Latin Hypercube One-factor-At-a-Time (LH-OAT) global sensitivity analysis procedure (Van Griensven *et al*., 2006). The average monthly stream flow data of ten year from 1990-2000 of the sub basin gauging station were used to compute the sensitivity of stream flow parameters.

Moges *et a*l., (2018) done sensitivity analysis on Guder catchment. Hence, 22 flow parameters were included for the analysis with default values as recommended by (Van Griensven, 2006). Moreover, rank of sensitivity was based on the value of t-sat and p-values.

2.7.2. Land Use Modeling

2.7.2.1. Land use and land cover change

The terms land use and land cover are not synonymous and the literature draws attention to their use and land cover change. Land cover is the biophysical state of the earth's surface differences so that they are used properly in studies of land and immediate subsurface (Parveen and Ahmed, 2015). In the disaster prone areas of landslides, the destruction of forests and the vegetative cover that binds the top soil at an increasing pace and the conversion of forest land into agricultural and horticultural holdings (Khan *et al*., 2017) brings changes in land use and land cover.

Recent rapid rate of exploitation has brought unprecedented changes in ecosystems and environmental processes at local, regional and global scales. Presently, land use/land cover changes encompass the environmental concerns of human population including climate change, biodiversity depletion and pollution of water, soil and air. Today, the monitoring and mediating the adverse consequences of land use/land cover change while sustaining the production of essential resources has become a major priority of researchers and policy makers around the world (Erle and Pontius, 2007). Unsustainable human activities are becoming key environmental concern as they deteriorate the quality of water . The relationship between land use and water quality helps in identifying threats to water quality rivers (Ding *et al.,* 2015) and built an understanding of about 'access' to sanitation is crucial for human survival.

2.7.2.2. Modeling Land use/ land cover change scenario in Upper Blue Nile.

Land use Scenario is powerful used to analyze the causes of LULC change and to evaluate land use policy (Verburg *et al*., 2004). Based on model analysis and the simulation of land use spatial patterns, the driving factors of LULC change can be revealed, clarifying the rate of land use and making possible multiple LULC scenarios in order to predict future land use demand. At present, models of LULC change have been developed to explore where, when and why it occurs based on the goals of a particular study.

It is difficult to develop realistic land use and world market scenarios for a period of >20 to 30 years (Roosmalen *et al*., 2009). For this reason, short-term scenarios from 2021 to 2040 were considered in this study. Simulations based on altering LULC for the same climatic condition was applied to evaluate the impact of LULC on Stream flow and water balance components. The projected land use and cover change scenarios of Guder catchment was also followed the storyline of changes in future biophysical and socioeconomic drivers of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Sohl *et al.,* 2014; Zhu *et al*., 2010; IPCC-SRES, 2000.

The likely future scenarios in the basin in the near future (2015-2030) would be an expansion of large scale irrigation following the tributaries of the upper Blue Nile upland area forestation particularly near existing or proposed dam location. Expansion of private large-scale irrigation schemes in the lowlands through foreign direct investment. Because of the current trend of building dams in Ethiopia, it is expected that the area of the basin covered by water will increase in the near future. The grand millennium dam and the completion of the dams at Megech, Rib, Birr and Guder dam are expected to create large reservoirs in the basin.

Table 2.2 Existing and future land use change scenarios for the upper Blue Nile basin.

S.No	Land use type	Abbreviation	Existing coverage (km^2)	Future coverage (km^2)	PI/PD*
1	Afroalphine	AFR	256.32	256.32	0.00
2	Arid rangeland	SWRN	8207.62	8207.62	0.00
3	Agriculture	AGRL	71975.60	76278.00	5.98
4	Grassland	RNGE	20151.50	19948.70	-1.01
5	Bamboo	BAMB	1072.03	1019.26	-4.92
6	Forest evergreen	FRSE	1614.84	1019.26	0.00
7	Forest mixed	FRST	252.55	558.63	121.20
8	Shrub land	SHRL	15428.40	13844.50	-10.27
10	Water	WATR	3139.21	5017.90	59.85
11	Wetland	WETL	651.36	635.53	-2.43
12	Wood land	WODL	34719.70	30087.80	-13.34

*PI=Percentage increase; PD=Percentage decrease. Source: (WBISPP, 2012)

2.7.2.3 Driver of land use and land cover change

2.7.2.3.1. Population growth

From 1982 to 2016, population grew by 200% in Guder and the average growth rate was 2%. The increase was consistent and positively correlated with the expansion of cultivated land between 1982 and 2006, while that relationship was reversed after 2006. This change was primarily a result of the increase of vegetation cover at the expense of cultivated land mainly because of farmers' growing interest in allocating more land to plantations (dominantly A. decurrens) to remedy a decline in soil fertility and to grow A. decurrens for fuelwood and charcoal production (Belete, 2015; Nigussie *et a*l., 2017a; Wondie and Mekuria, 2018). Conversely, increased population was positively correlated with vegetation cover (i.e.,A. decurrens plantation) at the Guder watershed agree with previous studies Minta *et al.* (2018), who pointed out that, even in a period of population growth, improved economic gains led to the rapid expansion of eucalyptus plantations into cultivated lands in the Ethiopian highlands.

2.7.2.2.2. Farming Practice

Belete (2015) reported that A. decurrens was first introduced into Fagita Lekoma in general and to the Guder watershed in particular in 1990. At that time, a few farmers started planting it at their homesteads and farm boundaries for fuelwood and forage. In 2002, the Amhara Regional Bureau of Agriculture designed agroforestry packages to implement on farmland, and farmers were advised to plant woodlots on degraded farmlands. The expansion of A. decurrens woodlot plantations began after the introduction of this package. Belete (2015) and Nigussie *et al.* (2017a) stated that the main driver for A. decurrensplantation expansion was its contribution to improving land productivity and income generation in addition to the provision of household fuelwood demands. Farmers appear to have been strongly motivated to expand the area of A. decurrens plantation at the Guder watershed, which is reflected in the rapid expansion of plantation area (100%) after 2006.

2.8. Climate and LULC Change Impact on Streamflow

Tekalegn *et al*., (2017) done the research on Catchment response to climate and land use changes in the Upper Blue Nile sub-basins, Ethiopia. His findings reveal that Seasonal and annual streamflows at the Tana watershed outlet might be offset under concurrent effects of FLULC and FCC compared to sole FCC scenario. On the other hand, the dry season streamflowat Gilgel Abay A and the sm all rainy season streamflow at Gummara B might amplify under combined scenarios in comparison to that in fCC alone. Streamflow response under combined FLULC and FCC at the Beles watershed outlet would be amplified compared to under FCC.

In the same way (Moges *et al.,* 2018) worked on Evaluating the impacts of climate and land use/land cover (LU/LC) dynamics on the Hydrological Responses of the Upper Blue Nile in the Central Highlands of Ethiopia. The result of this study reveal dry season streamflow shows 11.34% decline during the study period and the wet and short rainy season streamflow result an increment of 17.76% and 11.33% respectively. These results can be further explained by the fact that between the year 1973 and 2015, catchment built-ups (settlement area) increased by 85.12%. At the same time, cultivated land has increased by 7% at a cost of forestland which decreased by 60%. These results should be considered as the current trigger to pay a particular attention to land use policy and management in the basin.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1. Location

The Guder Catchment is located in the central highlands of Ethiopia. It stretches between latitudes of $9^0$56’0” and 8^0 41’0”N and longitudes of 37^0 22’0’’ and $37^0$13’0’’E (Figure 3.1), and it is part of Blue Nile basin. The watershed area is 662,767 ha; an average of 93% of which is used for agricultural practices. The watershed contains Guder River, which is a tributary of Abay rivers network, which drains to southwest. The river flows from the south to the north and has its outlet to the Abbay River. The Guder catchment borders with the Muger sub-basin to the east, the Awash Basin to the south and the Fincha Sub-Basin to the west.

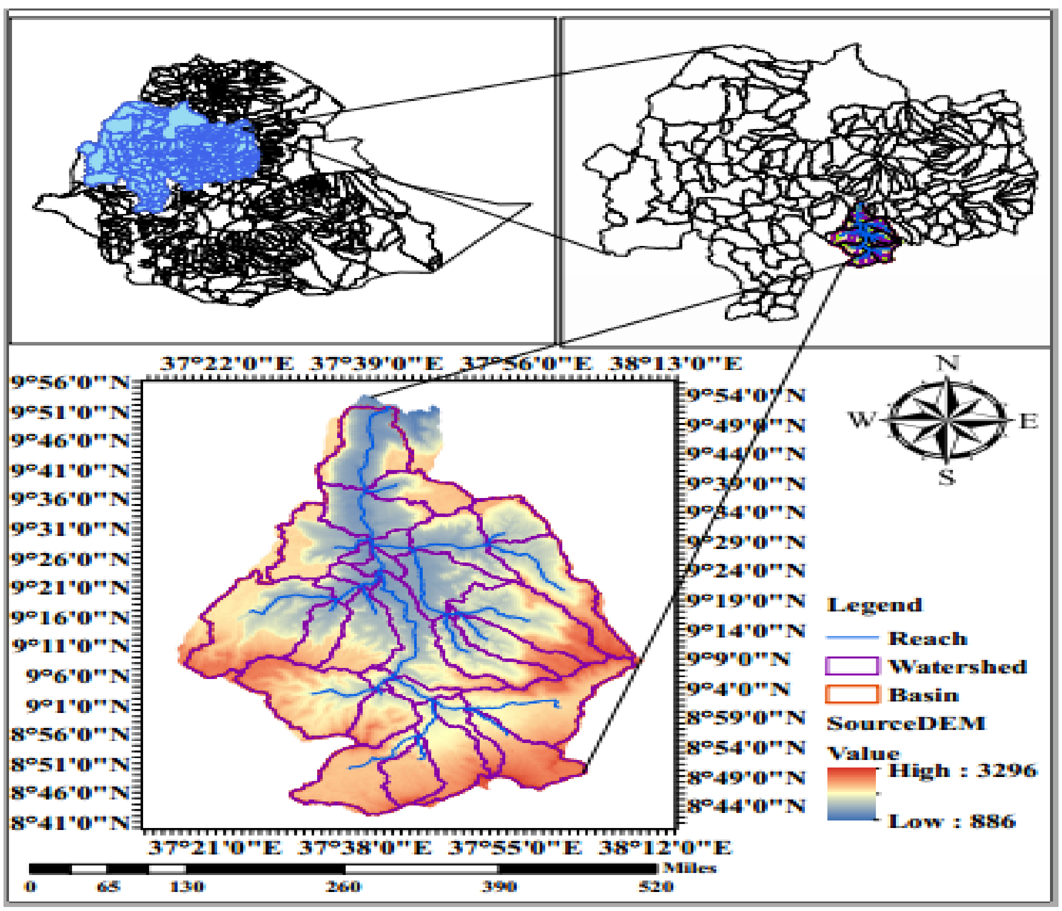

Figure 3.1 Location map of study area

3.1.2 Topography

The topographic features of Abay basin vary between the highlands in the center and eastern part of the basin and the lowlands in the western part of the basin with altitude ranges from 498 up to 4261 masl. The topography of Guder catchment is complex mountainous areas and elevation ranging from 1500-3000m.The higher elevation ranges are located on the mountainous area at the South of the town of Ambo and Guder.

3.1.3 Climate

The movement of the inter-tropical convergence zone mainly governs the rainfall distribution in the Upper Blue Nile basin (Haile and Rientjes, 2015). The main season divided in to a major rainy season (Kiremt), minor rainy seasons (Belg & Tsedey) and dry season. The majority of the catchment area lies within the Woina Dega zone and characterized by distinct dry and wet seasons. The watershed dry months occur between November and April; the wet season between May and October. The main rainfall season which accounts for about 80–90% of the annual rainfall occurs from June to September, while small rains also occur during December to March. The mean daily temperature of the watershed ranges between 17.3^0 C and 23.4^0 C. Lower annual rainfall less than 1600 mm in the major sub basin and higher rainfall greater than 1600 mm in same high lands of catchment.

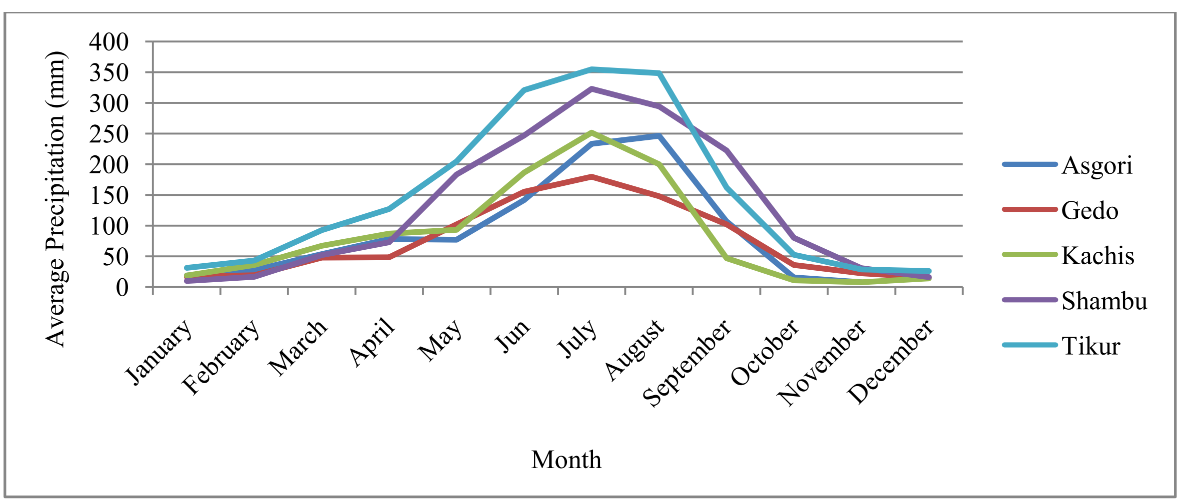

Figure 3.2 Mean annual Precipitation of various stations.

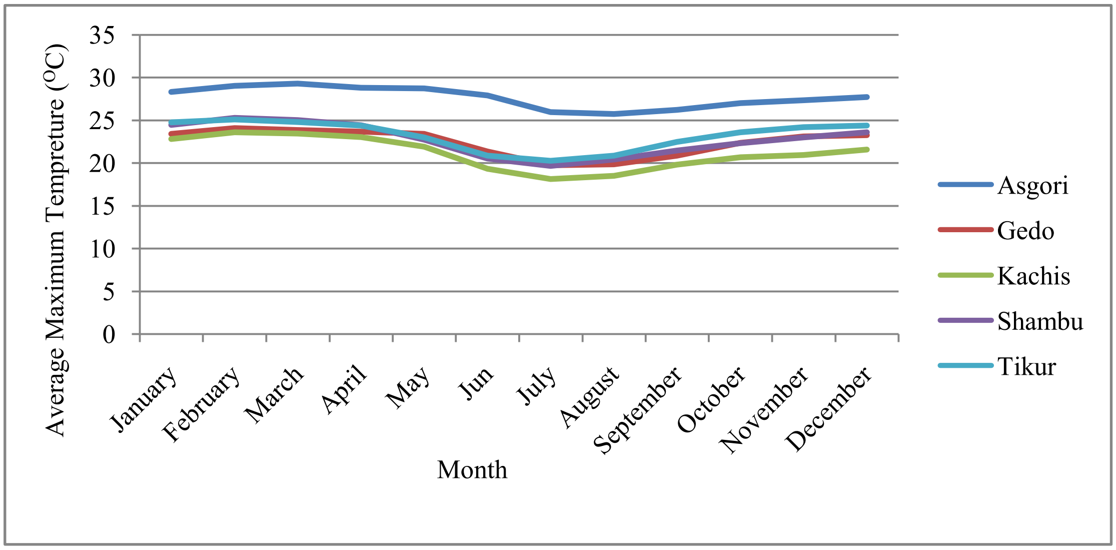

Figure 3.3 Mean annual Minimum Temperature of various stations

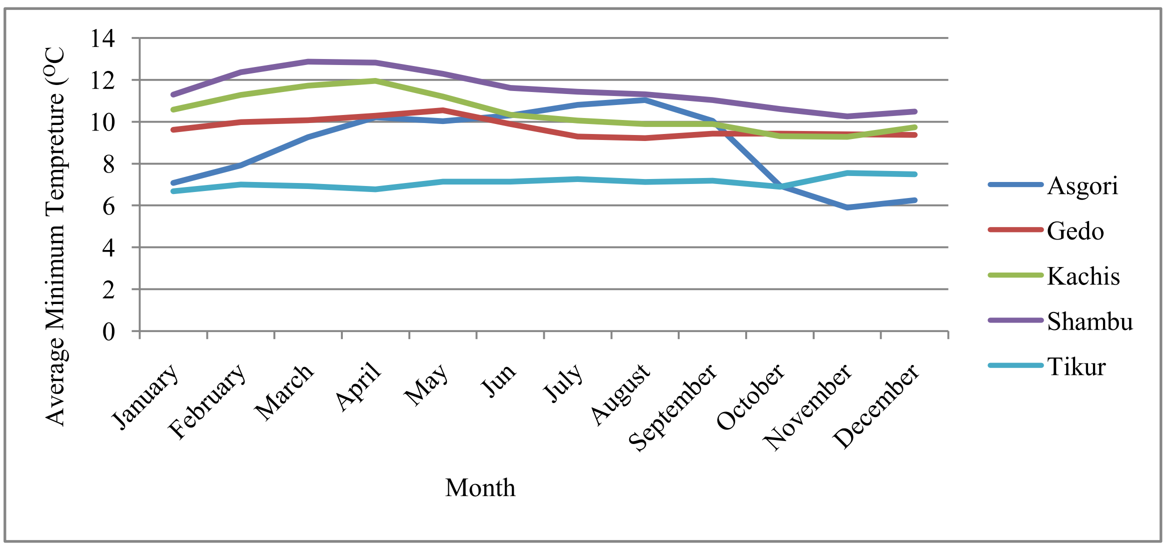

Figure 3.4 Mean annual Maximum Temperature of various stations

3.1.4 Land cover and land use (LULC)

Based on the land use/cover map of Ministry of Water, Irrigation and Energy (MoWIE) majority of the land in the study area is covered by Agricultural (Cultivated) and forest. The majority of the catchments are dominated by Agricultural areas and state farms. Forest are also used in the catchment with Woodlands in some parts of the watershed. However, Bushland, water, grassland and state farmland uses practiced in the catchment (MoWIE, 1999).

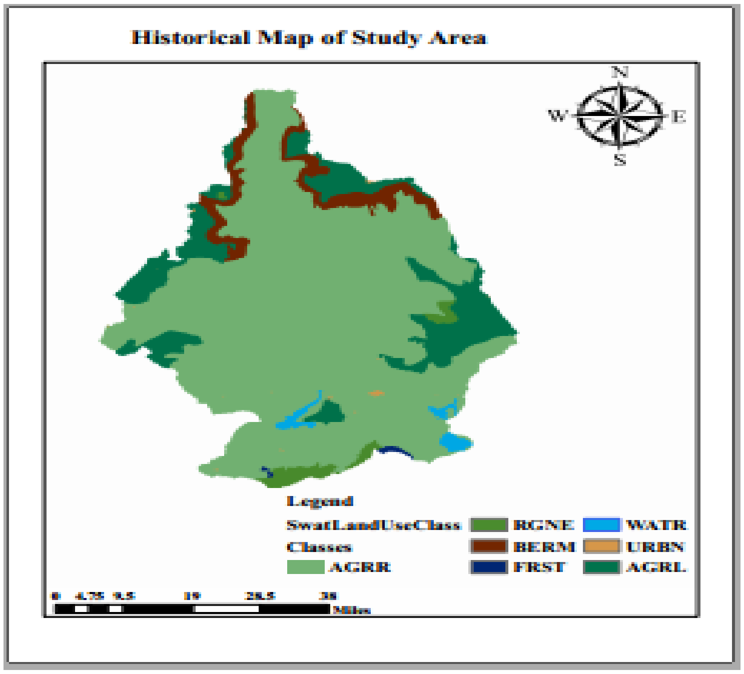

Figure 3.5 Guder Catchment Land use Land cover. Source; (MoWIE,1999)

3.1.5 Soil

According to FAO classification, thirty major soil groups were identified in the Guder catchment presented in Figure 3.6. SAWT model requires soil chemical and physical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained from MOWIE. To integrate the soil map with SWAT model, a user soil database which contains textural and chemical properties of soil was prepared for each soil layers and added to the SWAT user soil databases using the data management add tool in ArcGIS. Guder catchment are dominated by Haplic Alisols, Eutric Fluvisols and Chromic Luvisols. In addition, Eutric Vertisols, Eutric Leptosols and Calcic Vertisols were the soils of Catchment.

