IMPACT OF CLIMATE CHANGE ON WATER AVAILABILITY IN GIDABO WATERSHED, SOUTHERN ETHIOPIA

MSc THESIS

ADANE MEZEMIR MENIGISTU

HAWASSA UNIVERSITY
INSTITUTE OF TECHNOLOGY

HAWASSA, ETHIOPIA
February, 2020

IMPACT OF CLIMATE CHANGE ON WATER AVAILABILITY IN GIDABO WATERSHED, SOUTHERN ETHIOPIA

ADANE MEZEMIR MENIGISTU

MAJOR ADVISOR: MIHRET DANANTO (PhD)
CO-ADVISOR: MULUGETA DADI (PhD)

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING,

INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

IN
PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

HAWASSA, ETHIOPIA

FEBRUARY, 2020

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled "**Impact of Climate Change on Water Availability in Gidabo Watershed Southern Ethiopia** submitted in partial fulfillment of the requirements for degree of Masters with specialization in Hydraulic Engineering, the Graduate program of the school of civil Engineering, and has been carried out by **ADANE MEZEMIR MENIGISTU, Id No.PGHy /002/010** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the school.

Mihret Dananto (PhD)	______________________	_______________________
Name of the major advisor	signature	date
Mulugeta Dadi (PhD)	_______________________	_______________________
Name of the co-advisor	signature	date

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by **Adane Mezemir Menigistu** have read and evaluated his/her thesis entitled "**Impact of Climate Change on Water Availability in Gidabo Watershed, Southern Ethiopia** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters in "Hydraulics Engineering."

____________________	______________________	________________________
Name of the major advisor	signature	date
____________________	______________________	________________________
Name of the internal examiner-II	signature	date
____________________	______________________	________________________
Name of the internal examiner-I	signature	date
____________________	______________________	________________________
Name of the external examiner	signature	date
____________________	______________________	________________________
SGS approval	signature	date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the School Graduate Committee
(DGC/SGC) of the candidate's department.

Stamp of SGS Date: _____________

Remark

- Use this form to submit the theses with or without minor correction suggested the examining board
- 3 copies

DECLARATION

I hereby declare that all the corrections and recommendation suggested by the board of examiners are incorporated into the final thesis entitled **"Impact of Climate Change on Water Availability in Gidabo Watershed Southern Ethiopia ''** by **Adane Mezemir Menigistu**.

Adane Mezemir Menigistu	____________________	__________________________
Name of the designate	Signature	date

ACKNOWLEDGEMENTS

First of all my, credit goes to the Almighty of God because on his mercy and Jesus Christ his mother St. Marry all his Angels and Saints for his helpful gifts to me, nothing could be accomplished without his help, unconditionally. Grateful and special thanks to my advisors, **Dr. Mulugeta Dadi** for his supervision, inspiration, critical comments and helpful guidance. I also want to thank my co-advisor **Dr.Mihiret Dananto** for his comments and directions in all part of the thesis. I would like to express my sincere gratitude to ERA for providing me a chance to learn my MSc. Program.

I would like to express my whole hearted gratitude to my friend, Surafel A. For his continues support and pleasant concepts to my thesis work.

I am also thankful to the Ministry of Water, Irrigation and Energy of Ethiopia and the National Meteorological Agency of Ethiopia for providing me all the relevant data used as input for my research findings.

Finally, I must express my very profound gratitude to my family for providing me with honorable support and continuous encouragement throughout my years of study and through the process of researching and writing the thesis. This accomplishment would not have been possible without them.

ABSTRACT

Climate change significantly affects many hydrological systems, which in turn affects the water resource and the flow of rivers. The aim of this research was to investigate the impacts of future climate change on the water availability of the Gidabo watershed, which is one of the Ethiopian rift Valley sub-basins. Dynamic downscaling model was used as a representative concentration pathway (RCP) scenario for the daily precipitation, maximum and minimum temperature in the watershed. The large-scale climate variables for the RCP4.5 and RCP8.5 scenarios obtained from the Hadley Global environment model through CORDEX-Africa data outputs of HadGEM2-ES were selected under representative concentration pathway. The analysis was performed in two future projection of 2018- 2047's and 2048-2077's with baseline period of 1988-2017. Results showed that the average annual max/min temperature will increase by 1.23^{o}C/1.26^{o}C and 2.64^{o}C/3.27^{o}C (for 2018-2047) and by 2.57^{o}C/0.23^{o}C and 3.542^{o}C/2.3^{o}C (2048-2077) for RCP 4.5 and RCP 8.5 respectively. Average annual rainfall decreased 69.19mm and 72.3mm at RCP4.5 and RCP8.5 for (2018-2047) respectively and decreased 79.02mm and 85.12mm at RCP4.5 and RCP8.5 for (2048-2077) respectively. The SWAT hydrological model was used to simulate streamflow together with other water balance components after sensitivity analysis, calibration and validation of the model. The results indicated that water yield decrease by 21.8% and 23.9% of the rainfall in the case of RCP 4.5 and RCP 8.5 respectively. On the other hand, the trend test result on gaged data showed the presence of a no statistically significant trend in the precipitation and significant trend in the minimum temperature at most of the stations.

Keywords*: Climate change, RCP, SWAT, XLSTAT, Gidabo watershed*

Table of Contents

LIST OF FIGURE

LIST OF TABLE

LIST OF ABRREVATION and ACRONYMS

95PPU	95 Percent Prediction Uncertainties
AR4	Fourth Assessment report
AR5	Fifth Assessment Report
ARC SWAT	SWAT Integrated with Arc GIS
CMIP5	Coupled Model Inter comparison Project phase five
CORDEX	Coordinated Regional Climate down scaling Experiment
CV	Coefficient of Variation
DEM	Digital Elevation Model
DDSM	Dynamic Dawn Scaling Model
FAO	Food and Agricultural Organization
GCMs	Global circulation Models
GHGs	Green House Gases
GP	Grid Point
Hadcm3	Hadley Centre Global Circulation Model Third Generation
HadGEM2-ES	Hadley Global Environment Model 2 - Earth System
HEC-GeoHMS	Hydrologic Engineering Center Geospatial Hydrologic Model Extension
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
IPCC	Intergovernmental panel on climate change
ITCZ	Inter-Tropical Convergence Zone
IWMI	International Water Management Institute
MAE	Mean Absolute Error
GPS	Global Positioning System
HRU	Hydrological Response Unit
IHDM	Institute of Hydrology Distributed Model
IPCC	Intergovernmental Panel on Climate Change
MoWIE	Ministry of Water, Irrigation and Energy
NSE	Nash and Sutcliffe Efficiency
NMA	National Metrology Agency
SWWDSE	South Water Works Design and Supervision Enterprise
PET	Potential Evapotranspiration
RCM	Regional climate modeling
RCP	Representative Concentration Pathways

RMSE	Root Mean Square Error
USACE	United State Army Corps of Engineers
MWIE	Ministry of water, Irrigation and Energy
NMA	National Metrological Agency
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent Bias
Q_{base}	Base Flow
Q_{lat}	Lateral Flow
Q_{surf}	Surface Runoff
RMSE	Root Mean Square
SCS	Soil Conservation Service
SDSM	Statistical Downscaling Model
SHE	System Hydrologique European
SIMHYD	Simplified Hydrology Model
SNNPRS	Southern Nation Nationality and People Regional State
SRTM	Shuttle Radar Topographic Mission
SUFI-2	Sequential Uncertainty Fitting Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic

1. INTRODUCTION

1.1 Background

Water is not only influenced by human activities, but also by natural factors, such as climate change. Hence, the impact of climate change on water resources is the most crucial research agenda in the worldwide. Today this change affects certain components of the hydrological cycle, especially precipitation and temperature; this varies the spatial and temporal availability of water resources (IPCC, 2007).

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and the variability of its properties and that persists for an extended period, typically decade or more. Climate change may take place due to internal process and/or external forcing. Some external influences, such as changes in solar radiation and volcanism, occur naturally and contribute to the natural variability of climate system. Other external changes, such as the change in the composition of the atmosphere that began with the industrial revolution which are the result of human activity (IPCC, 2007a).

Today, environmental issues have become the biggest concern of mankind. One of these is the changing climate of the earth over the last half century and, most likely, more so, in the near future, as a consequence of increasing concentrations of greenhouse gases in the atmosphere. In fact, there is undisputed evidence that global temperatures have increased and may do so even more in the future, leading to significant impacts on the hydrological cycle, namely, by altering the amounts and the distribution of rainfall on regional scales (Cubasch et al., 2001).

There is strong scientific evidence that indicates the average temperature of the Earth's surface is increasing due to greenhouse gas emissions. The IPCC (Intergovernmental Panel on Climate Change) scenarios project temperature rises of 1.4-5.8ºC, and sea level rises of 9-99 cm by 2100 (Houghton, 2001). As for the continent Africa, warming is likely to be larger than the global annual average (Christensen et al., 2007).

Climate change will significantly impact water resources. There is a need to plan how to adapt to these changes, and how to mitigate the changes for water resources. In sub-Saharan Africa, there are many vulnerable river basins. These basins are vulnerable both in terms of the climate system that is highly variable and the potential future changes in climate, but also in terms of management as weak governance and high levels of poverty in the population restrict actions to adapt to climate change. (IPCC, 2007).

Developing countries, such as Ethiopia will be more vulnerable to climate change as stated by the IPCC (2007) report due to less flexibility to adjust the economic structure and being largely dependent on agriculture, the impact of climate change has far reach implication in Ethiopia. Mainly, under the prevalent rain fed agricultural production system the progressive degradation of the natural resource base especially in highly vulnerable areas of the highlands and lowlands coupled with climate variability as worse the incidence of poverty and food insecurity.

Changes in temperature and precipitation patterns as consequence of the increase in concentrations of greenhouse gases may affect the hydrological processes, availability of water resources, and water use for agriculture, population and mining industry, aquatic life in rivers and lakes, and hydro power. Increased evaporation, because of higher temperature, together with changes in precipitation patterns may alter the timing and magnitude of river flows (Kinfe, 2017). Although climate change is expected to have overall adverse impacts on socio-economic development globally, the degree of the impact will vary across continents and nations. The IPCC findings indicate that developing countries, such as Ethiopia, will be more vulnerable to climate change (NMSA, 2007).

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

In Gidabo watershed, the land and water resources of the watershed are in danger due to the rapid growth of population, deforestation, overgrazing, soil erosion, soil storage capacity reduction, drainage, water logging, and the shortage of rain. There is a need for climate change impact study on water availability research that can improve the watershed management programs.

1.2 Problem of Statement

Water shortage is one of several current and future critical problem facing Africa. About 25% of the contemporary African population experience water stress, while 69% live under conditions of relative water abundance (Vörösmarty et al., 2005).

climate change in Ethiopia will bring changes in precipitation patterns, rainfall variability, and temperature, which could increase the frequency and occurrence of floods and droughts through these the availability of clean drinking water is likely to decrease due to increasing evaporation and the increasing variability of rainfall events (Adem & Bewket, 2011).

One of the greatest important consequences of climate change is changes in major climate variables, such as precipitation, temperature, and Evapo-transpiration. This, in turn, leads to changes in the hydrological cycle, influencing the components of water balance of drainage basins in several ways such as runoff, the availability and distribution of water resources in space and time (Amba, 2016).

The potential impacts of climate change on runoff have received considerable attention from hydrologists during the last several years. Changes in the ramparted of runoff may be one of the most significant consequences of climate change. Moreover, the water yield is getting reduced in the study area-surrounding the watershed (Tatek, 2013).Therefore assessment of impact of climate change on water availability is essential for future development as well as for managing the current water resource in the surrounding area. Accordingly, a number of studies were conducted on the Gidabo watershed. However, a few studies investigated the impact of climate change on Gidabo watershed. There is no sufficient literature published related to impacts of climate change on water availability. Therefore, assessing of the significance of climatic change impacts on water availability of the water shed at catchment scale is crucial for the water resource developments and societies

1.3 Objectives of the Study

General

The main objective of this study was to investigate impact of climate change on water availability of the Gidabo watershed.

The specific objectives includes:

- To develop historical and future climate change projections of Gidabo Watershed by using bias corrected RCP 4.5 and RCP 8.5 scenarios
- To determine the change of water availability under the different scenario by using SWAT model
- To test the statistical trends in the observed meteorological data

1.4 Research Questions

- ❖ What will be the impact of climate change on the watershed future climate pattern?
- ❖ Does the water yield has a significant change at the future projection?
- ❖ What would be trend of the observed meteorological data?

1.5 Scope of the Study

Results of this study would contribute to water resources management efforts in the Gidabo catchment. Application of up to date climate change scenarios will help to gaining new insight about water resources problems and devising a compatible solution. It is not possible to cover the whole aspects of the study area with seated objective due to time and resource constraints. So it is better to limit the scope of the problem to a manageable objective.

Hence, this study focuses on the impact of climate change on water availability (catchments yield) in the catchment and do not include ground water aspect for the water availability. The study utilizes time series new plausible climate scenario outputs of enhanced greenhouse gases for medium and high emission scenarios (RCP 4.5 and 8.5) which are used as inputs for hydrological model (SWAT) for estimating the runoff depth and peak discharge on the catchments. The study assess the impact of climate change on these global scenarios as inputs for hydrological model assumes the land use land cover will remain the same, however in real world land use/ land cover are always changing and hence it affects the hydrology in addition to emission of greenhouse gases on catchment yield.

1.6 Significance of the study

Water resource is seriously affected by many factors such as climatological, environmental, and social factors. Hence, effective use of available water depends on the understanding and mitigating of these factors. The main significance of study are:

- It allows the planners, decision makers and concerned person to integrate their duties with climate change.
- It can be used as decision support system for development of different water resource projects.
- The result can further be used for selecting the probable adaptation measure for the climate change effects of different water resource projects within and around watershed.

2. LITERATURE REVIEW

2.1 Climate

"Climate" refers to the average weather in terms of the mean and its variability over a certain time-span in a certain area. Classical climatology provides classifications and descriptions of the various climate regimes found on earth. Climate varies from place to place, depending on latitude, distance from the sea, vegetation, presence, or absence of mountains and other geographical factors. Climate also varies with time; from season to season, year-to-year, decade to decade or on much longer time-scales, such as the Ice ages. Statistically, significant variations of the mean state of the climate or of its variability are referred to as climate change (IPCC 2001). In order to understand the environment and the possible impact of human activity on it a basic knowledge of weather and climate is required. The former is the physical condition of the atmosphere at a specific time and place with regard to wind, temperature, cloud cover, fog, and precipitation. Weather is highly variable and somewhat unpredictable. As a result, a longer-term view of the weather pattern of a particular locality is frequently more useful as an environmental tool (Andrew et al, 1996)

2.2 Global Climate Change

Global climate change is warming of the climate system in recent decades is obvious, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level (IPCC, 2008). The global average temperature showed a 100 years linear trend of increasing by 0.74 $^{\mathbf{o}}$C from 1996-2005 (IPCC, 2007).Climate change is facing the entire world nowadays. It is now widely accepted that climate change is by now happening and further change is unavoidable; the global average combined land and ocean surface temperature data calculated shows a warming of 0.85 ^{0}C over the period 1880 to 2012 (IPCC, 2014).

The earth's climate is governed by the interaction between many processes in the atmosphere, ocean, land surface and yell sphere. The interactions are complex and extensive so that quantitative predictions of the impact on the climate of greenhouse gas increase cannot be made through simple intuitive reasoning. For this reason, computer models have been developed which attempt to mathematically simulate the climate system, including the interaction between the system components (Coulibaly *et.al.* 2004)

2.3 Climate Change in Ethiopia

The IPCC finding indicates that developing countries, such as Ethiopia will be more vulnerable to climate change. Because of the less flexibility to adjust the economic structure and being largely dependent on agriculture, the impact of climate change has far reach implication in Ethiopia. Mainly, under the prevalent rain fed agricultural production system the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands and lowlands coupled with climate variability have aggravated the incidence of poverty and food insecurity. Climate change is already taking place now, thus past and present changes help to indicate possible future changes. Over the last decades, the average annual temperature in Ethiopia has been increasing by 0.37 C^0 every ten years, which is slightly lower than the average global temperature rise (Emerita, 2013).

According to Emerta (2013), the greater part of the temperature rise was observed during the second half of the 1990's and temperature rise is more pronounced in the dry and hot spots of the country, which are located in the northern, northeastern, and eastern parts of the country. The lowland areas are the most affected, as these areas are largely dry and exposed to flooding during extreme precipitation in the highlands.

Precipitation, on the other hand, remained fairly stable over the last 50 years when averaged over the country. However, the spatial and temporal variability of precipitation is high, thus large-scale trends do not necessarily reflect local conditions (NMSA, 2007).

Future temperature projections of the IPCC mid-range scenario shows that the mean annual temperature will increase in the range of 0.9ºC to 1.1ºC by 2030, in the range of 1.7ºC to 2.1ºC by 2050, and in the range of 2.7ºC to 3.4ºC by 2080 in Ethiopia compared to the 1961 to 1990 (Emerta, 2013)

However the country has both dry and wet periods over the past four decades, precipitation has a general decreasing trend since the 1990's (Abayneh, 2011). The average change in annual rainfall is projected to be in the range of 1.4 to 4.5 percent, 3.1 to 8.4 percent, and 5.1 to 13.8 percent over 20, 30, and 50 years, respectively, compared to the 1961 to 1990 period of time.

According to Abayneh (2011).The trend analysis of rainfall shows that rainfall remained more or less constant when averaged over the whole country. Studies conducted on Rift valley sub basin and Bilate River basins indicates that the basins are climate sensitive. Since the catchment under consideration is found in the Gidabo sub basin, climate change should be considered to evaluate the present and future condition of the main water resources. Precipitation variability, climatically rainfall variability and intensity in the catchment follows a humid to semi- arid tropical bimodal distributed precipitation pattern. In sub basin at two rainfall pattern exist in the area, uni modal in the northern and north western part which receives relatively higher precipitation amount (1307mm) and that of bimodal rainfall pattern in the Southern and South Eastern receives relative precipitation amount of 989.85mm (Birhanu ,2009).

2.5 Modeling Climate Change

Climate Models are the primary available tools for investigating the response of climate system for increasing greenhouse gas concentrations in the atmosphere with Global Circulation Models (GCMs) and attempt to project average temperature, precipitation and cloud cover over future decades or centuries (Goddess *et al*., 2007). Because of accepted physical principles inherent these models and their ability to reproduce present and past observed climate changes, there is considerable confidence that climate models provide plausible quantitative estimation of major features of climate change at present day (Randall *et al*., 2007).

2.6 General Circulation Model (GCM)

The general circulation climate model is a mathematical description of the Earth's climate system, broken into a number of grid boxes and levels in the atmosphere, ocean and land. The relative performance of GCMs can depend on the size of the region (i.e. small regions at sub grid scale are less likely to be well described than large regions at continental scale), on its location (i.e. the level of agreement between GCM outputs varies a lot from region to region) and on the variables being analyzed (for instance, regional precipitation is more variable and more difficult to model than regional temperature) (Carter, 2007).

2.7 Climate Change Scenario

The Climate scenarios are acceptable representations of future climate conditions (temperature, precipitation and other climatological phenomena) based on assumptions including future trends in energy demand, emissions of greenhouse gases, land use change as well as assumption about the behavior of the climate system over long time scales. It is largely the uncertainty surrounding this assumption which determines the range of possible scenarios (Carter, 2007).

When applied in climate change research, scenarios help to evaluate uncertainty about human contributions to climate change, the response of the Earth system to human activities, the impacts of a range of future climates, and the implications of different approaches to mitigation (measures to reduce net emissions) and adaptation (actions that facilitate response to new climate conditions).Emissions scenarios are descriptions of potential future discharges to the atmosphere of substances that affect the Earth‘s radiation balance, such as greenhouse gases and aerosols (Bjornaes, 2015).

2.7.1 Criteria for Selecting Climate Scenarios

Five criteria that should be met by climate scenarios if they are to be useful for impact researchers and policy makers are suggested in Smith and Hulme (1998):

- Criterion 1: Consistency with global projections. They should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases. This range is variously cited as 1.4°C to 5.8°C by 2100 (IPCC, 2001a), or 1.5°C to 4.5°C for a doubling of atmospheric CO_2 concentration (IPCC, 2001a).
- Criterion 2: Physical plausibility. They should be physically plausible; that is, they should not violate the basic laws of physics. Hence, changes in one region should be physically consistent with those in another region and globally. In addition, the combination of changes in different variables (which are often correlated with each other) should be physically consistent.
- Criterion 3: Applicability in impact assessments. They should describe changes in a sufficient number of variables on a spatial and temporal scale that allows for impact assessment. For example, impact models may require input data on variables such as precipitation, solar radiation, temperature, humidity and wind speed at spatial scales ranging from global to site and at temporal scales ranging from annual means to daily or hourly values.
- Criterion 4: Representative. They should be representative of the potential range of future regional climate change. Only in this way can a realistic range of possible impacts be estimated.

- Criterion 5: Accessibility. They should be straightforward to obtain, interpret and apply for impact assessment. Many impact assessment projects include a separate scenario development component which specifically aims to address this last point. Various types of climate scenarios are used in impact assessment. The most common scenario type applied is based on the outputs from the climate models. The other types have been applied with reference to or in conjunction, with model-based scenarios, namely: incremental scenario for sensitivity studies and analogue scenarios.
- I. Incremental scenario: Incremental scenario refers to arbitrary amount changes of a particular climate element. They are used to evaluate system sensitivity before the application of a more credible model based scenario. According to Carter (2007), adjustments of baseline temperature by +1, +2, +3, +4ºC and precipitation by ±5%, ±10%, ±15%, ±20 % could represent various magnitude of future change. However, such scenarios do not necessarily present a set of changes that are physically realistic; they provide information on an ordered range of climate changes for direct inter comparison of results.
- II. Analogue scenario: Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. Both temporal and spatial analogues have been used in constructing climate scenarios. Temporal analogues make use of climatic information from the past as analogue of possible future climate. Spatial analogues are regions which today have a climate analogues to that anticipated in the study region in the future. Since the causes of the analogue climate are most likely due to changes in the atmospheric circulation, rather than to greenhouse gas induced climate change, these types of scenarios are not ordinarily recommended to represent the future climate in quantitative impact assessments.
- III .Scenarios based on outputs from climate models: Climate models at different spatial scales and levels of complexity provide the major source of information for constructing scenarios. GCMs and a hierarchy of simple models produce information at the global scale. The most common method of developing climate scenarios for quantitative impact assessments is to use results from GCM experiments. GCMs are the most advanced tools currently available for simulating the response of the global climate system to changing atmospheric composition.

2.8 Representative Concentration Pathways (RCP's) scenarios

In climate research, different types of emission scenarios are used to assess the long-term impact of atmospheric greenhouse gases and pollutants based on assumptions of population growth, economic development level, etc. Scenarios previously approved by the IPCC include SA90 (IPCC, 1990), IS92 (Leggett *et al*., 1992) and SRES (Nakic´enovic´ *et al.*, 2000).

The latest scenarios developed by the research community are denoted by Representative Concentration Pathways (RCPs); (Van Vuuren *et al*., 2011). There are four RCPs defined by their level of the total radiative forcing pathway in the year 2100, and are representative for the existing literature about emission scenarios. Each RCP was developed by a different modelling group. Since the RCPs had been developed with different, independent models, they are not directly comparable. The definition of the RCPs allows for a parallel development of new socioeconomic, technical and policy scenarios that provide insights into the impact of policy decisions on the future climate (Van Vuuren *et al*., 2011).

Table 2.1 Overview of scenarios (Yitea Seneshaw, 2014).

