Available online at https://asric.africa/social-sciences
ASRIC Journal on Social Sciences and Humanities Vol. 5(1)(2024) 14-46

Predicting Climate Change Impacts on Stream flow of Mille Watershed, Lower Awash River Basin, Ethiopia

Abdela Yimer Endris

Wollo University, abdelag4@gmail.com abdela.yimer@wu.edu.et

Received 01 April 2024; revised 09 May 2024; accepted 03 June 2024

Abstract

Climate change manifests itself primarily through changes in average temperature and precipitation, affecting overall flow magnitude. This study evaluated the impact of climate change on the stream flow of the Mille watershed, which is situated in the northeast part of Ethiopia. Different materials and Soil and Water Assessment Tools were used to arrive at the stated objectives. Downscaled future climate projections of precipitation and temperature were developed from the Hadley Global Environment Model 2-Earth System (HADGEM2- ES) under two radiative forcing scenarios (RCP4.5 and RCP8.5). These climate scenarios were bias-corrected for each selected station and areal rainfall over the catchment was determined. This study used the period 1976-2005 as the baseline period, while 2041-2070 (2050's) and 2071-2100 (2080's) as the middle-future and the far-future respectively. The current average daily temperatures vary little throughout the year: The mean monthly minimum and maximum temperature of the station ranges from 7.93°C to 11.2°C and 23.91°C to 24.13°C respectively. As temperature is projected the climate would become warmer for both scenarios in the future. The future projection of climate variables showed an increase in minimum temperature by 1.4oC and 1.3oC for RCP4.5 and 1.5oC and 1.8oC for RCP8.5 in 2050's and 2080's respectively. The current rainfall distribution of the catchment is bimodal with a very short rainy season in March to April and the main rains from July to September As Rainfall is projected the climate would become drier under RCP8.5, which showed a decrease in Rainfall by 8.05% and 8.73%, while under RCP4.5 Rainfall decrease by 3.87% in the 2050s but it becomes rise by 4.64% in 2080's. The Soil and Water Assessment Tool (SWAT) model was calibrated and validated for streamflow simulation The result showed a change in stream flow by -6.37% and 5.8% for RCP4.5, -13.9%, and -26.3% for RCP8.5 in the 2050s and 2080 respectively. The results of this study are expected to arouse serious concern about water resource availability in the Mille watershed under the continuously warming climate. Therefore, there is a need to minimize the sensitivity to climate change by making stringent climate policies.

Keywords: Climate Change, Representative Concentration Pathways, Hydrology, Soil and Water Assessment Tool, Mille

1 Introduction

The Earth's climate is always changing, and that can occur for many reasons. To determine the principal causes of observed changes, we must first ascertain whether an observed climate change is different from other fluctuations that occur without any forcing at all. Climate variability without forcing is called internal variability which is the consequence of processes within the climate system. Large-scale oceanic variability, such as El Niño-Southern Oscillation (ENSO) fluctuations in the Pacific Ocean, is the dominant source of internal climate variability on decadal to centennial time scales (IPCC, 2013). The dominant cause of current climate change is our past and current emissions of greenhouse gases (GHGs), in particular carbon dioxide (IPCC, 2007).

Climate change will manifest itself primarily through changes in average temperature and precipitation, which are important drivers of the water cycle and hence the seasonal occurrence and flows of water in soils, lakes, rivers, wetlands, and groundwater aquifers (NBI, 2012).

The temperature of the Earth is determined by the balance between the incoming solar radiation and the outgoing terrestrial radiation energy. The energy coming in from the sun can pass through the atmosphere and therefore heats the surface of the Earth. But the radiation emitted from the surface of the Earth is partly absorbed by some gases in the atmosphere, and some of it is re-emitted downwards. The effect of this is to warm the surface of the Earth and the lower part of the atmosphere. However, this important function of the atmosphere is being threatened by the rapidly increasing concentrations of greenhouse gases well above the natural level while also new greenhouse gas replacement is added to the atmosphere as a result of human activities (for example, CO2 from fossil-fuel burning). This will add further warming which could threaten the sustainability of the Earth (Jenkins, 2005).

The impacts of climate change on water resources are high on the research agenda worldwide. Future changes in overall flow magnitude, variability, and timing of the main flow events are among the most frequently cited hydrologic issues (Frederick, 2008).

Anthropogenic climate change is one of many stressors on water resources. Nonclimatic drivers such as population increase, economic development, urbanization, and land use or natural geomorphic changes also challenge the sustainability of resources by decreasing Water supply or increasing demand. In this context, adaptation to climate change in the water sector can contribute to improving the availability of water (IPCC, 2014A).

One of the potential impacts of climate change will be in the frequency, intensity, and predictability of rainfall. This challenge will ultimately influence water availability which will have far-reaching consequences on water supply, agriculture, and hydropower generation among others (Willems and Taye, 2013).

Increasing temperature has a profound effect on evaporation, thereby affecting water storage in the atmosphere. This in turn affects the frequency and intensity of rainfall events, its seasonal and geographic distribution, as well as its variability from year to year (Knoesen, 2009).

Concerning hydrology, climate change can cause significant impacts on water resources by resulting in changes in the hydrological cycle. For example, the changes in temperature and precipitation can have a direct consequence on the quantity of evapotranspiration and runoff components. Consequently, the spatial and temporal availability of water resources can be significantly changed which in turn can affect agriculture, industry, and urban development (Frederick, 2008) and the impacts of climate change on other processes associated with water include changes in soil moisture, irrigation water demands, heat wave episodes and meteorological and hydrological droughts (IPCC,2007).

The elements of climate (rainfall and temperature) and aspects of hydrology (river flows, lakes, and underground water storage), coupled with human-landscape features (such as land cover or land use change) have sensitive interactions that ultimately affect the availability of water within a basin (UNEP, 2013).

Mean annual temperature rise over Africa, relative to the late 20th century mean annual temperature, is likely to exceed 2°C in the Special Report on Emissions Scenarios (SRES) A1B and A2 scenarios by the end of this century (IPCC, 2014B).

In regions of high or complex topography such as the Ethiopian Highlands, downscaled projections indicate likely increases in rainfall and extreme rainfall by the end of the 21st century (IPCC, 2014 B).

Climate model projections under the SRES A2 and B1 scenarios over Ethiopia show warming in all four seasons across the country, which may cause a higher frequency of heat waves as well as higher rates of evaporation (Conway, 2011).

UNDP Ethiopia 2011 indicates that agriculture, water supply, hydropower production, economic and social infrastructure, health, and biodiversity are the sectors primarily affected with stronger secondary downstream impacts on all sectors of the economy and the society (IPCC, 2014).

Even though the impact of different climate change scenarios is projected at a global scale, the exact type and the magnitude of the impact at the catchment scale is not investigated in most of the world (Andrew et al., 2010). Hence, identifying the local impacts of climate change at the catchment level is quite important. The Mille watershed is one of the sources of the Awash River basin and its water resources are an important input for water development projects and the livelihood support of the communities in the basin.

This research aims to evaluate the impact of climate change on the stream flow of the Mille watershed using the Soil and Water Assessment Tool (SWAT) driven by the downscaled future climate projection of Hadley Global Environment Model 2 - Earth System (HADGEM2-ES) climate model under two radiative forcing scenarios (RCP4.5 and RCP8.5) using bias correction methods. The two RCPs together span most of the range of all four RCPs. Representative concentration pathways (RCPs) of HADGEM2-ES climate model output stands for a pathway to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. The RCP4.5 is a stabilization scenario where total radioactive forcing is stabilized before 2100 by employing technologies and strategies to reduce greenhouse gas emissions, whereas RCP8.5 is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time.

1.2 Statement of the Problem

Climate change affects humankind in several ways. Drought and flood are among the main effects of climate change which significantly affects the livelihood of the people. One of the most important consequences of climate change will be alterations in major climate variables, such as temperature, precipitation, and evapotranspiration. This in turn will lead to changes in the hydrological cycle (IPCC, 2001).

Climate change will result in more intense precipitation events causing increased floods, landslides, avalanches, and mudslide damages that will cause increased risks to human lives and properties (IPCC, 2001). Likewise, warmer temperatures increase the water-holding capacity of the air and thus increase the Potential evapotranspiration, reduce soil moisture, and decrease groundwater reserves (IPCC, 2001).

Changes in the hydrological cycle due to climate change can lead to diverse impacts and risks, and they are conditioned by and interact with non-climatic drivers of change and water management responses. Water is the agent that delivers many of the impacts of climate change to society, for example, to the energy, agriculture, and transport sectors (2014).

Anthropogenic emissions of greenhouse gases are likely to lead to changes in climate over the 21st century and beyond, and the impacts of these changes have the potential to be substantial. However, the projected impacts of climate change depend on future emissions of greenhouse gases, how these emissions translate into geographical and seasonal changes in climate, the state of the society and economy to which these changes apply, and the models used to estimate impacts from specified changes on climate (Arnell, 2013).

Numerous studies have been carried out to understand the current and future impacts of climate change in the upper Blue Nile basin. The studies (Tarekegn and Tadege, 2006) projected that the water resource of Lake Tana is highly vulnerable to climate change and the runoff may become much more seasonal as a result, small streams may completely dry up for part of the year, this will become a reason for a drying of wetlands, small springs and wells which are source of water supply to the rural community.

The Awash River Basin has historically experienced significant climate variability, leading to recurrent droughts. Their drought analysis found that the basin is highly vulnerable to fluctuations in rainfall, with prolonged dry periods affecting water availability for agriculture and livelihoods. The research emphasizes the increasing pressure on the region’s water resources, particularly in the lower basin, where water scarcity is more pronounced. The study also underscores the importance of developing adaptive strategies for better water resource management to mitigate the impacts of future climate variability (Edosa, 2010)

Climate change has led to changes in the natural drought cycle which is impacting on local people of the watershed. Therefore, more detailed and reliable information is needed for running future water resource development. It is possible by evaluating the future stream flow situation and climate change impact on the water resource of the Mille watershed.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the study is to evaluate the impact of climate change on the stream flow of the Mille watershed.