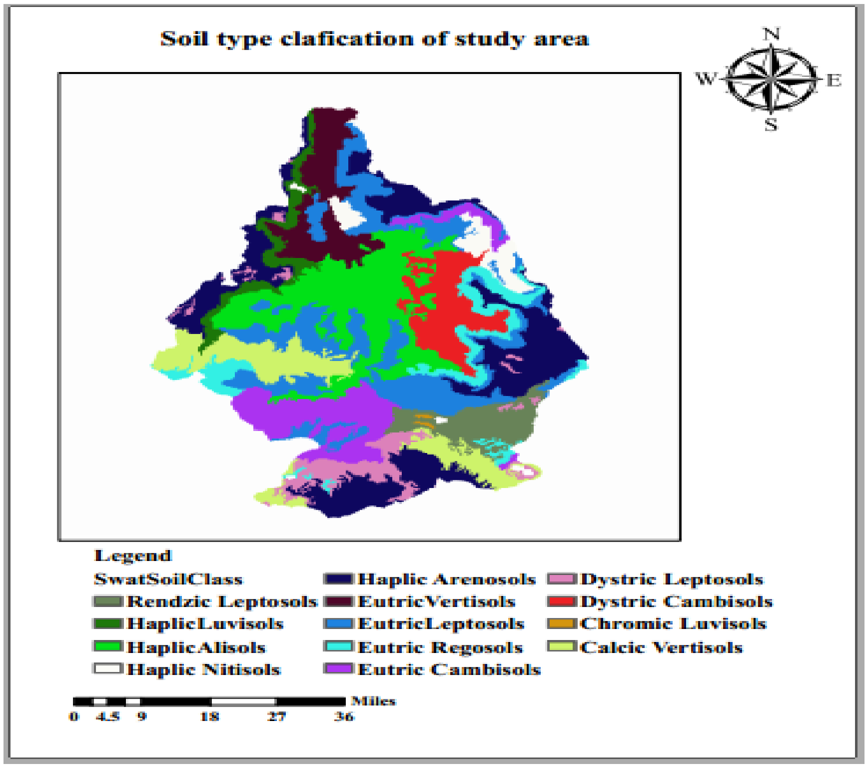

Figure 3.6 Map of the soil types of Guder Catchment. Source: MOWIE, (1999)

3.2 Performance Evaluation of RCM Outputs

3.2.1. Data source and quality assessment

For this study, various data required are includes digital elevation Model data (DEM), land use and land cover data, soil data, climatic data (daily precipitation, maximum and minimum temperature , relative humidity , wind speed and solar radiation).The land use land cover, Soil, DEM and hydrological data were collected from the MOWIE. The climatic data were obtained from the national metrological agency of Ethiopia (NMAE).The GCM data (daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation) Downloaded from CORDEX Africa (https://esgf-node.llnl.gov/projects/esgf-llnl). Data collected over a long period was checked for missing values, quality controls and consistency test for further analysis.

3.2.1.1. Estimating the missing data

In climate studies, it is common to check the gaps in the time series of precipitation and temperature before filling the missed data. Missed climate data for each station was estimated by using the meteorological climate data nearby or neighboring stations based on the principles indicated in (Subarmanya, 2008). For this study, Simple Arithmetic mean method used when the mean monthly rainfall of all the index stations is within 10% of the station under consideration station (x) Equation (6). But the normal ratio method used when the mean monthly rainfall of one or more of the adjacent stations differs from that of station (x) by more than 10%.The normal ratio method was used for this study and calculated by Equation (8)

$$\mathbf{P_X = \frac{1}{N}(P_A + P_B + P_C + \cdots + P_N)} \quad (5)$$

$$P_X = \frac{1}{N}\left(\frac{N_X}{N_A}P_A + \frac{N_X}{N_B}P_B + \frac{N_X}{N_C}P_C + \cdots + \frac{N_X}{N_N}P_M\right) \quad (6)$$

Where: N_{test}= annual normal rainfall at the station under consideration

Where, PX is the precipitation for the station with missed record, N is number of stations used in the computation, P_A, P_B, P_C….P_M are the corresponding precipitation at the index stations and N_A, N_B, N_C….N_N and N_X are the long term mean precipitation at the index stations and at station (x) under consideration respectively.

3.2.1.2. Areal rainfall determination

The area weighted average method was used to calculate the average rainfall from CORDEX RCMs received by the entire catchment. Average rainfall and temperature was considered for the stream flow projection. The weighing area of recorded rainfall station was done by Thiessen polygon method using Arc GIS to investigate Area contribution of each station. In this method, the data at each station is weighted based on the corresponding polygon area fraction and this weighted values gives the rainfall Pi in that area Ai represented by the polygon. The Area average rainfall P of the entire area A derived from n stations is then calculated as:

$$P_{ave} = \frac{P_1A_1+P_2A_2+P_3A_3+\cdots+P_NA_N}{A_1+A_2+A_3+\cdots+A_N} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: $P_1, P_2 and P_3 \ldots . P_n$ are rainfall recorded by the stations 1, 2 and 3 respectively and $A_1, A_2, A_3 \ldots A_N$ are respective areas of the Thiessen polygon and n is the number of stations.

3.2.1.3. Homogenization

The availability of reliable serially complete sets and homogenous meteorological data on different spatial and temporal scales are vital for climatological studies. Mainly, Homogenization used in hydrological modeling, analysis and design of water resource systems in this catchment. Studies using inhomogeneous time series as inputs result in biased outputs. Estimations of missing data and homogenization are therefore vital where meteorological stations are scarce and the observed data are influenced by topography.

Frequency analysis of data requires that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population. One of the test of homogeneity (Buishand, 1982) is based on the cumulative deviations from the mean:

$$S_k = \sum_{i=1}^{k}\left(X_i - \bar{\bar{X}}\right) \ldots\ldots\ldots\ldots (8) \qquad K = 1,2,3 \ldots n$$

Where X_i are records from the series X_1, X_2… X_n and $\bar{X}$ the mean. The initial value of $S_{k=0}$ and last value $S_{k=n}$ are equal to zero. When plotting the S_k's also called a residual mass curve changes in the mean are easily detected. For a record X_i above a normal the $S_{k=i}$ increase, while for a record below normal $S_{k=i}$ decrease. For a homogenous record, one may expected that the S_k's fluctuate around zero since there is no systematic pattern in the deviations of the X_i's from their average value$\bar{X}$.

3.2.1.4. Consistency

A consistent record is one where the characteristics of the record have not changed with time. Double mass curve (DMC) was used to check the consistency of rainfall for adjustment of inconsistent data. This technique is based on the principle that when each record data comes from the same parent sample, they are consistent. A double-mass curve is graph of the cumulative catch of rain gage of interest versus the cumulative catch of one or more gage in the region that has been subjected to similar hydro metrological occurrence and is known to be consistent.

If a rainfall record is consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope. A change in the slope of the double mass curves would suggest at an external factor has caused changes in character of the measured values. If a change in slope is evident, then either the record needs to be adjusted with the early or the later period of record adjusted (Yozgatligil *et al*, (2013)).

3.2.1.5 Trend Analysis

A number of tests are available to detect and estimate trends. The Mann–Kendall (MK) test is the most used mathematical method for detecting trends in time series. It was commonly applied to detect significant trends in hydro-meteorological time series and is highly recommended by the World Meteorological Organization (WMO). According to Tabari *et al*., (2011), the MK test has important advantages; it is a nonparametric test and does not require the data to be normally distributed. Again, the test has low sensitivity to abrupt breaks due to in homogeneous time series. The tests were carried out at 5 % level of significance. The major variables for test interpretation were the p-value and the Sen's slope.

The MK test statistic is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(xj - xk) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where Xj and Xk are the sequential data values of the time series in the year's j and k (k > j) and n is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The sign function was given as:

$$\mathrm{sgn}(X_j - X_k) = \begin{Bmatrix} +1 \ldots\ldots\ldots\ldots \mathrm{if}(X_j - X_k) > 0 \\ 0 \ldots\ldots\ldots\ldots \mathrm{if}(X_j - X_k) = 0 \\ -1 \ldots\ldots\ldots\ldots \mathrm{if}(X_j - X_k) < 0 \end{Bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

In cases where the sample size n>10, the statistics S is approximately standard normal distribution with the mean zero and variance is denoted by the following.

$$\text{Var(S)} = n\left(\frac{n(n-1)(2n+5)-\sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18}\right)\text{.......................} (11)$$

Where n is the number of data, m is the number of tied groups (a tied group is a set of sample data with the same value), and it is the number of data points in the i^{th} group. First, the presence of monotonic increasing/decreasing trend was tested using the MK test. The highest positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend:

In this case, the standard test statistics Z is computed as follows (Jaagus 2006):-

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{VAR\ (S)}} \text{ if} S > 0 \\ 0 \quad \text{if} S = 0 \\ \frac{S+1}{\sqrt{VAR\ (S)}} \text{ if} S < 0 \end{Bmatrix} \text{..........................} (12)$$

The presence of a statistically significant trend will evaluated using the Z value; where positive Z indicates increasing trend and negative Z denotes decreasing trend (Jain and Kumar, 2012).

The test statistics Z is used as a measure of significance of trend. If the value of Z is positive, it indicates increasing trends, while negative values of Z show decreasing trends. If $|Z_S|$ is greater than Zα/2, where α the chosen significant level (5% with Z 0.025= 1.96) then the null hypothesis is invalid implying that the trend is significant (Modarres & da Silva, 2007). Accordingly, if Z tabulated is greater than |Z calculated|, the graph will not have significant trend. If Z tabulated is less than |Z calculated|, the graph will have significant trend.

If a linear trend is present in the time series, the true slope can be estimated using a simple non-parametric test known as Sen's slope method. Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$T_i = \frac{x_j - x_k}{j - k} \text{...........} (13) \qquad i = 1, 2, 3 \ldots N$$

Where Xj and Xk represent the data value at the time-steps 'j' and 'k' with 'j' correspondingly greater than 'k'. The median of these 'N' values of Ti is termed as Sen's estimator of slopes and is calculated by the above formulae

3.2.2 Performance evaluation of RCM outputs

Historical RCM simulation outputs (1986–2005) driven by four CMIP5 GCMs were used in this study. The GCMs which were used as initial boundary conditions were CNRM-CM5, EC-EARTH and MPI-ESM-LR). The historical simulations of these GCMs were initialized with the atmosphere, ocean, land and sea surface temperature (SST) conditions and forced by observed natural and anthropogenic CO2and aerosol concentrations (Taylor *et al*., 2012). The RCMs used to regionalize these GCMs were the Rossby Centre Regional Climate Model (RCA4). These RCMs were selected for evaluation since they (especially CCLM and RCA models) were used to downscale historical and future simulations of multiple CMIP5 GCMs (e.g. CNRMCM5, EC-EARTH and MPI-ESM-LR) in the CORDEX project. The RCA4 RCMs driven by these three GCMs were frequently evaluated and showed reasonable performance over Africa (Nikulin *et al*., 2012; Kim *et al.,* 2013).

The downscaling was accomplished by the latest version of Rossby Centre using their Regional Climate Model RCA-4. The Rossby Centre has developed four versions of RCA-4 since 1997. Compared to its previous version, RCA-4 is more physically consistent with improved energy flux parameterization, reduction of compensating errors and, a better representation of the diurnal temperature cycle. Spatially, the RCA-4 simulations cover the CORDEX-Africa domain at resolution of $0.44^o \times 0.44^o$ (~50km × 50 km) for the 1951-2100 period which is divided into two: historical (1951-2005) and scenario (2006-2100) periods.

In this study, outputs from RCMs are evaluated against observations using some of the statistical measures recommended by the World Meteorological Organization (WMO). The Equation was written as follows:

$$\text{BIAS} = 100 * \frac{\overline{R_{RCM} - R_{Gauge}}}{\overline{R_{Gauge}}} \text{……………………. (14)}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{n=1}^{n}(R_{RCM} - R_G)^2}{\overline{R_{Gauge}}}} \text{………………………. (15)}$$

$$\text{Correl} = \frac{\sum_{t=1}^{n}(R_{RCM} - \overline{R_{RCM}}) - (R_{Gauge} - \overline{R_{Gauge}})}{\sqrt{\sum_{t=1}^{n}(R_{RCM} - \overline{R_{RCM}})\sum_{t=1}^{n}(R_{Gauge} - \overline{R_{Gauge}})}} \text{……………………… (16)}$$

$$CV = 100 * \frac{\sigma_R}{\bar{R}} \text{……………………..(17)}$$

Where, R_{RCM} is a rainfall of RCMs, R_{Guage} is a rainfall of stations, the bar over the variables denotes the average over a period of 1986–2005, and N represents the analysis period (20 years). R denotes basin-averaged rainfall amount on a certain year (t); subscripts RCM and Gauge indicate basin rainfall amounts obtained from either RCM simulations or the reference gauge network respectively; σ refers to standard deviation of either the RCM or gauge data. R without subscript indicates that the statistics is estimated separately for either RCM or Gauge basin rainfall amount.

The correlation is often used to evaluate the linear relationship between areal averaged RCM rainfall and observed rainfall. Values close to 1.0 indicate a better linear relationship between the variables and a value away from 1.0 indicates less agreement. BIAS is used to measure the volumetric difference between the RCM rainfall and observed rainfall. A BIAS value close to 0 indicates a minor systematic difference between RCM rainfall and observed rainfall amounts, whereas a BIAS value far from 0 suggests a deviation. RMSE measures the difference between RCM rainfall and observed rainfall. An RMSE value close to zero indicates better performance. CV calculated for both the gauged and RCM simulated rainfall amounts to evaluate how well the rainfall variability by the network stations is captured and represented by the RCMs.

3.3. Detection of future climate change

3.3.1. Climate change scenario

Different study reveals that in UBN using extreme case (RCP 2.6 and 8.5) may experience a longer and more intensive and frequent flooding in the feature (Aich *et al,* 2014). Furthermore, selection of emission scenario is less significant for the near term climate projections since they give similar magnitude and pattern of climate change (Praskievicz and Chang, 2009; Roosmalen *et al*., 2009) meaning that the choice among RCP2.6, RCP4.5, RCP6.0 and RCP8.5. Particularly this study is interested to understanding the implication on global warming under 2^0 C for Guder Catchment. Eventually, RCP 4.5 that is next to mitigation scenario was considered in this study.

3.3.2. Future Temperature and Rainfall RCM data sets

The climate data of high-resolution regional climate models of CORDEX-Africa (Coordinated Regional Climate Downscaling Experiment (Giorgi *et al*., 2009) obtained from CORDEX-Africa database website was used. For this study, the driving model or GCMs are selected depending on performance evaluation of Regional Climate Model output. Accordingly, CNMR, ICHEC and MPI driving model was selected for performance evaluation and the downscaling was accomplished by the latest version of Rossbey Center using their regional climate model_RCA4. This regional climate model taken for analysis for the reason that as compared to previous version RCA4 is more physically consistent with improved energy flux parameterization, reduction of compensating errors and better representation of diurnal temperature cycle (Haile and Rientjis, 2015). Spatially, the RCA-4 simulations cover the CORDEX-Africa domain at resolution of $0.44^{o} \times 0.44^{o}$ (~50km × 50 km) for the 1951-2100 time period which is divided into two: historical (1951-2005) and scenario (2006-2100) periods. Thus, this data were used for the impact analysis over Guder catchment.

3.3.3. Climate projections for the study area.

The need to use climate models and scenarios that capture a full spread of the study area is necessary for model predictions. Future Temperature and Rainfall scenario was downloaded for the baseline period of the study area of non-overlapping 20-year period from (1986-2005) to represent baseline from this study depending on data availability.

Even though WMO and IPCC recommend 30-year time slice for baseline data, this study was evaluated in time slice of 20 years for both baseline and future periods with respective to RCP 4.5. Since this study incorporate both climate and LULC impact on stream flow, The main reason why short-term time slice is selected is that, it is difficult to develop realistic land use and world market scenarios for a period of >20 to 30 years (Roosmalen *et al*., 2009). In addition, it was very challenge to have long-term hydro- climate data in Upper Blue Nile river basin (Conway, 2000).

3.3.4. Bias correction

The outputs of CORDEX are evaluated and used for climate change impact studies in different parts of Africa and showed reasonable standard (Nikulin *et al*. 2012; Haile and Rientjes 2015). Nevertheless, yet the output of downscaled RCMs showed persistent biases and cannot be directly used without tailoring and bias correction for climate change impact assessment (Yang et al. 2018).

Bias correction is the science of scaling climate model values to reflect the statistical properties such as mean, variance or wet-day probabilities of observed climate (Teutschbein, 2012). There are several bias correction methods; Delta method is one of the most widely and commonly used correction methods for RCMs scenarios of future conditions for climate change studies and selected due to its simplicity and easily applicable (Sahilu and Niguse., 2015). The average monthly precipitation/temperature is corrected to match the average monthly precipitation/temperature for 20 years. The formulas used for rainfall and temperature bias correction (Teutschbein., 2012) are indicated in Equations 18 and 19, respectively.

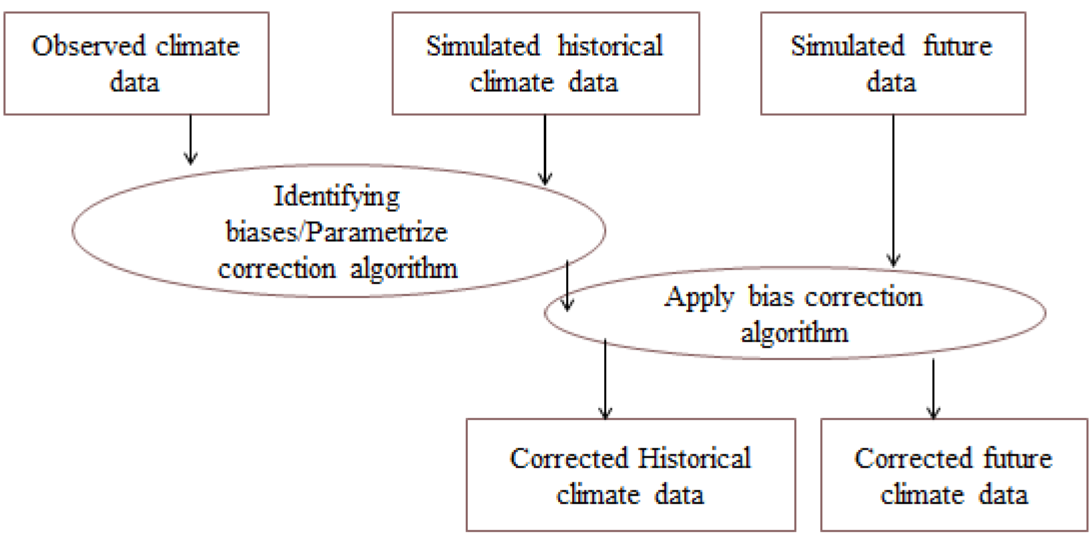

Figure 3.7 Bias correction Framework: Source (Rathjens *et al*., 2016)

$$P_{bc} = \left(P_P \frac{P_o}{P_T}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$T_{bc} = T_P + T_O \pm T_R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Where, P_{bc} is Bias corrected future rainfall amount in mm:. P_P is predicted future rainfall amount in mm;. Po is mean of observed rainfall amount in mm:. Pr is mean of computed historical rainfall during the observation period in mm. T_{bc} is Bias corrected future temperature in ^{0}C.T_p is predicted future temperature in ^{0}C; To is mean of observed temperature in ^{0}C;Tr is mean of computed historical temperature during the observed period in ^{0}C.

3.4. Hydrological Modeling

3.4.1. Modeling SWAT for Guder catchment hydrological impact analysis

The modeling of the streamflow in any hydrological model entitles following a detailed procedures. Zelalem and Kumar (2017) summarize the steps followed while using the SWAT model.