RCP	Radiative forcing	CO_2 in 2100	Comparable SRES withmedian temperature increase by 2100	Particular difference for comparable SRES and RCP
RCP2.6	Peak at ~ 3W/m² before2100 & decline & ΔT (K) is 1.5	400 ppm	None	
RCP 4.5	Stabilizing without over shoot, to 4.5 W/m² & ΔT(K) is 2.4	500 ppm	SRES B1	Median temperatures in RCP4.5 rise faster than in SRES B1until mid-century.

RCP 6	Stabilizing, without over shoot, to 6W/m²at stabilization after 2100 & ΔT(K) is 2.9	600 ppm	SRES B2	Median temperatures in RCP6 rise faster than in SRES B2 during the three decades between 2060 and 2080.
RCP8.5	Rising, leading to 8.5 W/m² in 100 & ΔT(K) is 4.6	950 ppm	SRES A1FI	Median temperatures in RCP8.5 rise slower than in SRES A1FI during the period between 2035 and 2080.

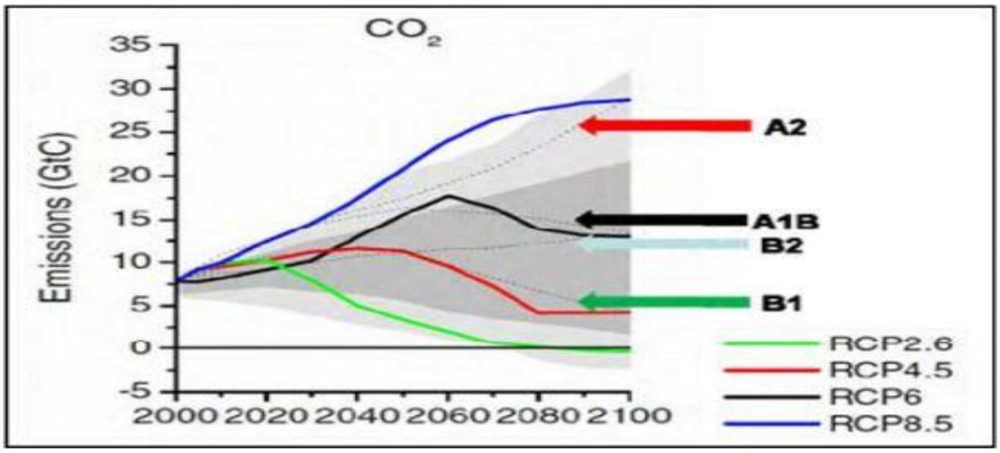


Figure 2.1 Comparison of the SRES and RCP scenarios (Van Vuuren et al., 2011).

A key difference between the new RCPs and the previous scenarios is that there are no fixed sets of assumptions related to population growth, economic development, or technology associated with any RCP. Another key difference is that the RCPs are spatially explicit and provide information a global grid at a resolution of approximately 60 kilometers. This gives the spatial and temporal information about the location of various emissions and land use changes. This is an important improvement as the location of some emissions affects their warming potential.

Developing counters like Ethiopia was under middle/ intermediate emissions scenarios. Hence, for this study the intermediate emission scenarios RCP 4.5 and high emission RCP 8.5 were selected to analyze how driving forces may influence future emission outcomes and to evaluate the associated impacts of future climate change

2.9 Downscaling Method and Tools

Downscaling is the term used to describe the various methods used to translate the climate projections from coarse resolution GCMs to finer resolutions deemed more useful for assessing impacts. Projections of future climate are produced using complex, coupled atmosphere-ocean models (GCMs). The GCMs are most reliable at the continental scale. Due to the inherent uncertainty of the climate system and the inevitable existence of model errors, multi-model ensemble is the recommended approach for characterizing expected climate changes. Due to the inherent uncertainty of the climate system and the inevitable existence of model errors, multi-model ensemble is the recommended approach for characterizing expected climate changes. As downscaling is dependent on the ability of GCMs to successfully project the climate change signal, it is limited to where that signal is clear. Selections of GCMs that "do better" over Africa, or any region, is difficult and probably no warranted, given the general parity in model skill and the difficulty in identifying which models are more skillful. Ensemble means or medians offer the highest level of projection accuracy The complete modeling chain for future hydrological projections includes the employment of three kinds of models: GCMs, downscaling models (Stastical downscaling or Dynamic downscaling) and hydrological models (Figure 2.2). Downscaling approaches are generally categorized as dynamical, using regional climate models, and statistical, using empirical relationships. However, dynamical downscaling often includes statistical modeling in the form of bias correction.

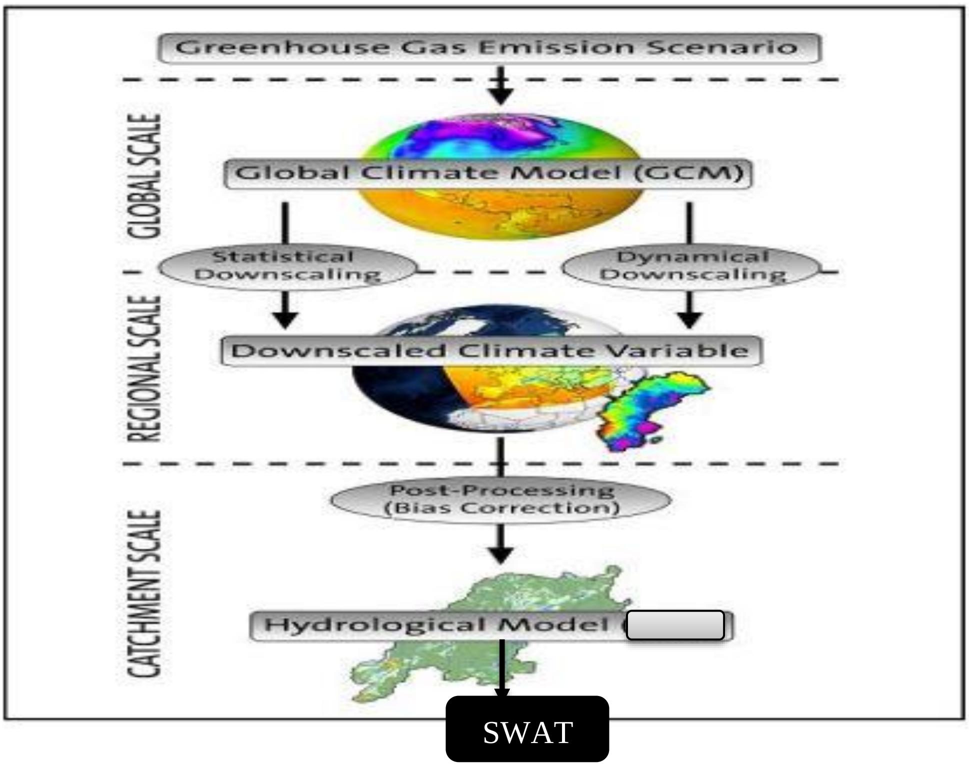


Figure 2.2 climate change transfer from global to catchment scale (Teutschbein, 2013).

2.9.1 Dynamic down Scaling

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 (Giorgi & Mearns, 1991). Thus, this method is also called ‘nested’ RCM approach, which was first applied in climate change studies in the late 1980s by (Dickinson *et al*., 1989). RCMs, also referred to as Limited-Area Models (LAMs), produce highly resolved spatial and temporal climate information (Mearns *et a*l., 2003). Dynamical downscaling seeks to couple large scale climate dynamics and local climate and hydrological features. It does so by utilizing higher resolution regional climate models (RCMs) that respond to the output of GCMs.

The GCM output is provided as boundary conditions, which are the values at the edges of the spatial domain of the RCM. RCMs are used for downscaling seasonal climate forecasts and for diagnostic studies of regional climate in addition to their use with climate change projections. The main drawbacks are the requirement of powerful computing capacities and the dependency on initial and boundary conditions. There is also still a lack of readily available climate scenario ensembles for most regions in the world, although the number of publically available ensemble archives from European projects on similar grid size is increasing, e.g., CORDEX (Evans, 2011)

2.9.2 Statistical Downscaling

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. 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).

Statistical downscaling involves the establishment of empirical relationships between historical and/or current large-scale atmospheric and local climate variables. Once a relationship has been determined and validated, future atmospheric variables that GCMs project are used to predict future local climate variables. Statistical downscaling can produce site-specific climate projections, which RCMs cannot provide since they are computationally limited to a 20–50 kilometers spatial resolution.

Table 2.2 Merit, Dimerits of DDS and SDS. Source (Sylwia & Emilie, 2014)

	Dynamical downscaling	Statistical downscaling
Merit	• Based on consistent physical mechanism • Resolves atmospheric and surface processes occurring at sub-GCM grid scale • Not constrained by historical record so that novel scenarios can be simulated • Experiments involving an ensemble RCMs becoming available for uncertainty analysis.	• Methods range from simple to elaborate and are flexible enough to tailor for specific purposes • Relies on the observed climate as a basis for driving future projections • Can provide point-scale climatic variables for GCM scale output • Tools are freely available and easy to implement and interpret; some methods can capture extreme events
Demerits	• Computationally intensive • Due to computational demands, RCMs are typically driven by only one or two GMC/emission scenario simulations • May require further downscaling	• High quality observed data may be unavailable for many areas or variables • Assumes that relationships between large and local-scale processes

2.9.3 Coordinated Regional Climate Downscaling Experiment (CORDEX)

The Coordinated Regional Downscaling Experiment (CORDEX) is an international programmer sponsored by the World Climate Research Program (WCRP) to develop a coordinated ensemble of high-resolution, regional climate projections for the majority of land regions of the world. CORDEX involves more than 20 regional climate modeling and statistical downscaling groups.

The goal of the initiative is to provide regionally downscaled climate projections for most land regions of the globe, as a compliment to the global climate model projections performed within the fifth Coupled Model Inter comparison Project (CMIP5). CORDEX includes data from both dynamical and statistical downscaling. It is anticipated that the CORDEX dataset will provide a link to the impacts and adaptation community through its better resolution and regional focus. Participation in CORDEX is open and any researchers performing climate downscaling are encouraged to engage with the initiative (Evans, 2011).

The first part of this framework is a set of common regional domains. These domains are shown in Figure 2.3. The Rossby Centre, with extensive experience in climate model development and application, is producing future climate projections for a number of the regional CORDEX domains, e.g. Africa, Europe, South Asia, the Middle East and the Arctic. CORDEX results will serve as input for climate change impact and adaptation studies within the timeline of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and beyond. To develop an inter-comparable downscaling protocol with newly developed future scenarios, (CORDEX) project has launched to provide unified framework for the downscaling researches (Giorgi *et al.*, 2009).

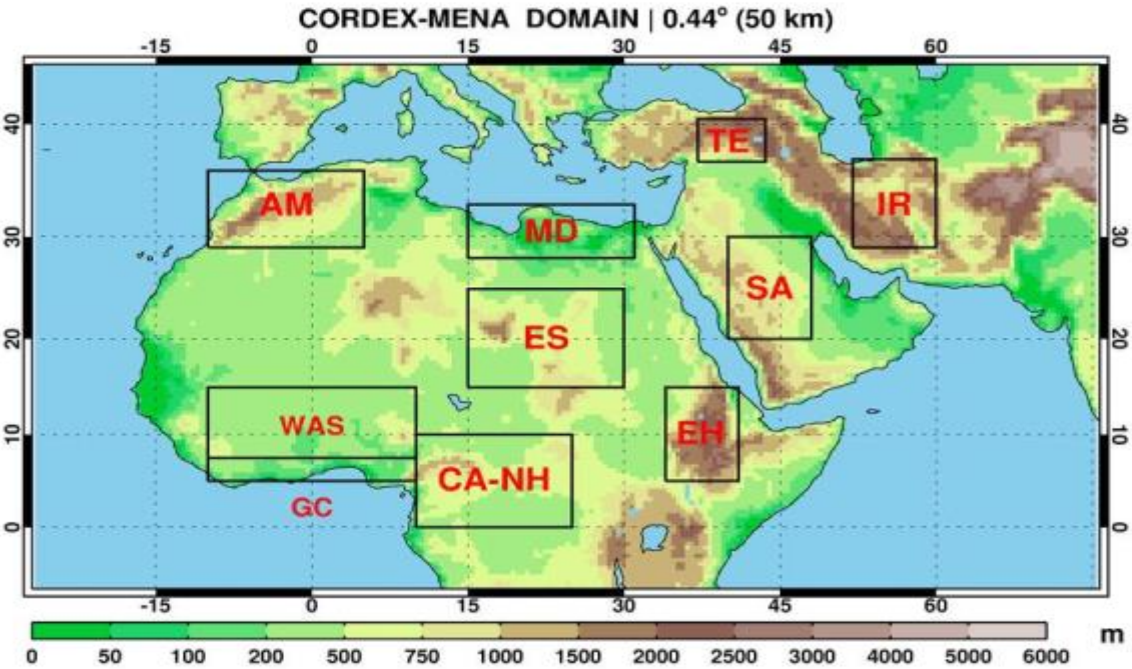


Figure 2.3: CORDEX-MENA and sub-regions at 50 km resolution (Grigory, 2013)

2.10 Hydrologic Modeling

Hydrological models are mathematical formulations which determine the runoff signal which leaves a watershed basin from the rainfall signal received by this basin. They are primarily used for hydrologic prediction and understanding of hydrologic processes. Changes in global climate are believed to have significant impacts on local hydrological regimes. In addition to the possible changes in total volume of flow, there may also be significant changes in frequency and severity of floods and droughts. Hence hydrological models provide a framework to conceptualize and investigate the relationship between climate and water resource (Abdo, 2008).

Hydrologic models are broadly classified as physical model which describe the system as on a reduced scale and mathematical model in which the system operation links input and output variables with a set of equation (Chow *et al.*, 1988).Additionally, hydrological models are classified as deterministic and stochastic hydrological models. The deterministic hydrological model is the most common model approach in hydrology which can be further classified as lumped, distributed and semi-distributed (Chow *et al.*, 1988).

Lumped hydrological models; Parameters of lumped hydrologic models do not vary spatially with in the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. Hence, do not represent physical features of hydrologic processes and usually involve certain degree of observation. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan *et al*., 1998). Example of such models include: HBV, IHAC-RES, SRM, and WATBAL etc.

Distributed hydrological models: Such models require input data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior so as to model the physical process in detail for highest degree of accuracy in the output. Example of such type of models includes: MIKE-SHE, VIC etc.

Semi-distributed hydrological models: These models are simplified form of distributed models where parameters are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. Sub division of sub-catchments in to a number of different homogeneous zones can be accomplished based on various catchments characteristics (topographic elevation, soil type and land use). Examples of such type of models are SWAT, HEC-HMS etc.

2.10.1 Hydrologic Model Selection

The choice of a (deterministic) hydrologic model is generally dependent on the hydrologic components to be incorporated into the water balance system. There are a number of physically based semi-distributed hydrological models, one where SWAT is the most promising and computationally efficient model to operate on large basins in a reasonable time [Arnold and Allen, 1996; Neitsch *et al.,* 2005].

Moreover, SWAT is used in this study for a couple of reasons:

- A physical based model: It is based on readily observed and measure information and it attempts to simulate many hydrological components.
- It is a continuous time model and is capable of simulating long periods for computing the effects of climate change, thus allowing the computation of the effects of climate change.
- It is public domain with for free and online access.
- Its compatibility with ArcGIS interface: for ease of data base management.
- It’s easy linkage to sensitivity, calibration and uncertainty analysis tools.

- Its smart and coordinated user groups: for helpful assistance.

2.10.2 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a semi-distributed, continuous time step, process-based river basin model (Arnold *et al*., 2012). SWAT has been widely used to analyze hydrological processes at watershed scales. This model was developed to evaluate the impact of climate and land management practices on the water in large and complex watersheds with varying soils, land use, and management conditions over long periods of time (Arnold *et al*., 1998).

The hydrological component of the model is based on a water balance equation with processes that include precipitation, surface runoff, water yield, evapotranspiration, lateral flow, percolation and groundwater flow (Arnold *et al*., 1998).

The model is physically based rather than incorporating regression equations to describe the relationship between input and output variables. SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, crop growth, nutrient cycling etc. are directly modelled by SWAT using this input.

The model is computationally efficient simulator of a very large basin or a variety of management strategies can be performed without excessive investment of time and money. The model Enable the users to study long-term impacts. Many of the problems currently addressed by users involve the gradual buildup of pollutants and the impact on downstream water bodies. To study these types of problems, results are needed from runs with output spanning several decades. SWAT is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single even flood routing (Neitsch *et al*., 2011).

For modelling purpose, a watershed may be partitioned into a number of sub-watersheds and HRUs. The use of sub-watershed in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to influence hydrology. By portioning the watershed into sub-watershed, the user is able to reference different areas of the watershed to another spatially. Input information for each sub-watershed is grouped or organized into following categories: climate, hydrologic response unit (HRU), ponds/wetlands, groundwater, and the main channel, or reach, draining the sub-watershed. Hydrologic response units are lumped land areas within the sub basin. Hydrologic response units are lumped areas within the sub-watershed that are comprised of the unique land cover, soil, and management combinations.

No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed. To predict accurately, the movement of pesticides, sediments or nutrients the hydrologic cycle as simulated by the model must conform to what is happening in the watershed can be separated into two major divisions: Land phase of the hydrologic cycle and water or routing phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The water phase of the hydrologic cycle can be defined as the movement of water and sediments etc. through the channel network of the watershed to the outlet (Neitsch *et al*., 2011).

2.10.3 SWAT-CUP2

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. This is demonstrated by the program links GLUE, Parasol, SUFI2, and MCMC procedures to SWAT. It is automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide link between the input/ output of calibration and model (Abbaspour, 2007).

2.11 Trend Analysis

Trend analysis in hydro-climatic variables is one way to assess how the climate has changed over time. Trend detection refers to methods used to extract an underlying behavioral pattern in a time series otherwise that would be partly or fully hidden by noise. The detection of abrupt and gradual changes in hydrological and meteorological records has been explored in considerable detail by researchers.

Information about Spatial-temporal variability in hydro-climatic time series is of great importance from both scientific and practical viewpoints. For example, the interpretation of the significance of trends existing in the annual maximum (flood), mean, and low flows in rivers is very valuable for flow regulation (Tharme, 2003).

2.11.1 Application of Mann-Kendall Statistics Test for Trends

Mann-Kendell test is a statistical test widely used for the analysis of trends in climatological and in hydrological time serious. It has two advantage of using it. First, it is non-parametric test and doesn’t require the data to be normally distributed. Secondly the test has low sensitivity to abrupt break due to inhomogeneous time serious (Karmeshu, 2012).

The study Belihu et al. (2018) conducted a study concerned with the changing trend of rainfall of the in Gidabo River Catchment to detect trends the analysis was done by using Mann-Kendal (MK), Sen's graphical method and to detect change point using the Pettit test. The comparison of trend analysis between MK trend test and Sen graphical method results showed the most similar pattern. The annual rainfall trends exhibited a significant decrease by about 12 mm per year in the upstream, which is largely driven by the significant decrease in the peak season rainfall. The Pettit test revealed that the years 1997 and 2007 were the change points.

The study Belete (2013) conducted a study concerned with the changing trend of rainfall of the in Lake Hawassa, by using the Mann-Kendall test Results of the Mann-Kendall trend analyses revealed the significant increasing trend of the lake level and streamflow. On the contrary, a decreasing trend of evaporation was observed while rainfall exhibits no trend over the study period.

3. MATERIALS AND METHOD

3.1 Description of the Study Area

The Gidabo watershed is located in the Abaya-Chamo sub-basin of the Rift Valley Basin situated in the southern part of Ethiopia. It is found with in the southern main Ethiopian Rift valley System, Northeast of Lake Abaya in Southern Nations Nationalities and People's Regional State (SNNPRS) and the watershed area covers is 3262.3km^2 which lies in Sidama and Gedeo Zones of the SNNPRS and the Borena Zone of Oromiya Regional State.

Gidabo watershade is bordered by the catchment of Lake Hawassa to the North, River Bilate to the West, River Galana to the South and Genale-Dawa Rivers to the East. In terms of Geographic coordinate the catchment is bounded between latitude 6°8‘ N to 6°57‘ N and longitude 38° E to 38°38‘ E, within UTM zone 37 and covers 3262.3 km^2 drainage area which extends from the center of the rift floor

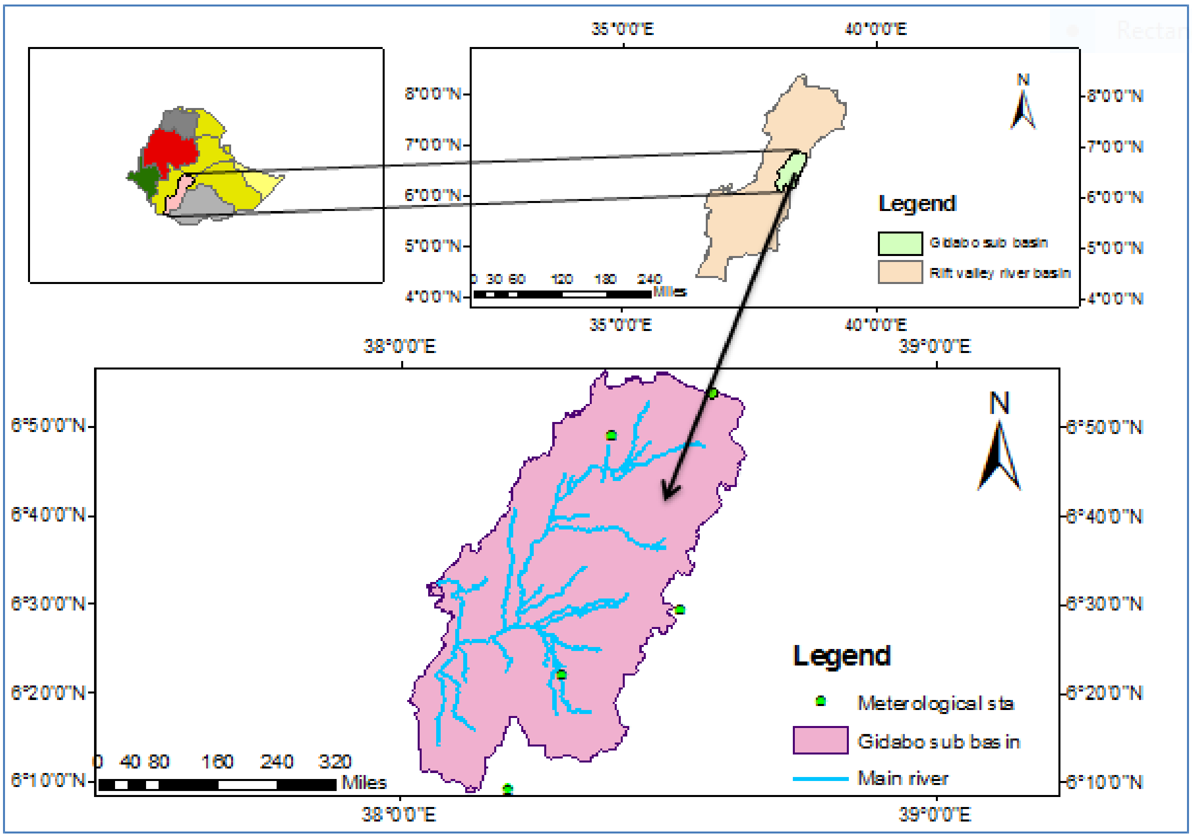


Figure 3.1 Location of Gidabo river basin and stream net work

3.1.1 Topography

The altitude of the watershed ranges from 1172-3212 m.a.s.l. The watershed is categorized in to three agro ecological zones, namely, dega, woyna dega and kola Zone. The traditional climate classification of the country is based on altitude and temperature shows the presence of five climatic zones namely: Wurch (cold climate at more than 3000 m altitude), Dega (temperate like climate-highland with 2500-3000 m altitude), Weyna Dega (warm-1500-2500 m altitude), Kola (hot and arid type, less than 1500 m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001)

The topography in the area is characterized by moderately dissected to undulating local reliefs. The Gidabo watershed can be treated in three different sections: The Upper, Middle, and Lower Courses of the major rivers. The relief of Gidabo watershed, mainly at the upper courses of the rivers in the watershed, is characterized by strong vertical differences over short distances between the rift valley floors. It is supposed to be the reflection of the terraced / stepped slope nature of the eastern escarpment of the rift valley system mainly in Sidama and Gedeo Zones.