1.3.2 Specific Objectives

i. To assess the change of climate variables (precipitation and temperature) in the watershed.
ii. To calibrate and validate the SWAT model simulations at the Mille watershed.
iii. Evaluate the impact of climate change on the future stream flow of the study area.

1.4 Research Question

i. What changes in precipitation and temperature for future periods in the watershed?
ii. Is the SWAT model suitable for the Mille watershed?
iii. What will be the impact of climate change on the stream flow of the watershed?

2. Materials and Methods

2.1 Description of the Study Area

2.1.1 Geographical Location

Mille catchment is one of the largest sub-catchments in the lower Awash basin found in the Amhara and Afar regional states. The area lies between 11°10‘-11°45‘North Latitude and 39°35‘- 40°55‘East Longitude. The majority of the catchment area is reaching an elevation of 1800m above mean sea level. The total catchment area of Mille is 4853 km^2. This catchment is drained by the Mille River, which flows part of the North Wollo and South Wollo of the Amhara region as well as the administrative zone of the Afar region. The Mille River rises in the Ethiopian highlands of west Sulula in Twehuledere Wereda. It flows first to the north, and then curves to run east finally joining the Awash River.

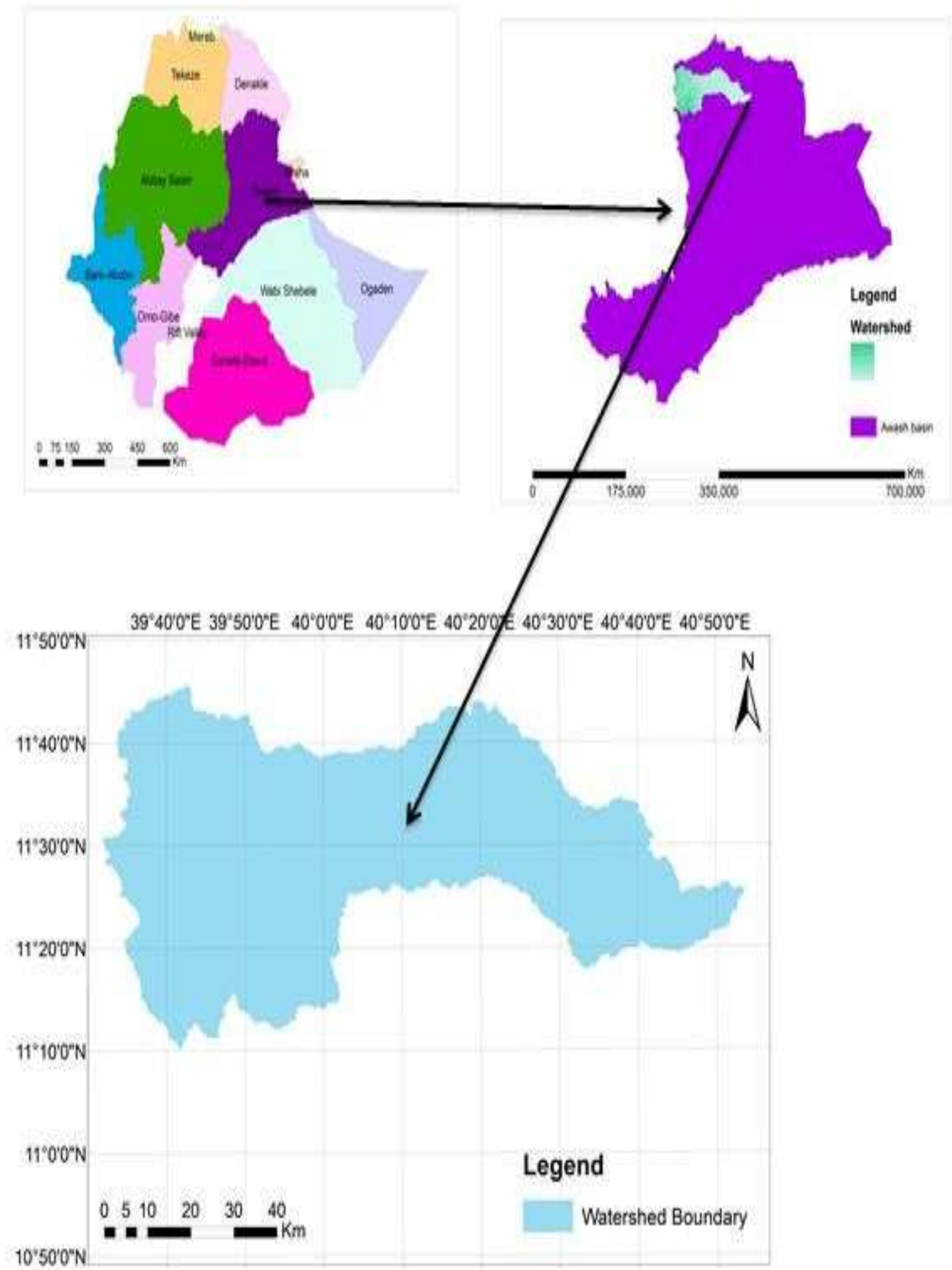


Figure 3.1: Location of the Study area

3.1.1 Topography

The Mille watershed is characterized by a complex topography with an elevation range of over 3600m in the headwater and about 401m in downstream parts.

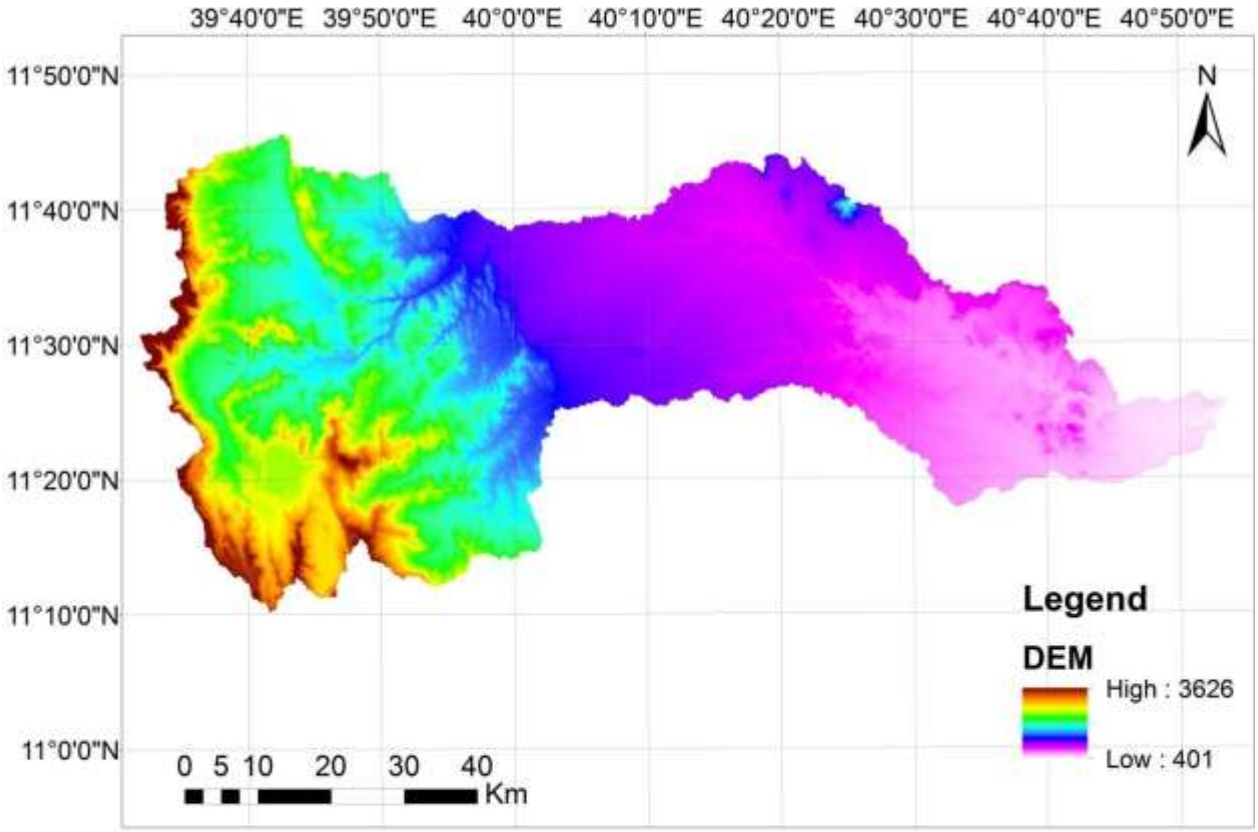


Figure 3. 2: Digital Elevation Model (DEM) of Mille watershed.

3.1.2 Climate and Hydrology

3.1.2.1 Climate

The climate of the Mille catchment varies from semi-humid subtropical over the western part to semi-arid in some parts of the east. The rainfall distribution of the catchment is bimodal with a very short rainy season in March to April and the main rains from July to September (figure 3.3).