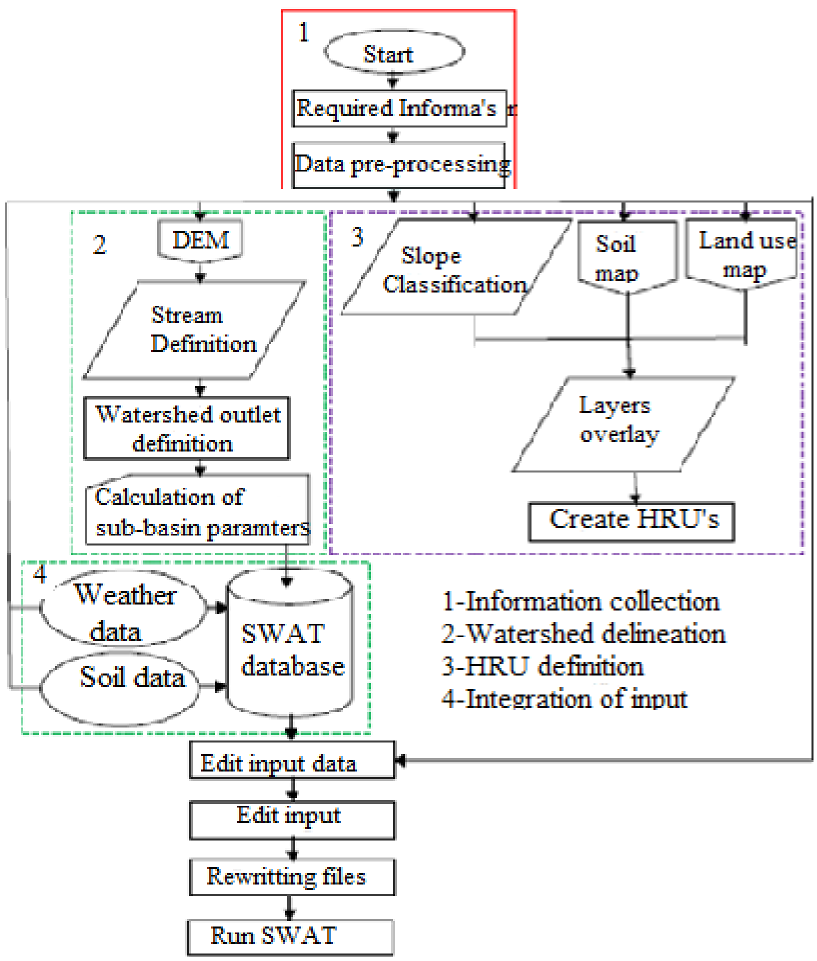

Figure 3.7: Conceptual flow chart of SWAT model (Zelalem and Kumar, 2017)

3.4.2. SWAT model input

3.4.2.1. Digital elevation model

Digital Elevation Model (DEM) data is required to calculate the flow accumulation, stream networks, and watershed delineation using SWAT watershed delineator tools. A 30m by 30m resolution ASTER Global Digital Elevation Model was obtained from the (MOWIE).

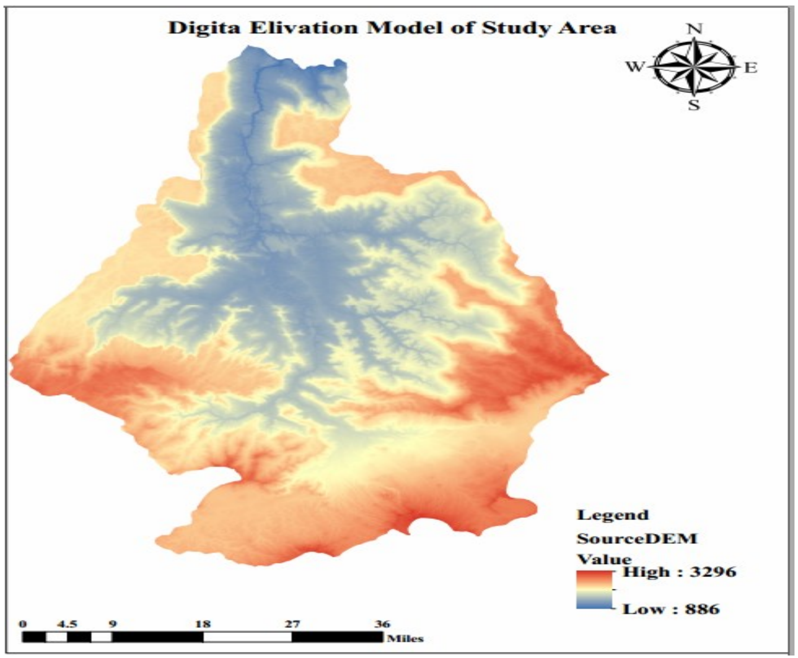

Figure 3.8 Digital Elevation Model of Guder Catchment. Source: MOWIE, (1999)

3.4.2.2. Soil data

The soil data of the study area which had been prepared on a 1:250,000 scales were obtained from Ethiopian Ministry of Water Irrigation and Electricity (MWOEI, 1999). SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type (Table3.1). These basic physico-chemical properties of major soil types in the watershed were mainly obtained from the following sources: Abbay River basin Integrated Development Master Plan Project - Semi detailed Soil Survey, (FAO, 1998), Harmonized world Soil database viewer V1.2 (HWSD), GIS-based hydrological zones and soil geo-database of Ethiopia.

Table 3.1 Soil types of Guder catchment with their symbols and areal coverage

S/No	Soil name	Symbol in SWAT model	% of Watershed Area
1	Rendzic Leptosols	Lpk	4.723
2	Eutric Cambisols	Cme	8.344
3	Dystric Cambisols	Cmd	6.187
4	HaplicAlisols	Alh	25.743
5	EutricVertisols	Vre	7.459
6	EutricLeptosols	Lpe	0.38
7	Chromic Luvisols	LVx	21.109
8	Dystric Leptosols	Lpd	4.392
9	Haplic Arenosols	Arh	17.681
10	HaplicLuvisols	Lvh	0.011
11	Calcic Vertisols	Vrk	0.521
12	Eutric Regosols	Rge	0.547
13	Haplic Nitisols	Nth	2.903

Source: MOWIE, (1999)

3.4.2.3. Land use and land cover data

The land use/cover data of the study area which had been prepared on a 1:250,000 scales were obtained from the Ethiopian Ministry of Water Irrigation and Electricity (MOWIE, 1999). SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces (Table 3.2). Hence, while preparing the lookup-table, the land use types are made compatible with the input needs of the model.

Table 3.2 LULC classification of Guder catchment.

S. No	Name	Symbol	% of Watershed Area
1	Moderately Cultivated Land	SAVN	76.33
2	Shrub Land	RGNB	1.95
3	Grass Land	BERM	5.52
4	Forest Land	FRST	0.22
5	Urban Land	URBN	0.12
6	Water Land	WSTR	1.16
7	Dominantly Cultivated Land	AGRL	14.70
8	Crop Irrigational Land	CRIR	-

Source; (MOWIE, 1999)

3.4.2.4. Slope

Slope is derived from inputted DEM, so that the model uses this slope for the development of Hydrological Response Unit (HRU) in addition to Land use and soil input parameters. After classifying DEM into five FAO slope classes, 5.01% of the total area has gentle slope (0-2^0), whereas 20.32% and 20.03% of the total areas are characterized as slightly undulating (2.1-5^0) and moderate steep (>5.1-8^0) slopes respectively. The rest land slope is labeled as steep and very steeper which range 8.1–15^0 (33.06%) and>15^0 (21.57%) respectively.

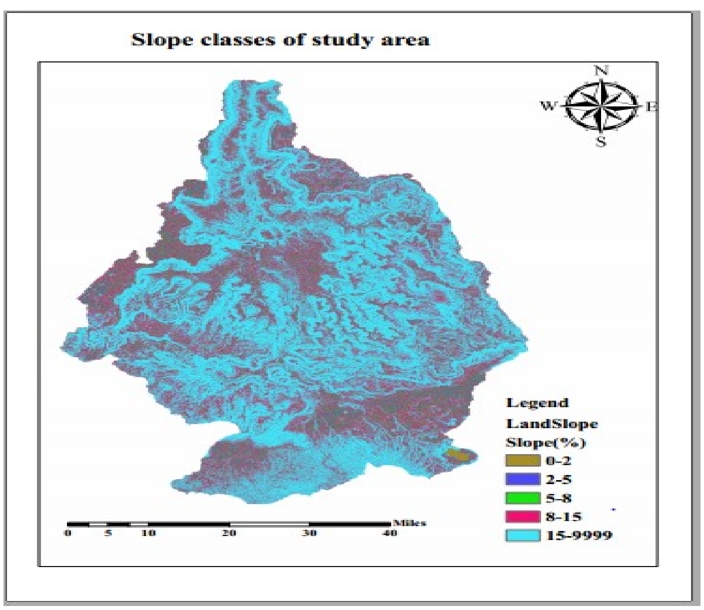

Figure 3.9 Slope of Guder catchment; Source (MOWIE)

3.4.2.5 *Meteorological data*

Weather data are among the main demanding input data for the SWAT simulation. The weather input data required for SWAT simulation includes daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. These were obtained from the Ethiopian National Metrological Agency. The weather data used were represented from five stations in and around the watershed. Such as, Asgori, Gedo, Kachis, Shambu and Tikur Inchini stations as shown in Figure 3-13. The first three stations are the first classes that have records on all climatic variables, whereas the last two is the third class station (Table: 3.3).

The climatic data used for this study covers 30 years from 1987-2016. Based on the class of the stations, the number of weather variables collected varies from station to station that are grouped in to two. The first group contains only rainfall, Max and Min Temperature data. The second group contains variables like maximum and minimum temperature, humidity, sunshine hours, and wind speed in addition to rainfall. However, missing values were identified in some of the climatic variables. These values were assigned with no data code (-99) which when filled by weather generator embodied in SWAT model from monthly weather generator parameters values. The monthly generator parameter value were estimated from the one weather station (Shambu).

Table 3.3 Location of meteorological stations in and around the Guder catchment (NMAE)

No	Station name	Latitude (deg)	Longitude (deg)	Rain fall	Max Temp	Min Temp	Relative humidity	Sun shine	Wind speed
1	Asgori	8.79	38.334	✓	✓	✓	×	×	×
2	Gedo	9.021	37.457	✓	✓	✓	✓	×	✓
3	Kachis	9.583	37.458	✓	✓	✓	✓	×	×
4	Shambu	9.383	37.409	✓	✓	✓	✓	✓	✓
5	Inchini	8.836	37.667	✓	✓	✓	×	×	×

× = Not presence of factor any √ = presence of Factor

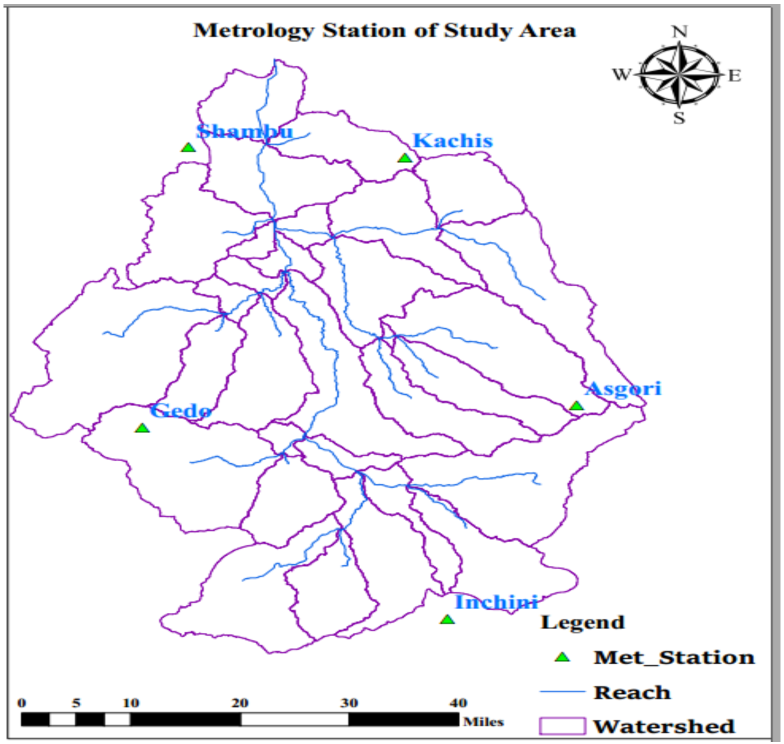

Figure 3.10.Location of Meteorological stations in around the Guder Catchment (NMAE)

3.4.3. SWAT model set up

3.4.3.1. Watershed delineation

The watershed and sub watershed delineation was done using 30m by 30m DEM resolution data by the help of Arc SWAT model watershed delineation function. The watershed delineation processes consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlet selection definition and calculation of sub basin parameters. Once the DEM setup was completed and the location of outlet was specified, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tools. The stream definition and the size of sub basins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of streams.

3.4.3.2. Hydrologic response units

The sub watershed were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. In general, the threshold level used to eliminate minor land use and land covers in sub basin, minor soil within land use and land cover area and minor slope classes within a soil on specific land use and land cover area. Following minor elimination, the area of remaining land use and land covers, soils and slope cases are reapportioned so that 100% of their respective area modeled by SWAT. The SWAT user's manual suggests that a 20% land use threshold, 10% soil uses which form at least 10% of the sub basin area and soils which form at least 20% of the area within each of the selected land uses was considered in HRU.

However according to Koch and Cherie (2013) suggestion HRU definition with multiple options that account for 10% land use, 20% soil and 10 slope threshold combinations gives a better estimation of runoff and stream flow . Therefore, for this study, HRU definition with multiple options that accounts for 10% land use, 20% soil and 10% slope threshold combination was used to eliminate minor land use and land covers in sub basin, minor soil within a land use and land cover area and minor slope classes within a soil on specific land use and land cover area.

3.4.3.3. Weather generator

The SWAT Model contain weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather Generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently. To generate the data, SWAT Weather Database is designed to be a friendly tool to store and process daily weather data to be used with SWAT projects. It is capable of storing relevant daily weather information; easily creating .txt files to be used as input information during an Arc SWAT project setup; efficiently calculating the WGEN statistics of several weather stations in one-step run. As for any SWAT project, missing values must be entered as -99.0.

3.4.3.4 Sensitivity Analysis

Calibration is necessary to optimize the values of the model parameters, which help to reduce the uncertainty in model outputs. However, such type of model with a multiple parameters, the difficult task is to determine which parameters are to be calibrated. In this case, sensitivity analysis is important to identify and rank parameters that have significant impact on the specific model output interest (Van Griensven, 2006).

Table 3.4 Parameter selected for sensitivity analysis

Parameter	Description	Min	Max	Category
r__CN2	runoff Curve Number	35	98	.mgt
v__ALPHA_BF	Base flow alpha factor (days)	0	1	.gw
v__GW_DELAY	Ground water delay (day)	30	450	.gw
a__GWQMN.gw	Deep percolation(mm)	0	25	.gw
r__SOL_Z	Soil depth (mm)	-0.8	0.8	.sol
v__CANMX	Maximum Canopy Index (mm)	0	10	.hru
v__RCHRG_Dp	Deep aquifer percolation fraction	0	1	.gw
a__ESCO.hru	Soil evaporation compensation factor	0	0.2	.hru
r__SLSUBBSN	Average slope length	0	0.2	.hru
r__HRU_SLP	Average slope steepness	0	0.2	hru
v__CH_N2	Manning coefficient of tributary channel	0	0.5	.rte
v__CH_K2	Hydraulic Conductivity (mm/hr)	5	130	.rte
v__ALPHA_BNK	Base flow alpha factor for bank storage.	0	1	.rte
v__SURLAG	Surface runoff lag coefficient	0	10	.bsn
r__OV_N	Manning's "n" value for overland flow	-0.2	0	.hru
v__REVAPMN	Threshold depth of water (mm)	0	500	.gw
a__SOL_ALB	Soil albedo	-0.01	0.3	.sol
a__EPCO.hru	Plant uptake factor	0	0.2	.hru
r__SOL_K	Soil hydraulic conductivity (mm/hr)	-0.5	0.5	.sol
r__LAT_TTIME	Lateral flow travel time	0	180	.hru
r__SOL_AWC	Available water capacity of a soil (mm/mm)	-0.5	0.5	.sol
r__GW_REVAP	Ground water evaporation coefficient	0	0.2	.gw

3.4.3.5. SWAT Calibration and validation by SUFI-2

The model was calibrated using version 2012 of the SWAT-CUP (SUFI-2)software package. The SWAT-CUP is an interface for auto-calibration that was developed for SWAT (Abbaspour, 2015). The calibration was carried out in year 1990-1997 and the validation in year 1998-2001. Nash-Sutcliff efficiency (NSE), coefficient of determination (R^2) and Percent Bias (PBIAS) were used to evaluate the result of the calibration and the validation. The NSE is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). The coefficient of determination (R^2) describes the proportion variance in measured data by the model. The PBIAS measures the average tendency of the simulated data to be larger or smaller than the observations. The optimum value is zero, and low magnitude values indicate better simulations.

Statistical measures providing quantitative estimates for the goodness of fit between the observed and predicted values were used as indicators of the extent to which model predictions matched observation. The model performance was evaluated for both the calibration and validation period. The model was calibrated using version 2012 of the SWAT-CUP software package. The SWAT-CUP is an interface for auto-calibration that was developed for SWAT (Abbaspour, 2015). The SWAT model was calibrated (manually and automatically) and validated using measured daily stream flow data collected at the four gauged stations. The total available historical stream flow data (1990-2001) were divided into two sets: 8 years (1990-1997) for calibration and 4 years for validation (1998-2001) for all stations.

In this study, three model evaluation methods were used, which were Model bias (PBIAS), Nash-Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2). Model bias is the relative mean difference between the predicted and observed streamflows for a sufficiently large simulation sample, reflecting the ability to reproduce water balance. It is an important criterion for comparing whether a model is working well or not by measuring the presence of under or over prediction.

The coefficient of determination (R^2) describes the proportion the variance in measured data by the model. It is calculated as the sum of the squares of the deviations of the simulated and observed discharges from the average observed discharge (Eq.(20). Nash and Sutcliffe (1970) developed model evaluation criteria into the Nash-Sutcliffe coefficient (NSE), which is used to describe how well the discharge is simulated by the model. This efficiency criterion is commonly used for model evaluation (Eq.(21).

SWAT model performances were assessed using the coefficient of determination (R^2) and the Nash–Sutcliffe (E_{NS}) to evaluate stream flow calibration efficiency using the following equations below.

$$R^2 \frac{\left[\sum_{i=1}^{n}[Q_{obs} - Q_{obs,m}][Q_{sim} - Q_{sim,m}]\right]^2}{\left[\sum_{i=1}^{n}(Q_{obs} - Q_{obs,m})^2 \sum_{i=1}^{i}(Q_{sim} - Q_{sim,m})\right]^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$E_{NS} = \frac{[\sum_{i=1}^{n}(Q_{sim} - Q_{obs,m})]^2}{[\sum_{i=1}^{n}(Q_{obs} - Q_{obs,m})]^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

$$\text{PBIAS } \% = \frac{\sum_{i=1}^{n}(Q_{sim} - Q_{obsOi})}{\sum_{i}^{n} Q_{sbd}} \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

Where, Q_{obs} is the Observed value and Q_{sim} is the average simulated value. R^2 ranges from 0(which indicates the model is poor) to 1 (which indicates the model is good), with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Santhi., 2001).

Table 3.5 Standard value of SWAT performance Evaluation

Performance Rating	R^2	E_{NS}	**PBIAS (%)**
Very good	$0.75 < R^2 \leq 1$	$0.75 < NSE \leq 1.00$	PBIAS ≤ ± 10.0
Adequate/good	$0.60 < R^2 \leq 0.75$	$0.65 < NSE \leq 0.75$	± 10 ≤ PBIAS < ± 15
Satisfactory	$0.50 < R^2 \leq 0.60$	$0.50 \leq NSE \leq 0.65$	± 15 ≤ PBIAS < ± 25
Unsatisfactory	$R^2 < 0.50$	$NSE < 0.50$	PBIAS ≤ ± 25

Source; Nash and Sutcliffe, (1970).

3.4.4. Quantify impact of future climate change on Streamflow

The analysis and simulation of stream-flow has been carried out in one time horizon 2020's (2021-2040) in future periods covering non-overlapping 20 years considering river flow (1991-2000) as baseline flow. The future time horizons are applicable for only RCP 4.5 climate scenario. In fact, SWAT needs other hydroclimatic parameters like humidity, wind, solar radiation and updates spatial data like land use/cover and soil for computation of all parameters for the future period.

3.5 Quantify the Impact of Future LULC on Streamflow.

3.5.1. Land use and land cover change scenario

The observed LULC changes at the study watersheds have a notable influence on the surface runoff response, a conclusion supported by a study conducted in the Guder watershed by Ebabu *et al.* (2018). Eventually, there is a strong commitment from the government to tackling erosion and sedimentation, as well as rehabilitating degraded lands.

The analysis of LULC was evaluated in one period time slice of 20 years for both baseline and future periods with respective to RCP 4.5. The main reason why short-term time slice is selected is that, it is difficult to develop realistic land use and world market scenarios for a period of >20 to 30 years (Roosmalen *et al*., 2009). This reveal that, the medium and long-term synergistic impacts on surface water flows of future detailed urban land use configurations, under various medium and long climate emission scenarios may be fuzzy (Cuo *et al*. 2013). For this reason, short-term scenarios from 2021 to 2040 were considered in this study.

According to Abay Basin Authority (2016), Guder catchment is supposed to be one of the major irrigation potential sites of the Abay basin. Indeed, Feasibility study has been completed for about 6,282 hectare of land in order to irrigate a variety of crop, which is around 7.42 % of the Area. Based WBISPP (2004) reclamation, the percentage of change in Grassland and Shrub in the near future (up to 2040) of upper Blue Nile will reduced by -10.27 and -1.01 respectively.