The middle courses of the rivers in the watershed is characterized by fragmented patches and pockets of considerable open lands largely in Sidama zone and particularly at the south of Gidabo watershed. There are considerable wetlands both at the upper and lower courses in Borena, Sidama and Gedeo Zones. The lower courses of the major rivers are confined to the rift valley floor. It is characterized by relatively flat and plain of extensive land. This part forms the mouth of the major rivers in general and the delta of the Gidabo River (Birhanu, 2009).

3.1.2 Geology

Gidabo watershed is generally comprised of volcanic rocks. The rocks in the watershed are qualitatively classified into three permeability groups: low, medium and high. Thus, rock formations with similar hydro geological character are grouped into one hydro geological unit.Trap-series (Old) aphanitic basalts and ignimbrites volcanic abundantly found in the rift escarpment of the watershed with the highest part corresponding to the edge of the Somalian plateau (Hagereselam town area) and in the structural old basaltic reliefs to the West of Yirga Chefe-Wonago Asphalt road.

Young rhyolites cover a small area in the western part of the watershed, North of Lake Abaya, where they form fairly low reliefs. They separate the Gidabo Catchment from the adjacent Lower Bilate Catchment serving as surface water divide (Birhanu, 2009).Young ignimbrites are by far the most representative rocks in the watershed of Gidabo.

3.1.3 Climate

The climate of Ethiopia is mainly controlled by seasonal migration of Inter tropical Convergence Zone (ITCZ) and its associated atmospheric circulation but the topography has also an effect on the local climate. The traditional climate classification of the country is based on altitude and temperature shows the presence of five climatic zones namely: Wurch (cold climate at more than 3000 m altitude), Dega (temperate like climate-highland with 2500-3000 m altitude), Weyna Dega (warm-1500-2500 m altitude), Kola (hot and arid type, less than 1500 m in altitude), and Berha (hot and hyper-arid type) climate (NMSA,2001).

In general, the climate of Ethiopia varies from humid to semiarid typically tropical in the south-eastern and north central highland regions of the country. Mean annual temperatures are around 15-20 ^{0} C high altitude regions, whilst 25-30°C in the lowlands over the last decades, is such that However, the increase in minimum temperatures is more pronounced with roughly 0.4° C per decade. The average precipitation stable over the last 50 years when averaged over the country (Keller, 2009).

The climate of the area Gidabo watershed varies between sub humid and sub- tropical, and according to the traditional classification of climate which is mainly based on altitude variation, the climate is classified as Dega , Weyna Dega , kola and wurch .

As computed from the long-term (1988-2017) rainfall record of five meteorological station, the annual average rain fall varies from 600mm to 1615mm. The main rainy season in the Gidabo River Basin occurs between March and June with a second peak in September-October (Fig.3.2). These two peaks are separated by a relatively small rain season in July-August. Figure 3.2&3.3 shows the long-term average monthly distribution of rainfall and temperature at Gidabo watershed meteorological station. The mean monthly maximum and minimum temperature considering in the watershed station varies between 18.4^{o}C to 30.26^{o}C and 6.87 ^{o}C to 13.78 ^{o}C which corresponds to respectively.

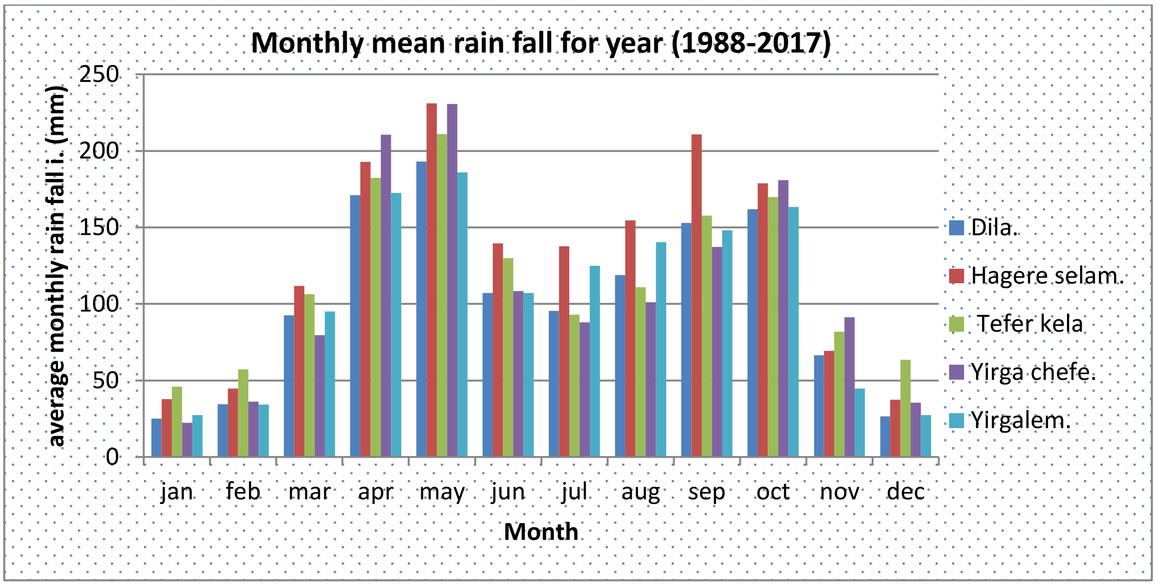


Figure 3.2 Monthly average Rainfall of selected stations (mm/month)

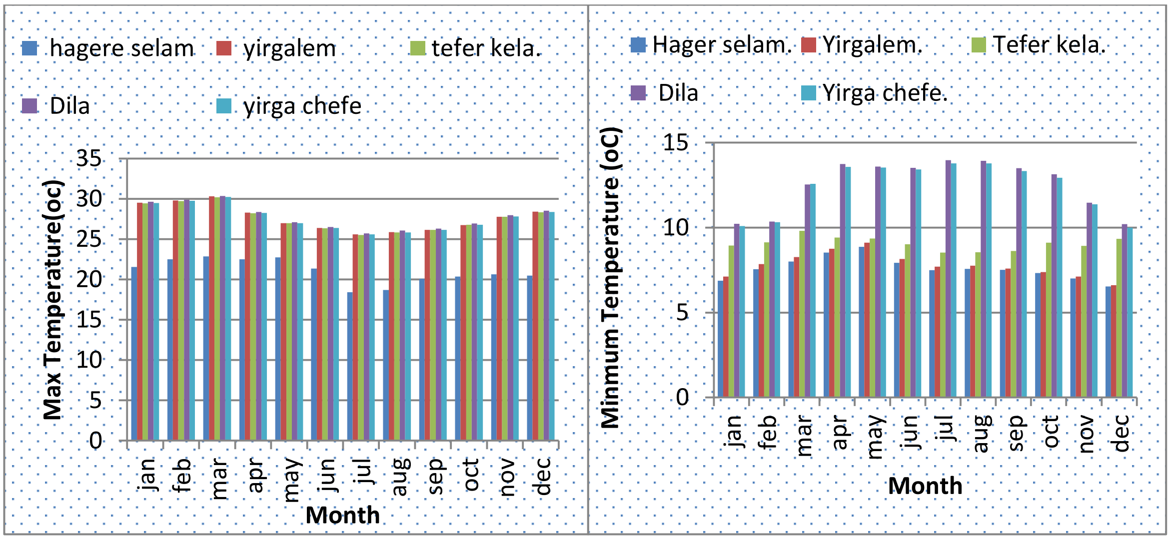


Figure 3.3 Maximum and Minimum Temperature in the water shed (1988-2017)

3.1.4 Soil

According to soil data of MWIE (2007) in Gidabo watershed, six main soil types are found which include; Chromic Luvisols (Lvx) (20.60%), Chromic Vertisols (VRe) (29.79%), Eutric Cambisols (NTu) (12.04%), Orthic Luvisols (Lvh) (32.317%) and Pellic Vertisols (Lpe), (5.39%) is shown Figure 3.4 blow. According to Kediri (2002), soils of Gidabo watershed can be divided into four textural classes: sandy loam (including the Red and Gray varieties), silty loam, clays and thin gravelly sand soils.

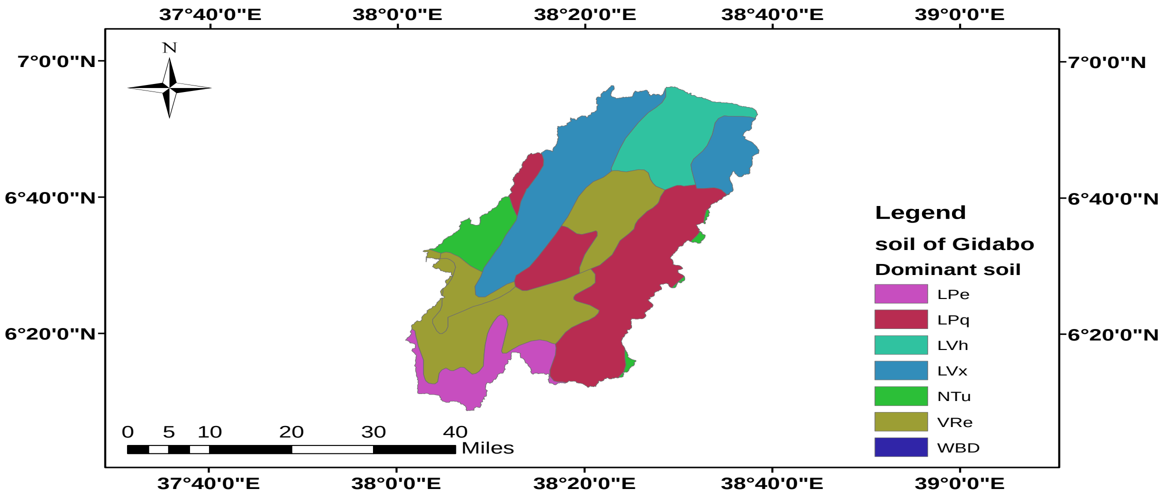


Figure 3.4 Soil map of Gidabo watershed

3.1.5 Land Use and Cover

In terms of areal coverage of the land use and land cover shown Figure 3.5 are cultivated land, grassland, bush shrub land, wood land, bare land, and permanent open water body (Abaya Lake) and swamp settlement covers a small area. Generally, the watershed is well known by the agroforestry system. Major types of crops grown in the area include; coffee, enset, avocado, Chat (Catha edulis), banana (Ensete ventricosum). In some upper parts of the watershed: maize, teff, barley, wheat and to a small extent pulses and oil crops. In this watershed, some farmers also practice traditional irrigation development activities from perennial rivers and springs. Moreover, livestock production is an important and integral component of the agricultural sector in the Gidabo watershed.

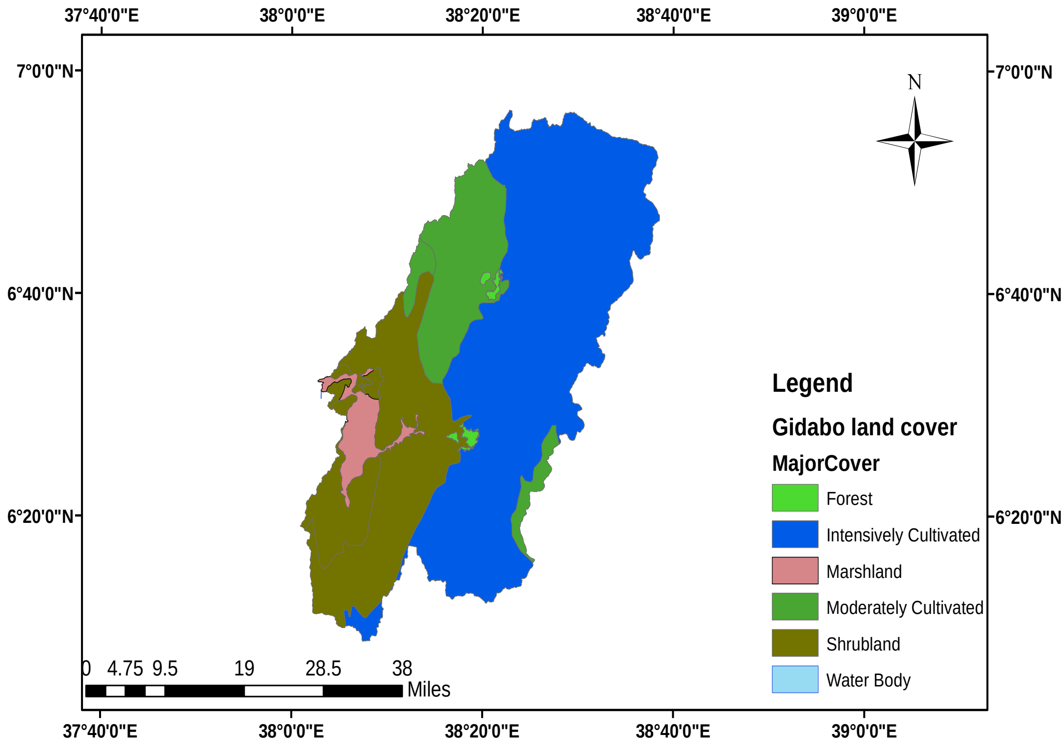


Figure 3.5 Land use land cover map of Gidabo watershed

3.1.6 Hydrology

The Gidabo watershed is drained by some major rivers running from the east into Lake Abaya. The Gidabo River drains predominantly the Heleya Mountains as part of the Eastern Uplands in Sidama Zone. The Kolla River is another major river draining in\ to Gidabo watershed originating from the highlands of Sidama Zone. The Dara River also supplies the Gidabo watershed with ample water draining from the highlands of both Sidama and Gedeo Zones. Chichu / Wallame River is the second largest river after Gidabo in the catchment area. The highlands of Gedeo Zone and supplies the watershed with its annual flow as shown in Annex- Fig. A3. The discharge gauging of Gidabo River found in Aposto which is located at lat.6.7^{O} N and lon.38.3 ^{O} E.

3.2 General Methodology

The general methodology of this study is shown in the Figure 3.6 depending on the data which are collected from different organization and also site observation. In order to achieve the objectives of the study, all the necessary data were collected from meteorological stations, hydrological stations, and respective organizations and prepared DEM for the study area. Meteorological data in and around Gidabo watershed like daily precipitation, maximum and minimum temperature, sunshine hours, relative humidity and wind speed was collected from National Meteorological Service Agency (NMSA) of Ethiopia.

This study concerned on the assessment of climate change impact on water availability with the application of a semi-distributed conceptual hydrological model SWAT in the Gidabo gauged watershed. For this study, meteorological, hydrological, and water resources development data were required. Data such as rainfall, temperature and other climate parameters for ET estimations were collected from the National Meteorological Agency (NMA) of Ethiopia. Stream flow data was obtained from Ministry of Water, Irrigation and Energy (MoWIE). Digital Elevation Model data with a resolution of 30*30m was also collected from Ministry of Water, Irrigation and energy (MoWIE) of GIS Department. This data was used for watershed delineation by serving as input for Arc GIS that prepares input data for SWAT hydrologic model.

Regionally downscaled climate change data was provided from international water management institute (IWMI). The data derived from HadGEM2-ES Global climate model outputs that is dynamically downscaled by the CORDEX-Africa program using RCA5 regional model for the representative concentration pathway scenario RCP 4.5 and RCP 8.5 projection scenarios. The study required different materials and models to arrive at the stated objectives. Arc GIS 10.3 was used to analyze spatial data including preparing base maps and other maps that serve as inputs to the model used in this study. Microsoft EXCEL was used to analyze hydrological data, metrological data and model outputs

The overall conceptual flow chart of the research methodology used reviewed

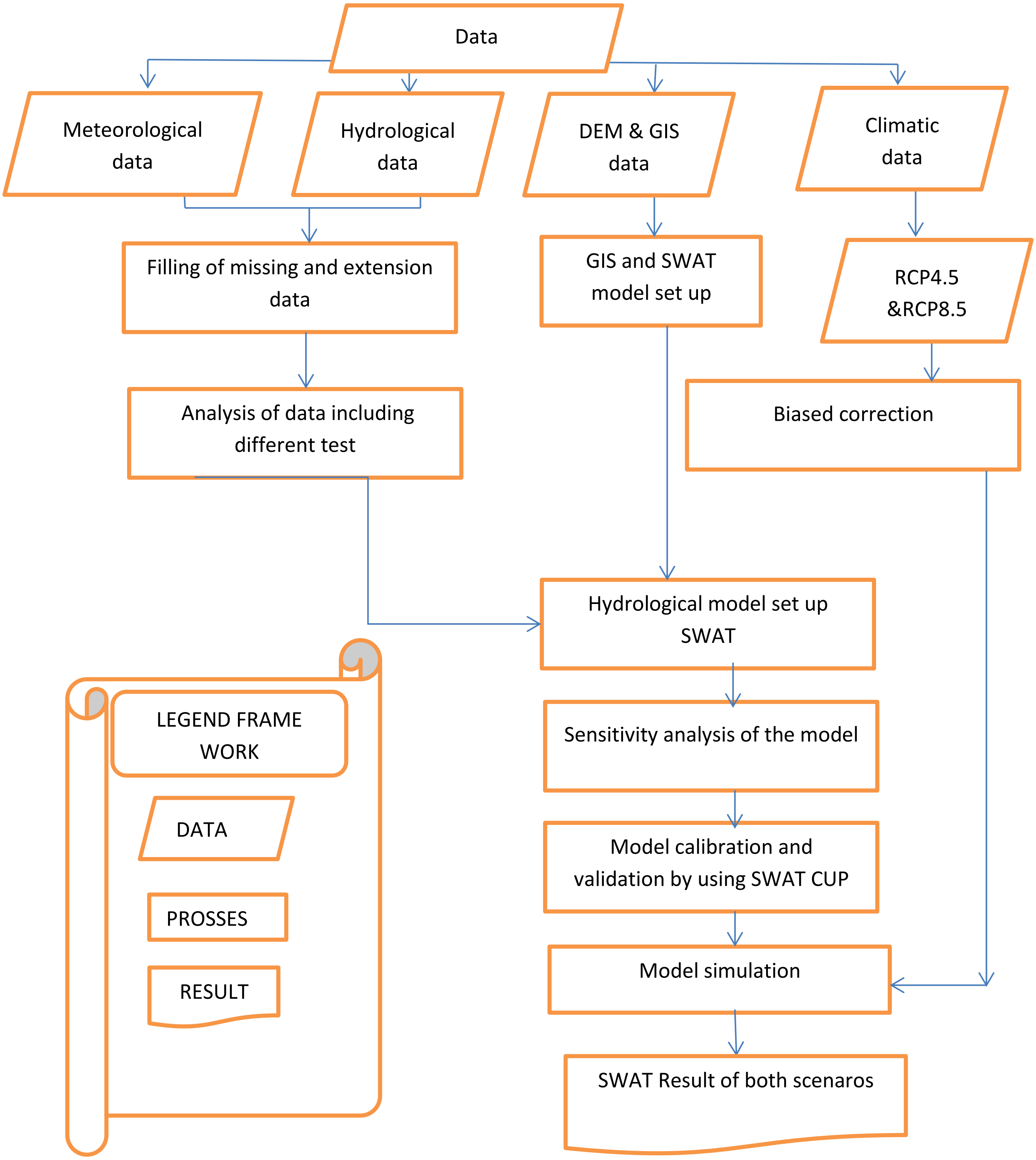


Figure 3.6 Conceptual Framework of the Study

3.2.1. Spatial Data

Digital Elevation Model (DEM) is one of the spatial data that describes the elevation of any point in a given area at a specific spatial resolution as a digital file. DEM is the primary input data for the SWAT model to delineate the study area. In this study, DEM with a resolution of 30*30m obtained from Ministry of Water, Irrigation and energy (MoWIE). Other spatial data like land use/land cover map and the soil map are also collected from South Water Works Design and Supervision Enterprise (SWWDSE).

3.2.2. Meteorological Data

Meteorological data are among the most important time series data necessary for hydrological design and analysis of water resources projects. The meteorological data include, precipitation, minimum and maximum temperature, wind speed, relative humidity and sunshine hour. They were collected from National Meteorological Service Agency (NMSA).At present there are several meteorological stations, which were installed by National Meteorological Service Agency (NMSA) of Ethiopia. Even if there is sufficient number of meteorological stations has been established throughout the project area, information regarding the detail climatic conditions of the area is very limited because of malfunctioning of gauging stations, absence of timely recorded data etc.

Depending on the availability, quality of required elements and quantity or long term record of data, ten meteorological stations with 30 years precipitation data (1988–2017) were selected to achieve the objective of the study Table3.1 shows.

Table 3.1 Location of selected rainfall stations with in the catchment

Station name	Latitude	Longitude	Elevation(m)
Dilla	38.52	6.49	1515
Yirgalem	38.40	6.87	1831
Teferi kela	38.23	7.0	1870
Yirga chafe	38.39	6.82	1786
Hager selam	38.20	6.15	2809

3.3.3. Hydrological Data

Hydrological data are also among the most important time series data necessary for hydrological design and analysis of water resources projects. Observed hydrological data series is very essential in model calibrations to generate flow at different spatial and temporal points of interest. The daily stream flow for seventeen years of three stream gauging stations for the period from 1990 to 2006 with in the watershed were collected from flow data. Hence, for this study daily flow data of those stations were collected from Ministry of Water, Irrigation and electricity (MoWIE) was adopted.

Table 3.2 presents the longitude, latitudes and selected stream gauging stations.

ID	Station Name	Easting(x) UTM	Northing(y) UTM
1	Bedessa near Dilla	422585.34	705631.95
2	Gidabo near Aposto	431814.8	746155.53
3	Kola near Aleta wondo	433677.77	733218.71

3.3.4. Climate Change Model Data

Downscaled rainfall and temperature (minimum and maximum) projected climate data for the period 1988-2077 have been obtained from CORDEX-Africa database and is available at a spatial resolution of (approximately 50 km × 50 km). CORDEX is a program sponsored by World Climate Research Program (WCRP) for using the latest generation of regional climate models (RCMs).

CORDEX data projections are presented showing possible future regional climate change scenarios on several domains of the worldwide including East Africa. For this study, down scaled CORDEX precipitation and temperature data which ranges from 1988-2017 to historical periods and between 2018-2077 to future projections for RCP4.5 and RCP8.5 scenario periods were obtained from International Water Management Institute (IWMI). This data is dynamically down scaled form regional climate model by nesting RCMs into GCMs under representative concentration pathways (RCP4.5, RCP8.5)

Outputs from GCM for the 1988–2017 (baseline), 2018–2047 and 2048–2077 were used to generate climate change scenarios. The 2018–2047 and 2048–2077 correspond to short-term and long-term future, respectively. Data's regarding climate scenarios were then transferred to the hydrological model where simulated inflows were performed.