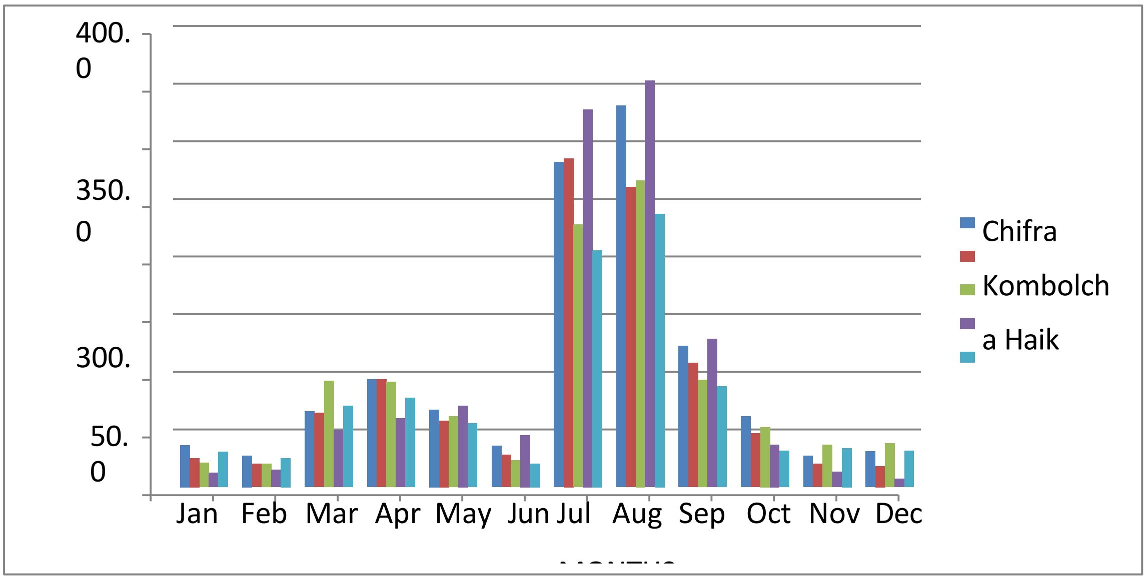


Figure 3. 3: Mean monthly Rainfall pattern of selected stations (1989-2016)

Average daily temperatures vary little throughout the year: The mean monthly minimum and maximum temperature of the station ranges from 7.93°C to 11.2°C and 23.91°C to 24.13°C respectively.

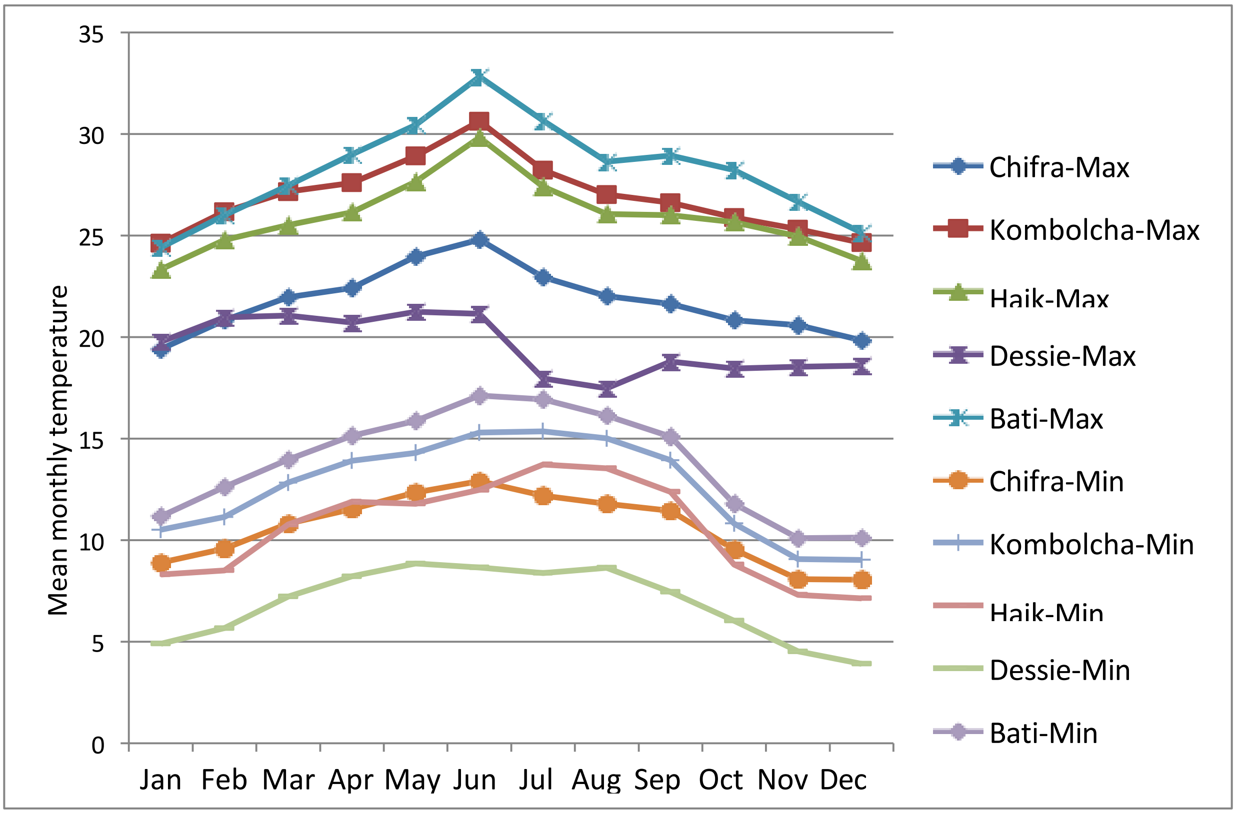


Figure 3.4: Mean monthly maximum and minimum temperature of selected stations (1989- 2016)

3.1.2.2 Hydrology

Mille is one of the major rivers which contributes a significant amount of flow to the Awash River. For this reason, the Ministry of Water, Irrigation and Electricity (MWIE) installed one gauging station downstream of the river near the small town called Mille. The flow of the Mille River is strongly seasonal. Peak flows usually occur in August.

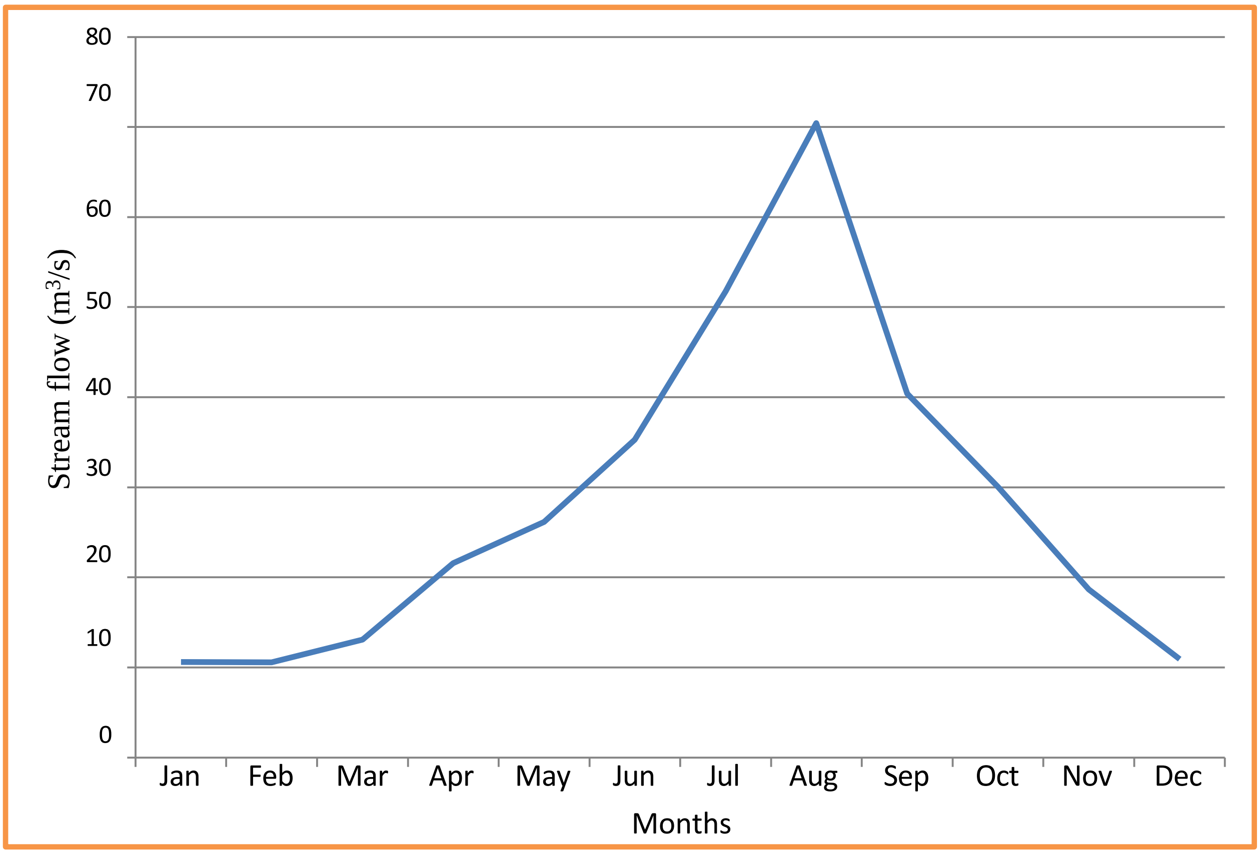


Figure 3. 5: Average monthly flow of Mille River

3.2 Overall frame work of the study

The study required different materials and methods to arrive at the stated objectives. Regionally downscaled climate, meteorological, hydrological, digital elevation model, land use and land cover and soil data were required. Regionally Downscaled Climate change data derived from HadGEM2-ES Global climate model outputs that are dynamically downscaled by the CORDEX-Africa program using RCA4 regional model for the Representative Concentration Pathway scenario, RCP4.5 & RCP8.5 scenarios. Those data were selected to the local impact based on the grid points which are fitted to the study area by using bias- correction method. The data downscaled by bias-correction power transform method is used to estimate the future climate change and as input in hydrological model and its impact on hydrology of the catchment.