3.5.2. Quantify the impact of future LULC on Streamflow.

In order to investigate hydrological impacts of LU change, simulations are carried out keeping climate fixed at 1986-2005, while LU is changed progressively up to 2040. To identify effect of changes in LU/LC, vegetation type and vegetation density on stream flow, different LU/LC, vegetation type and vegetation density data on 2040 years were considered. This different period LU/LC, vegetation type and vegetation density with soil data and DEM were given to GIS to generate different parameters for SWAT model. These generated parameters together with time series data (daily minimum and maximum air temperature, daily precipitation and daily stream flow) feed to SWAT model to simulate stream flow for the years 2040. From the time series data, climate changes (daily maximum and minimum temperature and daily precipitations) were kept the same as baseline period (1986-2005). The stream flow of baseline period (1987-2006) and the effect of future LU/LC, vegetation type and vegetation density was simulated SWAT model. FLULC was done by reviewing different journal on UBNRB and by taking into consideration government policy toward watershed.

3.6. Analyze both LULC and climate change Implication on Future Streamflow

To evaluate the effects of LULC and climate change on the stream of the study area, three scenarios are considered. The first two scenarios are based on the single factor approach (Li *et al.*, 2009); i.e., one driving factor is changed at an instant keeping the other constant. In the first scenario, climate is considered invariant while LU is varied with time, whereas in the second scenario, LU is considered invariant while climate is varied with time. These two scenarios are constructed to understand how streamflow would respond if only one of the driving forces is changed with time thereby assisting in quantifying the influence of individual factors on streamflow. In reality, both LU and climate change simultaneously with time and the hydrologic response is generated based on their integrated effect which is addressed by the third scenario.

Finally, from the integrated response, contributions of LU and climate on the streamflow variability are segregated using results from the other two scenarios. In-depth analysis in the first two scenarios is carried out due to a lack of detailed studies that examine the effects of LU and climate change on streamflow in the Guder Catchment.

3.7. Conceptual Framework on General Methodology of the Study

This study utilizes the hydrologic model SWAT and Climate model for estimation of stream flow response due to Land use /Land cover and Climate Change. Figure 3.14 describe the basic data sets were used to develop the input database for the models are spatial, meteorological, hydrological data and downscaled data as well as other watershed data. The following framework illustrates the general workflow of the study.

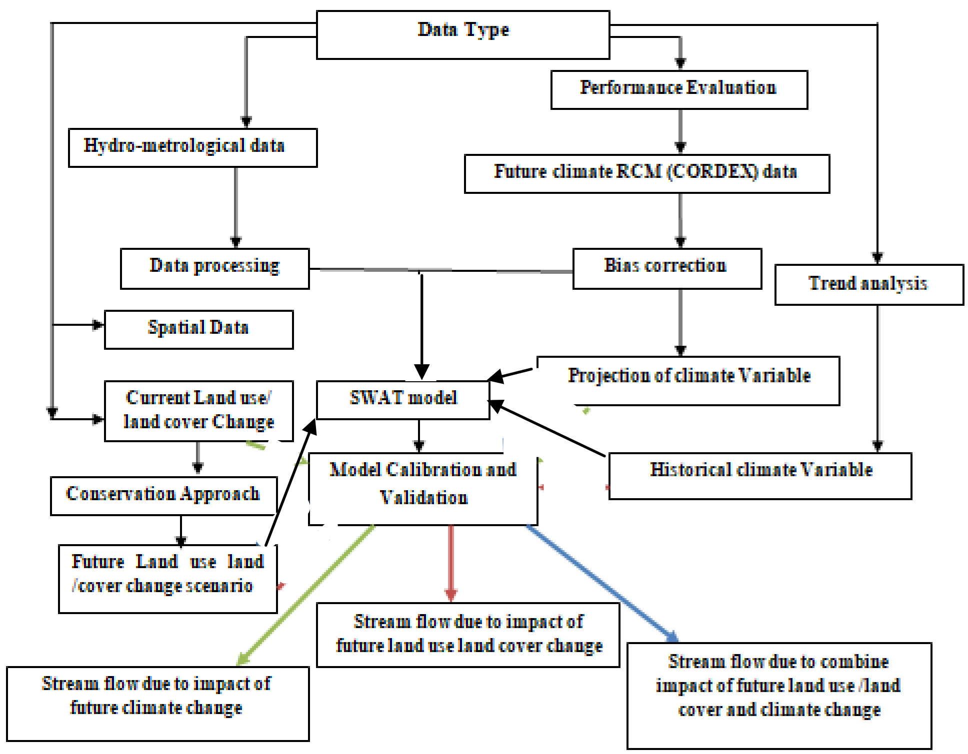

Figure 3.11.Flowchart of methodology adopted in this study

4. RESULTS AND DISCUSSIONS

4.1. Climate Change Projection (Scenario Generation)

4.1.1 Performance evaluation of regional climate model output

Mean annual rainfall amount of Guder catchment compared as obtained from gauged data and model. The 20-year mean annual rainfall amount is 1477 mm. When comparing the gauged mean annual rainfall to model based counterparts (Table 4.1), there exists smaller differences showing overestimation 99 mm and underestimation 8 mm respective RCMs. All the models except CNMR overestimate the observed UBN's annual rainfall amount. There is a weak correlation between the annual rainfall amount from most models and the reference data. Moreover, the correlation coefficient is higher than 99 for only two models (ICHEC and ENSEMBLE) with ENSEMBLE performing best as the correlation coefficient is 99.69.

In terms of bias, CV (Covariance) and RMSE (Root Mean Squer) the CCNMR model performed best whereas the MPI model performed poorest. The ENSEMBLE overestimated the observed annual rainfall amount by almost 2.7% and poorly captured the rainfall variability as compared to most individual models with an exception for MPI. The low CV of the ensemble mean rainfall (13.3%) suggests that variability is small as compared to all separate models. Further, using the ensemble mean led to somewhat reduced RMSE of 47.6 mm.

Table 4.1 Performance of the dynamically downscaled model of Guder catchment

Name	Annual rainfall (mm)	Bias (%)	CV (%)	RMSE	Correlation
Gauge	1330.10	-	13.28	-	-
CCNMR	1322.25	-0.82	13.36	23	96.18
ICHEC	1359.78	1.99	13.33	35.60	99.57
MPI	1429.50	40.78	13.99	123.60	96.69
ENSEMBLE	1370.5	2.8	13.3	47.6	99.7

The models' bias also shows moderate relation with terrain elevation (Table 4.1). The correlation coefficient values between model bias and terrain elevation are between 0.52 and 0.66 with an exception for the bias of CNMR which is weakly related to elevation (correlation = 96.1). According to Kim *et al*., (2014) report, the ensemble mean of simulated rainfall is often to result in better accuracy than using simulations of individual models. Eventually, this study shows that for Guder catchment the bias of the ensemble mean rainfall amount is larger than that of the two models except MPI.

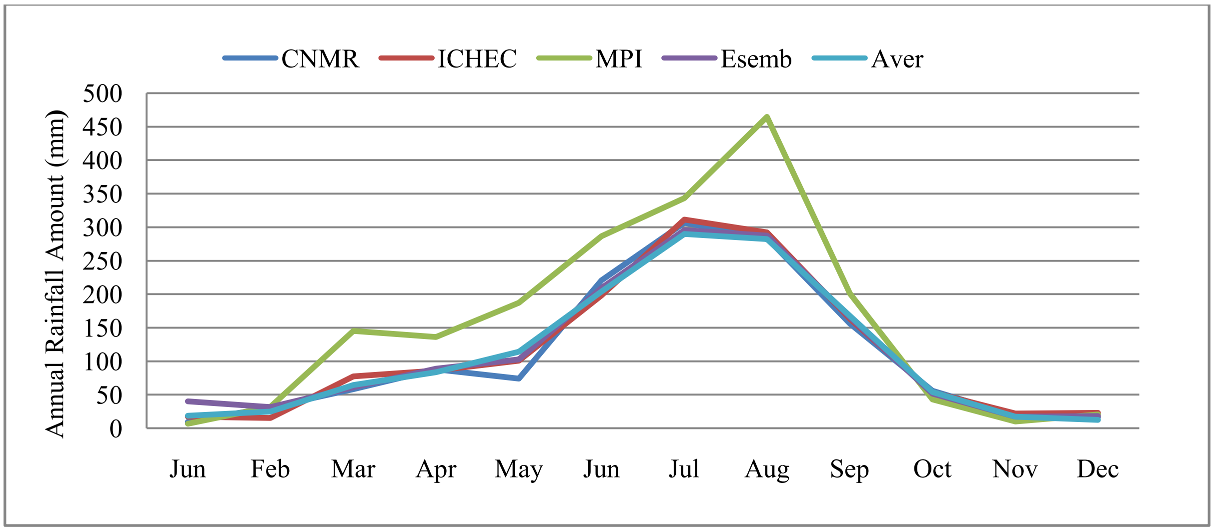

Figure 4.1. Dynamically downscaled climate model simulations and gauged rainfall data

All the models captured monthly patterns of rainfall of the basin with a slight in peak-time when rainfall amount is highest. Most models overestimated the highest rainfall amount in July and August by up to ~90 mm per month while significantly underestimating the rainfall amount in other months. Various studies have shown that the rainfall of the Upper Blue Nile basin shows significant space-time variability which is controlled by topography and presence of Lake Tana (Haile *et al*., 2009; Rientjes *et al*., 2013). This figure illustrate that, MPI resulted in the poorest performance in capturing monthly rainfall amount, highest rainfall amount and pattern where as CCNMR model resulted in better representation of the annual cycle and magnitude as compared to other models. In this study, CCNMR was used to downscale temperature and rainfall from Global climate to project future stream flow.

4.1.2. Bias correction for data obtained from climate model

The outputs of the raw RCMs underestimate and overestimate the mean monthly rainfall and temperatures as compared to a real precipitation and temperatures. Bias correction improves the efficiency coefficients for the RCMs with rainfall correlation being about 0.99 and R^2 is greater than or equal to 0.98.

Similar improvements are found in temperature where performance measures are ranges from 0.99 to perfect fit between simulated and observed temperatures at base period. The results of the long term mean monthly temperature and precipitation of the observed and the outputs of the RCM within the base period show good agreement. This implies that the bias corrected output of the model is well capturing and representative of the study area.

Table 4.2 Statistical performance measures of the selected RCMs

Station	Variable	Before			Bias corrected		
		Correlation	R^2	% bias	Correlation	R^2	% bias
Asgori	PCP	0.88	0.79	-6.71%	1	1	0
	Tmax	0.98	0.953	4.21%	1	1	0
	Tmin	0.13	0.62	35.33%	1	1	0
Kachis	PCP	0.915	0.83	8.7%	1	1	0
	Tmax	0.937	0.88	-9.49%	1	1	0
	Tmin	0.75	0.61	-7.07%	1	1	0
Gedo	PCP	0.89	0.799	-3.9%	1	1	0
	Tmax	0.96	0.92	1.84%	1	1	0
	Tmin	0.66	0.54	-16.87%	1	1	0
Shambu	PCP	0.95	0.92	15.15%	1	1	0
	Tmax	0.93	0.86	-0.52%	1	1	0
	Tmin	0.97	0.937	-12.92%	1	1	0
Tikur	PCP	0.958	0.918	5.052%	1	1	0
	Tmax	0.97	0.94	12.40%	0.999	0.9999	0
	Tmin	-0.3349	0.137	-45.96%	0.99	0.998	0.22

4.1.3. Projected future climate variables.

4.1.3.1 Projected Precipitation.

The average annual projected rainfall was expected to increase by 5% in the 2020s. However, the monthly rainfall projection for the coming century did not show a consistent trend, unlike the temperature, which has indicated a consistent increasing trend throughout the horizons. The maximum increment and reduction would be occurred in the months of July (52%) and December (-23%) respectively. During seasonal change, there would be more precipitation in JJAS (June, July, April and September) as compared to MAM (March, April and May) and ONDJF (October, November, December, January and February). The major rainfall moths June and July did not show consistent trends.

Studies (Beyene *et al*. 2010; Dile *et al.* 2013) show a similar trend of rainfall in the Upper Blue Nile River basins in the future period. Dile *et al*. (2013) found a decrease in rainfall by about − 30% during 2010–2040 in Gilgel Abay watershed using statistically downscaled outputs of the HadCM3 model.

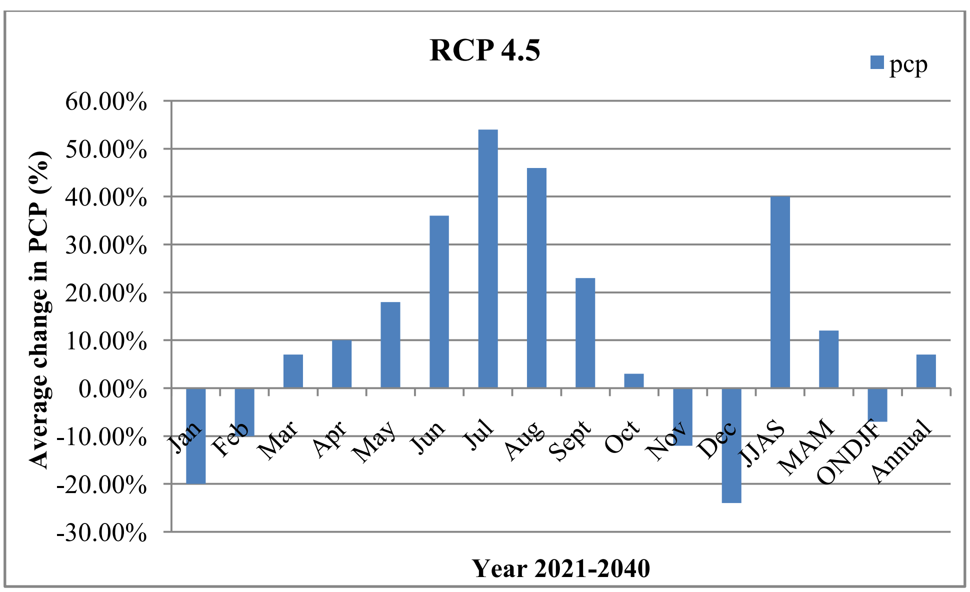

Figure 4.2 Average change of monthly, annual and seasonal PCP (2021-2040)

4.1.3.2 Maximum Temperature

The projected maximum temperature showed there would be an increment of annual average temperature of 1.4 ^{0}C with 2020's scenarios. As shown in Figure 4.4, change in seasonal average maximum temperature would be higher during ONDFJ seasons, which is 1.7^{0}C. In the same way, projection using RCP 4.5 scenarios predicted an increment from the base line time horizon, which showed an increment of maximum temperature. The increment would go down from January (2.1^{0}C) which is peak until Jul (0.5 ^{0}C) which was lowest and would go up in December (2^{0}C). The temperature change projection for Guder catchment is in line with the range produced in by other researcher over the UBNR (Gebre *et al*., 2015, Meresa and Getachew, 2016).

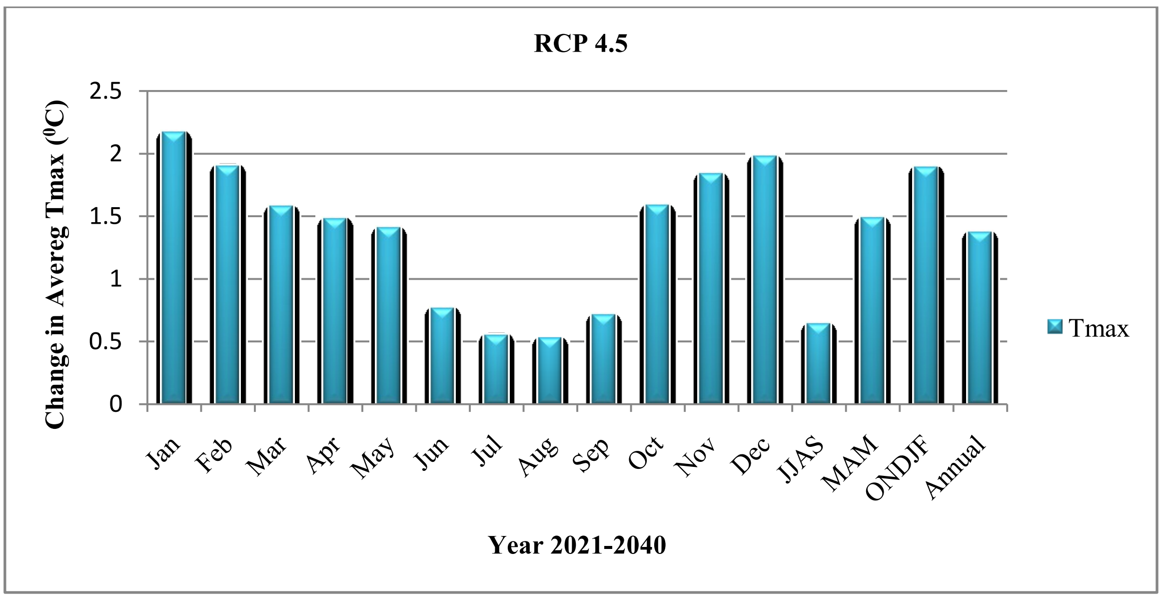

Figure 4.3 Change in Average monthly, Seasonal and annual Tmax (2021-2040).

4.1.3.3. Minimum Temperature

The projected minimum temperature shows an increment of annual average temperature of 0.8^0C during the 2020's future time horizon. Unlike maximum temperature, projection of minimum temperatures showed a maximum increment during ONDJF season with 1^0C. During 2020's time horizon's, RCP4.5 projection predicted a reduction in minimum temperature by the months of July (0.36 ^{0}C) and August (0.35 ^{0}C). The projected minimum temperature showed a wave like pattern of increment value during January (1 ^{0}C) and would go down up to Sept (0.42 ^{0}C). Afterward it was start to increase until it reaches peak November (1.2 ^{0}C). The temperature change projection for the catchment is in line with the range produced in by other researcher over the UBNRB (Tekleab *et al*,. 2013)

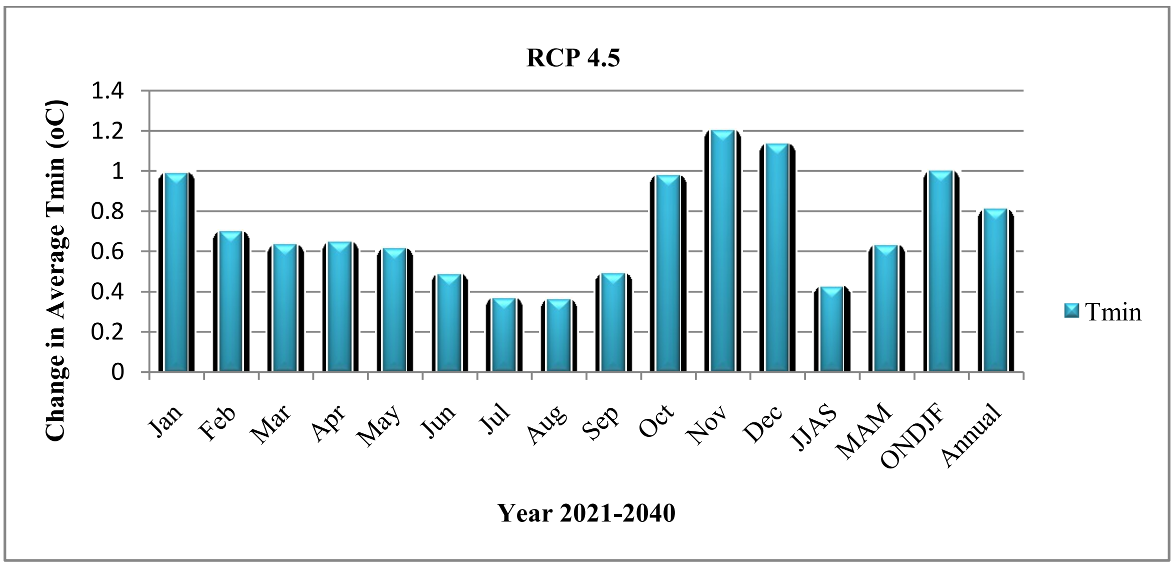

Figure 4.4 Change in Average monthly, Seasonal and annual Tmin (2021-2040)

4.2. Hydrological Modeling

4.2.1. Watershed delineation

For effective simulation of stream flow, the whole Guder catchment is divided in to 31 sub-basins based on default threshold area and about 271 hydrologic response units (HRU's).