Table 3.3 sources of future climate data

Data Source (RCM)	Project	Institute	GCM name	Country	Scenario's
SMHI-RCA4	CMIP5	MOHC	HadGEM2-ES	UK	RCP (4.5,8.5)

Instead of choosing the nearest grid data to observation stations, precipitation and temperature scenarios from 1988–2017 and 2018-2077 with daily temporal resolution have been interpolated with bilinear interpolation from the four nearest grid points, as this method helps in conserving properties of robustness and eliminating unrealistic jumps (Abdella, 2013),.The interpolation procedure of the grid is shown as blow

$$P\,(x,y) = \frac{(X2-x)(Y2-Y)}{(X2-X1)(Y2-Y1)}W11 + \frac{(X-X1)(Y2-Y)}{(X2-X1)(Y2-Y1)}W21 + \frac{(X2-X)(Y-Y1)}{(X2-X1)(Y2-Y1)}W12 + \frac{(X-X1)(Y-Y1)}{(X2-X1)(Y2-Y1)}W22..\,(3.1)$$

Where: - P is one of observation point

W11, W12, W21 and W22 are Historical and Future selected station grid data value

X, X_1, Y and Y_1 distance of these four stations relative to the observation stations figure 3.7 and Table3.4 below describes the location of the CORDEX and Observed data stations.

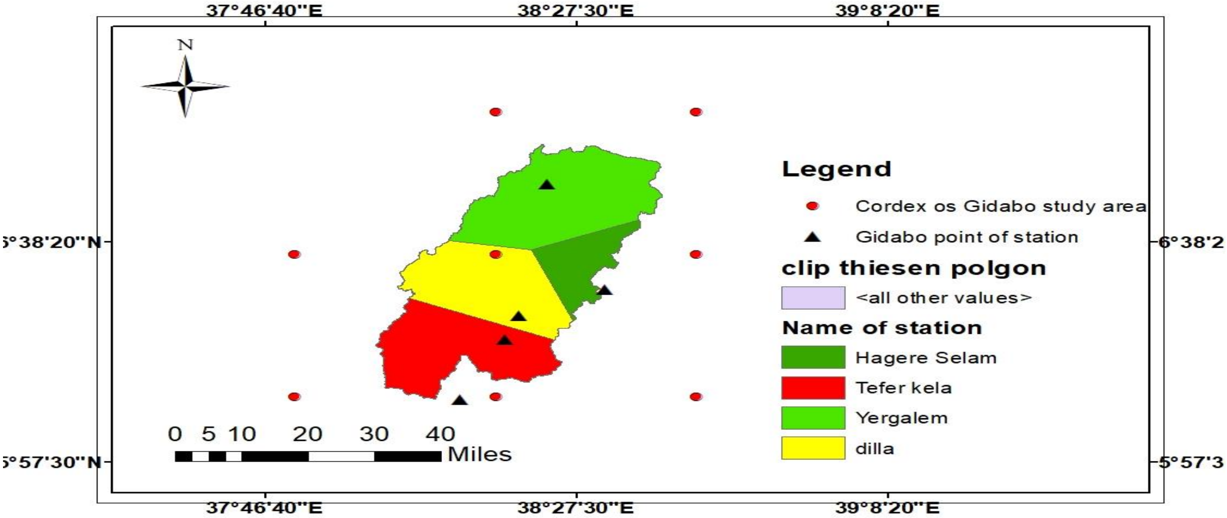


Figure 3.7 Location of the CORDEX & Observation Station of the Gidabo watershed

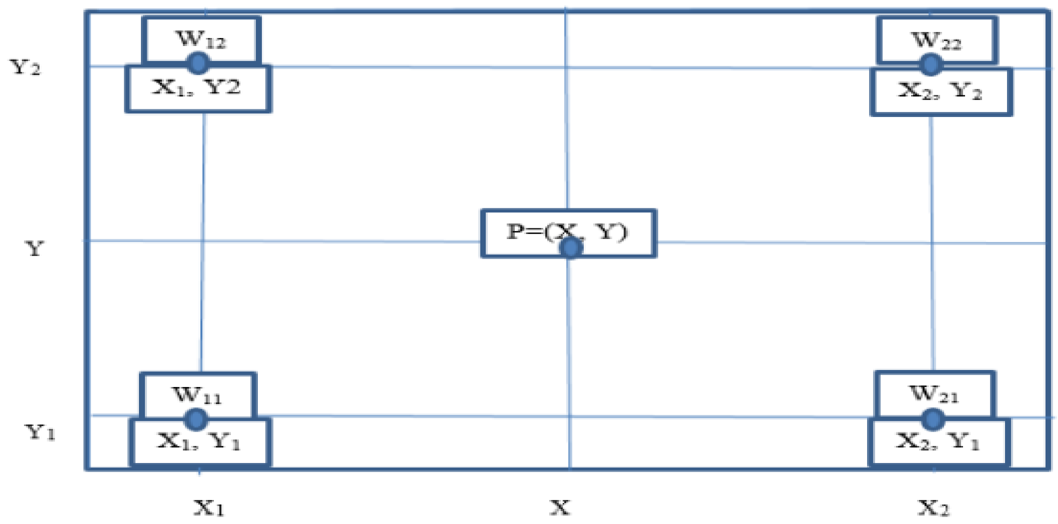


Figure 3.8 Representations of grid nodes and observation station (Ermias, 2018)

Table 3.4 the grid points which were selected in the Gidabo water shed blow

Station Name	Grid point	LAT	LONG	ELEV
Dilla	GP113208	6.16	38.28	1949.41
	GP113209	6.6	38.28	1869
	GP114208	6.16	38.72	2098
	GP114209	6.6	38.72	2271.4
Hagere selam	GP113208	6.16	38.28	1949.41
	GP113209	6.6	38.28	1869
	GP114208	6.16	38.72	2098
	GP114209	6.6	38.72	2271.4
Tefer kela	GP112208	6.16	37.84	1657.3
	GP112209	6.6	37.84	1642.47
	GP113208	6.16	38.28	1949.41
	GP113209	6.6	38.72	2271.4

Yirga chefe	GP112208	6.16	37.84	1657.3
	GP112209	6.6	37.84	1642.47
	GP113208	6.16	38.28	1949.41
	GP113209	6.6	3828	2271.4
Yirgalem	GP113209	6.6	38.28	1869.19
	GP113210	7.04	38.28	1864.03
	GP114209	6.6	38.72	2271.4
	GP114210	7.04	38.72	2240

3.4 Data Analysis and Quality Test

In order to construct detailed climate change scenarios for the Gidabo watershed and assess their impacts on water availability, a hydrological SWAT model is used. Before beginning any hydrological analysis, it is important to make sure that data are sufficient, complete, correct, and homogeneous with no missing values. Simulation depends on the quality of the available data, data checking were made for their reliability. SWAT normally uses solar radiation values rather than daily-sunshine-hours data. Statistical analysis of the daily data (monthly daily averages, standard deviations, probability of wet and dry days, skew coefficient) were carried out, which were latter used as an input for the data generator.

3.4.1. Filling of Missing Data for Precipitation

Data records may have some errors due to the absence of observer or instrumental failure or some technical errors. In such a case before using any data for analysis, the data have to be tested and the missing data need to be filled. Failure of any rain gauge or absence of observer from a station causes short break in the record of rainfall at the station.

The gaps should be estimated first before using the rainfall data for any analysis. The surrounding stations located within the basin help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations. There are different methods which are used to full fill the missing data. Most of the rainfall stations in the study area have missing data in their records and it is necessary to estimate the values to keep the continuous time series of the data. There are a number of missing data's to the selected stations due to this, rainfall data of the stations have been used to infill the missing data and to check its consistency.

The rainfall data from these stations have been checked for their consistency and the missing data have been calculated. In this study arithmetic mean method and normal ratio method was used.

Arithmetic mean method was used when the normal annual rainfall of the missing station is within 10% of the normal annual rainfall of the surrounding stations. This is the case for the stations near the study area. The arithmetic mean method may be given by:

$P_X = 1/n\,(P_1+P_2+\ldots\ldots+P_n)$ ………………………………………………………... (3.2)

Where P_1, P_2, Pn are the precipitations of index stations and Px is that of the missing station, n is the number of index stations

Normal Ratio Method is used when the normal annual precipitation of the index stations differs by more than 10% of the missing station. This is the case for the stations near the study area. The general formula for computing missing precipitation by this method is

$$P_m = \frac{1}{N}\sum_{n=1}^{n}\left(\frac{Nm}{Ni}\right)pi \quad \text{…………………………………….. (3.3)}$$

Where Pm = the computed missing data on each station

Nm = average annual rainfall at rain gauge that the data were missed

Ni = the total average annual rainfall on the station

N = number of stations

Table 3.5 Percent of missing precipitation in study area

SN	Station	Total daily data with missing data	Total no of missing	%missing	Filing method
1	Dilla	11334	1132	9.9	Arithmetic
2	Hager selam	11334	910	8.03	Arithmetic
3	Teferi kela	11334	832	7.35	Arithmetic
4	Yirga chefe	11334	1362	12.02	Normal Ratio
5	Yirgalem	11334	1721	15.199	Normal Ratio

3.4.2. Consistency Test

Rainfall data reported from a station may not be always consistent over the period of observation of rainfall record. Another problem occurs when the catchment rainfall at rain gauges is inconsistent over a period and adjustment of the measured data is necessary to provide a consistent record. Consistency of time series data analyzed based on theory that a plot of two cumulative quantities that are measured for the same time period should be straight line and their proportionality remain unchanged which is represented by the slope. To check the consistency of data, double mass curve analysis was used to correct rainfall data for the station. In this method the accumulative annual rain fall of an uncertain Dilla station has been compared with the concurrent accumulated value of mean rain fall of group of four surrounding base stations.

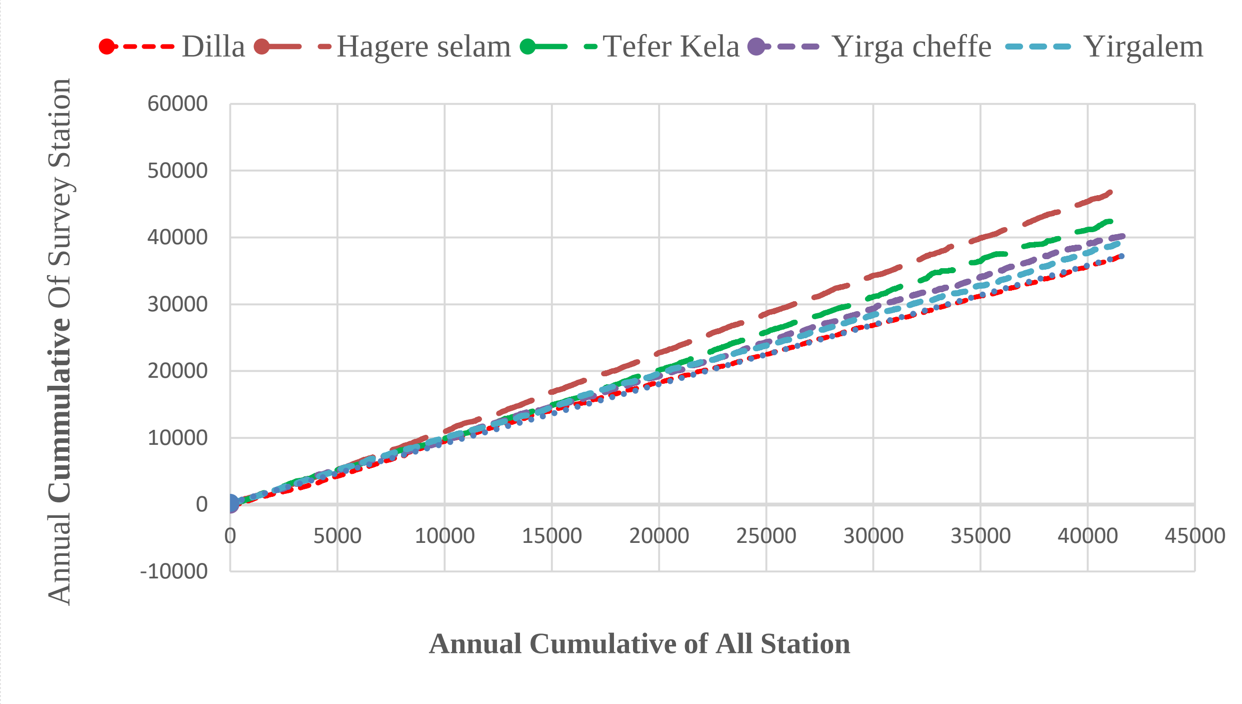


Figure 3.9 Double mass curve of rainfall data

3.4.3. Homogeneity Test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data which was caused by either natural or man-made like alterations to land use and relocation of the observation gauging station. Therefore, checking homogeneity of group stations is essential to select the representative meteorological station for the analysis of areal rainfall estimation. The homogeneity of the selected gauging stations daily rainfall records were carried out by non-dimensional equation. The non-dimensional observed precipitation data is said to be homogeneous if the periodic data are proportional to an appropriate simultaneous period, method, materials, place, and environment (McKuen, 1998).

The restrictions of homogeneity assure that the observations are from the same population. The non-dimension of the month's values were calculated as;

$Pi = \frac{Pi*}{P1} * 100\%$.. (3.4)

Where Pi: - is non-dimensional value of rainfall (month)

Pi∗:-is over year averaged monthly rainfall at the station I and

P1:- is the over year average yearly rainfall of the station.

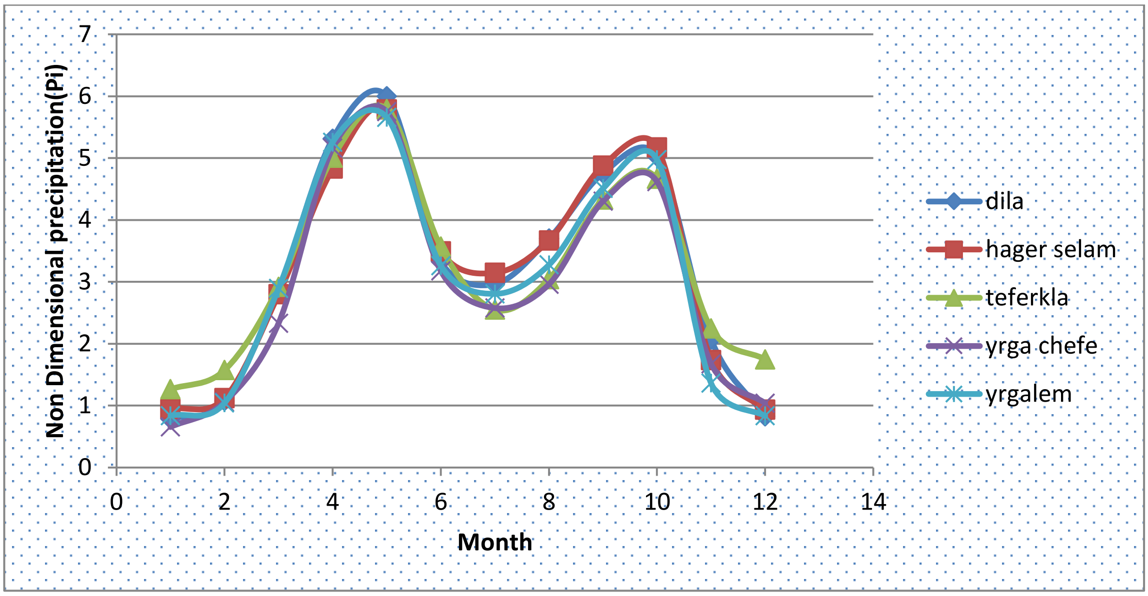


Figure 3.10 Homogeneity test of rainfall data

3.4.4 Areal Rainfall

Areal rainfall is derived from the idea that evenly distributed rain gauge stations in a given drainage basin into sub-basins have their own point observation that may not be used as a representative value for the specified sub-basins. Hence, to get the representative record of those stations areal precipitation value in the specified basin is worked out. The most common methods used for areal parameter estimation are station-average method, arithmetic mean, grid point, Thiessen polygon method and Isohyetal method. For this study, Figure 3.11 shows Thiessen polygon method was used due to its sound theoretical basis, large differences in the watershed at the rain gages and non-uniform distribution of the rain gauges throughout the study area. Thiessen area formed around each station by drawing the perpendicular bisectors of the lines joining adjacent stations using Arc GIS tool. The polygons areal contribution of the stations is clipped using the shape of the catchments that include stations of the selected ones for this study. If there are n-number of stations and n-polygons, the average depth of precipitation over the total area (A) is given by:

$$P *= \frac{\sum_{i=0}^{n} AiPi}{A} \qquad (3.5)$$

Where, P_*= Areal average rainfall

P_i = Rainfall measured at station i,

A_i= Area of sub-region of i station and

A = total area of sub-basin.

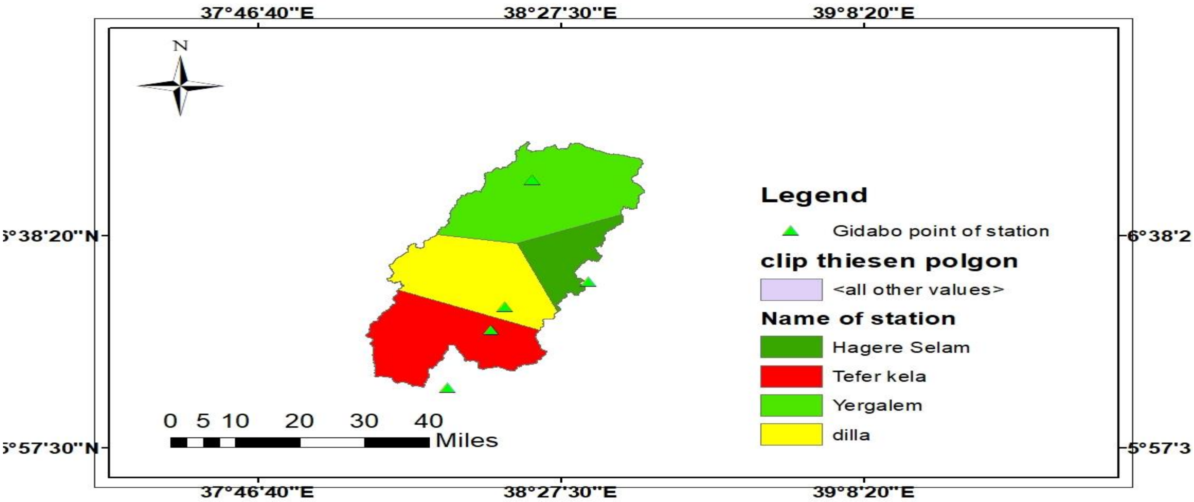


Figure 3.11 Thiessen polygons for Gidabo watershed

3.4.4 Bias Correction of RCP Data

Bias correction describes the process of scaling climate model output because climate models often provide biased representation of observed time series due to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. Typically, biases are occurrences of too many wet days with low intensity rain or incorrect estimation of extreme temperature in RCM simulations (Ines and Hansen 2006).

The basic principle is that biases between simulated climate data and observed data are identified and then used to correct both control and scenario runs. The main assumption is that the same bias correction applies to control and scenario conditions. The downscaled future climate parameters is corrected by Using CMhyd software tool (i.e. Precipitation, maximum and minimum temperature) were corrected by linear and power transformation bias correction method

3.4.4.1 Precipitation Bias Correction

Bias corrections of precipitation and temperature were carried out for the whole study based on areal data, (Leander, 2007).Used a power transformation which corrects the CV (coefficient of variation) as well as the mean of the data service. In this nonlinear correction each daily precipitation amount P is transformed to a corrected precipitation P_* using for base and future period. The power transforms method of is given by (Leander 2007):

$P_* = aP^b$……………..………………………………………….……...…..…… (3.6)

The parameter 'a' is determined such that the mean of the transformed daily values corresponds with the observed mean. The resulting parameter 'a' depends on 'b'. The parameter b depends only on the CV and is independent of the value of parameter a.

At the end, each block of one month has its own a and b parameter, the bias correction was done for a total length of 30 years (1988-2017).

3.4.4.2 Temperature Bias Correction

Temperature cannot be corrected using a similar power law function used for correcting precipitation. Because the temperature is known to be approximately normally distributed. Correcting power law function bias for precipitation is not providing normally distributed data sets.

The correction of temperature only involves by linear to adjust method of the mean and standard deviation (Leander, 2007). Hence, for correcting the daily temperature a linear transformation technique was applied in this particular study. For the basin, the corrected daily temperature T_{corr} was obtained as:

$T_{corr} = OBS_{mean} + RCP_{STD}\ (RCP - RCP_{mean})$………………………….……………… (3.7)

Where; T_{corr} = corrected daily temperature (^oC)

OBS_{mean}= observed mean temperature (^oC)

RCP_{std}=standard deviation RCP

RCP_{mean}= Average RCP (^oC)

3.5 Evapotranspiration and Evaporation

Evapotranspiration

Estimation of evaporation from open water cannot be measured directly, it should be determined indirectly by one or more of several methods, such as water balance, energy budget, There are different methods to estimate potential evapotranspiration (ET_O) using observed and predicted climatological data for the study area for each month of the year.

Though it can generally be assumed that more meteorological data is better for a reliable PET estimation, none of these studies could indicate a significant superiority of the Penmanor the Priestley-Taylor PET methods over the less "data-hungry" Hargreaves method. The SWAT application of Earls and Dixon (2008), in particular, shows that the Hargreaves PET can produce adequate results even with scarce meteorological data. Based on these studies and the limited meteorological data available for the Gidabo study area, the Hargreaves PET method, which requires only temperature data was used the Hargreaves equation is given as (Earls and Dixon2008):

$$\lambda \mathbf{E_0 = 0023H_0(Tmax - Tmin)\ \hat{}\,0.5(T\ avg + 8.17)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.8)$$

Where:

- ✓ E_o is the potential evapotranspiration (mm/d),
- ✓ λ is the latent heat of vaporization (MJ/kg),
- ✓ T_{max} is the maximum air temperature for a given day (°C),
- ✓ T_{min} is the minimum air temperature for a given day (°C), and T_{avg} is the mean air temperature for a given day (°C).

H_0 is the extraterrestrial radiation (MJ/m2/d), which depends on the latitude and the day of the year and is computed using the solar constant and complex solar declination relationships as presented in the SWAT manual.