Arc GIS 10.3 and its extension Arc SWAT 2012 were used for hydrological model. The stream flow simulation by the SWAT model was calibrated and validated by comparing simulated stream flow with observed values. Finally simulate the stream flow corresponding to the RCP4.5 and RCP8.5 climate scenarios (predictions) to determine the changes in stream flow in comparison with the baseline period.

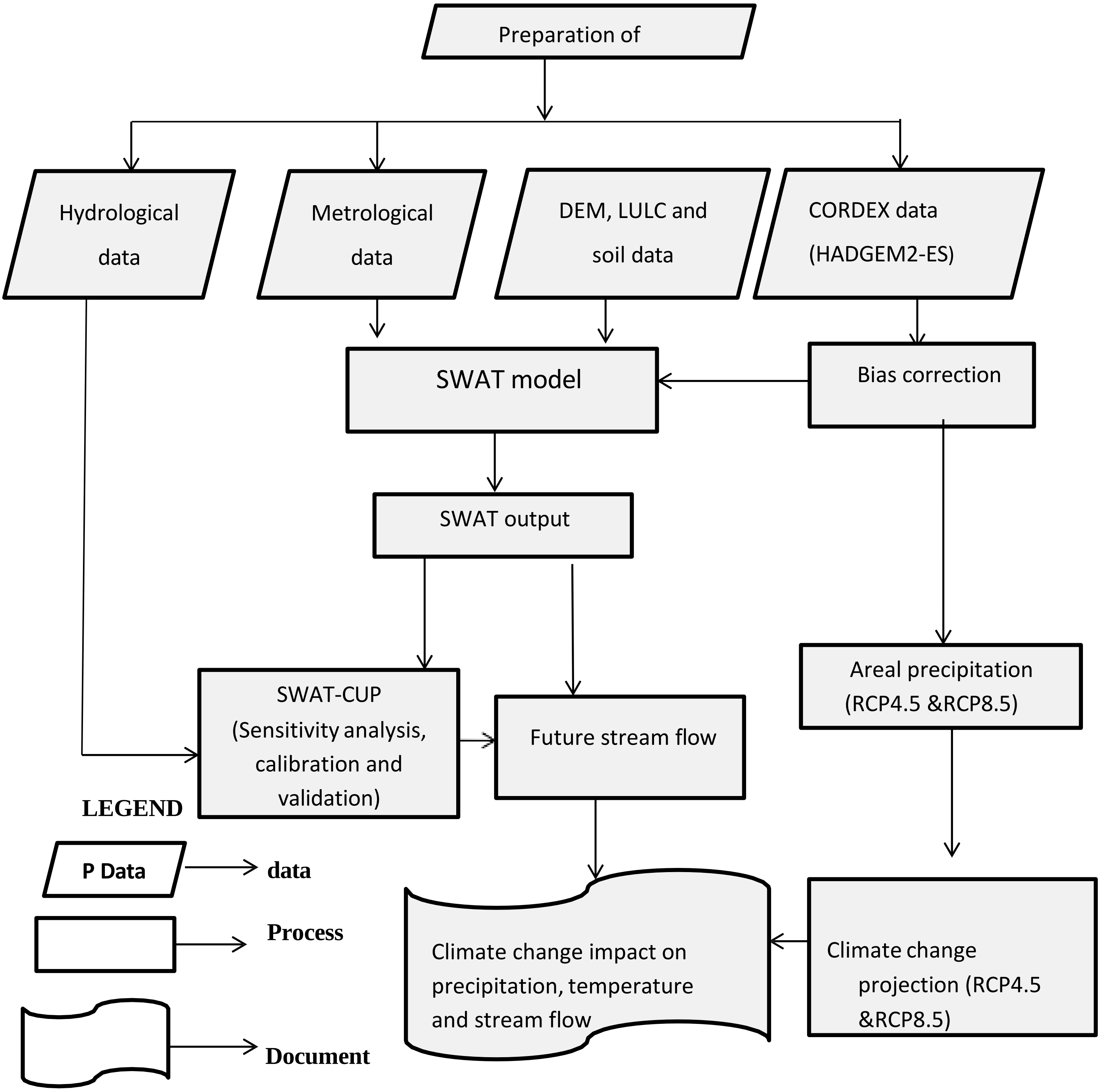


Figure 3.8: Overall flowchart used in the study

3.3 Data Collection

3.3.1 Weather Data

All climate data were collected from the Ethiopian National Meteorology Agency (NMA) head Office in Addis Ababa. The observation period of the collected data covers from 1989 to 2016 which are daily time series data of five climate variables (Rainfall, minimum and maximum temperature, relative humidity, wind speed and sunshine hour). The data obtained for five stations: two principals stations and three secondary stations. These stations selected based on the data availability and proximity to the study area. The station namely Kombolcha and Bati are principal weather station used as a weather generator. Table 3.1 show all meteorological stations and their location used for the study area.

Table 3. 1: Location of selected metrological stations

Station	Latitude (^{0}c)	Longitude (^{0}c)	Altitude (m.a.s.l)	Class
Kombolcha	11.0839	39.7176	1857	1st
Haik	11.3053	39.6802	1985	2nd
Dessie	11.124597	39.64056	2250	2nd
Chifra	11.6012	40.0182	1750	2nd
Bati	11.1967	40.0154	1820	1st

3.3.2 Hydrological Data

The study area is gauged station at Mille. The stream flow data for Mille River was collected from the Ethiopian Ministry of Water, Irrigation and Electricity.

3.3.3 Spatial data

A Digital Elevation Model (DEM)

Since topography was defined by a DEM which describes the elevation of any point in a given area of a specific spatial resolution. The catchment elevation ranges from 401m to 3626m. A resolution of 30m by 30m DEM was downloaded from the website (https://earthexplorer.usgs.gov/).

B land use and land cover data

The 2004 classification of Land use and land cover data were obtained from Ethiopian Mapping Agency (EMA). Since land use and land cover in a watershed is one of the major factor which affect surface runoff, evapotranspiration and erosion.

C Soil Data

Soil data is one of the major input data for the SWAT model. The soil map of the study area was obtained from FAO soil classification.

3.3.4 Regional Climate Model Data

Downscaled climate data have been obtained from CORDEX-Africa database and is available at a spatial resolution of 50km. For climate scenarios, two Representative Concentration Pathways, the RCP4.5 and the RCP8.5 were considered. IWMI provided the predicted future climate change parameters of rainfall and temperature data on grid based. The grid points which are closest to the centroid of the part of the Mille catchment were identified.

Table 3.2: Model source of climate data

Data source (RCM)	Resolution (^{o})	Model	Scenario
RCA4	0.44*0.44	HADGEM2-ES	RCP4.5 & RCP8.5

Table 3. 3: Summary of data collection

SNº	Data type	Period included	Data collected from
1	Precipitation ,temperature, wind speed, relative humidity and sunshine hour	1989-2016	National Metrology Agency (NMA)
2	Stream flow	1978-2010	Ministry of water, Irrigation and Electricity
3	Land use and land cover	2004	Ethiopian Mapping Agency (EMA)
4	Digital Elevation Model (DEM)		(https://earthexplorer.usgs.gov/
5	Soil	2003	FAO

3.4 Data Analysis

Before beginning any hydrological analysis, it is important to make sure that data are homogenous, consistence, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final results (Vedula, 2005).

3.4.1 Consistency Test

Rainfall data reported from a station may not be always consistent over the period of observation of rainfall record. Problem occurs when the catchment rainfall at rain gages is inconsistent over a period and adjustment of the measured data is necessary to provide a consistent record. A consistent record is one where the characteristics of the record have not changed with time.

Inconsistency may result from Change (unreported shifting of the rain gauge) in gauge location, significant construction work in the area might have changed the surroundings, Change in observational procedure incorporated from a certain period and A heavy forest fire, earthquake or landslide might have taken place in that area.

Such changes at any station are likely to affect the consistency of data from a station. It is difficult to set out direct analysis to detect possible errors. However, through checking consistency of individual stations, the data qualities with regard to possible temporal variations or errors been investigated by double Mass curve.

Double Mass Curve Analysis is used to adjust inconsistent data. In this method, the accumulated annual rainfall of a particular station is compared with the concurrent accumulated values of mean rainfall of groups of 5 surrounding base stations. The procedure consists of comparing the accumulated annual precipitation at the station in question with the accumulated annual precipitation for a group of surrounding stations. If the station affected by the trend, a break in the slope of the curve would indicate that conditions have changed at that location and needs to be adjusted for the consistency of the record.