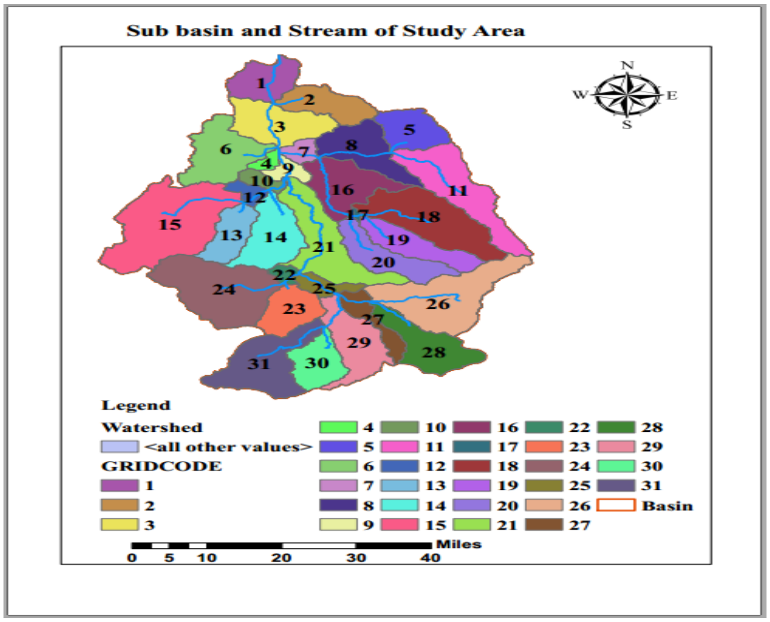

Figure 4.5 Guder watershed and stream flow

4.2.2. Hydraulic response unit

A summary of the land use and its respective SWAT land use code with areal coverage in the watershed that was used for HRU definition consists of five-land use and the spatial distribution of each land use type over the study watershed is shown in Figure 4.7. The catchment highly covered by moderately cultivated (76.33%) followed Dominantly Cultivated (14.7%) and Grassland (10.28%) respectively.

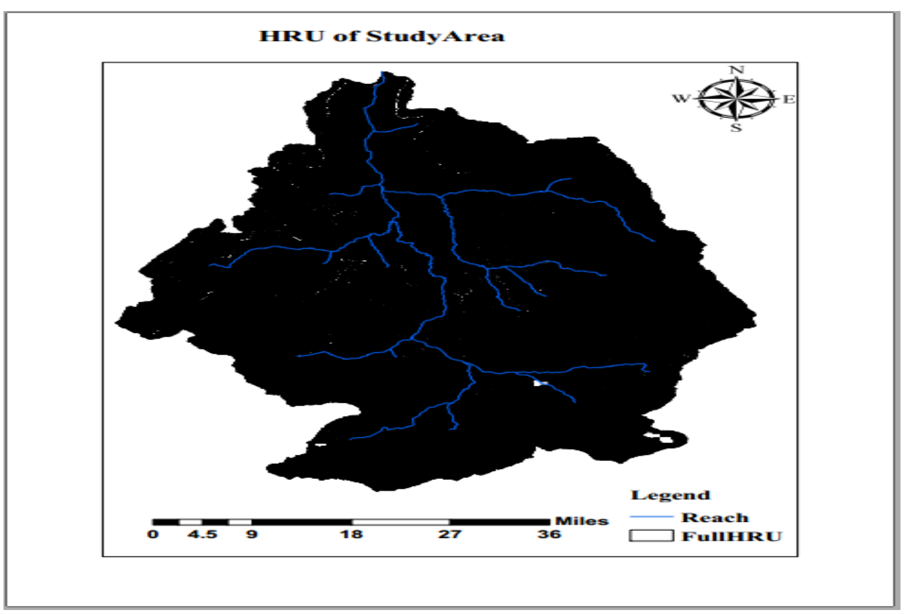

Figure 4.6 Map of overlaid Land use, Soil and Slope (HRU)

4.2.3. Parameter sensitivity analysis

A total of 24 hydrological parameters were tested for identifying sensitive parameters to facilitate model calibration and validation of stream flow using the SWAT CUP. SWAT CUP program were run 500 iterations with 24 parameters (Table 3.4) to determine most sensitive parameters using global sensitivity design method. SWAT-CUP uses t test and p-value to rank the most sensitive parameter that corresponds to direct change in stream flow response. A t-value provides measures of sensitivity with a larger in absolute values are more sensitive and p-values determined the significance a value close to zero has more significance. After the final iteration, 13 parameters were determined as sensitive parameters at a different degree of sensitivity (Table 4.3). The reason why they become sensitive is that, the small change in those parameter make a great varies on calibration value.

From the table below parameters such, curve number value;r__CN2.mgt; Manning's "n" value for overland flow; r-OV_N.hru; Soil hydraulic conductivity[mm/hr]; r__SloOL_K and Available water capacity [mm/mm]; r__SOL_AWC.sol have high influence on stream flow output.

On the other hand, Hydraulic conductivity [mm/hr]; v__CH_K2.rte, Threshold depth of water (mm); r_REVAP.gw, Deep aquifer percolation fraction [mm], a_GWQMN_gw ,Ground water delay, v__GW_DELAY.gw, Soil depth (mm); r_SOL_Z.sol and Deep aquifer percolation fraction r_RCHRG_DP are showed considerable sensitivity in stream flow. In addition, the response of the model towards parameter involving Manning's "n" value for overland flow; r__OV_N.hru, Soil albedo; a__SOL_ALB.sol, Average slope length r_SLSUBBSN.hru, Average slope steepness; HRU_SLP.hru, Base flow alpha factor (days); ALPHA_BF.gw, Soil evaporation compensation factor; r_EPCO.hru and Soil evaporation compensation factor a__ESCO.hru. A brief description of each hydrologic parameter is listed in the SWAT-CUP user's manual (Abbaspour, 2015).

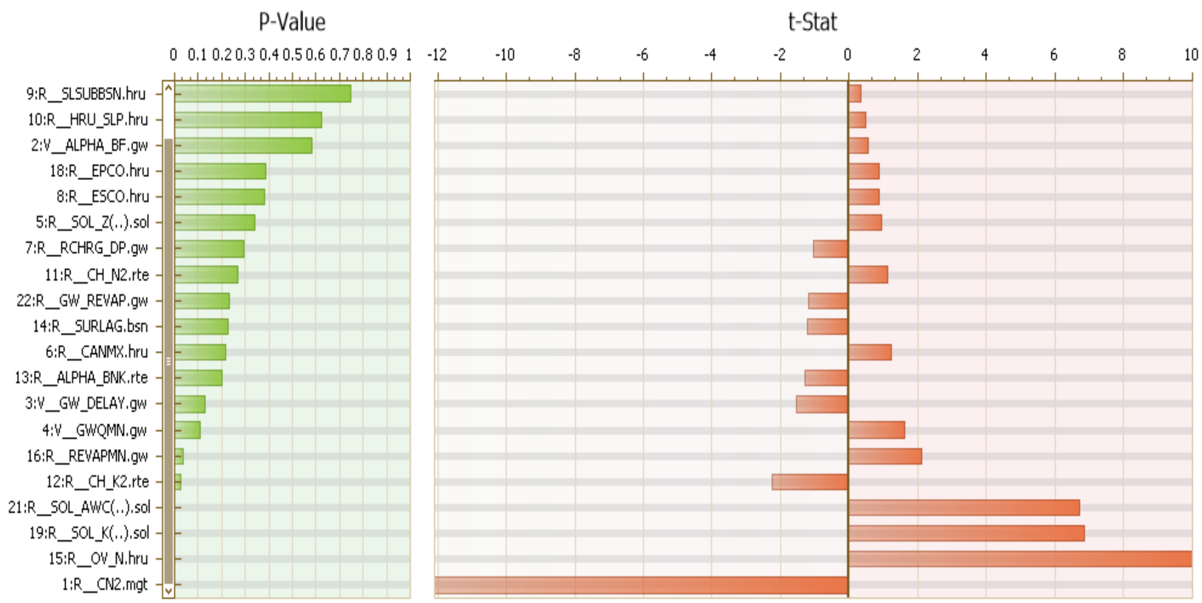

Figure 4.7 Result of sensitivity analysis for flow parameters on SWAT CUP (SUFI-2)

Table 4.3 Results of sensitivity analysis for flow parameter for SUFI-2.

Parameters	Ranking	t-test	p-value
r_CN2.mgt	1	-12.1	0
r_OV_N.hru	2	10	0
r_SOL_K.sol	3	6.8	0
r_SOL_AWC.sol	4	6.7	0
v_CH_K2.rte	5	-2.25	0.02
v_REVAPMN.gw	6	2.1	0.03
a_GWQMN.gw	7	1.6	0.1
v_GW-DELAY.gw	8	-1.5	0.12
v_ALPHA_BNK.rte	9	-1.27	0.2
v_CANMX.hru	10	1.23	0.21
v_SURLAG.bsn	11	-1.21	0.22
r_GW_REVAP.gw	12	1.19	0.23
v_CH_N2.rte	13	1.11	0.26

4.2.4. SWAT model calibration and validation

To improve the efficiency of the model during calibration the top thirteen ranking parameters were considered to account for the over and under prediction responses of the model as suggested by Neitsch et al. (2011). Model calibration were computed using 1990–1997 climate data against measured discharge data. Model validation consist the comparison of the model outputs with an independent data set without making further adjustments of the parameters obtained during the calibration process. Using the same parameter values the calibrated model setup were validated and found to prove the applicability and result acceptable performance. Model validation was performed from 1998 to 2001 against the measured due date value.

Table 4.4 Finally calibrated flow parameter values

Parameters	Range used in calibration	Fitted /Calibrated
r_CN2.mgt	-0.2 to 0.2	0.14
r_OV_N.hru	-0.2 to 0.08	0.02
r_SOL_K.sol	-0.1 to 0.4	0.1
r_SOL_AWC.sol	0.2 to 0.46	0.35
v_CH_K2.rte	123 to 194	156
v_REVAPMN.gw	0 to 500	48.3
a_GWQMN.gw	0.83 to 2.4	1.6
v_ALPHA_BNK.rte	0.004 to -0.48	-0.39
v_CANMX.hru	0 to 10	0.01
v_SURLAG.bsn	0 to 0.2	0.15
r_GW_REVAP.gw	0.02 to 0.1	0.07
v_CH_N2.rte	0.15 to 0.29	0.29

The measured and simulated average and total daily stream flow for the watershed were obtained. Statistical agreement between simulated and observed flow data during the calibration periods resulted in a high agreement using R^2, NS and BIAS with the result of 0.84, 0.83 and 8.3% respectively. These results indicate that there were high agreements between the measured and the simulated stream flow value during the calibration periods (Figure 4.9; 4.10; 4.11;). Based on the result, the model is efficient enough to represent and evaluate the impact of climate and LULC change on stream flow variability.

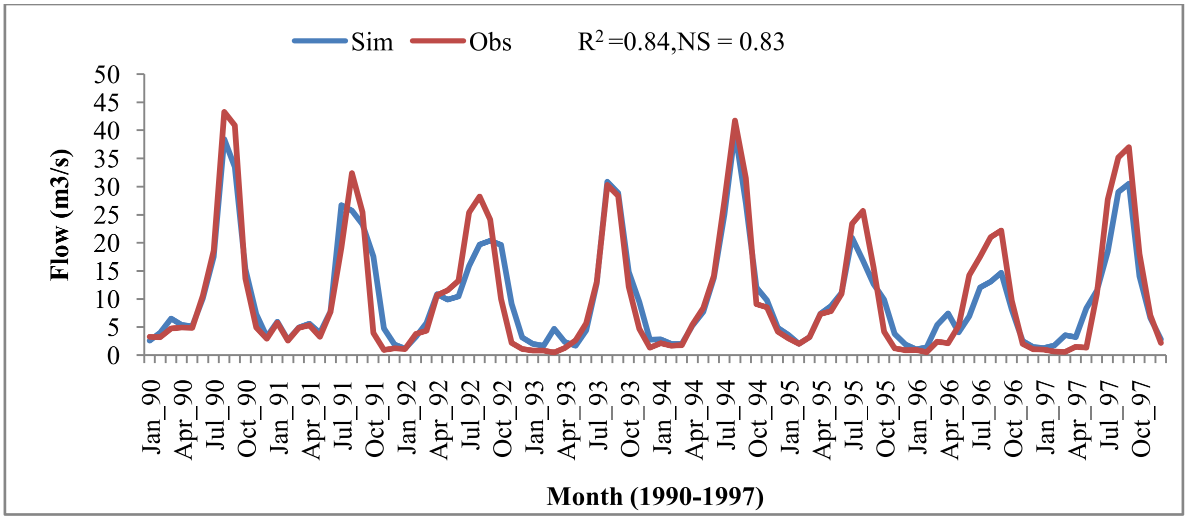

Figure 4.8 Observed versus simulated flow hydrograph at Guder near Guder station for the calibration

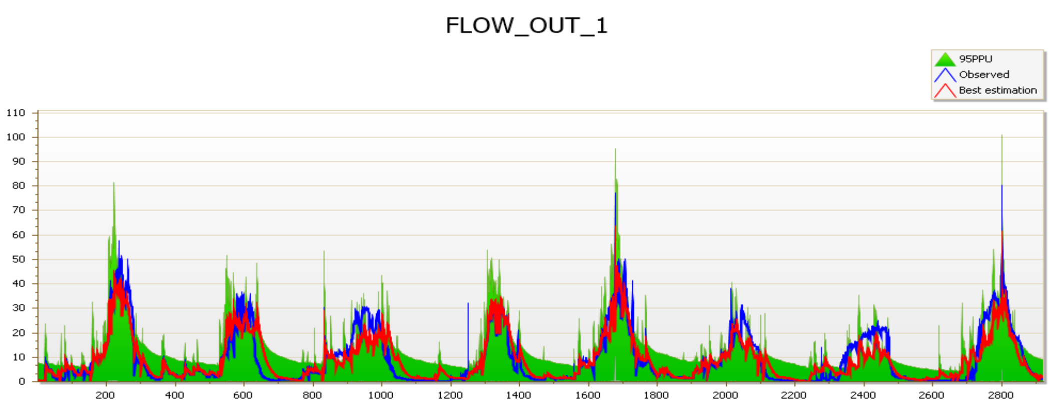

Figure 4.9 Observed versus simulated flow hydrograph at Guder near Guder station for the calibration from SWAT - CUP

Using the same parameter values the calibrated model setup were validated and found to prove the applicability and result acceptable performance. Model validation was performed from 1998 to 2001 against the measured due date value. The validation result in terms of average daily and total stream flow result evaluated against R^2 and NS model efficiency. Validation of SWAT model against observed data for respective years (1998–2001) in terms of R^2, NS and BIAS were 0.85, 0.80 and 2.3% respectively; which shows a high agreement between the simulated and observed data. This performance measures fulfilled the requirement recommended by Moriasi *et al*. (2007).

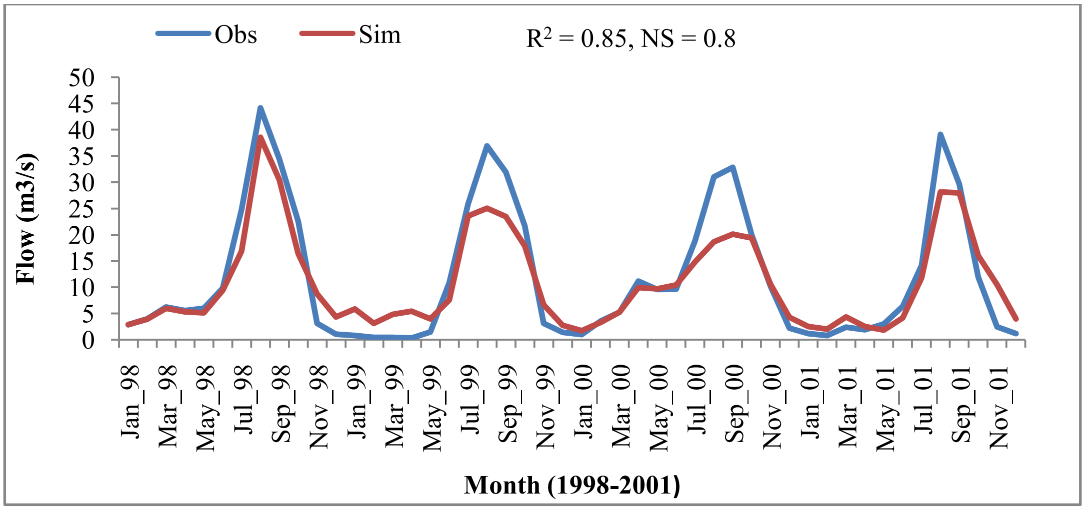

Figure 4.10 Observed versus simulated flow hydrograph at Guder near Guder station for the Validation

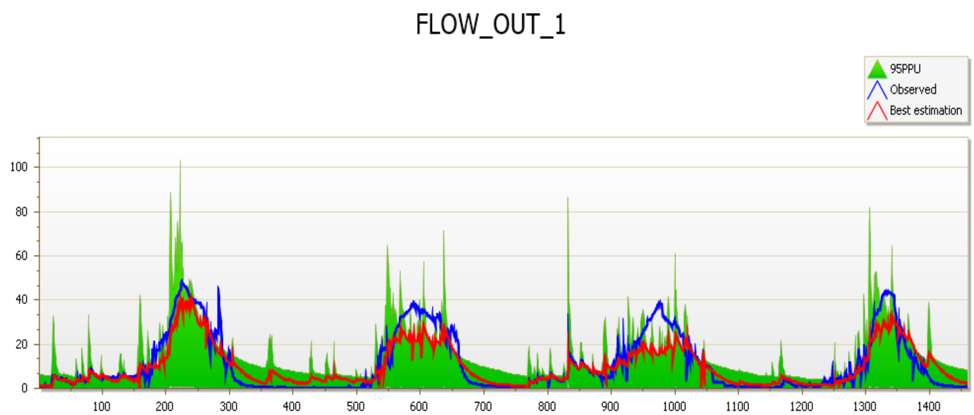

Figure 4.11 Observed versus simulated flow hydrograph at Guder near Guder station for the Validation from SWAT - CUP

A more quantitative picture of the performance of the calibrated model for the calibration and validation period is gained from the two regression line plots of the simulated versus observed stream flow of Figure (4.13). Most of the scatter points are uniformly clustered along the 1:1 line during calibration and validation period indicating a good agreement between the observed and simulated flow. Generally, model calibration entails the modification of parameter values and comparison of predicted output of interest to measured data until model efficiency is achieved (James & Burges, 1982).

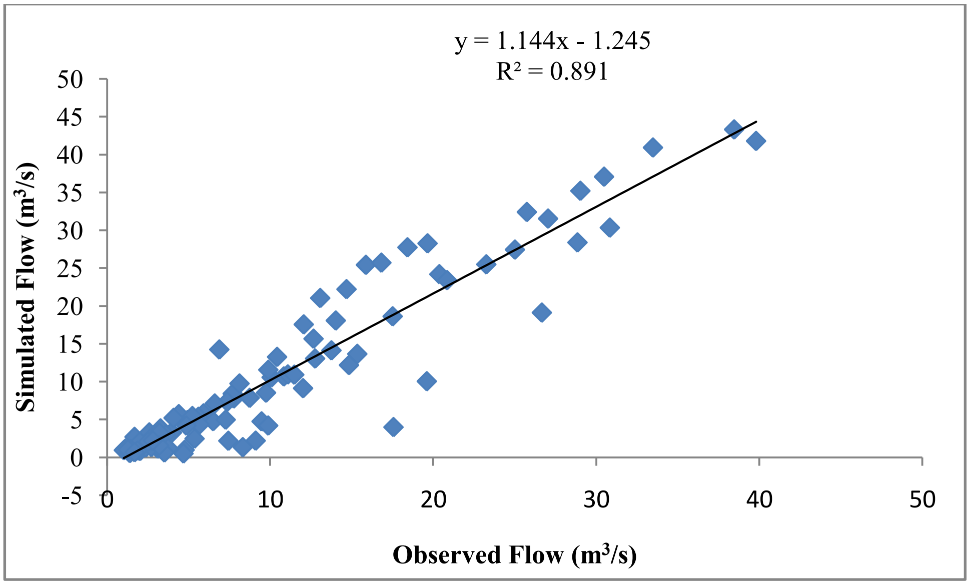

Figure 4.12 Scatter plot of observed and simulated flow for the calibration

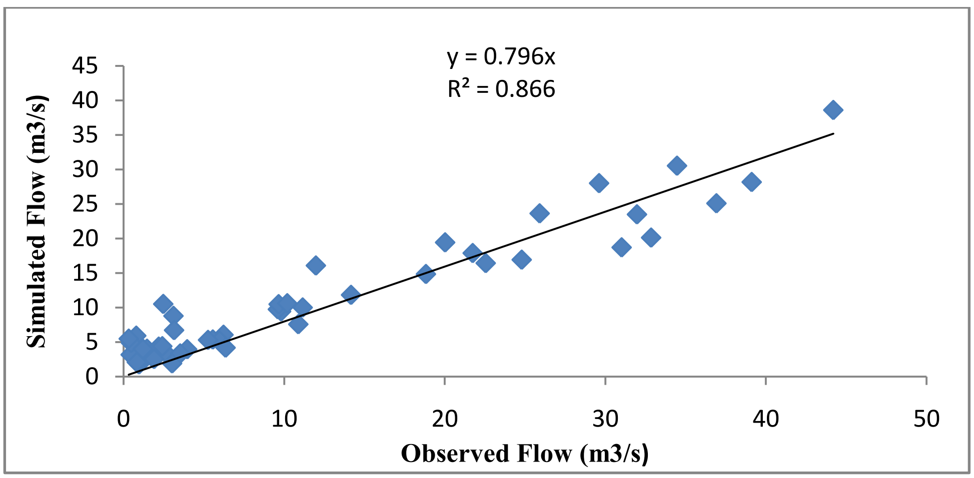

Figure 4.13 Figure 4.18 Scatter plot of observed and simulated flow for the Validation

Table 4.5 Model calibration and validation performance

Criteria	Calibration	Validation
Coefficient of determination (R^2)	0.84	0.85
Nash–Sutcliffe efficiency (NS)	0.83	0.8
% BIAS	8.3	2.3

4.2.5. Projection of streamflow due to climate change

The annual Streamflow due to climate change was expected to increase by 26% in 2040. The highest decrease in stream flow is observed during December, which could be a result of 22% decrease in precipitation by 2040. In the same path, stream flow was increased for the month of August by 38% in 2040. A significant increase in streamflow is expected to occur between Junes to September because of the 32% increase in precipitation in 2040. For March and May, precipitation changes are compensated by changes in ET and thus streamflow may show insignificant change during the same period compared to other months.