3.5.1 Performance measures of climatic model

Assessed spatial variation of the models' performance evaluated the rainfall simulations in terms of four performance measures and through visual inspection by plots of observed and simulated flow. The performance measures are statistically based and include Bias, Root Mean Square Error (RMSE), Coefficient of Variation (CV) and Mean Absolute Error (MAE) are defined as follows. Bias indicates the systematic error in rainfall amount. A value of zero indicates no systematic difference between simulated and observed rainfall amounts where as large bias indicates that the RCP rainfall amount largely deviates from the observed rainfall amount. Negative bias indicates under estimation whereas positive bias indicates overestimation

An RMSE value close to zero indicates favorable performance. Correlation is used to evaluate the linear relationship between the observed and modeled rainfall amounts with a value of 1.0 suggesting perfect linear relationship (Alemseged et al., 2015). Calculated CV for both the gauged and RCP simulated rainfall amounts to evaluate how well the rainfall variability by the network stations is captured and represented by the RCP. The performance measures are given by

$$\text{Bias} = 100 * \frac{\text{RRCP} - \bar{\bar{\text{R}}}\text{Observed}}{\bar{\bar{\text{R}}}\text{Observed}} \quad \text{(3.9)}$$

$$CV = 100* \frac{\delta\text{RRCP}}{\delta\text{Robs}} \quad \text{(3.10)}$$

$$\text{RMSE} = \frac{\sqrt{\sum(\text{RRCP}-\text{Robserved})^2}}{\sqrt{N}} \quad \text{(3.11)}$$

$$\text{Correl} = \frac{\sum_{i=1}^{N}(\text{RCP} - \text{RCP mean})(\text{Robserved} - \text{Robserved mean})}{\left(\sum_{i=1}^{N}(\text{RCP} - \text{RCP mean})\sum_{i=1}^{N}(\text{Robserved} - \text{Robserved mean})\right)^{0.5}} \quad \text{(3.12)}$$

Where:

- ✓ RCP is simulated rain fall in (mm),
- ✓ $\bar{\bar{\text{R}}}$Observed is gauged mean rainfall (mm)
- ✓ δRCP is simulated standard deviation
- ✓ δRobs is measured standard deviation
- ✓ Bias is biased correction for a given (%)
- ✓ CV is coefficient variation for a given (%)
- ✓ RMSE is root mean square error for a given (mm/year)
- ✓ Correl is correlation of the data for a given dimensionless
- ✓ N is the number of the simulated and observed data

3.6. SWAT Model Setup

There are two types of model algorithms developed in SWAT model which vary in their process of computing surface runoff called SWAT CN and SWAT WB. The earlier developed algorithm (SWAT_CN) models on the occurrence of runoff from infiltration excess processes and the new version SWAT _WB models runoff generated strictly from saturation-excess processes; no surface runoff will be generated with this algorithm until the soil becomes sufficiently saturated (Neitsch *et al,* 2000).

Infiltration excess method of runoff computation is used. Channel water routing method in the reaches and Potential evapotranspiration calculation by SWAT model in this study using, a default settled variable routing and Hargreaves method respectively. Skewed normal distribution for rainfall distribution during the simulation was selected

3.6.1 SWAT Model Input

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

3.6.1.1 Watershed Delineation

The watershed and sub-watershed delineation was performed using 30 m resolution DEM data using Arc SWAT model watershed delineation function. First, the SWAT project set up was created. The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters.

Once the DEM setup was completed and the location of the outlet was specified on the DEM. The model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub-watersheds and topographic parameters were calculated using the respective tools.

3.6.1.2. Hydrologic Response Units (HRU) Analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increased the accuracy in flow prediction and provided a much better physical description of the water balance.

To define the hydraulic response unit (HRU), both single and multiple HRU definition options are available. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definitions, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled.

3.6.2.3 Weather Generator

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed one (Danuso, 2002). The SWAT Model requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. The SWAT model contains a weather generator model called WXGEN (Shapley and Williams, 1990).

It is used in the 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 then relative humidity are generated. Lastly, the wind speed is generated independently. For this study, the weather generator for Ethiopia, prepared for Gidabo watershed was used only one synoptic weather station in the watershed.

3.6.2.4 Sensitivity Analysis

After an initial SWAT simulation was performed, a sensitivity analysis was performed to obtain watershed specific parameters that drive model simulations and create sensitivities to model outputs (Arnold *et al.*, 2012). Highlighting sensitive parameters is necessary for calibration to assess over and underestimation of output variables. Sensitivity analysis was conducted using SWAT-CUP and a chosen algorithm, the Sequential Uncertainty Fitting version.2 (SUFI-2) algorithm was used. SUFI-2 was chosen to produce of the result as simulations are not dependent on previous iterations (Srinivasan, 2015).

In SUFI-2, the assessment of the sensitive parameters is measured using the t-stat values where the values are more sensitive for a larger in absolute t-stat values. P-values are used to determine the significance of the sensitivity where the parameter becomes significance if the P-values are close to zero (Khalid *et al.*, 2016).

A t-test is then used to identify the relative significance of parameters. The sensitivities are estimates of the average changes in the objective function resulting from changes in each parameter while all other parameters are changing. The t-stat is the coefficient of a parameter divided by its standard error. The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). In this analysis the larger, the absolute value of t-stat and the smaller the p-value the more sensitive is the parameter.

Initially, twenty one parameters were considered which were thought to influence outputs. After an initial iteration run of the model, the most sensitive parameters were identified and only those ten parameters were adjusted so that the calibration efficiency can be improved and calibration variances can be minimized in the study area. The category of sensitivity defined based on the (Lenhart et al, .2002) is presented in Table 3.6.

Table 3.6 Sensitivity class for SWAT

Class	Index	Category of Sensitivity
I	0.00≤0.05	Small to Negligible
II	0.05≤I<0.2	Medium
III	0.2≤I<1	High
VI	I≥1	Very high

3.6.2.5 Model Calibration and validation

SWAT-CUP was developed by Eawag Swiss Federal Institute to analyze the prediction uncertainty of SWAT model calibration and validation results. It provides the user to make a choice between a number of algorithms to perform the calibration such as Sequential Uncertainty Fitting version.2 (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Markov Chain Monte Carlo (MCMC), and Parameter Solution (Parasol).

SWAT parameters were calibrated using monthly discharge data from the Gidabo station for a period of eleven years (1990-2000) and then validated using the monthly discharge data of seven years (2000-2006). Several iterations of 500 simulations each of monthly flows by adjusting the sensitive parameters obtained through sensitivity analysis until the shapes of predicted and measured stream flows were found to be in reasonable agreement and the criteria of objective functions are satisfied.

3.6.2.6 Uncertainty Analysis

Parameter uncertainty in SUFI-2 accounts for all sources of uncertainties in driving variables (e.g. rainfall), parameters, the conceptual model, and measured data (e.g., observed flow, sediment). The parameter uncertainty was described by a multivariate uniform distribution in a parameter hypercube, while the output uncertainty was quantified by the 95% prediction uncertainty band (95PPU) calculated at the 2.5% and 97.5%levels of the cumulative distribution function of the output variables.

The 95PPU stands for the 95Percent prediction uncertainty or P-factor. The 95PPU measured how well the observed data fit into a 95 per cent confidence range of uncertainty from the simulated output. R-factor measures the range of output uncertainty represented by the visual band. A well-calibrated model will have a small R-factor, represented as a thin 95PPU band that houses the observed measurements.

3.6.3 SWAT model Performance Evaluation

The predictive capacity of the SWAT model for discharge was determined by using three objective functions: the R^2, NSE and PBIAS.

3.6.3.1 The Coefficient of Determination (R^2)

A value shows how well a data fit into a statistical model. The range of coefficient of determination lies between 0 and 1. When R^2 is 1, it can be depicted that the regression line perfectly fits the data while R^2 is 0 indicates that the line does not fit the data at all.

$$R^2 = \frac{\left[\sum_i \left(Q_{m,i} - \overline{Q_m}\right)\left(Q_{s,i} - \overline{Q_s}\right)\right]^2}{\sum_i \left(Q_{m,i} - \overline{Q_m}\right)^2 \sum_i \left(Q_{s,i} - \overline{Q_s}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

Where, R^2 is coefficient of determination, Q is a variable (e.g. Discharge), and m and s stand for measured and simulated, i is the i^{th} measured or simulated data.

3.6.3.2 Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe model efficiency coefficient is used to show the predictive power of hydrological models. The Nash-Sutcliffe efficiency has a range between -∞ to 1. When efficiency is equal to 1 it indicates a perfect match of estimated discharge with the observed data whereas an efficiency of 0 suggests that the predictions of the model are as accurate as the observed data are meanwhile an efficiency which is less than zero corresponds tothe observed mean is a better predictor than the model.

$$NSE = 1 - \frac{\sum_i \left(Q_m - Q_s\right)_i^2}{\sum_i \left(Q_{m,i} - \overline{Q_m}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

Where, NSE is Nash-Sutcliffe efficiency, Q is a variable (e.g. Discharge), m and s stand for measured and simulated respectively and the bar stands for an average.

3.6.3.3 Percentage Bias (PBIAS)

PBIAS is the deviation of simulated data from observed data being evaluated, which is expressed as a percentage. The low magnitude values indicate accurate simulation of the model. Per cent bias measures the average tendency of the simulated data to be larger or smaller than the observations. The optimum value is zero where low magnitude values indicate better simulations. Positive values indicate model underestimation and negative values indicate model overestimation (Gupta *et al.*, 1999).

$$\text{PBIAS} = 100 * \frac{\sum_{i=1}^{n}(Q_m - Q_s)_i}{\sum_{i=1}^{n} Q_{m,i}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

Where, Q is a variable (e.g. Discharge) and m and s stand for measured and simulated respectively.

Model performance ratings based on the range of values for the RSE, NSE and PBIAS is shown in Table 3.7

Table 3.7 Model performance index

Performance Rating	RSR	NSE	PBIAS (%)
Very good	RSR > 0.7	0.75 < NSE ≤ 1.00	PBIAS < ±10
Good	0.60 < RSR ≤ 0.70	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15
Satisfactory	0.50 < RSR ≤ 0.60	0.50 ≤ NSE ≤ 0.65	±15 ≤ PBIAS < ±25
Unsatisfactory	0.00 ≤ RSR ≤ 0.50	NSE < 0.50	PBIAS ≥ ±25

3.7 Trends Analysis

Analysis of the observed meteorological data are presented for the 30 years of data 1988-2017. Although there is a tendency of increase in both maximum and minimum temperature, there is no as such considerably larger in magnitude of increment in both variables whereas for rainfall a trend cannot be revealed.

3.7.1 Mann-Kendall (MK) Statistical Test

It is non-parametric test for looking at trend in time series which is robust even for highly skewed hydro metrological data described by Mann, although the test lately proved by Kendall in 1975 as a special case for testing of correlation between two data serious (Y, X) using Kendall's τ. Because of this it called Mann-Kendell test and measures whether data value (Y) tends to increase or decrease with time (T) (Cherie, 2013).

Mann-Kendell test is a statistical test widely used for the analysis of trends in climatological and in hydrological time serious. It has two advantage of using it. First, it is non-parametric test and doesn't require the data to be normally distributed. Secondly the test has low sensitivity to abrupt break due to inhomogeneous time serious (Karmeshu, 2012).

4.7.2 Non-seasonal Mann-Kendall Test

According to this test, the null hypothesis H0 assumes there is no trend (the data was independent and randomly ordered) and this is tested against the alternative hypothesis H1, which assumes that there is a trend. Mann-Kendall test considers the time series of n data points T_i and T_j as two subsets of data where i = 1,2, 3,………………,n-1 and j = i+1,i+2, i+3,………,n. The data values are evaluated as an ordered time serious. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S

The Mann-Kendall S Statistic is computed as follows

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(y_j - y_i\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (3.16)$$

Where, x_j and x_k are the annual values in years *j* and *k*, *j* >*k*, respectively, and n is the length of the data set. If the value of S is positive, there is upward trend and vice versa.

$$sgn(T_j - T_i) = \begin{cases} 1\ if\ y_j - y_i > 0 \\ 0\ if\ y_j - y_i = 0 \\ -1\ if\ y_j - y_i < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.17)$$

Where *Tj* and *Ti* are the annual values in years j and i, j > i, respectively.

It can be simplified as;

$$Sg = P - M$$

Where

Tj > Ti

P = the number of times the Y's increase as $Yj>Yi$

M = the number of times the Y's decrease as $Yj<Yi$

It can be shown that is asymptotically normally distributed with the mean of E(S) =0 and standard deviation = ($variance$ 1/2)s given by

The mean of S is E(S) = 0 and the variance σ^2 is

$$\delta s^2 = \frac{\left[n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(2t_j+5)\right]}{18} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.18)$$

Where, p is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group.

In the case where there are no ties in either ranking, the distribution of S may be well approximated by a normal distribution with mean zero and variance,

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

The statistic S is approximately normally distributed provided that the z transformation is employed which may give as

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma}} if\ S > 0 \\ \frac{S-1}{\sqrt{\sigma}} if\ S = 0 \\ \frac{S+1}{\sqrt{\sigma}} if\ S < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

To test the significance, the Z-calculated (eqn.3.20) value is compare with the Z-table value for (1- α) from the standard normal distribution.

The test statistic Z is used as a measure of significance of the trend. This test statistics has been used to test the null hypothesis, Ho. If | Z| is greater than Zα/2, where alpha α is the chosen significance level, and hence the null hypothesis is rejected, indicates the trend is significant (McBean & Motiee, 2009).

The Mann-Kendall‘s test Kendall‘s tau is a measure of correlation and hence measures the strength of the relationship between the two variables. Kendall‘s tau, like spearman‘s rank correlations carried out on the ranks of the data. For each variable separately, the values are put in order and numbered, 1 for the lowest value, 2 for the next lowest and so on. Kendall‘s tau will take values between ± and +1 with other measures of correlation. A positive correlation indicates the rank of both variables increase together while a negative correlation indicates

The presence of a statistically significant trend is evaluated using the Z value. A positive and Negative value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. To test for either an upward or downward monotonic trend (a two-tailed test) at α level of significance, H_o is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. For this study, confidence level of 95% was used to by the test statistics.

The null hypothesis H_o stated above (no trend exists) is tested through the significance of S or 0, being significantly different from zero, i.e. the null hypothesis is rejected at a significant level X (significant trend exist in the time series) if the computed value

$|Z| > Z_{1-\alpha/2}$ ………………………………………….…………………………..(3.21)

where:

$Z_{1-\alpha/2}$ is the value of the standard normal distribution with the probability of exceedance of $\alpha/2$ For 5% significance level, the critical $Z_{1-\alpha/2}$, value which is computed from any standard normal distribution table is 1.96.

The Mann-Kendall test is essentially limited to testing the null hypothesis that the data are independent and identically distributed. But our time series data may be auto-correlated and may have seasonal components. These factors, of course, can be removed by using annual data but it has an effect of reducing the power of the trend test.

4. RESULTS AND DISCUSSION

4.1 Climate Change Scenarios

4.1.1 Selection of Representative Climate Station

To investigate the relation between the stations' temperature and precipitation values, inter- comparison of the stations' data was carried out. The data from 1988 to 2017 were average over a monthly period to calculate correlation coefficients of the stations.

Table 4.1 Correlation between Average Monthly precipitations of five stations

SN	Station	1	2	3	4	5
1	Dilla	1	0.71	0.82	0.91	0.75
2	Hager selam		1	0.83	0.78	0.77
3	Teferi kela			1	0.82	0.82
4	Yirga chefe				1	0.90
5	Yirgalem					1

The correlation involved five stations for precipitation maximum and minimum temperature. As shown in Table 4.1, the average monthly precipitation correlation analysis among the stations resulted in correlation coefficient ranging from 0.71 to 0.91. This shows presence of a good agreement among the general monthly trends of the stations' precipitation. The correlation of the other stations precipitation with that of Dilla station specifically showed very high values ranging from 0.71 to 0.91.

Likewise the correlation analysis of the average monthly temperature resulted in correlation Coefficients ranging from 0.911 for maximum temperature, and from 0.67 for minimum temperature. This still shows a strong relation among the temperature across the stations. Therefore Dilla Station can be taken as representative of the climate stations with respect to average monthly precipitation, maximum temperature, and minimum temperature.

4.2. Downscaled RCP Data Performance Evaluation

Table 4.2 shows the statistical test parameters indicating the correspondence of uncorrected RCP and bias corrected RCP data for base period of mean monthly Precipitation amount. The Standard error of mean (Mean Abs Error), Coefficient of variation (CV) and Root mean square error (RMS-Error) of bias-corrected rainfall data were showed highly close to observed value as compared to the uncorrected one.

Table 4.2 Performance of bias-corrected method on daily rainfall data.

Downscaled RCP Data	Precipitation l data			
	CV	RMSE	Correl	PBias
observed	1.02	0.78	0.86	-9.62
RCP_Corrected	1.04	0.76	0.74	-6.68
RCP_uncorrected	1.201	3.101	0.56	-16.64

The bias indicates the systematic error in precipitation value. A value zero indicates no systematic difference between simulated amount and the observed amount, whereas a large bias indicates that the GCM/RCM amount largely deviates from the observed value (Alemseged Tamiru and Tom.R, 2015) RMSE value close to zero implies favorable performance of the method. Table 4.2 also shows the variation between the uncorrected and corrected data with observed and hence the variation is relatively high in uncorrected RCP data as compared to the corrected one.

4.3. Scenarios Developed for the Base Period

In Gidabo watershed bias corrected RCP scenario with a grid resolution of $0.5^0*0.5^0$ was used for analysis. The base line period was from taken as 1988-2017 while the time periods from 2018-2047 and 2048-2077 are considered for impact study. Base period scenarios are generated to compare the observed, RCP bias linear corrected and transform corrected.

4.3.1. Bias Correction of Precipitation

Figure 4.1 Result shows the mean daily precipitation of RCP bias corrected rainfall in comparison with observed data for the baseline period (1988-2017). The simulated mean daily precipitation in the majority of the months is representative of the observed magnitudes. There is a relatively insignificant model error in linear transformation than power correction methods. In this specific study, rain fall is bimodal. In linear correction RCP shows under estimation ranging from Jan to Feb are shiny and to over estimation from June to July. In linear correction, shows under estimation of rainfall was observed the month of July and September respectively

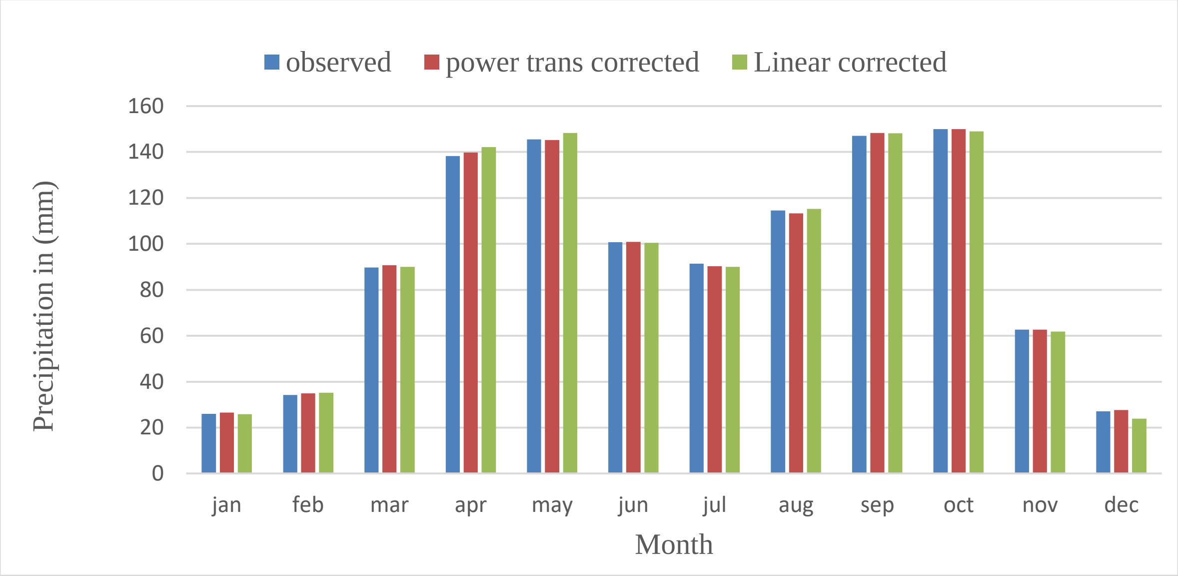


Figure 4.1 bias correction and observed PCP mean for the base line period (1988-2017)

4.3.2. Bias correction of temperature

A. Maximum Temperature

Downscaled mean daily maximum temperature ranges from 24.45°C to 32.73°C both in linear correction and power transforming RCM bias correction methods (Figure 4.2). The power transforming RCP bias corrected output indicated reasonable agreement with observed daily maximum temperature. RCP simulation shows insignificant difference at May by underestimating approximately 0.3°C both in linear and shifting and scaling methods

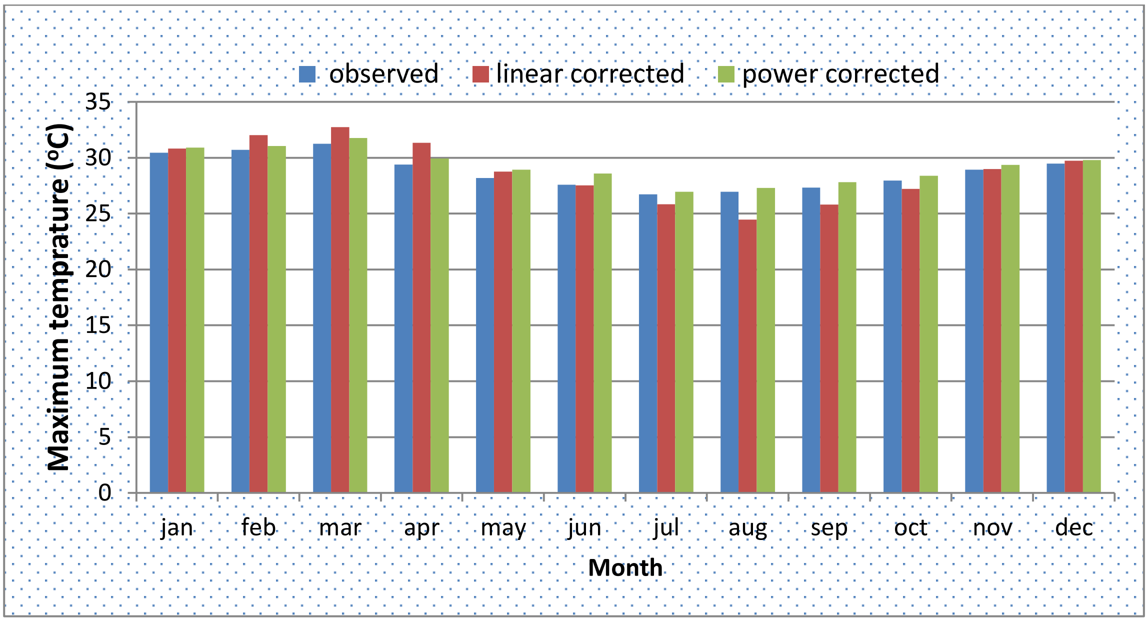


Figure 4.2 bias correction of mean month TMax for the base line period (1988-2017)

The highest maximum temperature based on RCM bias corrected and observed data is in the month of Feb –Mar and is approximately 32.73°C. The lowest maximum temperature is in the month of Jul – Aug approximately 24.45°C

B. Minimum Temperature

The power or shifting scaling bias correction mean daily minimum temperature indicated good agreement with observed mean daily data. Also, in linear correction mean daily minimum temperature shows unsatisfactory agreement for most months therefore shifting and scaling bias correction methods are not satisfactory in this catchment. The daily mean minimum temperature ranges from 10.5˚C and 14.7˚C. RCM simulation under power transform scaling bias correction shown in significant difference from observed by over estimating approximately 0.27˚C and 0.34˚C at Aprl and August respectively. However, in January and March shown under estimation by 0.26˚C.