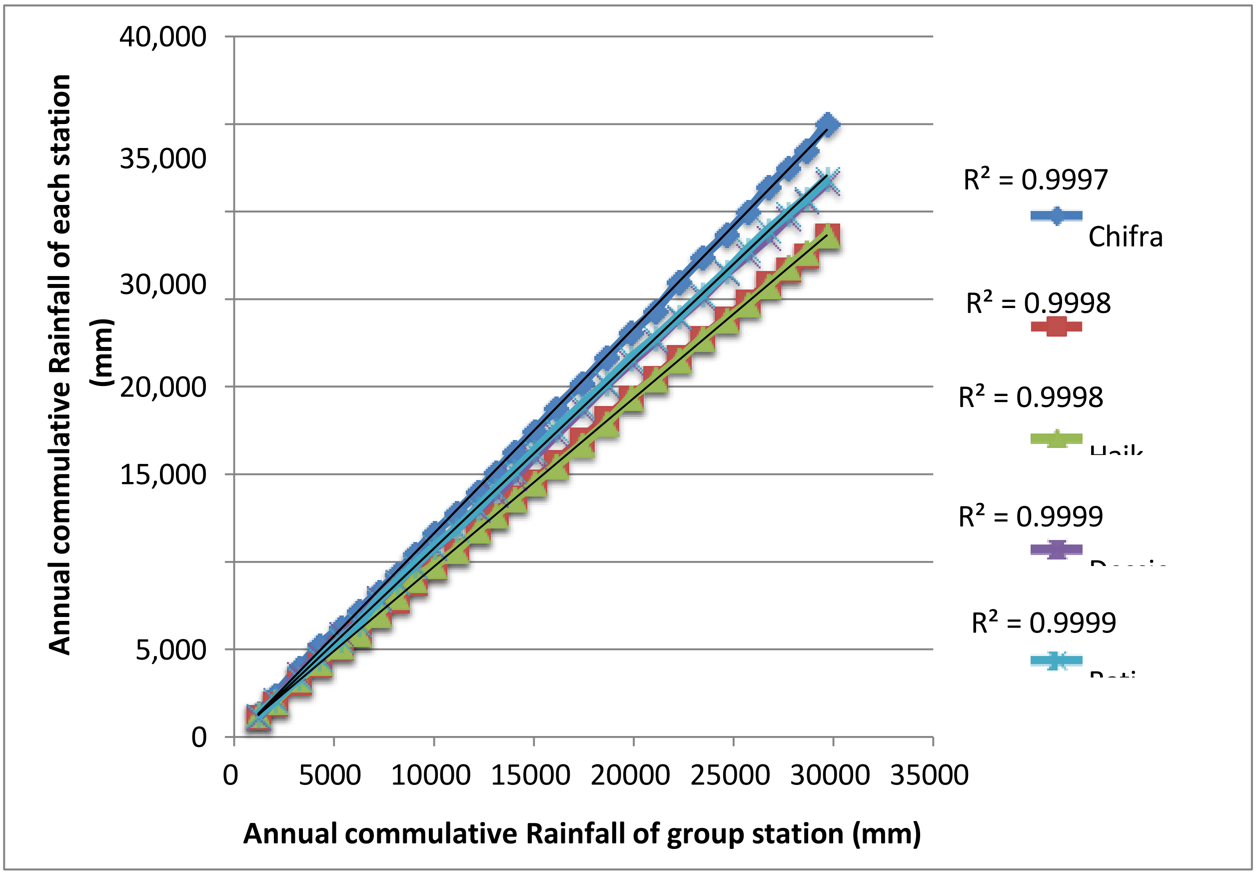
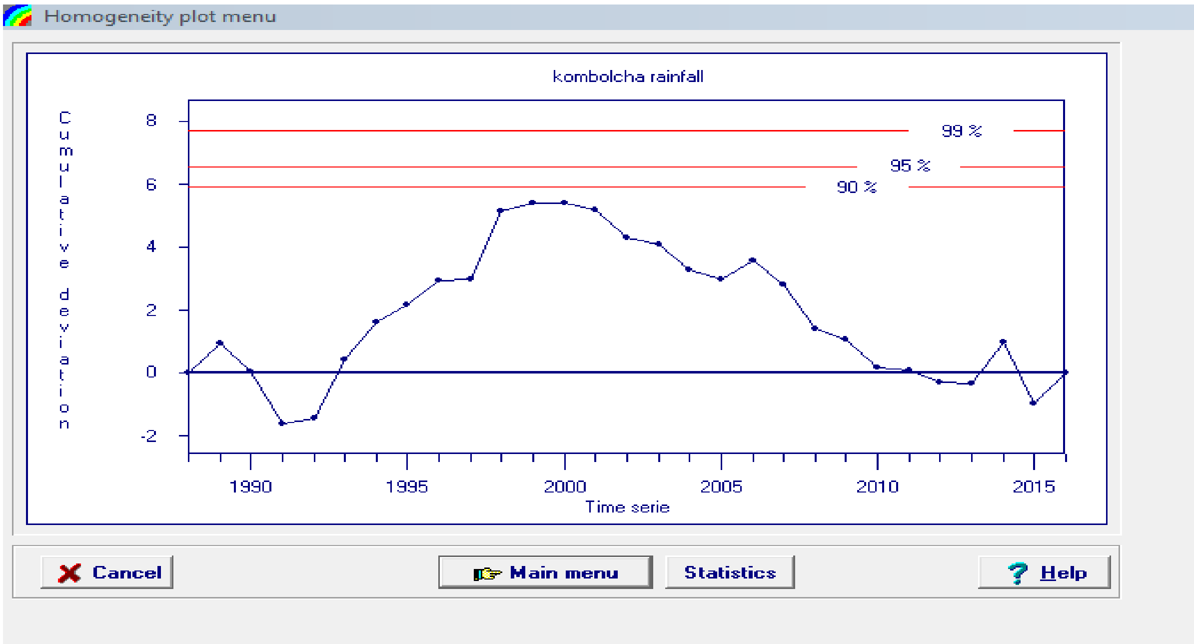


Figure 3. 9: Rainfall consistency checking result of selected meteorological stations

3.4.2 Rainbow Homogeneity Test

Rainbow software used to check the homogeneity of Rainfall data. Analysis of rainfall data requires the data be of long series; they should be homogeneous and independent. In RAINBOW, the test for homogeneity based on the cumulative deviation from the mean (Raes, 2006). The figure 3.10 shows the homogeneity test of Kombolcha station. Probability of rejecting homogeneity test is accepted at all significance levels (90, 95, and 99 %) for both range of cumulative deviation and maximum of cumulative deviation. Appendix 3 shows other stations homogeneity test of annual rainfall.



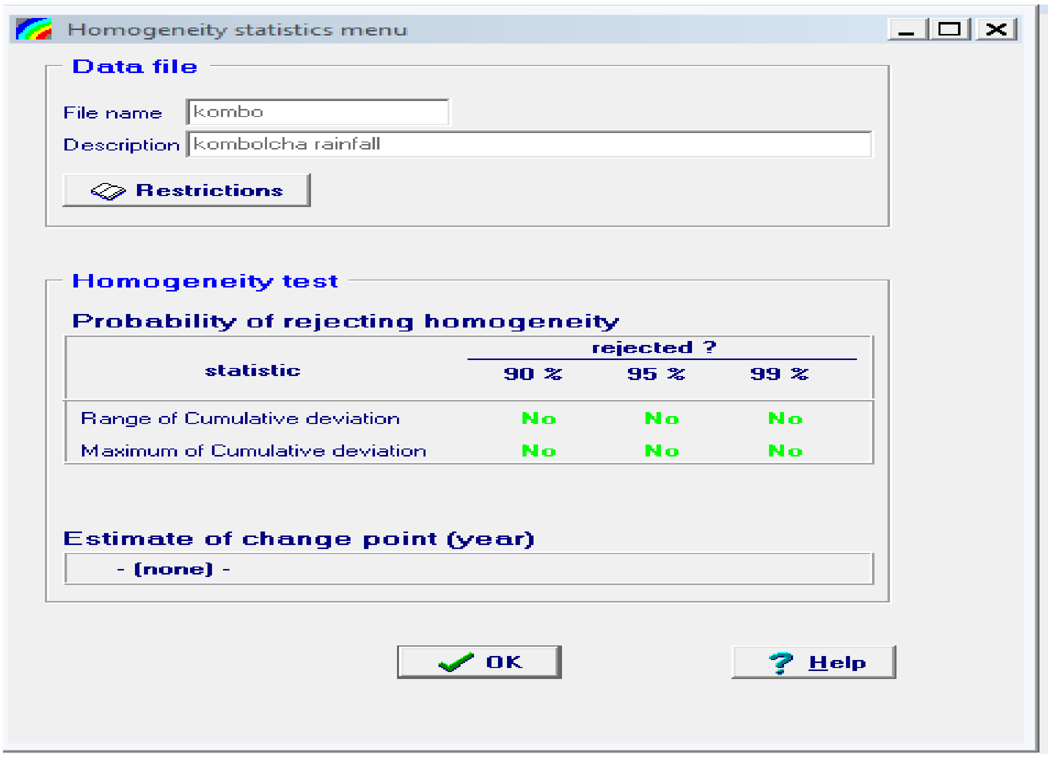


Figure 3.10: Cumulative deviation and probability of rejecting homogeneity test result of annual Rainfall at Kombolcha gauging station

3.4.3 RCM Data Analysis

The study focuses on HADGEM2-ES climate model outputs (RCP4.5 and RCP 8.5). The two RCPs together span most of the range of all four RCPs. Representative concentration pathways (RCPs) of CMIP5 climate model output stands for a pathway in order to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. This study uses the results for the most extreme RCP8.5 and moderate RCP4.5 emission scenarios. The RCP4.5 is a stabilization scenario where total radioactive forcing is stabilized before 2100 by employing technologies and strategies to reduce greenhouse gas emissions, whereas RCP8.5 characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time.

3.4.3.1 Grid Selection for RCM Data Downscaling

GCM output grid points data have been classified based on their grid location (latitude and longitude). The grids selection has carried out according to the grids location nearest distance with respect to the location of each meteorological station which is selected for this study. The grid point data has been selected as a predictor for a given meteorological station from the others grid point data by identifying the grid location which consists of the location of meteorological station. Depending on their distance from the selected station four-grid cell were selected to the watershed. After grid point selection to the nearest station, bias correction has been computed for each selected grid values.