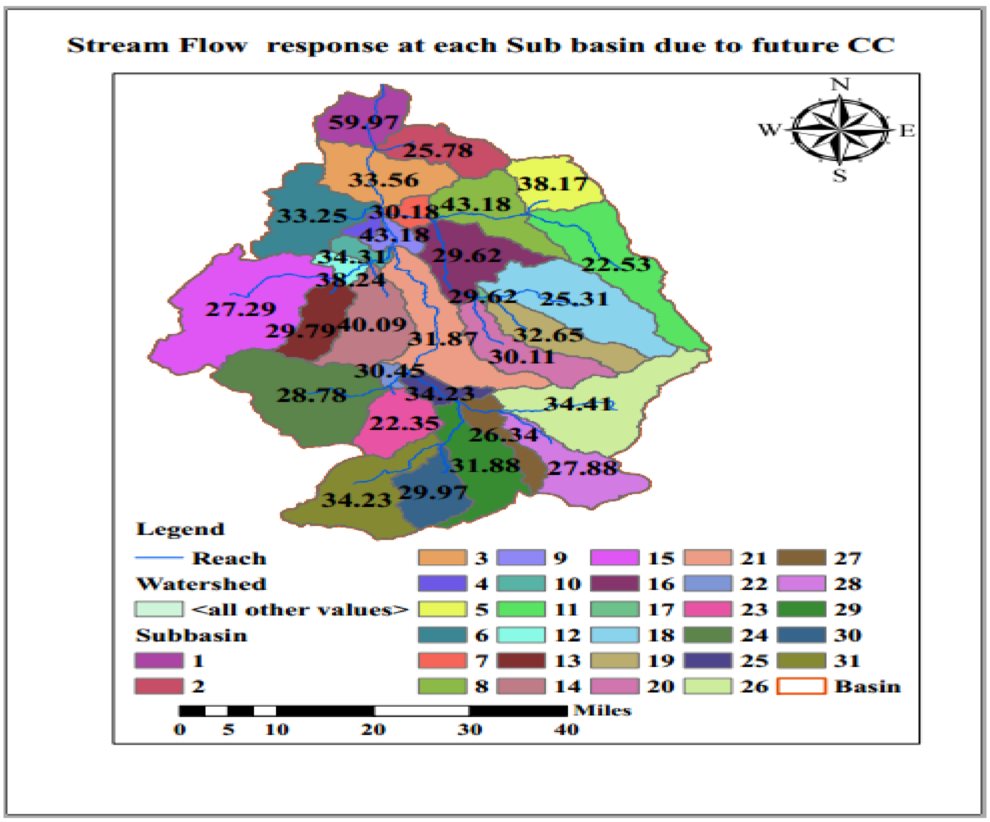

Figure 4.14 Stream flow at each Sub basin due to impact of future climate change

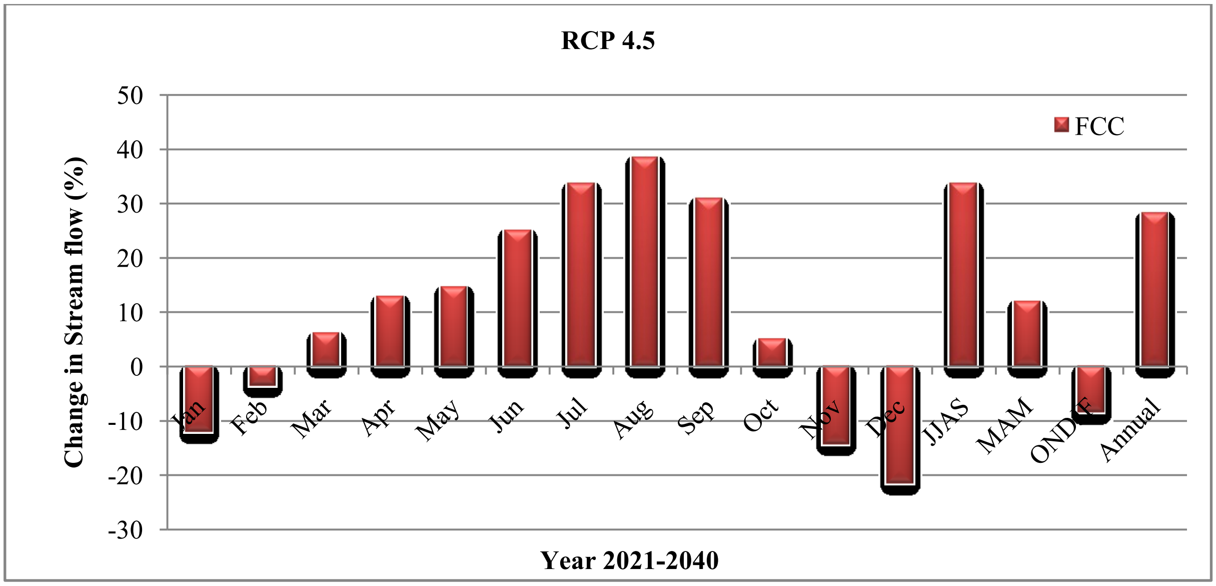

Figure 4.15 Change in monthly, seasonal and annual stream flow by FCC (2021-2040).

Simulation result showed that there will be a shift in wet season towards May to July. There will a reduction of peak flow for (August to October) 38% to 4%. This is mainly because for those periods Precipitation expected to be fall down up to −2%. For the low flow (October to December) SWAT models shows a decreasing trend. For low flow of the dry season (October to February), since there will be an increment of maximum temperature (+0.57˚C) and decrement precipitation (-19%), simulation result showed there was slightly increasing trend from 5% to 14% for the month of Mar to May for RCP 4.5 scenarios. Mishra and Lilhare (2016) were found similar stream projection flow during the wet season. They reveal that, the in dry season (Jun-September) stream projection was increased in the majority of the sub-continental river basin.

4.3. Projection of Streamflow due LULC change

4.3.1. Land use and Land Cover Change scenario

One of the plausible measures for the future LULC map could be converting cultivation land on steep slopes higher than 10% to forestland (Haregeweyn *et al.*, 2006). According to Girmachew, (2016) Guder catchment is supposed to be one of the major irrigation potential sites of the Abay basin. Once LULC scenario was prepared by using different conservation assumption, historical LULC was modified to future scenario by using Land use update (LUP). Final LULC scenario was used to simulate the stream flow by the help of edit SWAT input.

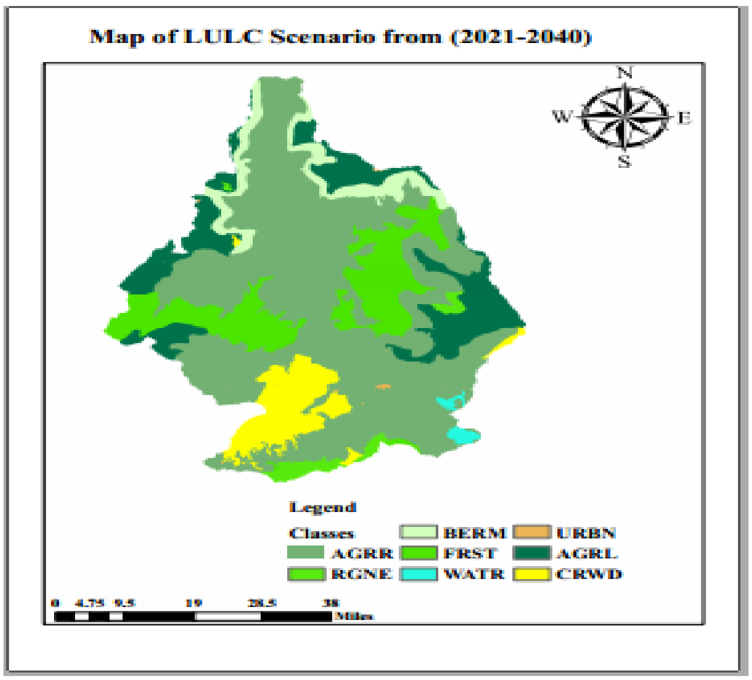

Figure 4.16 Land use and Land cover change of Guder Scenario

Table 4.6 Proportional extent of current and future LULC in Guder Catchment

S.No	Land use type	Name of LULC	Existing coverage (%)	Future Coverage (%)	PI/PD*
1	Moderate Agriculture	AGRR	76.33	56.44	-19.89
2	Rangeland	RGNE	2.04	1.95	-4.62
3	Grassland	BERM	5.5	5.46	-0.73
4	Forest mixed	FRST	0.22	14.12	98.44
5	Water	WATR	1.16	0.63	-84.13
6	Urban	URBN	0.12	0.12	0.00
7	Dominant Agriculture	AGRL	14.70	14.08	-4.40
8	Crop Irrigation	CRIR	-	7.20	100.00

The results of this study are in good agreement with the findings of previous studies conducted in the world highlands. For example, a study in China by (Ju *et al*., 2018) reported that the cultivated land showed a decreasing trend up to 2040 mainly as a result of the expansion of built-up area (42,822 km^2 (43.8%) at the expense of cultivated land from 2021 to 2040). The conversion of Grassland to water land in the Guder also agree well with the results of Dessie and Kleman (2007) in the south-central rift valley region of Ethiopia, Minta *et al.*, (2018) in Dendi-Jeldu in the centeral Ethiopia highlands, and (Ningal *et al,.* 2008) in Morobe Province of Papua New Guinea.

Similarly, Wondie and Mekuria (2018) reported that forest cover in Fageta Lekoma District (Guder watershed located in this District) showed a substantial increase (mainly through planting of A. decurrens).

4.3.2. Projection of streamflow due to LULC change

Figure 4.19 showed that Streamflow simulation based on projected land use change indicates increased in annual streamflow by 6.2 % due to land use change compared to that in the baseline period in the Guder catchment. The mean wet season, small rain season and dry season was 8 %, 2 % and -4 % respectively Figure 4.18 shows the amount of stream response by climate change. The results of the basin show that, sub basin 1 have high response (1.54) while basins 27 have lower stream response (0.57). Based on future projections, cultivated land use would cover less than 60% in 2040 of the watershed. This reduction in cultivated land use would lead to decrease in annual streamflow compared to the baseline scenario. Forest and settlement land is projected to increase while cultivated land would decrease under simulation scenarios (RCP 4.5) for 2040 land use scenarios, causing an increase in annual streamflow. In 2040, expansion of irrigational land (7%) which may result in an increase in streamflow.

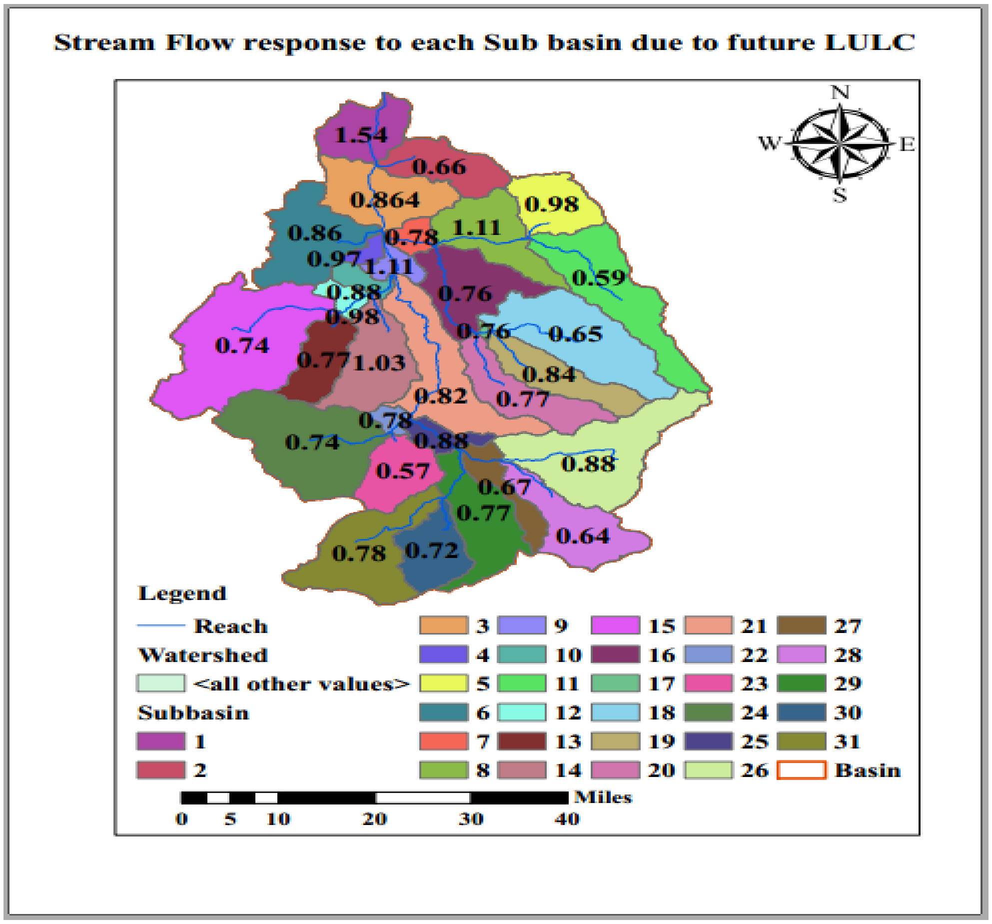

Figure 4.17 Streamflow at each sub basin due to impact of future LULC

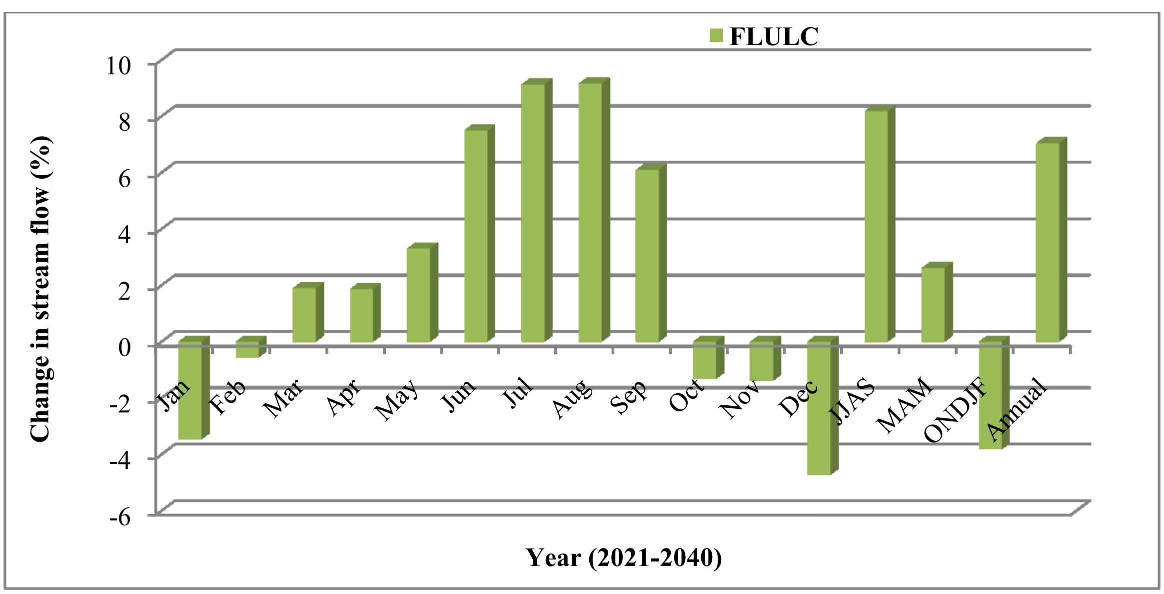

Figure 4.18 Change in monthly, seasonal and annual streamflow by FLULC (2021-2040).

Expansion of urban and cultivated areas in the watershed will likely result in increased streamflow as shown by other studies in other watersheds (Neupane and Kumar, 2015; Rajib *et al*., 2016c; Paul *et a*l., 2017). This result is supported by past studies in Upper Blue Nile basin at different temporal and spatial context (Gashaw *et al*., 2018 and mekonnen *et al*., 2017). Increase forest vegetation cover, expansion of cultivation land and urbanization at a cost of natural forest are known causes to decrease a streamflow during the wet and short rainy season. Similar studies in Chemoga watershed shows that decreases in forest cover result an increase of stream flow.

4.4. Projection of streamflow due to both combined impact of LULC and Climate change.

The analysis of land use and climate change impacts conducted this study demonstrates how and to what extent annual streamflow in the Guder catchment could be altered in the future. The total increases in mean annual streamflow in 2040s due to combined impact of future CC and LULC was 18%. The timing of the 23% of annual streamflow, in 2040s, was observed in August. Seasonal and annual streamflows at the Guder catchment outlet might be offset under concurrent effects of future land use land cover and climate change compared to sole future climate change scenario (Fig. 4.21). On the other hand, the dry season streamflow and the small rainy season streamflow might amplify under future climate change in comparison to that in combined scenarios. As usual, the stream response due to combine impact of LULC and Climate change is high sub basin 1 (57%) and low sub basin 27 (23.28%). This reveal that, each sub basin have different sensitivity due impact of climate change and LULC. Furthermore, type of LULC practiced in each sub basin, slope and other climate factor may vary the result.

The main rainy season, dry period and annual streamflows response for a concurrent scenario would be lower than that of future climate change. These varying responses of streamflow to the combined scenario, compared to the future climate change at different abstraction points indicate that the LULC change would have a significant influence on streamflow at different spatial scales. Streamflow would be more sensitive to climate change than to the LULC changes scenario, even though changes in land use have far-reaching influences on streamflow in the study region.