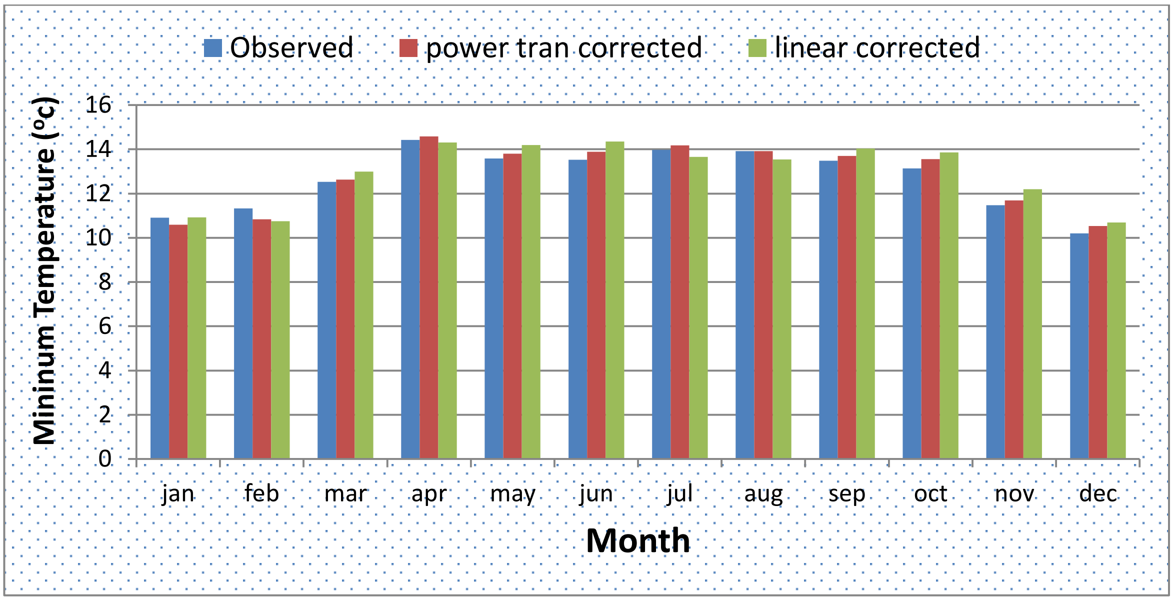


Figure 4.3 bias correction of mean monthly TMax for the base line period (1988-2017)

4.4 Scenarios Developed for Future (2018-2077)

The future climate change pattern includes precipitation, temperature (minimum and maximum), was analyzed under RCP 4.5 and RCP 8.5 scenario's for Gidabo watershed. To simulate the future flow, the future climate projection was carried out with down scaled and bias corrected RCP precipitation. The comparison was made between the baseline (1988-2017) period and two consecutive 30 years future periods: 2040s (2018-2047) and 2070s (2048-2077) respectively

4.4.1. Future Projection change of Rainfall Data

Projected changes in monthly rainfall data are vital means of evaluating the characteristics of rainfall at the study area. Appendixes A, Figure A.3 the general pattern of the change anomalies in annual areal precipitation against the baseline period (1988-2017). Anomalies were calculated as the difference from baseline period average areal precipitation to future periodic monthly average areal precipitation value.

Figure 4.5&4.6 Result shows the projected areal precipitation experiences a mean annual increase by 51.6mm in August and decrease by 69.19mm in April, other month are slightly decrease at RCP4.5 scenario at both period. For the result of RCP8.5 scenario at (2018-2047) are increase by 66.96 mm in August and decrease by 79.02mm in November. Also, the precipitation exhibits a mean annual decrease by 56.94mm in April and increase by 72.3mm in August and decrease by 85.12mm in November and increase by 75.62mm in

August for RCP 8.5 scenario at (2048-2077). As can be shown from Figure 4.5 and 4.6 below, in all periods there may be an increase in precipitation for months January, February, March , June and July for both RCP 4.5 and RCP 8.5 scenario and decrease in all other months for RCP 8.5 scenario. Generally, for the both projection periods the (January, February ,March, June and July) the rainfall exhibits a relative increase from the baseline period for both RCP 4.5 and RCP 8.5 scenario in all future time horizons. Results also indicate that the variation in mean annual rainfall is smaller than the variation in the monthly rainfall. The monthly precipitation change will be highly variable in August for both RCP 4.5 and RCP 8.5 scenarios in all time horizons.

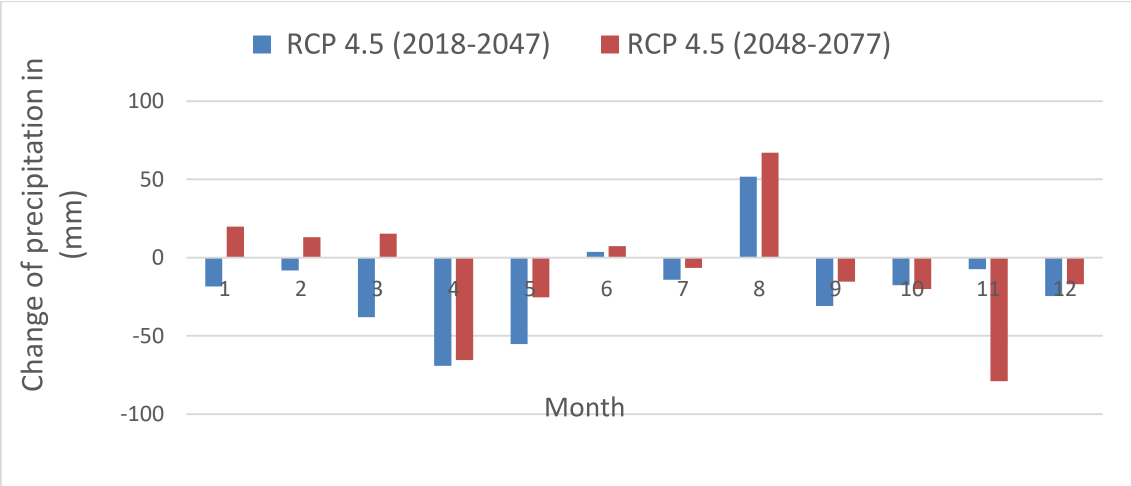


Figure 4.5 change in monthly precipitation in the future period from the baseline for RCP 4.5

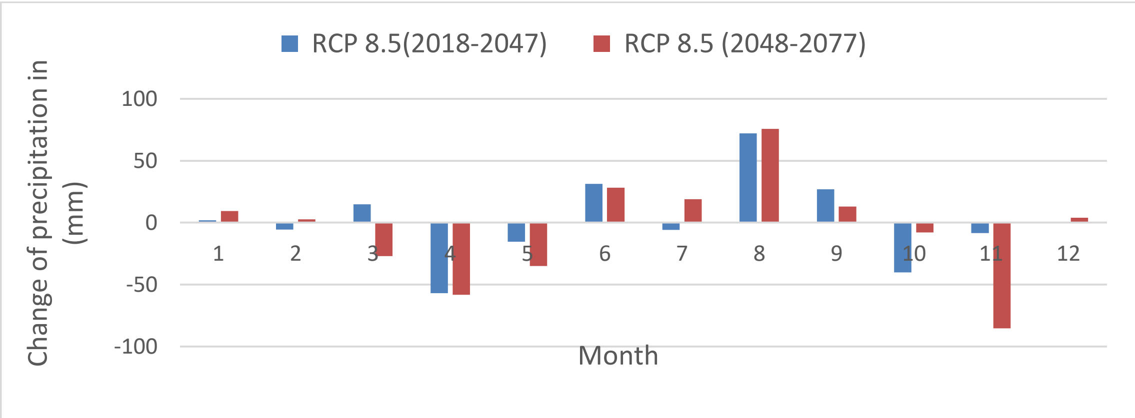


Figure 4.6 change in monthly precipitation in the future period from baseline for RCP 8.5

4.4.2 Future projection of Maximum Temperature

The projected maximum temperature result shows a distinct increase for both RCP 4.5 and RCP 8.5 scenarios. The relative change of maximum temperature from the baseline period for both scenarios in future time horizon are shown in the Figures 4.7 and 4.8

The average annual maximum temperature in June (2018-2047) will be shown an increase by 2.23°C and 2.74°C for RCP 4.5 and RCP 8.5 scenario, respectively. For the period (2048-2077) the average annual maximum temperature in June will be increased by 3.45 °C and 4.21 °C for RCP 4.5 and RCP 8.5 scenario respectively. An increase for RCP 8.5 scenario is greater than RCP 4.5 scenario because RCP 8.5 scenario represents a high emission scenario which produces more CO_2 concentration than the RCP 4.5 scenario which represents a low emission scenario. Increasing maximum temperature showed variation at the monthly time step with arrange from 0.1°C to 3.45°C in both future period, 0.1°C to 4.21°C in both future period for RCP 4.5 and RCP 8.5 scenario respectively.

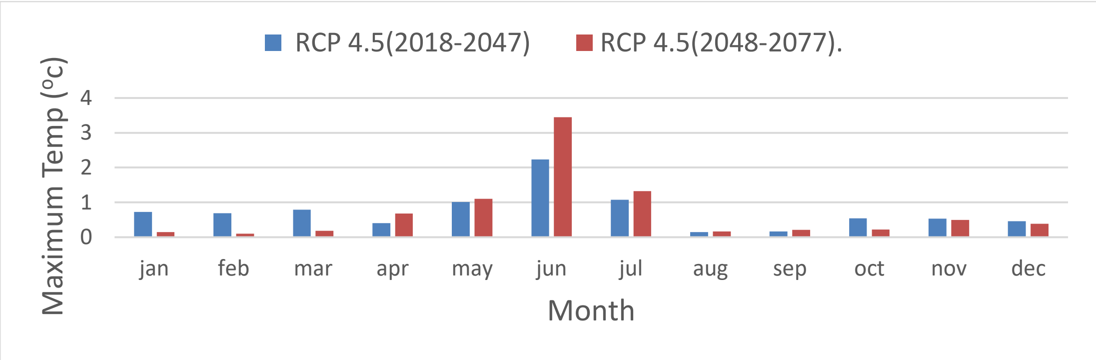


Figure 4.7: Change in monthly Tmax between the baseline period and future for RCP 4.5

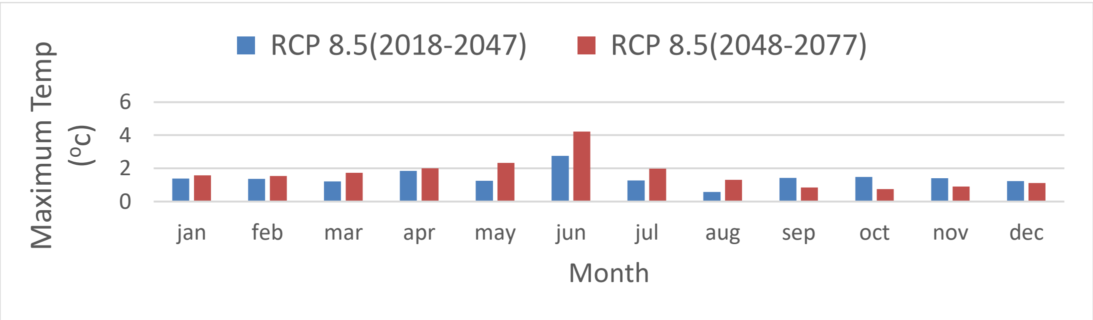


Figure 4.8: Change in monthly Tmax between the baseline and future period for RCP 8.5

4.4.3 Future projection of Minimum Temperature

The projected minimum temperature result also shows a distinct increase for both RCP 4.5 and RCP 8.5 scenarios. The average annual minimum temperature for the period (2018-2047) will be increased by 1.709°C and 2.87°C for RCP 4.5 and RCP 8.5 emission scenario respectively. For the (2048-2077) periods the average annual minimum temperature at June will be increased by 2.72°C and 3.02°C for RCP 4.5 and RCP 8.5 emission scenario respectively. The relative change of monthly minimum temperature varies from month to month. The maximum relative change of minimum temperature is observed in June where the minimum temperature will be increased by about 3.02°C for (2048-2077) for both RCP 4.5 and RCP 8.5 scenarios. . Increasing minimum temperature showed more variation at the monthly time from 0.117°C to 2.8°C in 2018-2047 and 0.83°C to 3.02°C in 2048-2077 and for both RCP 4.5 and RCP 8.5 emission scenario.

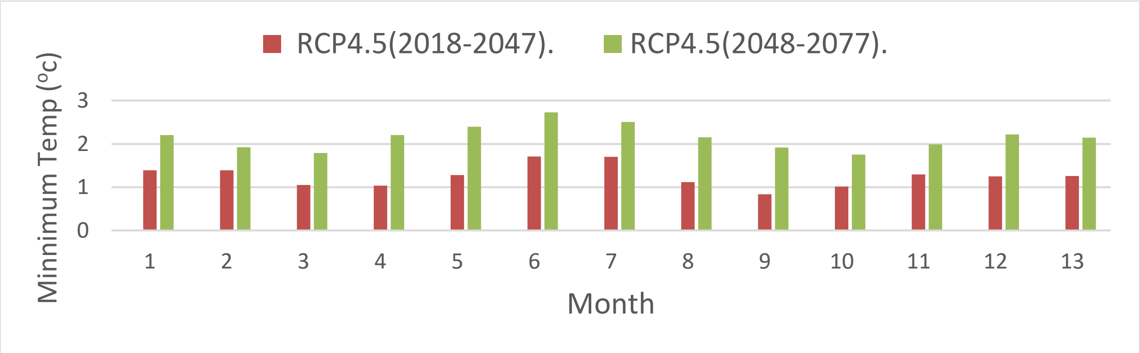


Figure 4.9: Change in monthly Tmin between the baseline period and future for RCP 4.5

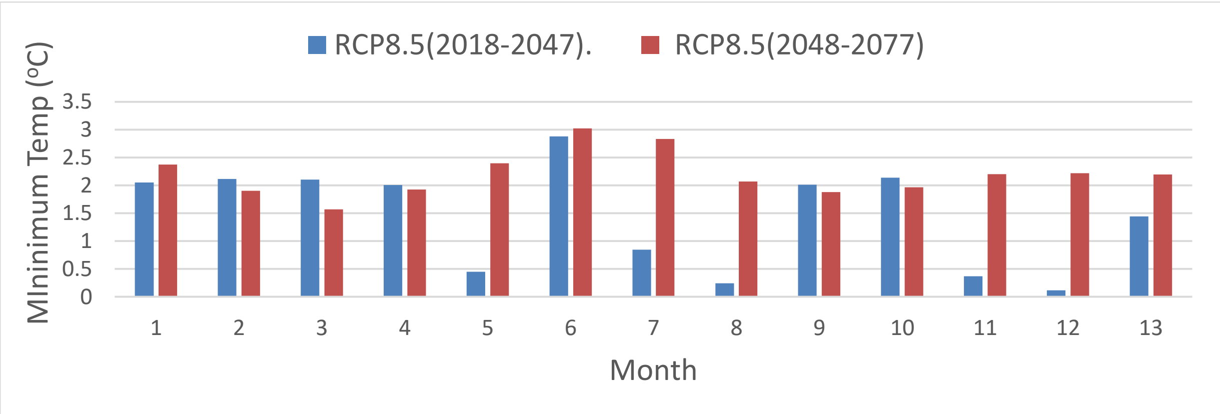


Figure 4.10: Change in monthly Tmin between the baseline and future period for RCP 8.5

4.5. SWAT Model Result

The Gidabo watershed modeling was done by using a time series dataset of 17 years from 1990 to 2006 out of which nine years (1992 to 2000) were used for calibration period and six years (2001 to 2006) for validation period. The simulated flow at the outlet of the watershed sub basin 29 were compared with the observed flow. The sensitivity analysis and calibration for land use phases were done at the outlet sub basin of the Gidabo watershed (sub basin 18).

4.5.1 Sensitivity Analysis

The results of the sensitivity analysis gave the degree of sensitivity of 10 parameters and the parameter selected based on p-value and t-value from twenty one parameters ten parameters were selected as the most sensitive parameters. The parameters the absolute value of t-value is high and p-value close to zero that parameter is the sensitive parameters mostly responsible for the stream flow assessment of the Logia watershed were ranking and description painted in table 4-2 with their fitted value.

Table 4.3 the most sensitive parameters

Parameters name	t-Stat	P-Value	Rank
v__ALPHA_BF.gw	-20.72	0.00	1
r__SOL_K (...).sol	-12.88	0.00	2
r__HRU_SLP.hru	-2.51	0.01	3
v__GW_DELAY.gw	-2.11	0.04	4
r__CN2.mgt	-1.57	0.12	5
r__SLSUBBSN.hru	-1.40	0.16	6
v__ESCO.hru	-1.16	0.25	7
a__GWQMN.gw	-0.91	0.36	8
v__GW_REVAP.gw	-0.70	0.48	9
r__CANMX.hru	-0.49	0.62	10

4.5.2 Model Calibration and Validation

After identification of the most sensitive input parameters, the SWAT model was calibrated based on the observed monthly streamflow at the Aposto gauging station for the 1992-2000 time periods and validation periods is 2001-2006 time periods .The first two years of this calibration period were used for the “spin-up” or “warm-up” of the simulated hydrological system, i.e. for its stabilization. The coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE) were used to evaluate the model performance for both calibration and validation time periods. Final simulated streamflow statistics for the Gidabo watershed were SWAT_CUP model where performance measure is statically calibration and validation included all twenty one parameter inputs. Visual representation of simulated outputs for calibration and validation were represented in Figure 4.14.

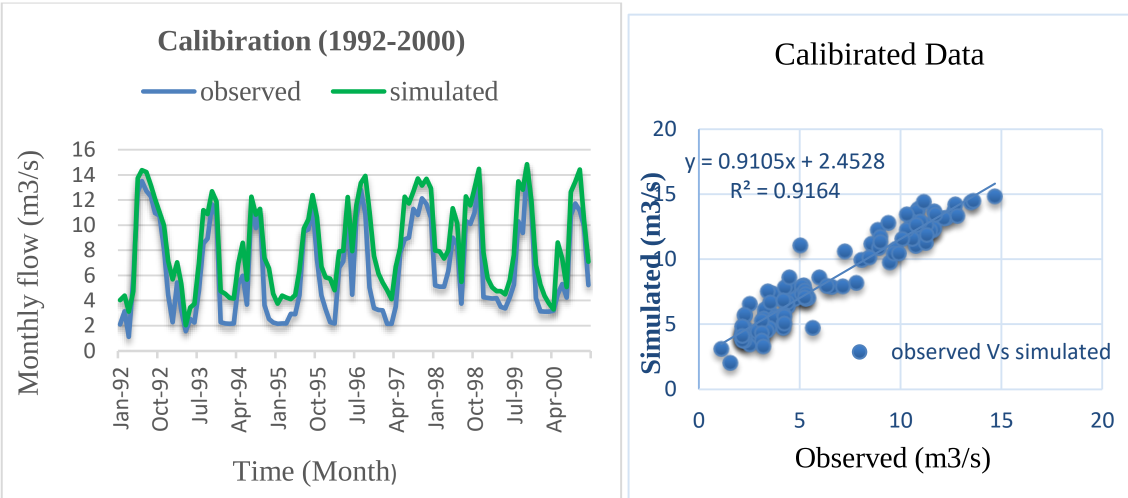


Figure 4.11 Monthly Simulated and observed stream flow Calibrations and scatter plot

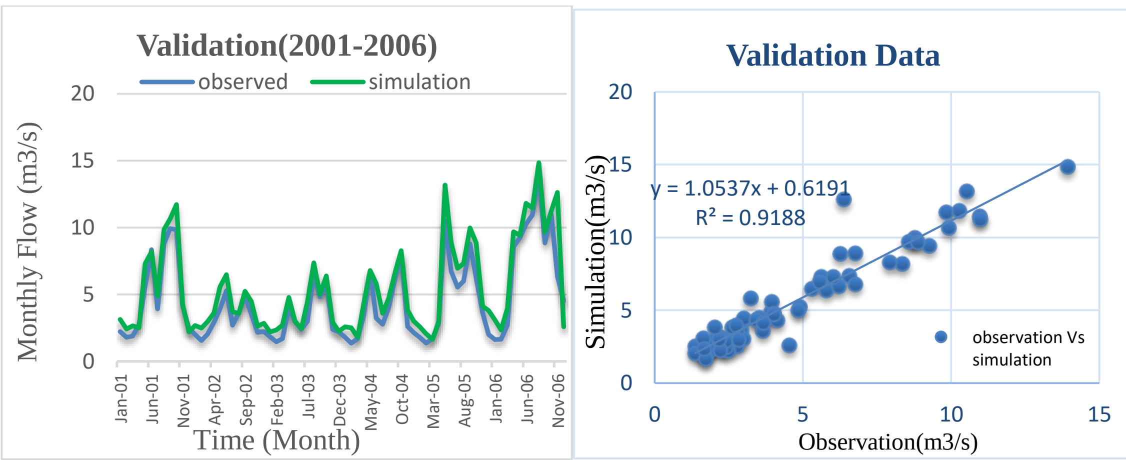


Figure 4.12 Monthly Simulated and observed stream flow Validation and scatter

Table 4.4 Model performance of the Gidabo River by calibration and the validation

Criteria	Calibration period	Validation period
R-factor	1.133	1.2
NSE	0.75	0.81
P-factor	0.75	0.74
PBIAS (%)	-8.7	-9.2
R^2	0.91	0.91

4.5.3 Uncertainty Analysis

All sources of uncertainty were mapped to a set of parameter ranges. Two different indices were used to quantify the goodness of calibration uncertainty performance. The percentage of data bracketed by the 95% prediction uncertainty (95PPU) band (P-factor) and a measure of the average width of the 95PPU (R-factor), Abbaspour (2015) suggested for P-factor, a value of >70% and R-factor of around 1.

Identifying the sensitive parameter not only assists to screen the important parameters for calibration but also to reduce uncertainty. The percentage of range shows the likely range of the model outcome for that particular parameter. Hence the narrower the percentage range, the smaller the model error, i.e. the higher is the confidence on the calibrated parameter. As the number of runs increases, the maximum and minimum values of the uncertainty range will be zeroing the optimal, calibrated value, eventually resulting in an uncertainty width close to zero as number of run increases

For this study, the P-factor and R-factor were described in table 4.3 and Annex Figure-A9 The result showed that the observed flow was bracketed in the 95PPU suggesting very good results or a minimal uncertainty in the model, which indicates SUFI-2 was able to capture most uncertainties.

4.6. Water Balance of the Gidabo Watershed

To estimate the Water Balance for the Gidabo watershed, the optimized parameters that have been obtained during calibration were transferred to un-gauged part by simulation using SWAT model. SWAT model has great advantage to estimate water yield for un-gauged catchments by assigning HRUs in the sub-catchments. Sub catchments with the same HRUs have the same responses for Water yield generation and in this research work, after modeled the gauged watersheds lumped parameters were transferred.

Table 4.5 Average annual water balance components of the GWS for the total simulated

Hydrologic parameters	1988-2017 (mm)	Calibration (1992 -2000) (mm)	Validation (2001-2006) (mm)
precipitation	1379.3	1373.4	1476
surface runoff	360.06	360.19	405.06
lateral flow	46.87	46.28	47.9
ground water flow (base flow)	686.15	664.8	680
Revap. shallow aquifer recharge	7.88	8.04	8.3
deep aquifer recharge	33.88	33.19	33.86
total aquifer recharge	727.9	706.04	722.9
total water yield	1076.3	1056.4	1114.9
percolation out of soil	677.65	663.76	677.1
evapotranspiration	362.4	394.6	421.4
potential evapotranspiration	623.1	462.2	516.2

Water yield was estimated by summing up surface runoff, lateral flow into stream & groundwater contribution to stream with consideration of percolation to shallow aquafer. Table 4.4 and Annex Figure 8 shows the time-series comparison between measured and simulated monthly flow at Gidabo River gauge station during calibration and validation periods. The results indicated that 21.2% of the annual precipitation is lost by evapotranspiration in the watershed during calibration as compared to 20.71% during validation period. Surface runoff contributes 26.2% and 27.43% of the rainfall during calibration and validation periods, respectively. While deep aquifer recharge contributes 2.41% and 2.3% of rainfall the during calibration and validation period respectively. Based on the comparison of the water yield is decrease both calibration and validation result of observed flow data

4.7 Simulation Results for Future Climate Scenarios

One of the objectives of this study is to show the impacts of possible climate change on the water resources in the Gidabo watershed. The outputs from the downscaling tools result are used as input in the SWAT hydrological model to simulate the future water responses in the region. By using of the downscaling combinations, uncertainties due to the choice of the RCM.