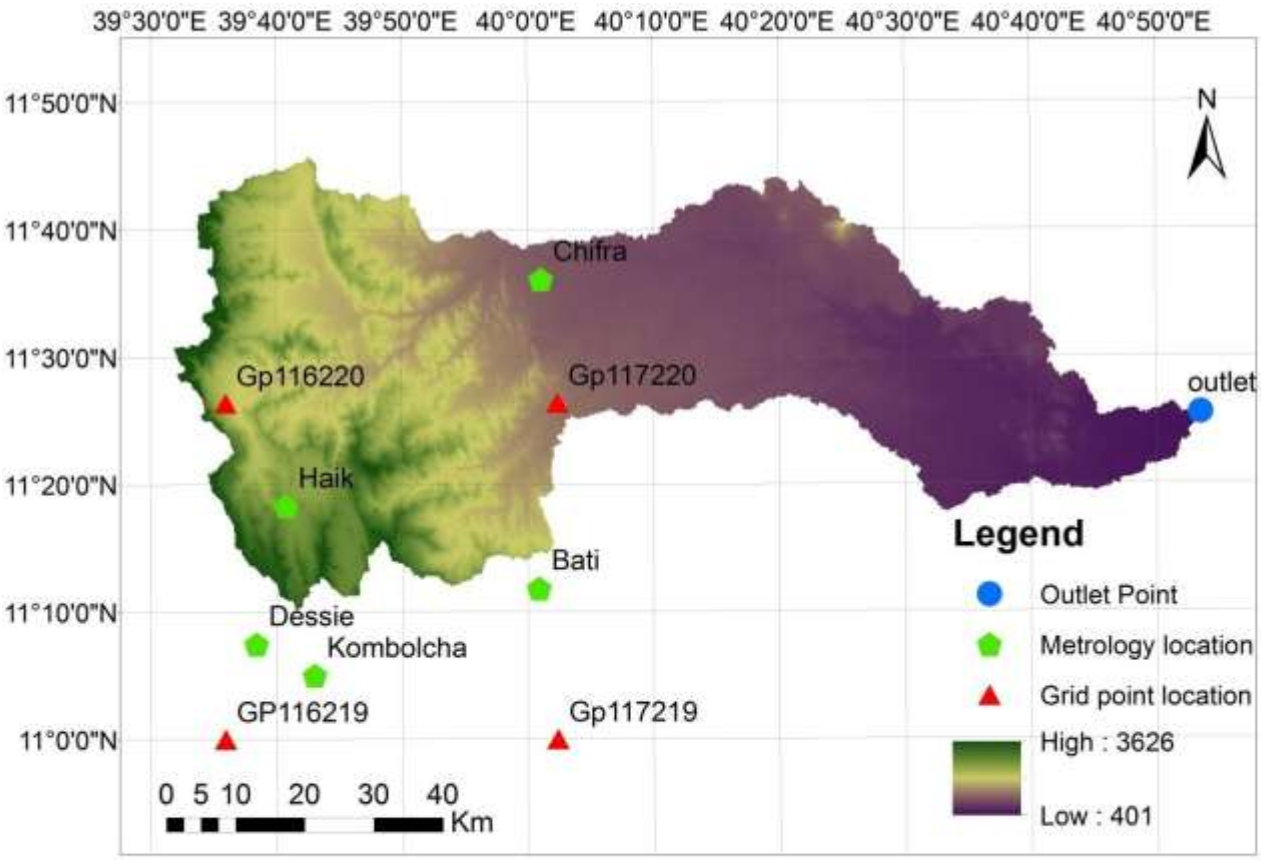


Figure 3.11: Mille catchment selected meteorological stations with RCP grid points and hydro gauged station locations.

3.4.3.2 Bias-correction

Bias correction is an adjustment of modeled values to reflect the observed distribution and statistics. While performing climate change impact studies, bias associated with climate model data can be roughly but safely, defined as the time independent component of model error or the component of model error, which remains constant throughout the length of datasets (Ehret et al. 2012).

I Precipitation Bias-correction

The RCP precipitation data has been corrected by using a nonlinear power transform method (Leander and Buishand, 2007) to correct the CV, Standard deviation and the mean of the observed and the simulated baseline RCP data. This nonlinear bias correction method transforms each daily precipitation amount P to a corrected P∗ using:

$P^{*} = aP^{b}$…………………………………………………..3.3

Where, the parameters a and_b_was determined for the period of the year of 12 months.

The determination of the parameter could be computed through iteration and the CV of the corrected daily precipitation should match with the CV of the observed daily precipitation (Terink et al., 2010). In this way, the CV is only a function of parameter b according to:

CV (P) = f (b)

In which P is the precipitation, CV is the coefficient of variation. With the determined parameter b, the transformed daily precipitation values were calculated using: $P^{*} = P^{b}$

The parameter a _then determined such that the mean of the transformed daily values corresponds with the observed mean. The resulting parameter a _depends on b_. The correction parameters are subsequently applied to the future climate scenarios.

II. Temperature Bias-correction

Temperature cannot be correct using a similar power law as used for correcting precipitation, because temperature is known to be approximately normally distributed. Correcting a normally distributed data set with a power law function results in a data set which is not normally distributed (Terink et al, 2010).

The bias correction of temperature simply involves a shifting to adjust for the mean and scaling to adjust for the standard deviation (Leander and Buishand, 2007). For each station, the corrected daily temperature T^* was obtained as:

$$T* = \overline{T} + \sigma(Tobs)\,(T - \overline{T}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.5$$

Where T_{unc} is the uncorrected daily temperature from the model output and T_{obs} is the observed daily temperature from the NMA data set. In this equation an over bar denotes the average over the considered period and σ is the Standard deviation.

After this grid data has been bias-corrected for each selected stations, climate parameters (maximum and minimum temperatures and Rainfall), were changed in to areal climate of the catchment .This task was held by changing point data in to areal using Arc-GIS tool by creating Thissen polygon for the catchment.

3.4.4.1 Estimating Areal Precipitation

Average rainfall over the catchment has been determined from the station measurements which are used in practical hydrological applications. Among the methods of determining areal rainfall, Thiessen polygon is the famous one for computing this task. The method assumes that recorded rainfall in a gauge is representative of the area and also the adjacent gauged stations. Thiessen area is formed around each station by drawing the perpendicular bisectors of the lines joining adjacent stations using ArcGIS tool. The polygons of the stations areal contribution has been clipped using the shape of the catchments which includes stations of the selected ones for this study. The weighted average areal precipitation is found using the formula (Subramanya, 2008).

$$\overline{P} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i} = \frac{[(P_1 A_1) + (P_2 A_2) + \cdots + (P_n A_n)]}{[A_1 + A_2 + \cdots A_n]} \ldots\ldots 3.6$$

Where; P is precipitation

A is area of each site (meteorological stations), n is number of station

3.5 SWAT Model Setup and Input of the model

3.5.1 Watershed delineation

The purpose of Watershed delineation is to carries out advanced GIS functions to aid the user in segmenting watersheds in to several hydrological connected sub-watersheds for use in watershed modeling with SWAT (Arnold et al., 2010). SWAT allows the user to delineate the watershed and sub basins using the Digital Elevation Model (DEM).

The watershed delineation tool uses and expands the ArcGIS, spatial analyst functions to perform watershed delineation (Arnold et al., 2005) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub-basins and details of stream network depends on this threshold area (Winchell et al., 2007). In this study the threshold area of 15000ha is taken and the watershed outlet is manually added and selected for finalizing the watershed delineation. So that the model automatically delineate a watershed area of 4853km^2 with 23 sub-basins.

3.5.2 HRU Definition

The second step of the model setup is to define HRU. The Hydrologic Response Units (HRUs) analysis tool in Arc SWAT helps to load land use and soil maps to the project and also classify the slope of the sub-basins. The 2004 land use/cover map of the study area was obtained from Ethiopian Mapping Agency (EMA). Then this land cover was converted in to SWAT code land cover which is embedded in the SWAT land use data base. SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use map of the study area to SWAT land use databases in the GIS interface.

The dominant land uses/cover in the watershed is the crop/agricultural land and it covers about 38.5% of the watershed area, followed by shrub land that accounts about 23.75% of the basin area. About 6.68% land of the watershed is covered by forest and the rest area is covered by water, grass, wood land etc. (figure 3.12 and table 3.4).

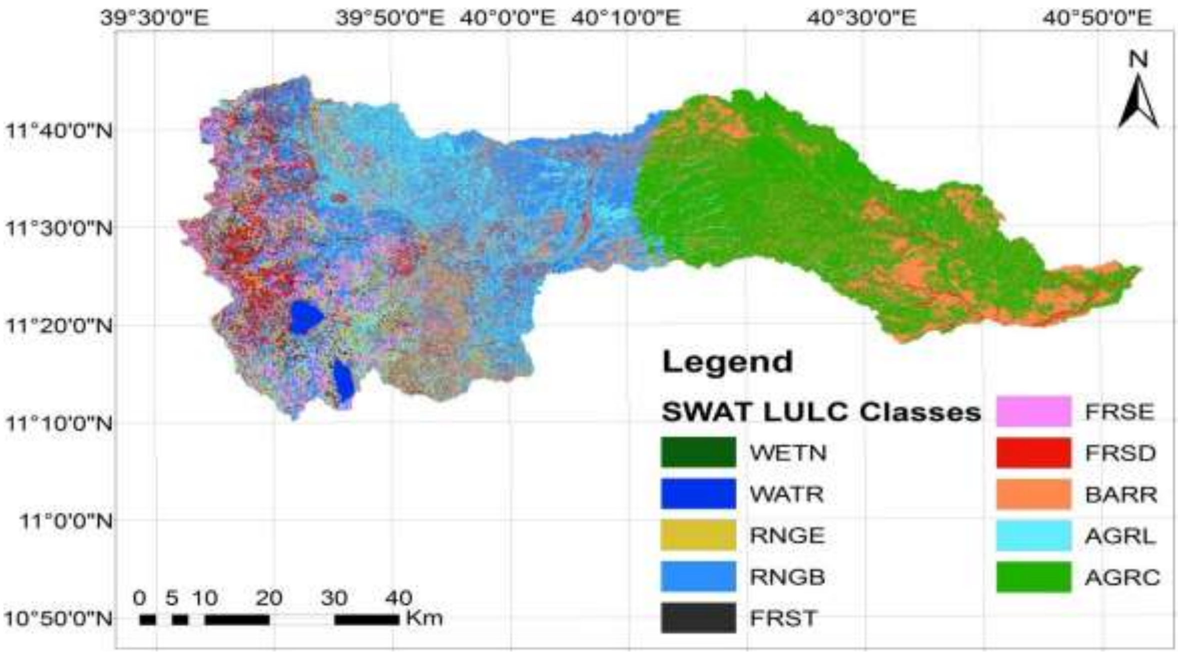


Figure 3.12: Land use classification of the watershed according to SWAT classification