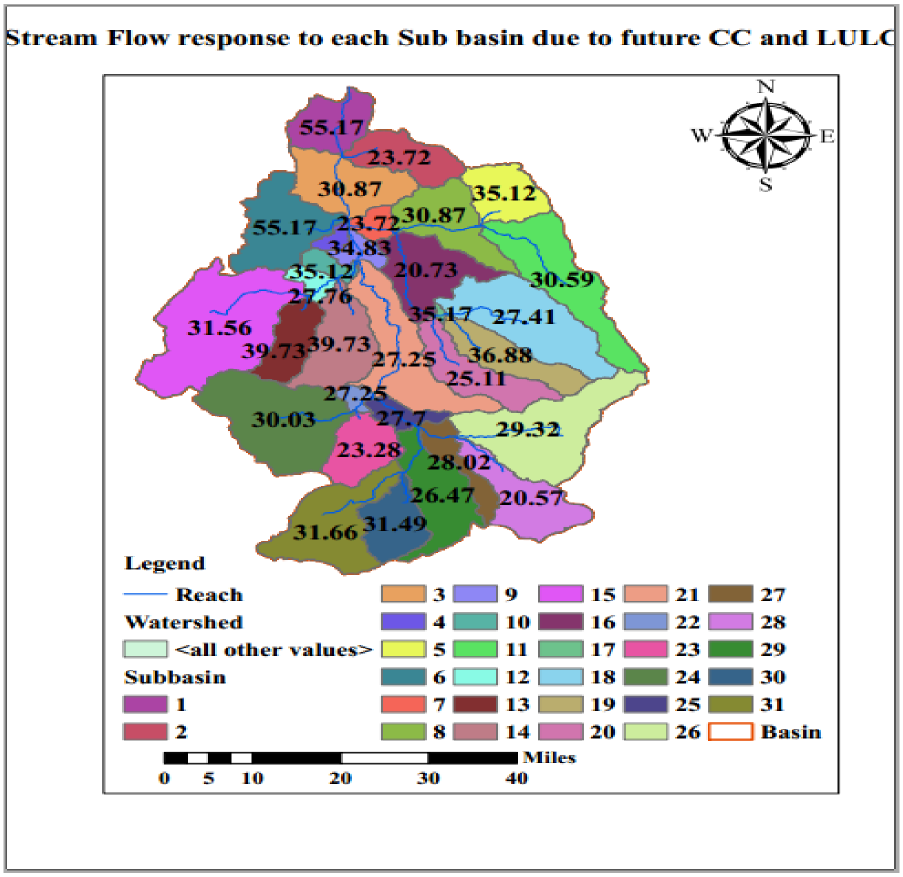

Figure 4.19 Streamflow at each sub basin due to impact of future CC and LULC

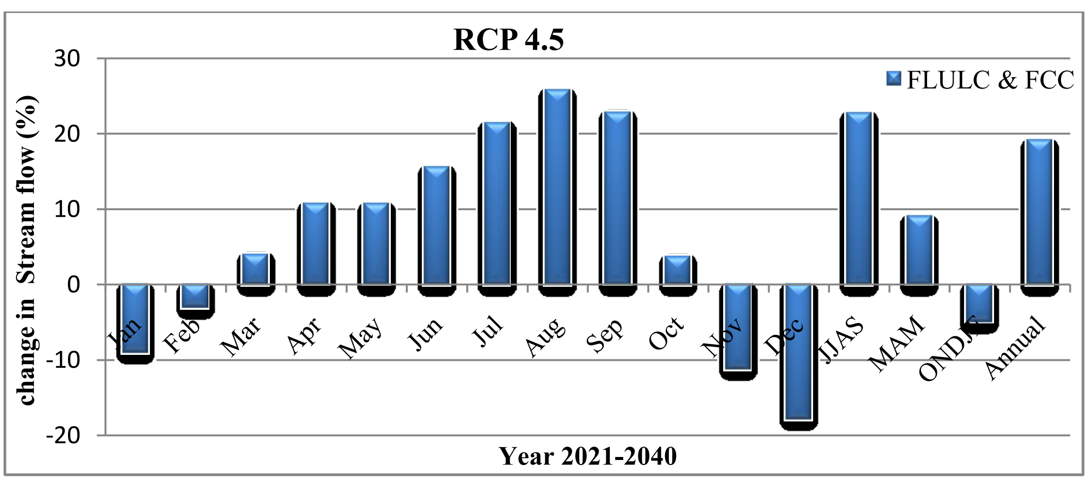

Figure 4.20 Change in monthly, seasonal and annual streamflow by fLULC and fCC (2021-2040).

The combined effects of climate and LU/LC change indicated that there are differences in streamflow in the seasons. During wet season streamflow was expected to increase over the study period and decreased during the dry season. The short rainy season and annual average have shown an increasing trend in stream flow the results from the present Guder catchment study are also consistent with findings from other researchers who pointed to large influence of climate change over land use change on streamflow in other Midwest watersheds (Wu *et al*., 2013).

In a similar climate and land use change impact study, Tavernia *et al*. (2013) reported that projected water stress (i.e. water demand/water supply) would be more sensitive to climate change than land use change in the Northeast and Midwest, United States. Some studies have also noticed future climate change scenarios are more extensive than fLULC scenarios in determining stream flow (Roosmalen *et al*., 2009). Such variation between seasons in streamflow due to the combined effects of climate and LU/LC changes Corroborate other findings (Yin *et al.*, 2017).

In General, the combined effects are much more serious than only LU/LC. This result signifies the roles of the synergetic effects of both variables in affecting the overall streamflow and water management practices at a watershed level.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In evaluation of future climate and LULC change impact and adaptation decisions, it is pertinent to identify climate model outputs that can reproduce the climate of the region under study. In line with this, performance evaluation of three RCMs (CCNMR, ICHEC and MPI) and ENSEMBLE downscaled using RCA-4. It was found that CCNMR perform better in representing the annual rainfall events in Bias and RMSE. ENSEMBLE performed best in terms of the correlation coefficient between gauged and simulated annual rainfall amounts. In addition, all individual models reproduced the observed inter-annual variability of rainfall better than the ensemble mean in which variability was suppressed. Therefore, successful use of CCNMR means may depend on the rainfall characteristic under study.

Based on the RCMs, the study watershed may experience higher precipitation (-12–52%) and warmer temperature (0.5 °C–2.2 °C) in the future compared to the baseline conditions (1987-2016). From the climate change analysis, it is observed that rainfall may decrease during the ONDJF months and increase during the winter months which may result in a shift in seasonal rainfall pattern. All the changes in rainfall, Tmax and Tmin pertaining to climate change scenario are found to be statistically significant from the baseline period, indicating that deviation in their magnitudes is likely to cause serious impacts on the hydrologic response.

The combined impacts of climate change and LULC dynamics can be rather different from the effects that follow-on from LULC or climate change alone. The important inference from these findings is that, it could be possible to alleviate intense floods or droughts due to future climate change by planning LULCs to attain particular hydrological effects on land cover in the basin. All the findings in this study are only applicable under the aforementioned future climate and land use change scenarios. In reality, a systematic bias was found when the climate data generated from the scenarios were compared to the observed historical climatological data for the base period of 1986–2005.

Compared to climate change scenarios, the LULC change scenarios applied in this study are a bridged without taking into account land use policy and socio-economic development. Notwithstanding that the modeling results have the aforementioned limitations, the outcomes of this study are appropriate, dependable and credible under the present climate change and land use scenarios. Moreover, the techniques are beneficial for evaluating the combined effects of climate and land use changes on basin hydrology.

Generally, an increase in mean annual streamflow in the Guder catchment would support aquatic ecosystems and recreational opportunities. While this is a positive outcome from the impacts of climate and land use changes, it is also a call for researchers, practitioners, and policy makers to be well prepared to adopt best practices in water resources management. Increased streamflow, for example, may lead to increased subsurface drainage in the future, which in turn has known water quality implications without sound in-field and edge-of-field practices to minimize excess nutrient losses.

5.2 Recommendation

The following points recommended as emanated from the study result.

In many aspects, the ENSEMBLE climate model performed best in terms of bias and RMSE. However, it was found that the performance of the models differs subject to the performance measures used for evaluation. The use of the ensemble mean rainfall simulation did not improve representation of assessed rainfall characteristics in the basin. Based on the findings in this study, CNMR climate model was not compulsory in order to capture different aspects of the Guder catchment rainfall.

This study also considered as indicative of the likely future rather than accurate predictions. There are many sources of uncertainty in climate and in hydrological models. However, it is possible to use varieties of models and scenarios. This reduces uncertainty of the hydroclimatic conditions in the study area. Therefore, future studies of the same objective over Guder catchment should consider a combination of downscaling techniques; different RCMs outputs and hydrological models to achieve comparative results.

The LULC change scenario was set up based on the assumption of more conservation practices in the future in order to reduce erosion and sedimentation. This might not be the actual trend of future LULC change in the study region. It recommended that, future research should use land modeling for socioeconomic development and biophysical driving forces to asses' future land use dynamics.

Generally, the results of this study pointed out that the climate change and the land use change potentially become important drivers to the future discharge fluctuation in Guder catchment. The implementation of mitigation actions such as soil and water conservation in agriculture plantation to reduce the decrease of the minimum discharge during dry season and the adaptation measures for increased the maximum peak discharge during wet season are necessary.

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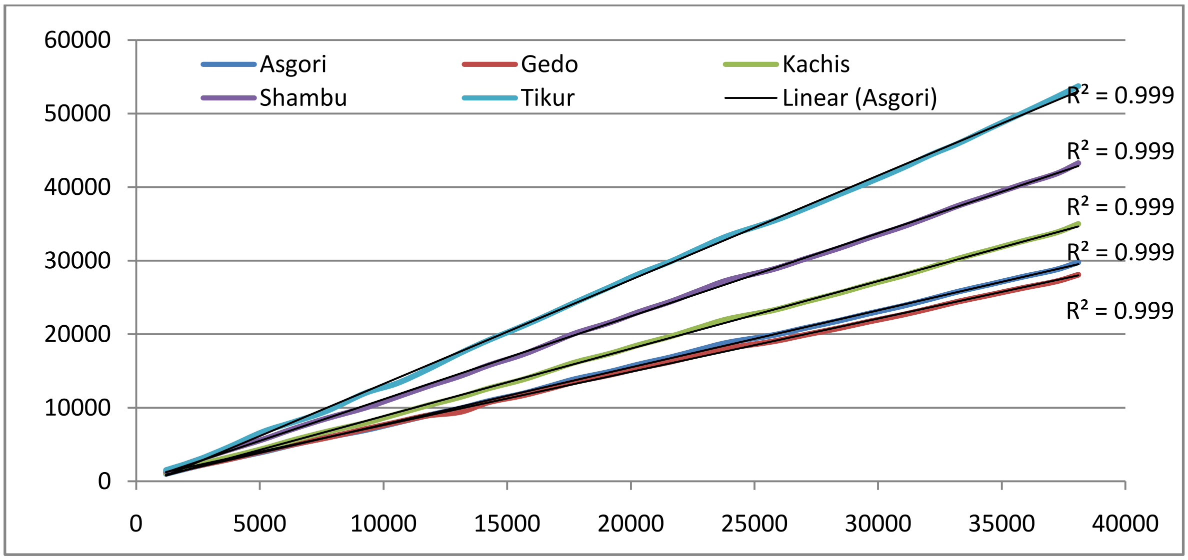
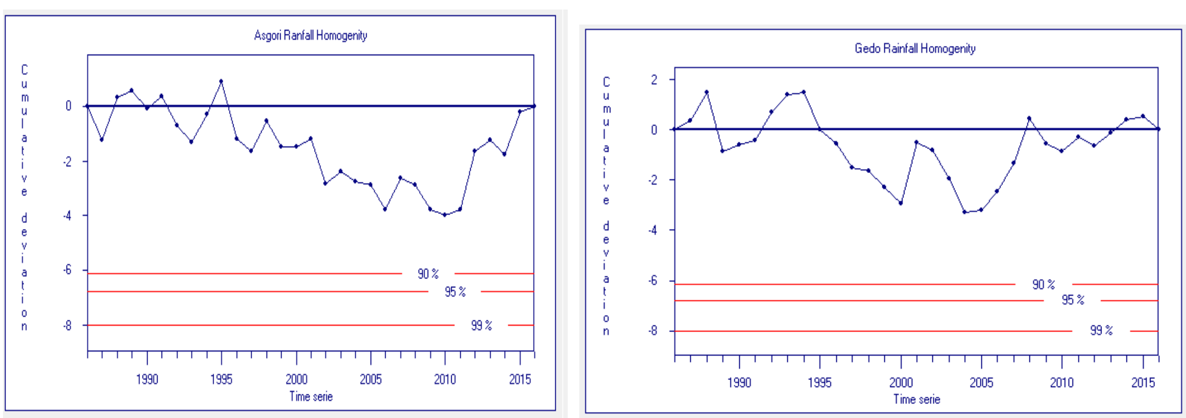
7. APPENDICES

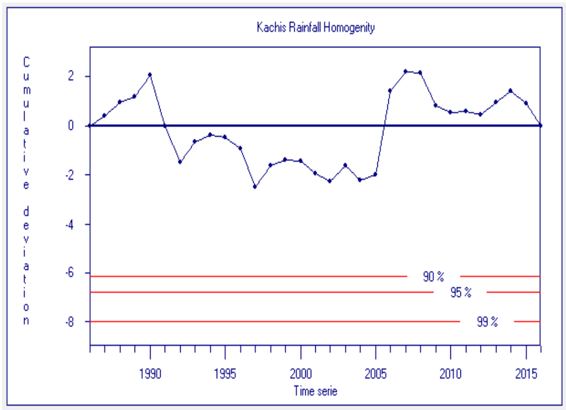
Appendix I: Data Quality and Homogeneity test.

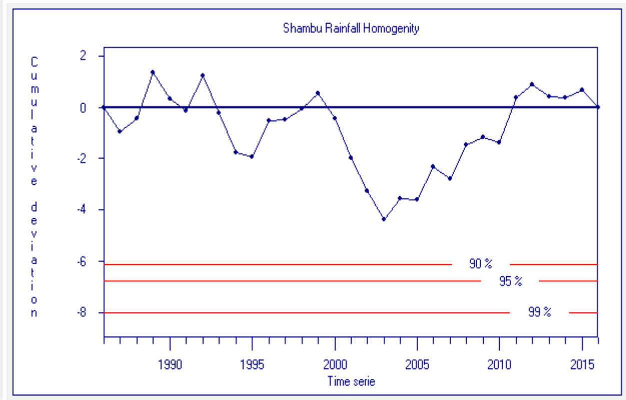
Appendix Figure 1: Double Mass Curve of Guder catchment station.

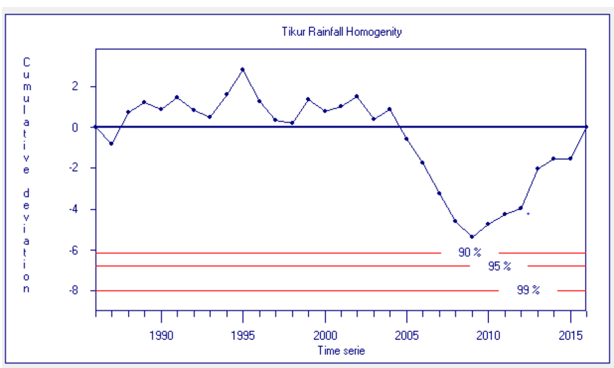


Appendix Figure 1: Homogeneity test of Guder station

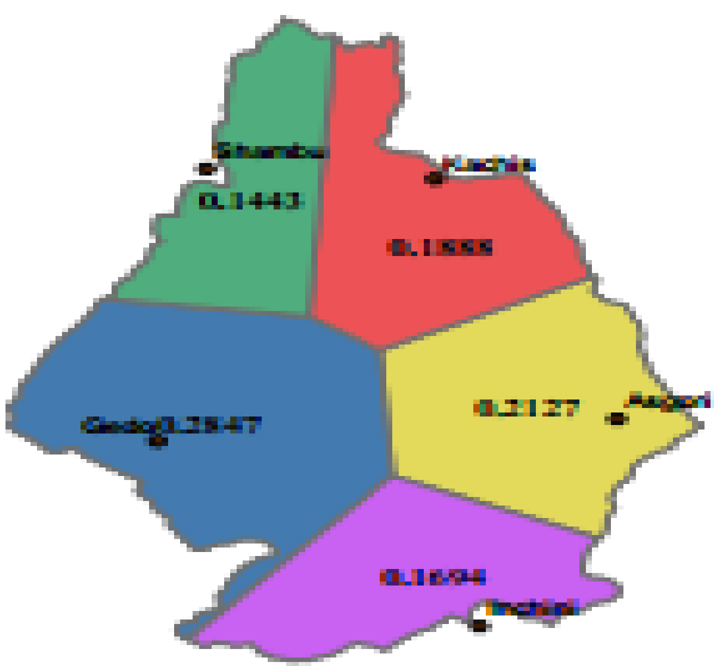








Appendix Figure 2: Areal Thiessen polygon for selected rainfall stations



Appendix Table 0.1: Areal rainfall interpolated using Thiessen polygon method for catchment

S/N	Station	Area in (ha)	Areal ratio	Annual rainfall in (mm)	Weighted rainfall in (mm)
1	Asgori	137398.2	0.2127	1014.17	215.7
2	Gedo	183908.2	0.2847	890.99	253.7
3	Kachis	121959.5	0.1888	1101.87	208
4	Shambu	93213.8	0.1443	1548.76	223.5
5	Tikur Inchini	109427.7	0.1694	1790.87	1303.4
6	Total	645907	1	6346.66	1216.27

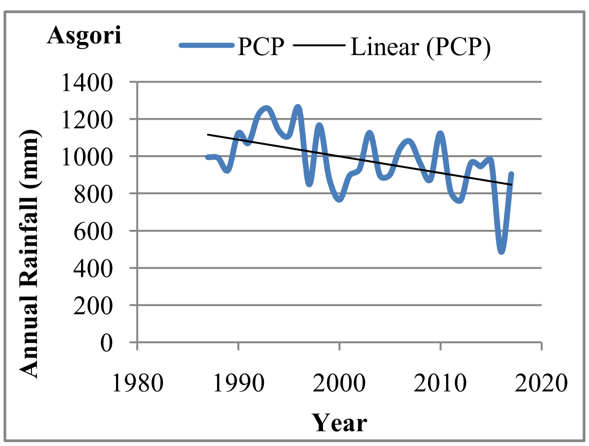
Appendix II: Trend Analysis Test

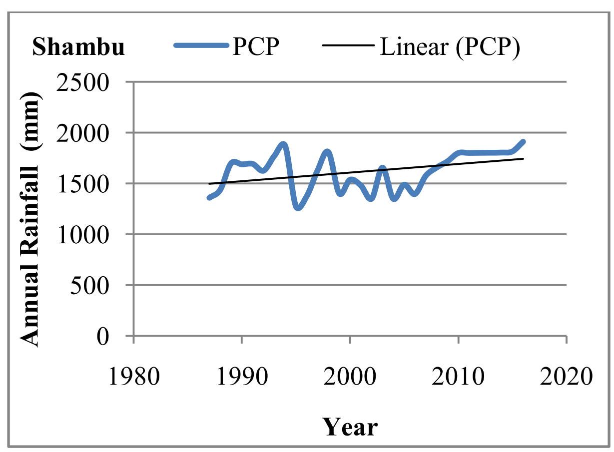
Appendix Table 2: Trend analysis of rainfall of Guder catchment.

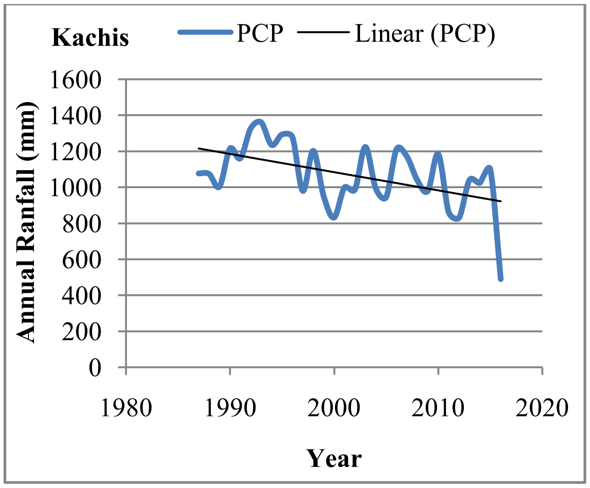
Name	Last Year	First Year	N	S	VAR	Z	Trend	Sen's Slope
Shambu	1988	2017	30	22	3802.67	0.34	Not Significant	1.300 ^{0}C/year
T.Inchini	1988	2017	30	17	3461.67	1.22	Not Significant	4.464 ^{0}C/year
Kachis	1988	2017	30	-53	3396.33	-0.89	Not Significant	-0.122 ^{0}C/year
Gedo	1988	2017	30	33	3141.67	0.57	Not Significant	0.000 ^{0}C/year
Asgori	1988	2017	30	-111	3461.67	-1.87	Not Significant	-7.346 ^{0}C/year

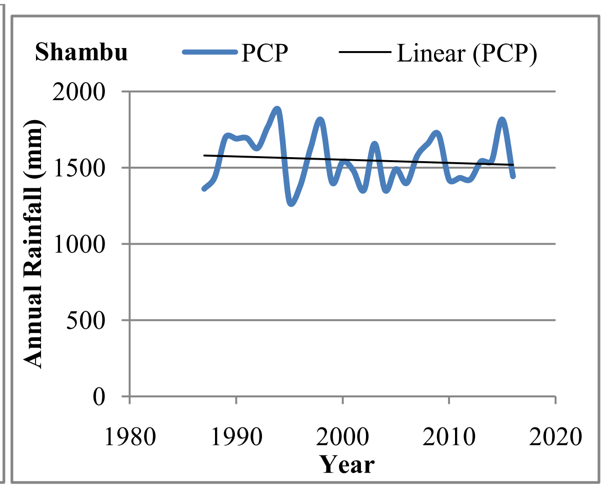
Note: (+) increasing trend; (-) decreasing trend, 0 – no change trend.