Table 4.6 Hydrological modeling cases for future climate scenarios

Case	**Downscaling Tools**	**RCM**	**Scenario**	**simulation period**
1	DDSM	HadGEM2-ES	RCP4.5and RCP8.5	2048s and 2077s

4.8 Results using RCP Downscaled scenario Output in the SWAT Model

RCP downscaled, HadGEM2-ES GCM predictors in the SWAT model. As usually, RCP 4.5 and RCP 8.5 scenarios are simulated for the two future time periods, the (2018- 2047) and the (2048-2077). The results obtained for the various water balance components in the SWAT model are summarized in the Table 4.6 the values obtained the impacts of climate change can immediately change in the watershed future climate. The monthly future variations of precipitation, water yield, and PET and ET water balance components for the two RCP- scenarios and the two future time periods the table reveal that, compared with base period total water yield decreases in both RCP-scenarios. This is mainly due to a decrease of the future precipitation and an increase of the future temperatures and PET.

This is easy to understand, as the PET is computed in the SWAT model by the Hargreaves method (see Eq.3.8), where only the maximum and minimum temperatures were used. As the latter are expected to increase in the future (see Table 4.5), the PET must also increase.

A future increase of temperatures (Appendix-Fig A4) accompanied by a decrease of precipitation facilitates a decrease of surface runoff, lateral flow and base flow and, consequently, an overall decrease of the total water yield in the basin.

Table 4.7 Average future annual basin values using RCP scenario output in the SWAT

Hydrologic parameters	**1988-2017 (mm)**	**RCP4.5 2018-2047s (mm)**	**RCP4.5 2048-2077 (mm)**	**RCP8.5 2018-2047 (mm)**	**RCP8.5 2048-2077 (mm)**
precipitation	1379.3	1260.5	1112.2	1222	1010.5
surface runoff	360.06	329.8	281.43	307.6	331.4
lateral flow	46.87	40.73	28.3	34.3	35.9
ground water flow (base flow)	686.15	424.2	392.1	407.1	226.4
Revap. shallow aquifer recharge	37.88	35.51	28.4	35.51	36.4
deep aquifer recharge	33.88	16.08	14.49	11.61	12.44
total water yield	1076.3	882.3	781.29	846.9	679.15
percolation out of soil	677.65	321.6	289.83	232.27	249.3
evapotranspiration	362.4	768.1	761.1	747	754.1
potential evapotranspiration	623.1	1452.3	1504.2	1357.4	1819.8

Water yield was estimated by summing up surface runoff, lateral flow into stream & groundwater contribution to stream with consideration of percolation to shallow aquafer. Table 4.6 shows the time-series to future projection scenario of (2018-2047) and (2048-2077) comparison Water yield between measured monthly flows at Gidabo River gauge station. The results indicated that RCP4.5 and RCP8.5 at (2018-2047) and (2048-2077) of the water yield is decrease by 18.02%/21.3% and 27.45%/36.9%, respectively

4.9. Results of the Trend Analyses

For the trend analyses of the Gidabo watershed meteorological data, that the statistical software Auto-MK XLSTAT were used. The trend test result shows that the presence of a statistically significant trend in the precipitation. Similarly, show a statistically significant trend in the minimum temperature, whereas for only one sub-station a trend in the maximum temperature is observed.

It should be noted that if null hypothesis is accepted in some cases that doesn't mean that it was proven that there is no trend rather, it is a statement that the evidence available is not sufficient to conclude there is not trend (Helsel and Hirsch, 2002). But the Mann-Kendall test general result that sows which accounts monthly time series (i.e., 12 months) is shown in Table 4.7 of the Gidabo watershed of representative station such as Dilla, the result that significant trends of precipitation, and minimum temperature in the watershed and maximum temperature is shown positive statistically significant trend test This describes annual mean monthly precipitation and temperature are no significant trend. Although seasonal Mann-Kendall tests result shows almost similar results as the monthly Mann-Kendall trend test.

The trend analysis was done for annual observed time series of precipitation, maximum and minimum temperature for the study area using statistical software XLSTAT, this trend analysis was done for the observed data from 1988 to 2017 to show the trend results increasing or decreasing. On running the Mann-Kendall test on observed temperature and precipitation data, the following result are for Dilla station

Table 4.8 Mann-Kendall test result for precipitation, maximum and minimum temperature of Dilla station

	Mann-Kendall test result			
variables	**Zs**	**Zcrit,.05**	**Son slope**	**Test interpretation**
Precipitation	-0.07.	> 1.96	-0.85	Accepted Ho (no statistical significant rainfall trend)
Maximum temperature	1.55	> 1.96	0.021	Accepted Ho (there is statistical significant maximum temperature trend)

Minimum temperature	2.8	> 1.96	0.036	Rejected Ho (no statistical significant minimum temperature trend)

If Zcrit, .05 value is greater than Zs the Ho is accepted. Rejecting Ho indicates that there is a trend in the time series, while accepted Ho indicates was detected. On rejecting the null hypothesis the result is said to be statistically significant. Mann-Kendall test shows a trend for rejected and accepted Ho with their statistical significance. Table 4.7 maximum temperature was only indicates statistical significant increasing trend. In case of precipitation and minimum temperature shows statistical insignificant trend. The Mann-Kendall test results for mean annual of precipitation, maximum and minimum temperatures (Table 4.8). Mean annual maximum temperature trend is statistical significant increasing trend the rest is insignificant trends (Figure 5.1).

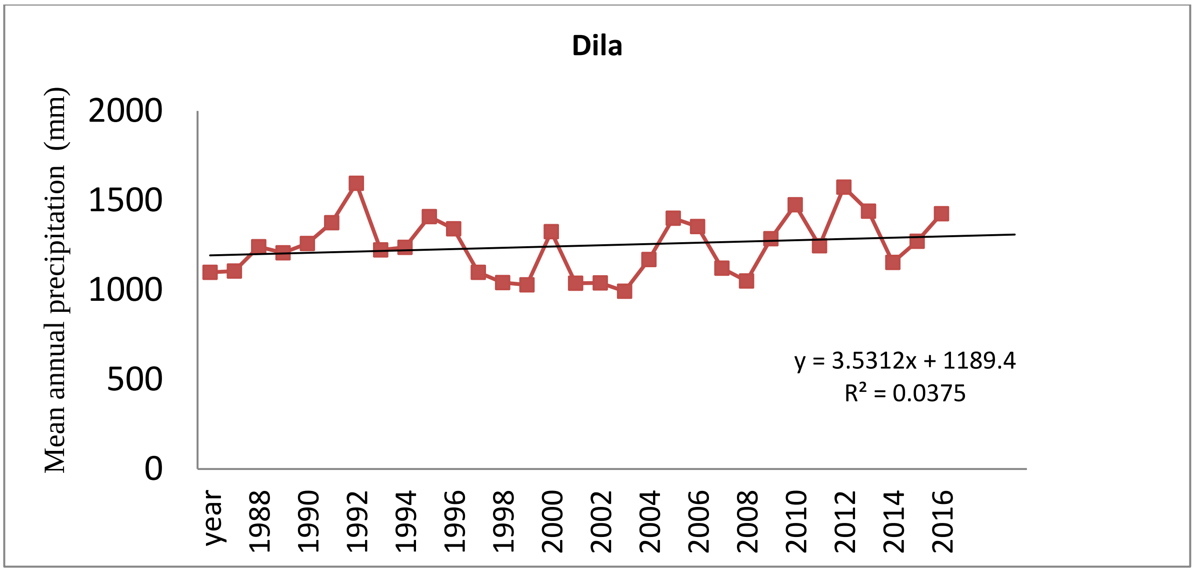


Figure 4.13 Annual observed time series for precipitation of Gidabo watershed from 1988 – 2017 in Mann-Kendall trend test

The Mann-Kendall result of precipitation shows that the observed period (1988-2017) is not sufficient to conclude either increasing or decreasing. The trend of mean annual precipitation highly change in observed time period.

If null hypothesis is accepted in some case that doesn’t mean there is no trend rather it is statement of the available observed period is not sufficient to conclude there is no trend (Helsel and Hirsch, 2002; Cherie, 2013). Statistical insignificant trends that neither increase nor decreases for mean annual minimum temperature and precipitation may due to the available data is not sufficient to conclude there is no trend (Figure 4.13 and Figure 4.14).

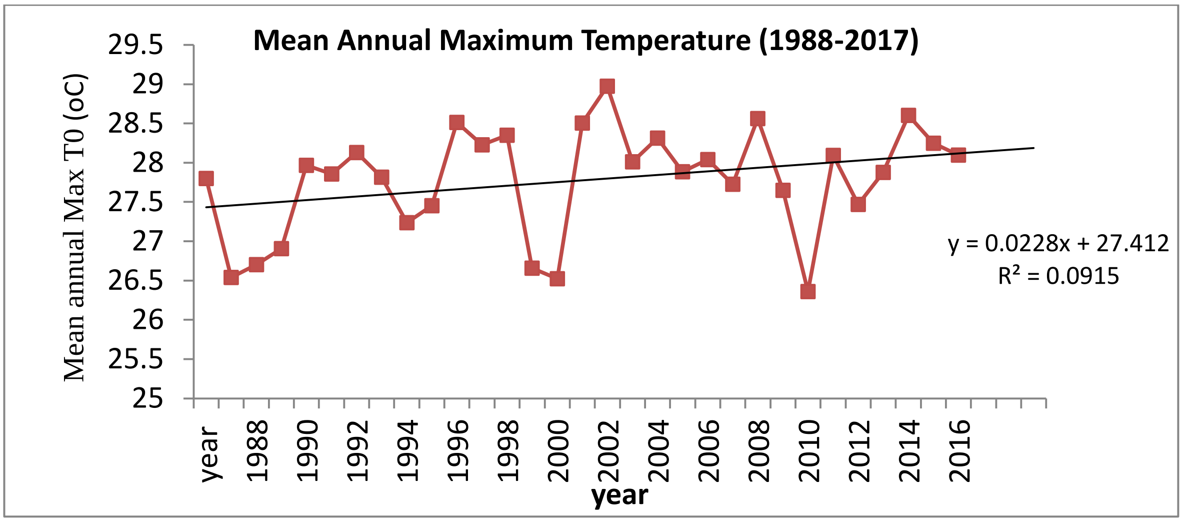


Figure 4.14:- Annual observed time series for Maximum Temperature of Gidabo watershed from 1988 – 2017 in Mann-Kendall trend test

The Mann-Kendall trend test result of mean annual maximum temperature shows positive difference is higher than the negative difference. The test conclude its increasing though observed time period. Mean annual maximum temperature shows increasing and decreasing trend in observed time period. The maximum mean annual temperature observed in 2002 by 28.93 °c and the minimum observed 2010 by 26.3°c (see Figure 4.14).

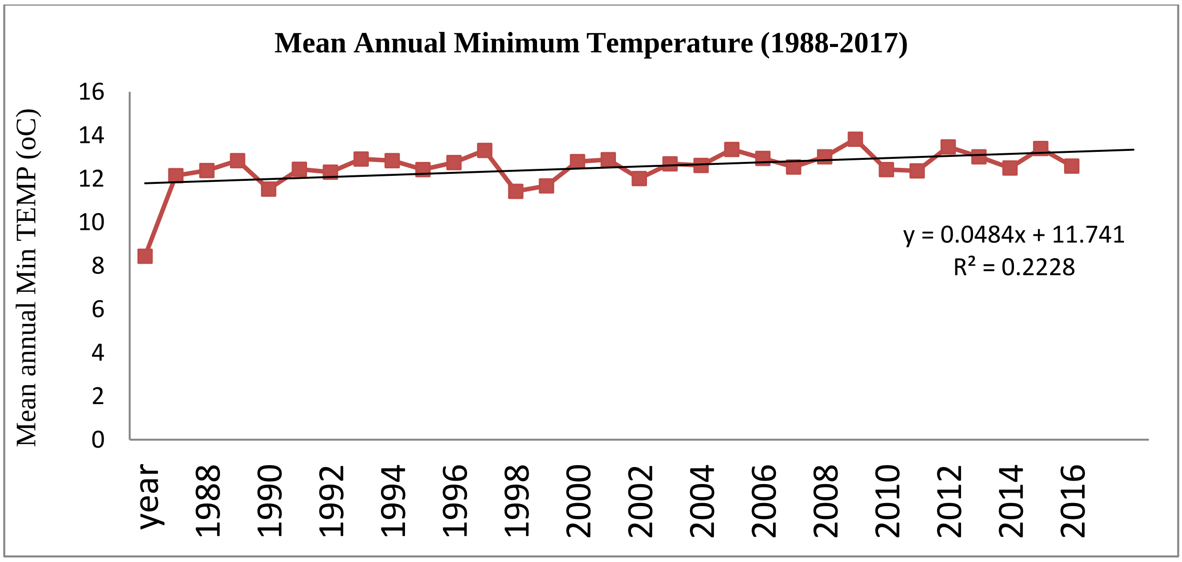


Figure 4.15:- Annual observed time series for Minimum Temperature of Gidabo watershed from 1988 – 2017 in Mann-Kendall trend test

Mean annual minimum temperature shows similar trend in most of observed time period. The lowest mean annual minimum temperature observed in 1988 by 8.4 °c and the higher is observed in 2009 by 13.7 °c. The Mann-Kendell trend test result of mean minimum temperature is not sufficient to conclude that it increases or decreases (see Figure 4.15).

Table 4.9 Mann-Kendall trend test results of precipitation, maximum and minimum temperate

	Mann- Kendall trend result		
	Precipitation	Maximum Temperature	Minimum Temperature
Observed time series (1988 – 2017)	No trend	Sign (+)	No trend

Table 4.8 were shown Mann-Kendall trend test result that describes "**No**" implies there is no statically significant trend, "**Sign**" represents the presence of statically significant trend, and **(+)** increasing trend and **(-)** decreasing trend with the values of X which is the time series

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study impact of climate change on water availability of Gidabo watershed for 2017's, 2048's, 2077's under HadGEM2-ES (GCM) RCP4.5 and RCP8.5 climate scenario using DDSM climate model and SWAT hydrological model.

The DDSM result indicated Gidabo watershed is susceptible to climate change. The model indicated that both minimum and maximum temperature shows an increasing trend in all future horizons for RCP 4.5 and RCP 8.5 scenarios. The annual average maximum temperature for (2018-2047) increased from 1.23 °c to 2.64 °c for RCP 4.5 and RCP 8.5 scenarios respectively. For the (2047-2077) periods the annual average maximum temperature increased from 2.57°c to 3.54°c for RCP 4.5 and RCP 8.5 scenarios respectively. Although annual average minimum temperature for (2018-2047) increased from 1.26°c to 3.27 °c for RCP 4.5 and RCP 8.5 scenarios respectively. For the (2047-2077) periods the annual average minimum temperature increased from 0.23°c to 2.3°c for RCP 4.5 and RCP 8.5 scenarios respectively of the same time period. In Gidabo watershed the average annual minimum temperature highly change in comparing with maximum temperature and both temperatures of all months shows increasing. . Average annual rainfall decreased 69.19mm and 72.3mm at RCP4.5 and RCP8.5 for (2018-2047) respectively and annual mean rainfall decreased 79.02mm and 85.12mm at RCP4.5 and RCP8.5 for (2048-2077) respectively

The SWAT model is calibrated and validated on streamflow observed at the Aposto gauging station during the 1990-2006 period. The model performance is evaluated using the percent of bias (PBIAS), the Nash-Sutcliffe model efficiency (NSE), the standardized root mean square error (RSR) and the square of the Pearson's product-moment correlation the values indicate that the model performed well during calibration and validation period. The result of hydrological model calibration and validation indicated that the SWAT model simulates the flow significantly well for the study area. The model performance criterion which is used to evaluate the model result, the regression coefficient and the Nash-Sutcliffe simulation efficiency values gained showed this fact. The model performance criteria of Nash and Sutcliffe value R_2=0.91 for calibration and R_2 =0.91 for validation.

The downscaled result outputs of the climate model shows the time-series to future projection scenario of (2018-2047) and (2048-2077) comparison Water yield The results indicated that RCP4.5 and RCP8.5 at (2018-2047) and (2048-2077) of the water yield is decrease by 18.02%/21.3% and 27.45%/36.9% respectively.

Trend analysis has been third most task the presence of possible trends test for precipitation, maximum and minimum temperature in the Gidabo water shed is checked at the station level using the concepts of the Mann-Kendall and the seasonal Mann-Kendal tests, as implemented in the XLSTAT statistical software package. The result shows that mean monthly precipitation and temperature are no significant trend. Although seasonal Mann-Kendall tests result shows almost similar results as the monthly Mann-Kendall trend test. But Gidabo watershed of representative station such as Dilla, the result that significant trends of precipitation, and minimum temperature in the watershed and maximum temperature is shown positive statistically significant trend test and precipitation also slightly declined negative trend .

5.2 Recommendation

Based on the experiences gained during the execution of this study and the final results obtained of the following recommendations are given.

- This study was only based the outcome of Had GEM-ES model use RCP 4.5and 8.5 scenario's. However, it is recommended to apply different model scenarios to make comparison between their results.
- The physically based, spatially distributed, and public domain Soil and water assessment tool (SWAT) is found to be a very appropriate tool to simulate runoff in the water shed.The model simulations considered only future climate change scenarios assuming land use/land cover constant. But change in land use scenarios, soil, management activities and other climate variables will also contributes some impacts on runoff. Therefore; future studies on climate change impacts should include land use and different GCM out puts.

- Stream flow and water availability stress that may occur in the wake of climate change may be exacerbated by the large population increase and many other problems plaguing the country. Since the current and anticipated problems are inter-related with one depending on the other, the author of this research strongly believes that an integrated approach across different societal sectors and disciplines should be taken, and that there is a need to implement practical projects on the ground at the local scale. For successful implementation, such projects may need the support of professionals from various sectors, governmental and non-governmental organizations.

- Though the SWAT watershed model is very popular and has been applied all across the world it requires many input parameters for proper use. Most of the inputs used here are based on default values, as they have been measured in some watersheds of the USA. So, in order to better reflect the actual watershed characteristics, efforts should be made to measure more exactly some of the measurable inputs and archive these at the national level, so that they are easily accessible for use in future research.
- Since the soil and land cover of the Gidabo water shed is extremely varying, the soil and land cover data of this basin should be updated from time to time, using techniques such as field sampling and remote sensing technologies.

REFERENCES

Abbaspour, K. C. (2007). SWAT-CUP4: SWAT calibration and uncertainty programs–a user manual. Swiss Federal Institute of Aquatic Science and Technology, Eawag, 106.

Abdo, K. (2008). Assessment of climate change impact on Hydrology of Gigle Abay

Catchment in the Lake Tana basin, Ethiopia. M.Scs. Thesis. ITC, Netherlands.

Adem, A., & Bewket, W. (2011). A Climate Change Country Assessment Report for Ethiopia. Working Paper, Addis Ababa.

Alemseged Tamiru and Tom. R. (2015). Evaluation of regional climate model simulations of rainfall over the upper Blue Nile basin. Atmospheric Research 161-162(2015)57-64

Amba, S.S (2016) Evaluation of climate change impacts on runoff in the Gidabo river basin: Southern Ethiopia. Published Msc Thesis Arba Minch University, Ethiopia

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., ... & Kannan, N. (2012). SWAT: Model use, calibration, and validation. Transactions of the ASABE, 55(4), 1491-1508.

Arnold, J.G., P.M Allen, R. Muttiah, and G. Bernhardt. (1998). Automated base flow separation and recession analysis techniques. Ground Water 33(6): 1010-1018.

Arnold, J.G., P.M. Allen (1996). Estimating hydrologic budgets for three Illinois watersheds, Journal of Hydrology 176, 57-77.

Belihu, M., Abate, B., Tekleab, S., and Bewket, W. (2018). Hydro-meteorological trends in the Gidabo Catchment of the Rift Valley Lakes Basin of Ethiopia. Physics and Chemistry of the Earth. 104, 84-101.

Carter, T.R. (2007). General Guidelines on use of climate scenario data for climate impact and Adaptation assessment. Finish Environmental Institute Heli inky, Finland.

Cherie. (2013). Downscaling and Modeling the Effects of Climate Change on Hydrology and Water Resources in the Upper Blue Nile River Basin, Ethiopia. Germany: Department of Civil Engineering, University of Kassel

Chow, V.T., Maidment, D.R. and Mays, L.W., 1988. Applied hydrology McGraw-Hill International editions. New York, USA.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., Jones, R., Kolli, R.K., Kwon, W.K., Laprise, R. and Magaña Rueda, V., 2007. Regional climate projections. In Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press, Cambridge, Chapter 11 (pp. 847-940).

Coulibaly, P., & Dubik, Y. B. (2004). Downscaling of global climate model outputs for flood frequency analysis in the Saguenay river system. Final Project Report prepared for the Canadian Climate Change Action Fund, Environment Canada, and Hamilton, Ontario, Canada

Danuso, F. (2002). Climak: A Stochastic Model for weather Data Generation. Italian Journal of Agronomy 6 (1): 57-7, 67-68.

Debisso, B., 2009. Groundwater Resource Assessment in the Gidabo River Catchment. In the Southern Main Ethiopian Rift Province. /Yirgalem-Wonago (Doctoral dissertation, Addis Ababa Universty).

Earls, Dixon (2008). A Comparison of SWAT Model-Predicted Potential Evapotranspiration Using Real and Modeled Meteorological Data, Vadose Zone J. 7, 570–580.

Emerta, A. (2013) climate change, growth, and poverty in Ethiopia. The Roberts. Strauss center, working paper No.3..

Ermias.E. (2017). Evaluating climate change impact on koka reservoir performance, Ethiopia Unpublished Msc. Thesis, Institute of Technology, Hawassa University, and Hawassa.8pp.

Evans, J. P. (2011). CORDEX – An international climate downscaling initiative. Climate Change Research Centre.

Giorgi, F., & Mearns, L. (1991). Approaches to the simulation of regional climate change: A review. Rev. Geophys, 29, 191-216

Giorgi, F., Jones, C., & G. R., A. (2009). Addressing climate information needs at the regional level: the CORDEX framework. WMO Bulletin, 58 (3), 175-183.

Goddness, C., C. Anagnostopoulou, A. Bardossy, C. Frei, C Harpham, M. R. Haylock, Y Hundecha, P. Maheras, J. Ribalaygua, J. Schmidli, T. Schmith, T. Tolika, R.Tomozeiu, R. L. Wilby (2007). An inter comparison of statistical downscaling methods for Europe and European regions – assessing their performance with respect to extreme temperature and precipitation events.

Grigory, N. (2013). Regional Climate Modeling Resultsand Ensemble using RCA4. The Fifth Expert Group Meeting. Amman, Jordan.

Gupta, V., Sorooshian, S. and Yapo, P. (1999). Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of Hydrology engineering, 4, 135-143.

Haile T. (1990). Drought in Ethiopia, In 3rd WMO Symposium on Meteorological aspects of Tropical Droughts, Niamey, 30 April- 4 May 1990, WMO TMRP Series 36, 273-278.Zewude, K. (2016). Land use land covers change analysis and runoff estimation using Arc SWAT model in Gidabo watershed. Unpublished Msc. Thesis, Institute of Technology, Hawassa University, Hawassa.93pp.