Table 3. 5: Original and the redefined land use/land cover types of the Mille watershed

Original land use/cover according to Ethiopian mapping agency	Redefined land use/cover according to the SWAT database	SWAT CODE	Area (ha)	% of watershed
Moderate forest and sparse forest	Forest mixed	FRST	9196.47	1.89
Perennial crop	Agricultural Land-Generic	AGRL	65947.5	13.59
Annual crop and Rock out crop	Agricultural Land-Close-Grown	AGRC	120910.05	24.91
Wood land	Forest- Deciduous	FRSD	39214.17	8.08
Open grass and closed grass	Range-Grasses	RNGE	29513.97	6.08
Bare soil, salt pan and lava field	Barren	BARR	77286.24	15.93
Dense forest	Forest - Evergreen	FRSE	23268.24	4.79
Wet land	Wet lands-Non-Forested	WETN	676.44	0.14
Open shrub and closed shrub	Range- Brush	RNGB	115248.06	23.75
Water body	Water	WATR	4074.30	0.84

Soil map and soil data analysis is the next step after the land use map added into the model. In order to integrate the soil map within the SWAT model, it is necessary to make a user soil database that contains physical and chemical properties of each soil of the study area. To prepare this user database of the soils, the properties of the soils that required in the SWAT model were obtained from different sources like: soil and terrain database of northern Africa (FAO, 1998), digital map of the world and derived soil properties (FAO, 2002), properties and management of the soil of the tropics (FAO, 2003). According to (FAO, 2003), Eutric cambsols and calcic xerosols are the two dominant soil types in the area covering about 48.18 and 33.35 percent of the watershed area respectively (figure 3.13 and Table 3.5).

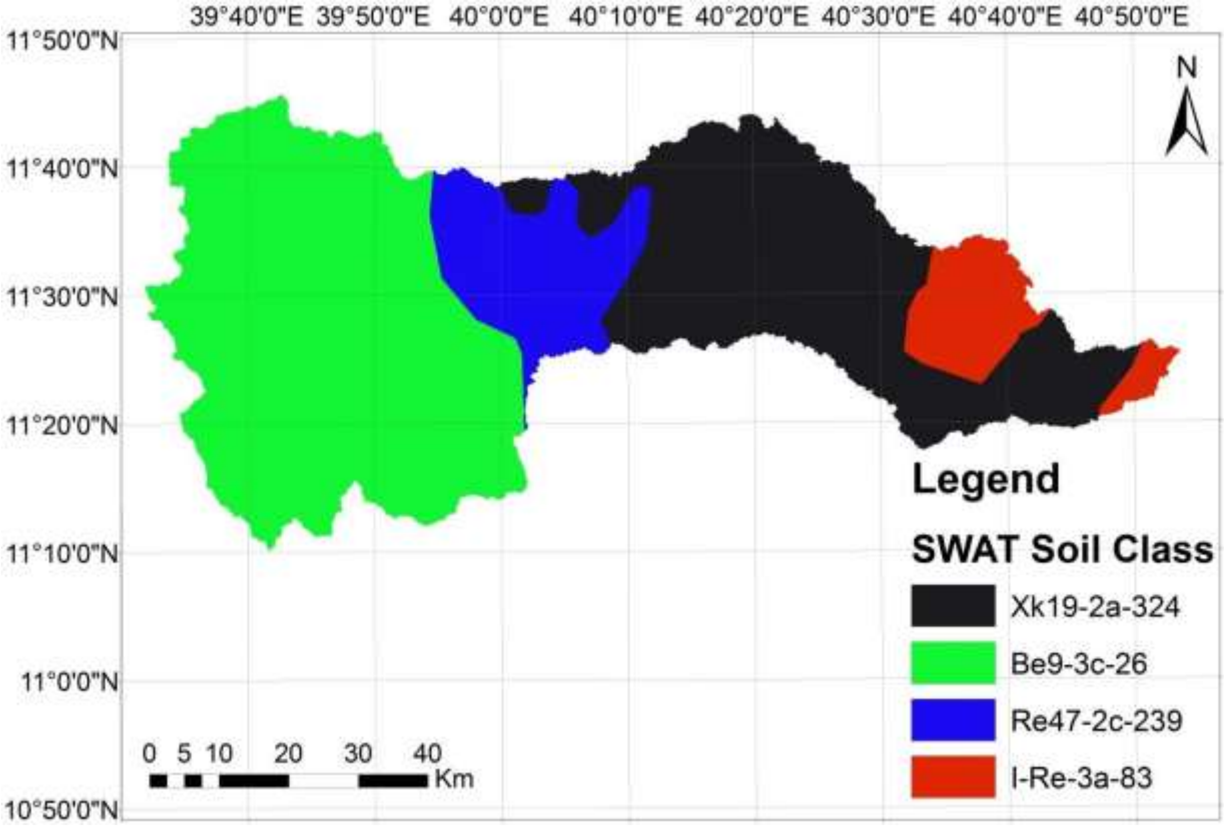


Figure 3. 13: Soil map of Mille watershed according to SWAT classification

Table 3. 6: Soil of Mille watershed with their area coverage

Soil name	SWAT code	Area (ha)	% of watershed
Calcic xerosols	Xk19-2a-324	161859.78	33.35
Eutric cambisols	Be9-3c-26	233831.70	48.18
Eutric gleysols	Re47-2c-239	56529.36	11.65
Lithosols	I-Re-3a-83	33114.60	6.82

HRU analysis in Arc SWAT includes division of HRUs by slope classes in addition to land use and soils. This is particularly important if sub basins are known to have a wide range of slopes occurring within them (Winchell et.al. 2010). The users to choose slope classification option as single or multiple, and to define the range of the slope as necessary as possible, if the multiple slope class is selected. In this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified in to three and the range was 0-15%, 15-30% and above 30-9999% (Table 3.6).

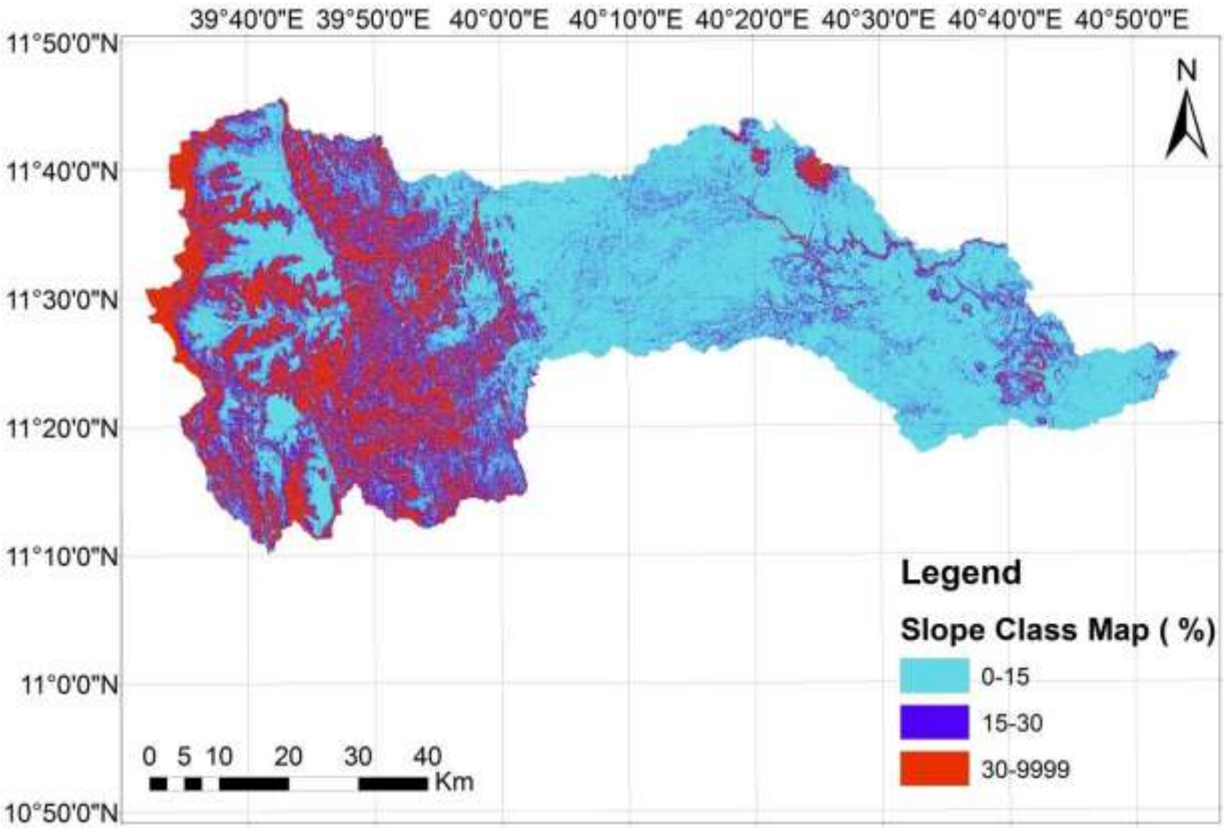


Figure 3. 14: SWAT slope classes of the watershed.