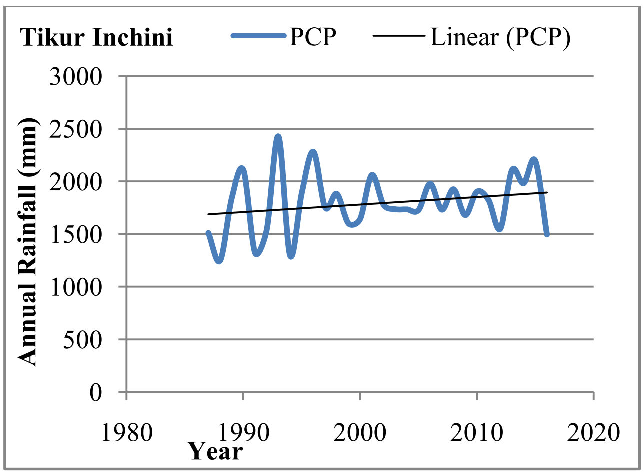
Appendix Figure 4: Trends of mean annual rainfall over Guder Catchment







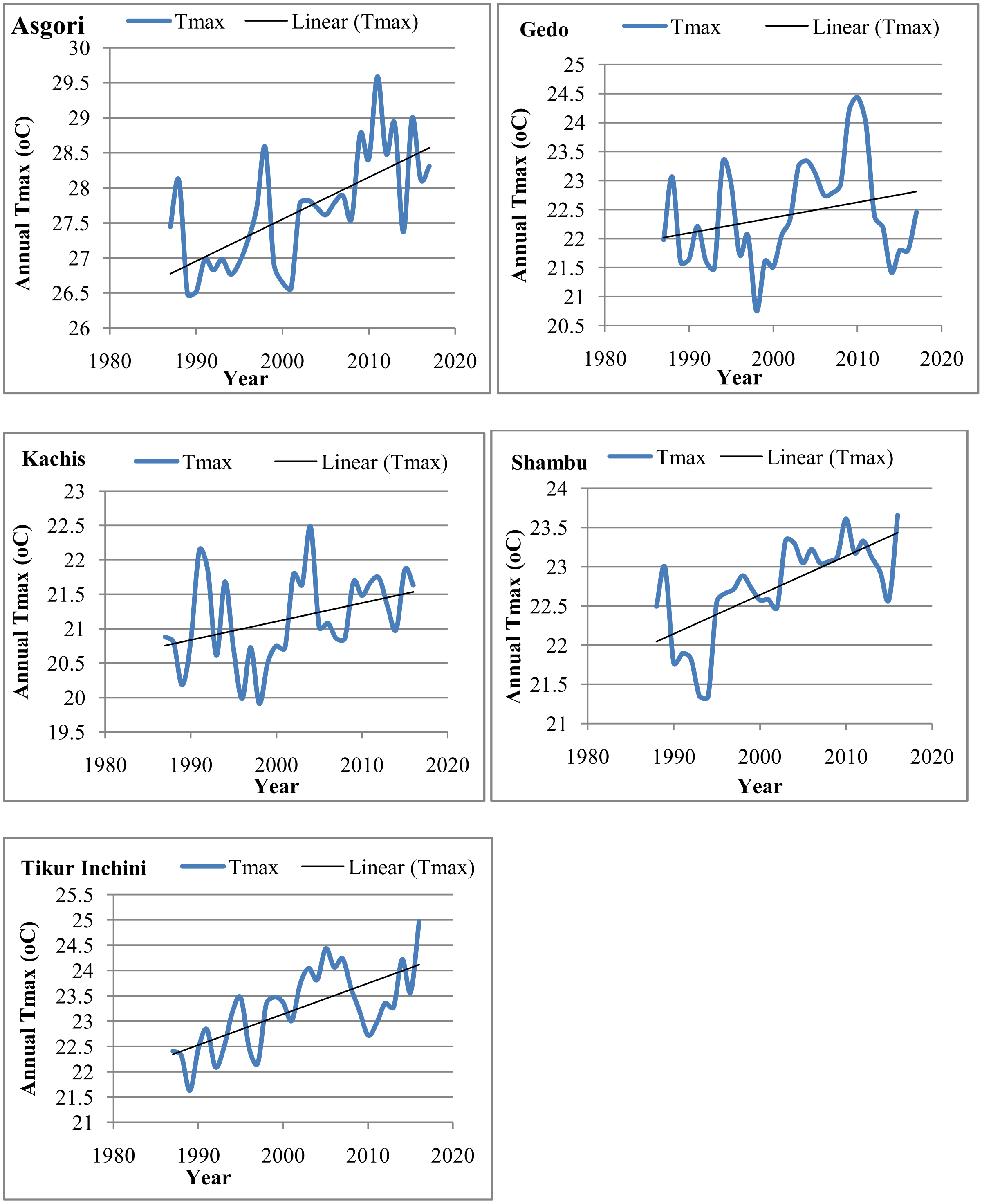




Appendix Table 3: Historical trend analysis of Maximum temperatures of Guder catchment

Name	Last Year	First Year	N	S	VAR	Z	Trend	Sen's Slope
Shambu	1988	2017	30	67	3141.67	1.18	Not Significant	0.051 ^{0}C/year
Kachis	1988	2017	30	83	3461.67	1.46	Not Significant	0.045 ^{0}C/year
Gedo	1988	2017	30	49	3141.67	0.86	Not Significant	0.021 ^{0}C/year
Inchini	1988	2017	30	57	3461.67	1.00	Not Significant	0.033 ^{0}C/year
Asgori	1988	2017	30	129	3461.67	2.28	Significant	0.048 ^{0}C/year

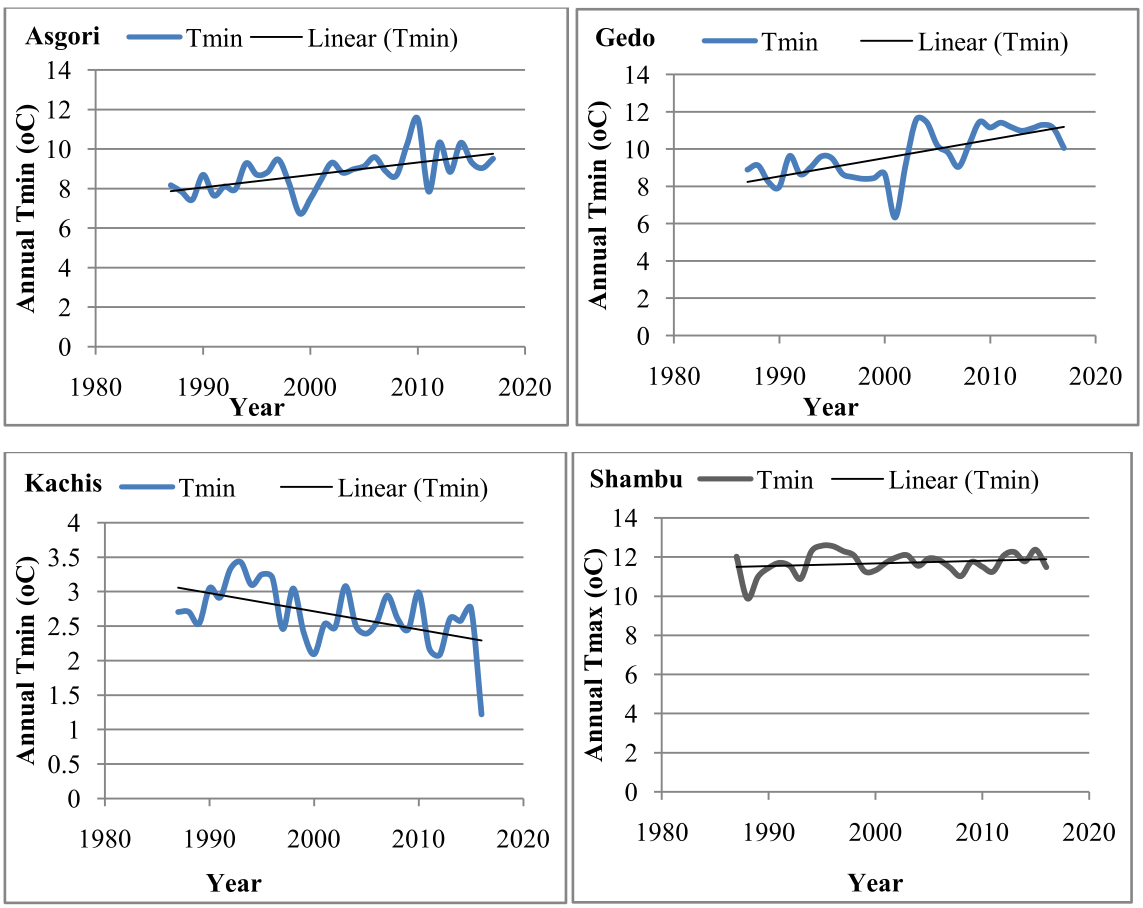
Appendix Figure 5: Trends of mean annual Tmax over Guder Catchment

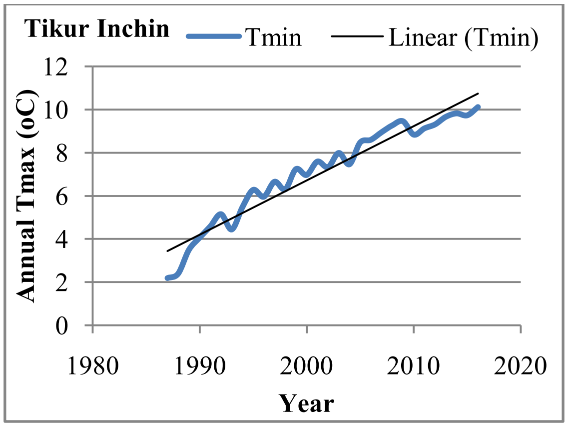


Appendix Table 4: Historical trend analysis of Maximum temperatures of Guder catchment

Name	Last Year	First Year	N	S	VAR	Z	Trend	Sen's Slope
Asgori	1988	2017	30	68	3802.67	1.09	Not Significant	0.001 ^{0}C/year
Kachis	1988	2017	30	115	3461.67	1.94	Not Significant	0.002 ^{0}C/year
Gedo	1988	2017	30	103	3141.67	1.82	Not Significant	0.035 ^{0}C/year
Shambu	1988	2017	30	-19	3141.67	-0.32	Not Significant	-0.043 ^{0}C/year
T. Inchini	1988	2017	30	209	3461.67	3.54	Significant	0.031 ^{0}C/year

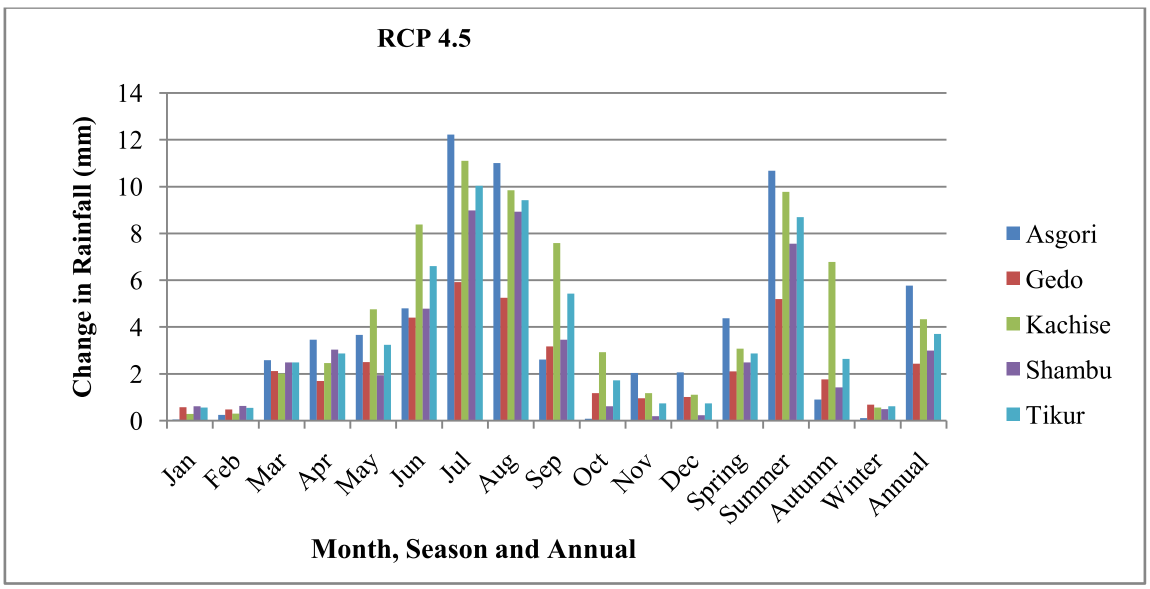
Appendix Figure 6: Trends of mean annual rainfall over Guder catchment



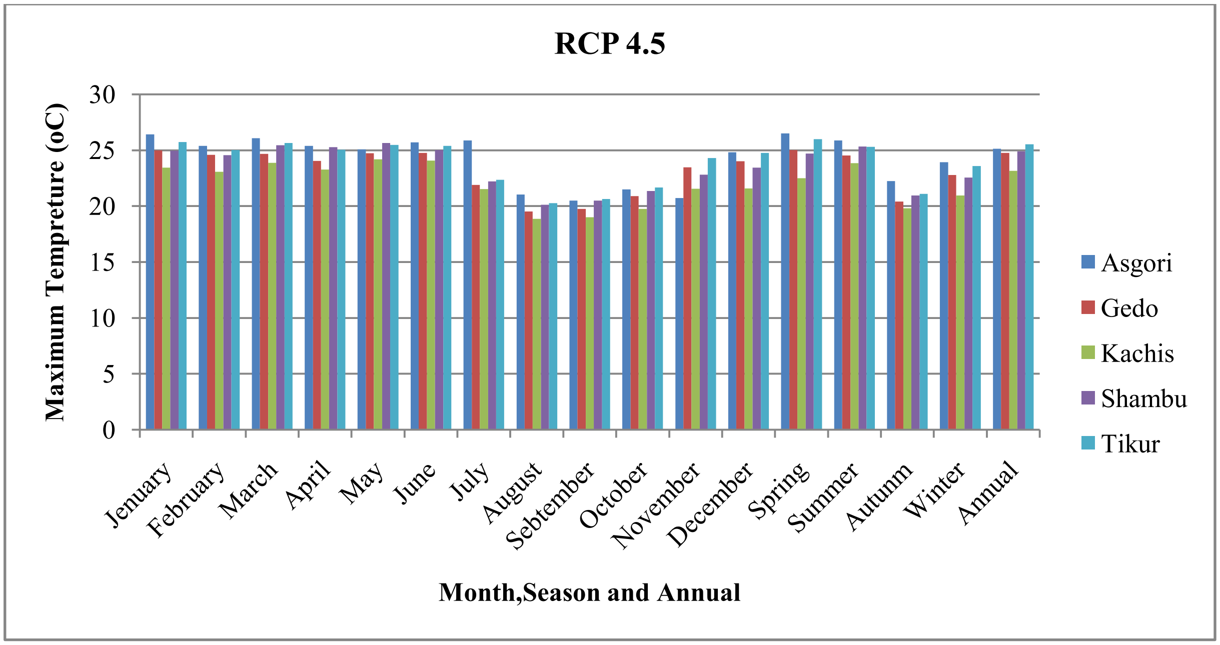


Appendix III: Climate Projection of Guder catchment station.

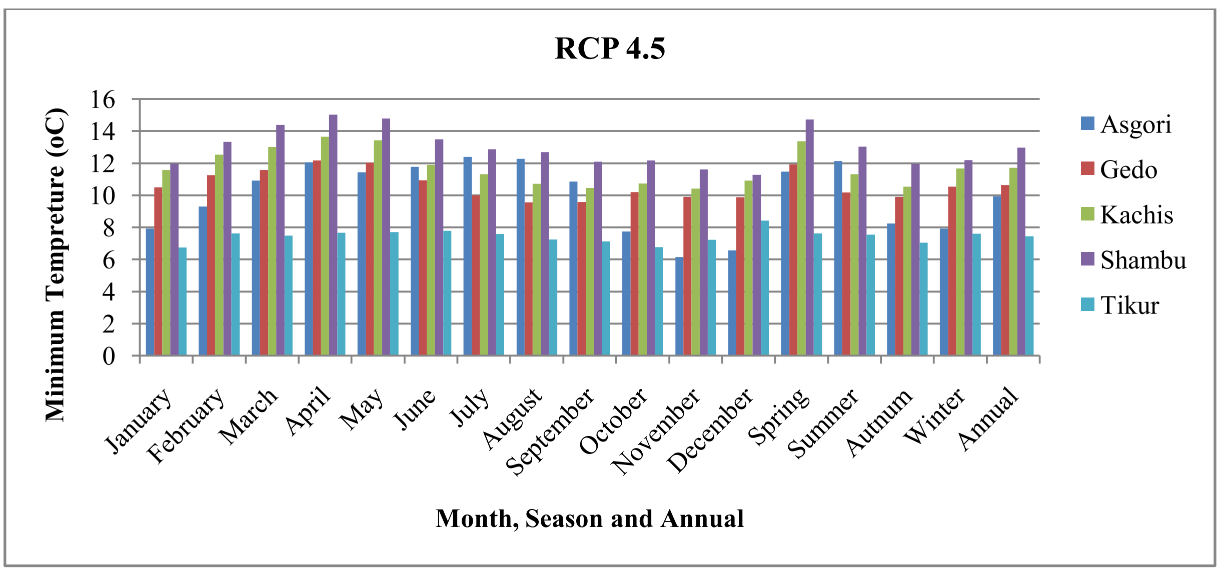
Appendix Figure 7: Projection of rainfall for all Guder station (2021-2040)



Appendix Figure 8: Projection of Maximum Temperature for all Guder station (2021-2040)



Appendix Figure 9: Projection of Minimum Temperature for all Guder station (2021-2040)



Appendix IV: Stream flow of study Area

Appendix Table 5: Mean Monthly stream flow of Guder catchment at near Guder station (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.69	1.29	1.78	1.25	2.20	17.14	47.13	53.65	44.81	10.61	1.35	0.76
1991	0.64	0.62	0.86	0.42	0.73	2.06	14.30	52.29	34.35	3.97	0.95	0.73
1992	0.87	1.16	0.81	0.61	2.04	13.72	48.47	56.76	40.74	10.03	2.18	1.12
1993	0.81	0.80	0.48	1.28	2.77	31.21	38.78	49.79	45.67	12.1	4.72	1.34
1994	0.87	0.62	0.81	0.63	1.19	5.94	38.04	41.55	32.15	3.91	1.32	0.81
1995	0.61	0.52	0.47	1.01	1.44	3.09	20.32	44.21	29.31	4.18	1.20	0.85
1996	0.92	0.54	2.44	2.16	6.73	29.46	39.47	45.81	26.49	9.73	2.03	1.07
1997	1.02	0.65	0.61	1.54	1.32	10.89	36.04	37.09	18.29	8.76	3.73	2.19
1998	1.34	0.76	1.29	0.62	0.97	6.97	32.69	45.44	33.39	22.55	3.11	1.06
1999	0.79	0.44	0.47	0.32	1.46	10.88	33.19	44.4	32.53	23.48	3.15	1.39
2000	0.96	0.67	0.55	1.42	2.09	9.58	21.44	41.19	46.16	21.51	6.02	2.19
2001	1.29	0.83	2.41	1.90	3.25	27.99	41.07	37.11	31.10	11.97	2.47	1.20
2002	0.89	0.74	1.08	1.10	2.18	14.08	34.25	45.77	34.58	11.91	2.69	1.23

Appendix Table 6: Observed and Simulated Mean Monthly stream flow of Guder catchment (m3/s)

Month	Flow (LULC & CC)	Flow (FLULC)	Flow (FCC)	Flow (FCC & FLULC)
Jan	0.89	0.93	0.79	0.82
Feb	0.75	0.75	0.72	0.72
Mar	1.09	1.00	1.15	1.13
Apr	1.10	0.92	1.24	1.22
May	2.19	1.96	2.50	2.42
Jun	14.08	12.39	17.6	16.28
Jul	34.25	29.52	45.78	41.6
Aug	45.7	38.73	63.4	57.59
Sep	34.59	29.65	45.26	42.5
Oct	11.91	10.76	11.31	11.46
Nov	2.69	2.55	2.21	2.59
Dec	1.23	1.25	0.97	1.01
JJAS	31.37	27.57	43.01	39.49
MAM	16.40	1.30	1.63	1.59
ONDJF	0.96	3.24	3.20	3.32
Annual	12.55	10.87	16.08	14.95

Appendex V: Land Use and Land Cover of the study area

Appendex Figure 10: Change in Land use and Land cover of Guder Watershed