Helsel, D. R., R.M. Hirsch (2002). Statistical Methods in Water Resources, U.S.Geological Survey Techniques of Water Resources Investigations; Book 4, Chapter A3.

Houghton, J. T. (2001). Climate change 2001: the scientific basis: contribution of working groupI to the third assessment report of the intergovernmental panel on climate change: Cambridge University Press.

Intergovernmental Panel on Climate Change. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In

Climate Change 2007: Impacts, Adaptation and Vulnerability; Parry, M.L., Canzoni, O.F., Politick of, J.P., van der Linden, P.J., Hanson, C.E., Eds.;Cambridge University Press: Cambridge, UK, 2007; p.1000

IPCC, 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2007a) Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by Parry et al. Cambridge Univ. Press, Cambridge, U. K.

Karmeshu, N., & Frederick, S. N. (2012). Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test – A Case Study to Assess Climate Change on Select States in the Northeastern United States. *Scholarly Commons*, 6 - 22.

Kedir, Y. (2002)**.** Hydrogeology of upper Gidabo River catchment, Southern Ethiopia. Unpublished Msc Thesis Addis Ababa University, Ethiopia.

Keller, M. (2009). Climate Risks and Development Projects: Assessment Report for a Community-Level Project in Guduru, Oromiya, Ethiopia.

Khalid, K., Ali, M., Rahman, N., Mispan, M., Haron, S., Othman, Z. and Bachok, M. (2016). Sensitivity analysis in watershed model using SUFI-2 algorithm. Procedia Engineering 162, 441-447

Kinfe, B. (2017). Multipurpose Reservoir Performance under Climate Change on Kesem Irrigation Dam, MSc thesis, Arbaminch University, Aribaminch Ethiopia

Leander, R., & Buishand, T. A. (2007). Resampling of regional climate model output for the simulation of extreme river flows. Journal of Hydrology, 332(3-4), 487-496

Leggett, J., Pepper, W.J., Swart, R.J. (1992) Emissions Scenarios for IPCC: an update. In Climate Change 1992. The Supplementary Report to the IPCC

Scientific Assessment Eds Houghton, J.T., B.A.Callander and S.K. Varney. Cambridge university press.Cambridge, UK.69 95.

Lenhart, T., K. Eckhardt, N. Fohrer, H. Frede (2002). Comparison of different approaches of sensitivity analysis, Physics and Chemistry of the Earth 27 (2002) 645–654.

McBean, & Motiee, H. (2009). An Assessment of Long Term Trends in Hydrologic Components and Implications for Water Levels in Lake Superior. *Hydrology research*, *40*, 564 - 579.

Mearns, L.O., M. Hulme, T.R. Carter, R. Leemans, M. Lal, and P. Whetton. (2003) Guidelines for use of climate scenarios developed from Regional Climate Model experiments. Data Distribution Centre of the International Panel of Climate Change, 38 pp. Available for download from: http://ipcc-ddc .cru. uea .acuk

Melese, S. (2016). Effect of Climate Change on Water Resources. Journal of Water Resources and Ocean Science. 5(1), 14-21.

Nakic´enovic´, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., et al. (2000). Emission scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, 599pp..

NMSA, (2007). Climate Change National Adaptation Prgramme of Action (NAPA) of Ethiopia. National Meteorological Service Agency. Addis Abeba, Ethiopia.

Ringius, L., Downing, T.E., Hulme, M., Waughray, D., Selrod, R., 1996. Climate change in Africa: Issues and challenges in Agriculture and Water for Sustainalbe Development. CICERO Report, 8. University of Oslo, Norway, p. 151.

Srinivasan, R. (2015). Soil and Water Assessment Tool Beginner SWAT Training Manual. Workshop at Spatial Science Laboratory, Texas A and M University. January 26-28th 2015.

Tatek, 2013.land use and climate change impacts on flow in Gidabo River.

Teutschbein, C., & Seibert, J. (2013). Regional Climate Models for Hydrological Impact Studies at the Catchment Scale: A Review of Recent Modeling Strategies. Geography Compass, 4 (7), 834–860,doi:10.1111/j.1749-8198.2010.00357.x.

Tharme, R.E. (2003). A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications, 19(5-6), 397-441.

Van Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., et al. (2011). The representative concentration pathways: an overview. Climatic Change, 109, 5-31, DOI 10.1007/s10584-011-0148-z

Vörösmarty, C.J., Douglas, E.M., Green, P.A. and Revenga, C., 2005. Geospatial indicators of emerging water stress: an application to Africa. AMBIO: A journal of the Human Environment, 34(3), pp.230-236.

Wilby, R. L., Hassan, H., & Hanaki, K. (1998). Statistical downscaling of hydro meteorological variables using general circulation model output. Journal of Hydrology, 205, 1-19.

Yitea Seneshaw, G. (2014). Assessing the Impacts of Climate and Land use Changes on Hydrology of the Upper Awash River Basin in Ethiopia, using a Conceptual Hydrological Model. M.Sc Thesis Hydrology and Quantitative Water Management

APPENDICES

Appendix-A: Meteorological Stations

Table A-1:- Location and collected data of meteorological stations around the study area

Stations	Latitude	Longitude	Rainfall	Temp Min	Temp Max	Sun shine hours	RH	Wind speed
Dil1a	38.52	6.49	Yes	Yes	Yes	Yes	Yes	Yes
Hagere selam	38.2	6.15	Yes	Yes	Yes	No	No	No
Teferi kela	38.23	6.0	Yes	Yes	Yes	No	No	No
Yrga chefe	38.9	6.82	Yes	Yes	Yes	No	No	No
yirgalem	38.4	6.87	yes	yes	yes	No	No	No

Table A-2:- Percent of missing precipitation in study area

SN	Station	Total no of missing	%missing	Filing method
1	Dilla	1132	9.9	Arithmetic
2	Hager selam	910	8.03	Arithmetic
3	Tefer kela	832	7.35	Arithmetic
4	Yirga chefe	1362	12.02	Normal Ratio
5	yirgalem	1721	15.199	NormalRatio

Figure A.1:- Consistency test for Gidabo water shed Meteorological Station

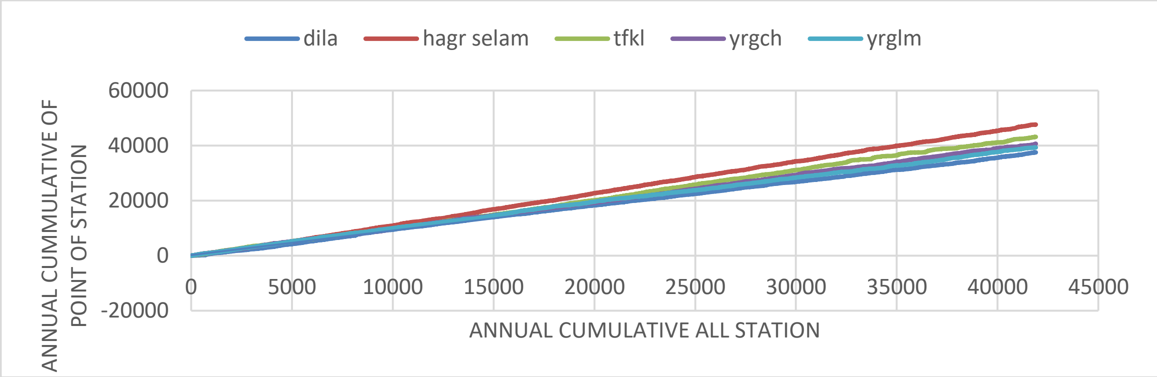


Figure A.2:- Homogeneity test for Gidabo water shed Meteorological Stations

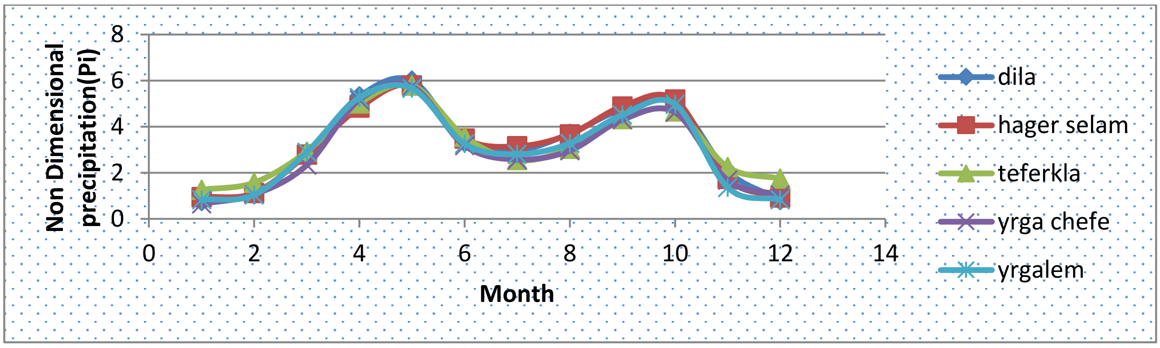


Figure A.3:- Hydrological gauged stream flow of Gidabo River

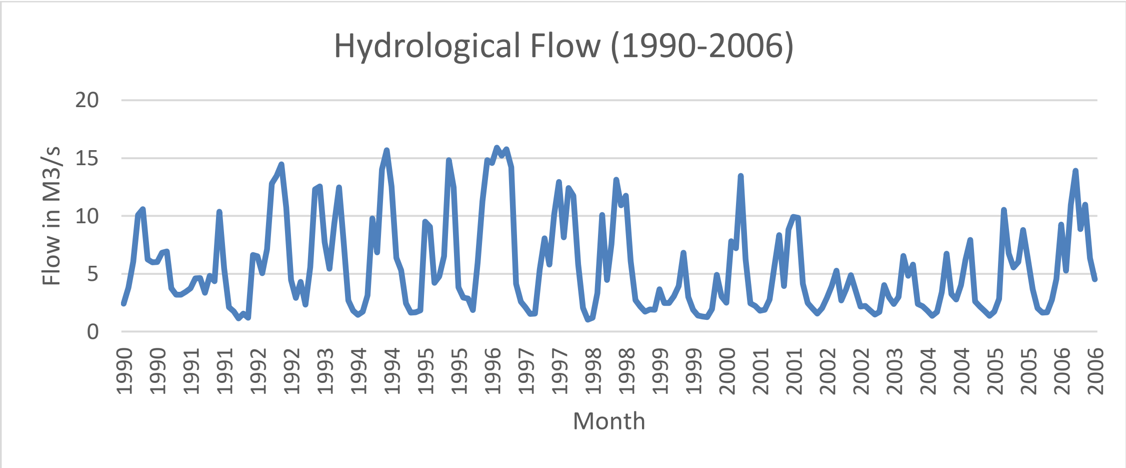


Figure A.4:- Annual Rainfall of projection of base period and future scenario (2018-2077)

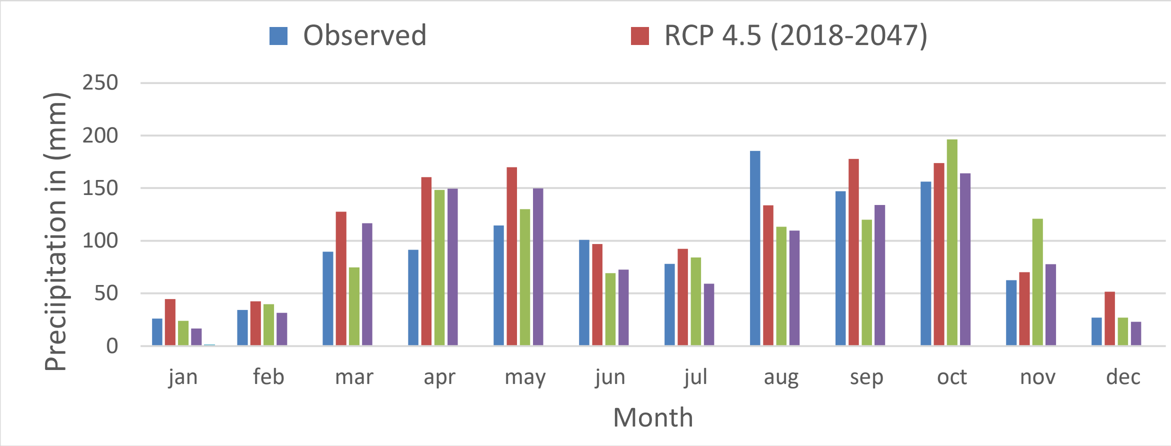


Figure A5. Average monthly Max Temperature base period and future scenario (2018-2077)

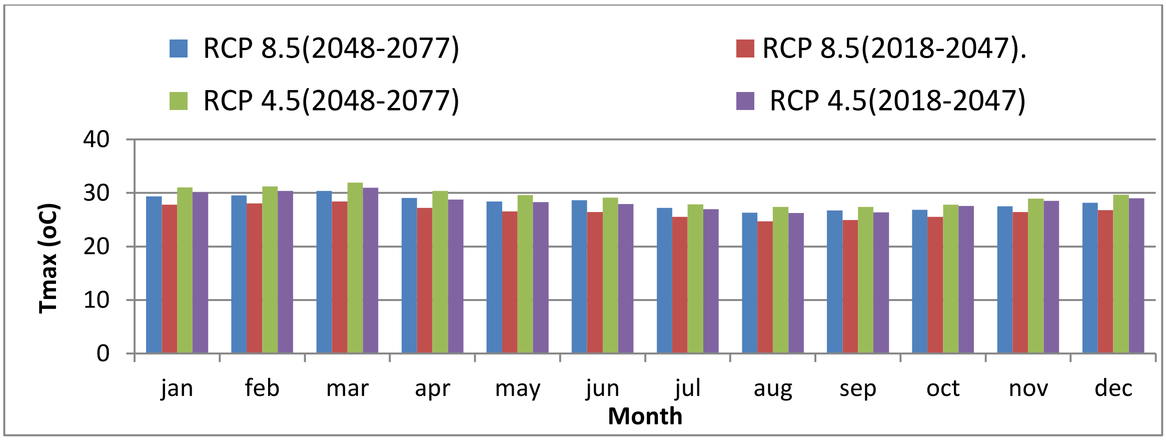


Figure A6. Average monthly Min Temperature base period and future scenario (2018-2077)

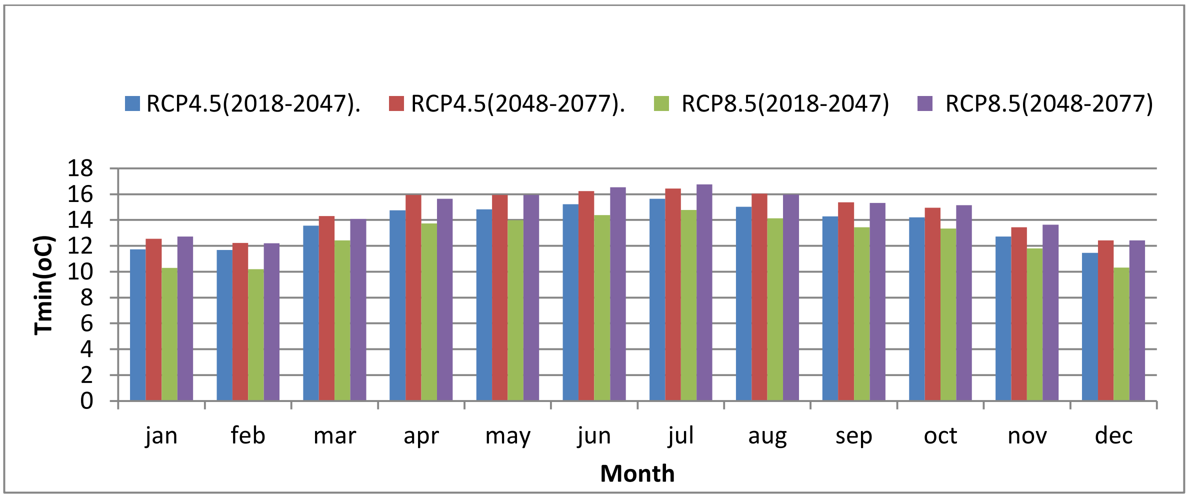


Figure A7. Water balance result of Gidabo Watershed from (1988-2017)

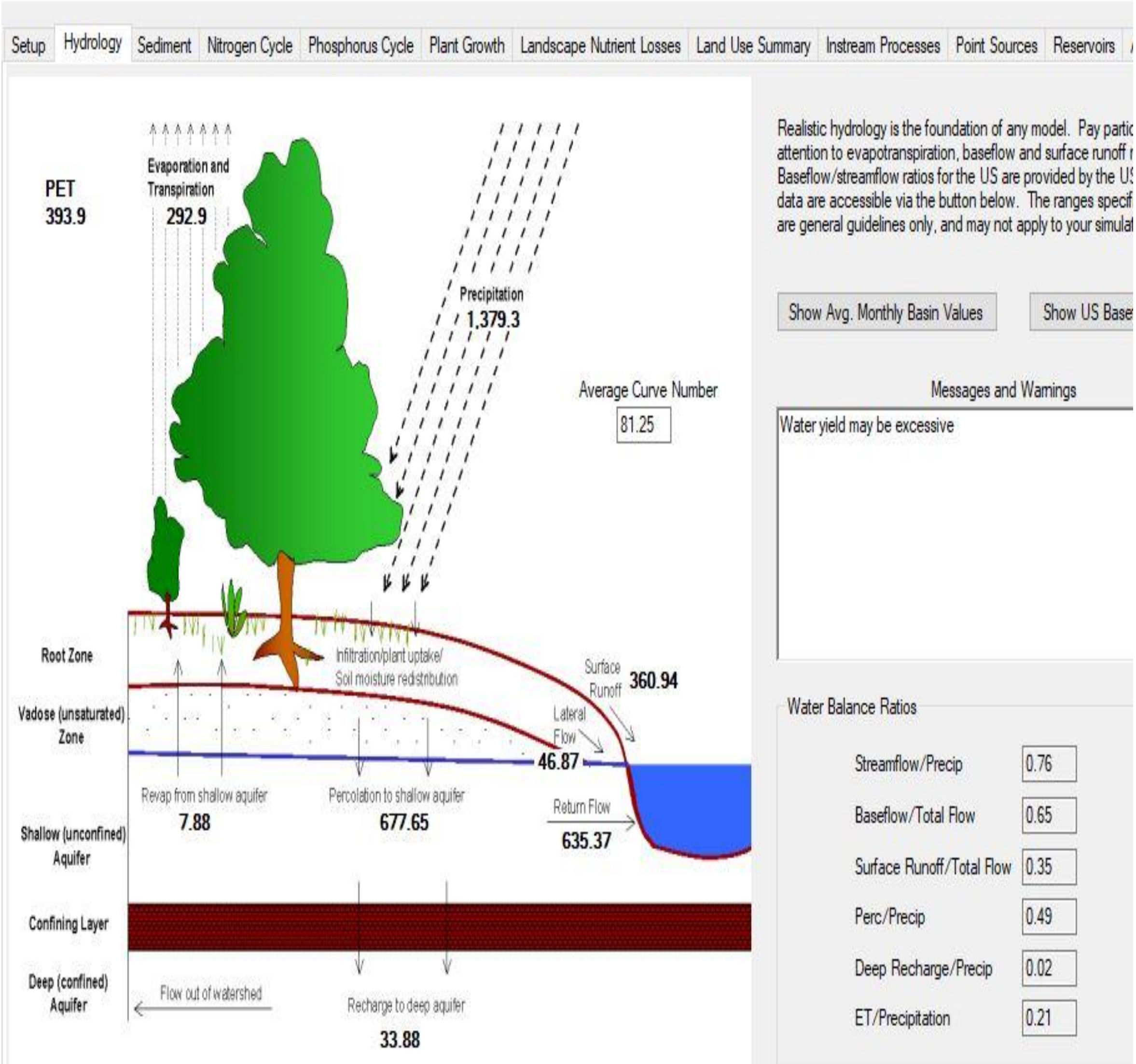
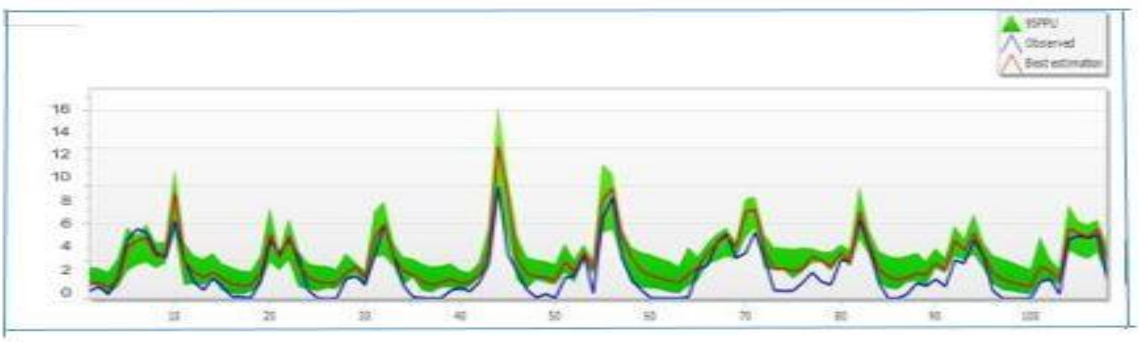


Figure A8. Calibration and uncertainty from (1992-2006) output of SWAT CUP model



Appendix-B: Hydrological Stations

Station name Aposto Gidabo station

Element: Monthly total stream flow (m3/s)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1990	2.409	3.804	6.050	10.096	10.583	6.258	6.007	6.013	6.817	6.941	3.747	3.185	71.911
1991	3.189	3.442	3.747	4.600	4.651	3.370	4.823	4.349	10.358	5.457	2.108	1.768	51.860
1992	1.158	1.555	1.205	6.633	6.513	5.041	7.143	22.809	19.479	27.461	10.742	4.467	114.206
1993	2.916	4.315	2.331	5.574	16.323	16.563	7.738	5.453	9.309	16.471	7.536	2.700	97.229
1994	1.805	1.449	1.719	3.135	9.789	6.866	16.017	17.685	12.564	6.370	5.314	2.443	85.156
1995	1.636	1.671	1.851	9.509	9.072	4.225	4.763	6.534	16.842	12.469	3.837	2.935	75.344
1996	2.862	1.867	5.976	11.293	14.826	14.582	15.923	18.215	18.784	19.228	4.131	2.596	130.284
1997	2.122	1.534	1.554	5.379	8.083	5.802	10.118	12.955	8.161	21.408	16.765	5.828	99.708
1998	2.060	1.050	1.193	3.336	10.100	4.480	7.578	23.145	10.925	29.748	6.108	2.733	102.456
1999	2.170	1.742	1.914	1.907	3.669	2.469	2.470	3.065	3.951	6.835	2.992	1.894	35.078
2000	1.406	1.304	1.271	1.965	4.910	3.018	2.511	7.830	7.204	18.478	6.272	2.453	58.622
2001	2.240	1.814	1.905	2.772	5.626	8.357	3.934	8.812	9.921	9.834	4.138	2.480	61.833
2002	2.009	1.558	2.041	2.929	3.939	5.288	2.712	3.657	4.893	3.526	2.185	2.242	36.979
2003	1.842	1.468	1.709	4.018	2.986	2.405	3.006	6.553	4.836	5.734	2.401	2.206	39.164
2004	2.379	2.313	3.303	6.064	10.474	7.608	10.725	15.169	12.413	15.913	7.433	4.302	98.095
2005	1.773	1.370	1.720	2.840	10.527	6.761	5.563	6.013	8.781	6.269	3.667	2.022	57.306
2006	1.647	1.666	2.746	4.564	9.252	5.268	10.964	13.929	8.866	10.985	6.368	4.535	80.790