Table 3. 7: Slope classification of the watershed in SWAT model

Slope (%)	Area (ha)	% of watershed
0-15	291765.42	60.12
15-30	100540.08	20.71
30-9999	93029.94	19.17

Once the land use, soil and slope data layers have been imported and overlaid, the next step is the determination of the distribution of hydrologic response units within the watershed. Subdividing the watershed in to areas having unique land use and soil combinations enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical descriptions of the water balance (Arnold et.al, 2010).

In this study the multiple HRU option was selected with sensitivities of 20%, 20% and 5% for the threshold area of land use, soil and slope in each HRU from the sub-basin values were specified respectively.

3.6 Impact of climate change on stream flow

As discussed above, the model output of HadGEM2-ES was used in this study to simulate the climatic effect of increased atmospheric concentration of greenhouse gases. Simulation of stream flow corresponding to future climate change scenario was done using the SWAT model which was calibrated and validated as discussed in the previous section. The downscaled climate scenario consists of maximum temperature; minimum temperature and precipitation together were used as input to the model.

The analysis of the simulated stream flow was carried out in three time horizons in baseline and future periods each covering non overlapping 30 years. These period consists of baseline (1976-2005); 2050s (2041-2070) and 2080s (2071-2100). The overall step that was used to investigate the hydrological impact of climate change was described by the following simple conceptual framework.

4. Results and Discussions

Based on the objective of the research, the result and discussion are presented in three parts. The first part has evaluated the current and projected future climate parameters (Rainfall, minimum and maximum temperature) in order to identify the changing climate over the catchment. The second part has focused the SWAT sensitivity analysis, calibration and validation. Finally it has been attempted to evaluate the impact of climate change on stream flow of the catchment.

4.1 Evaluating the Performance of RCP Simulations Against Observed

The output RCP precipitation, minimum and maximum temperature data is not directly used for climate change impact assessment. Therefore bias correction has been done using the observed weather data at each selected station. Each historical climate data output compared against observation data. The mean monthly precipitation, maximum temperature and minimum temperature of observed, RCPs uncorrected and RCPs corrected compared for the catchment. Areal precipitation has been computed under each scenario for general analysis of precipitation over the catchment.

4.1.1 Bias Corrected Precipitation

At monthly level, as shown in figure 4.1, some months have underestimated RCP precipitation as compared to the observed precipitation (January, February, March, July and December), while the rest months are overestimated especially the three months June, August and September which are found in the main rainy season.

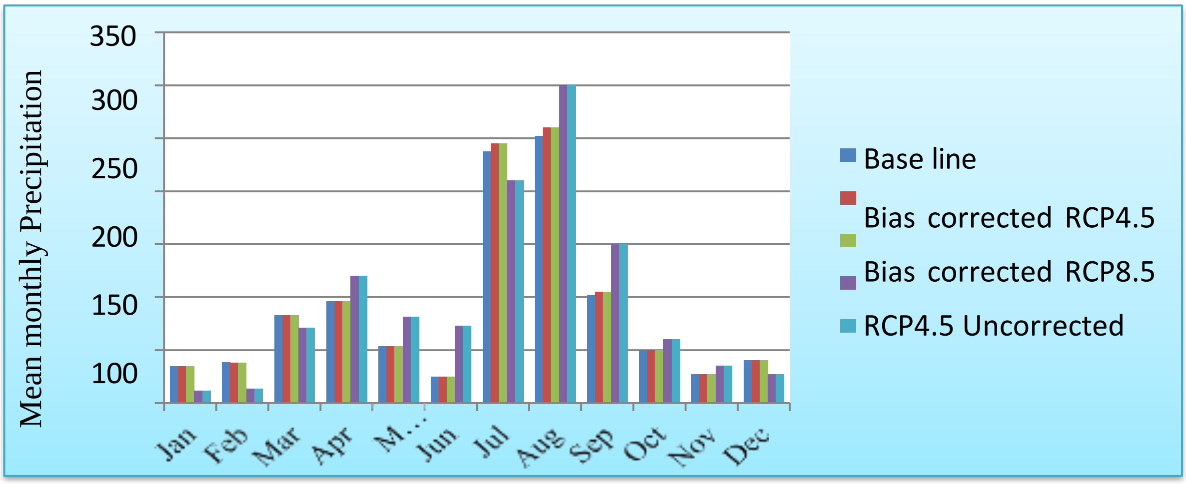


Figure 4. 1: Comparisons between monthly Precipitation bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed

4.1.2 Bias Corrected Maximum Temperature

With respect to maximum temperature, the average maximum temperature of the model shows, under estimation during all months (January-December). Observed, Uncorrected RCP and bias corrected mean monthly maximum temperature magnitudes presented in figure 4.2.

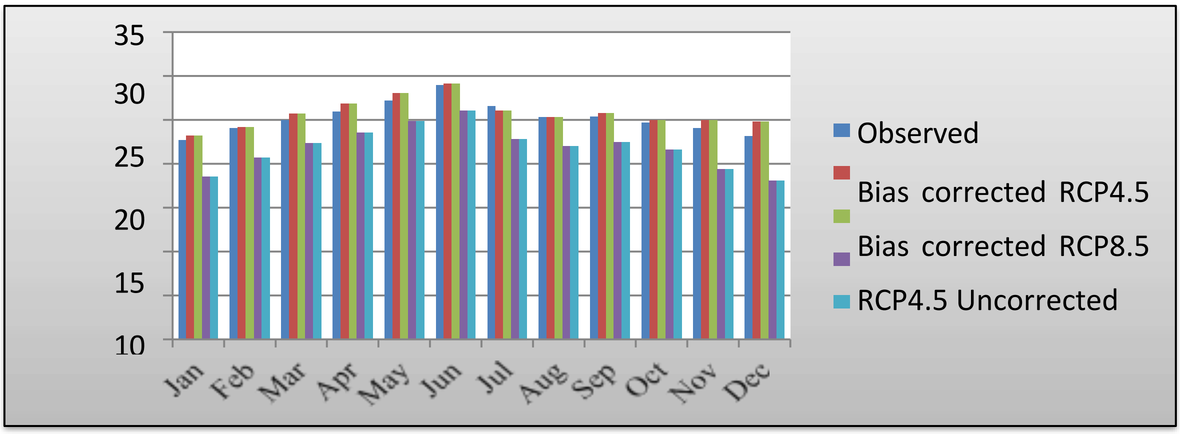


Figure 4. 2: Comparisons between monthly maximum temperature bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed.

4.1.3 Bias Corrected Minimum Temperature

As in the case with minimum temperature, the average minimum temperature shows that, slight overestimation during June, July and August, slight underestimation during September and high underestimation during most of the months. Like precipitation and maximum temperature, the bias correction minimum temperature shows a reasonably good agreement with the observed minimum temperature for all months.

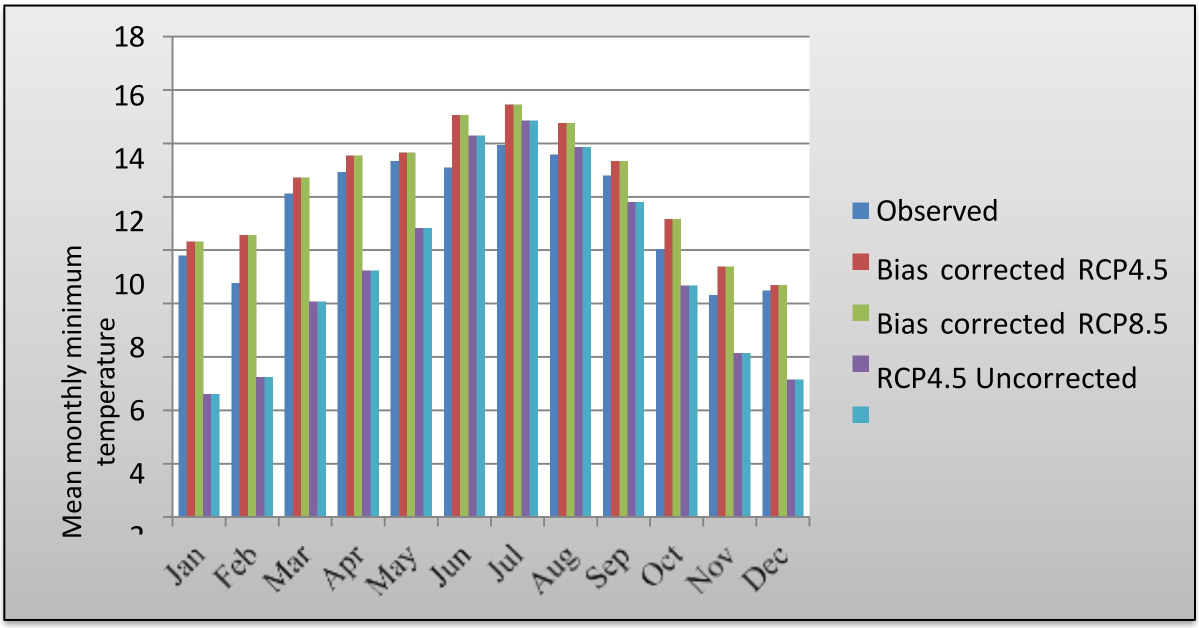


Figure 4.3: Comparisons between monthly minimum temperature bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed.

In comparison to the minimum and maximum temperature, the precipitation could not able replicate the historical data. This is due to complicated nature of precipitation process and its distribution in space and time. Climate model simulation of precipitation has improved over time but is still a problematic (Bader et al., 2008). (Thorpe, 2005) also added that rainfall predictions have a larger degree of uncertainty than those for temperature, this is because rainfall is highly variables are not adequate to fully capture that change.

Generally all the RCPs output predictions of precipitation, maximum and minimum temperature resembled in producing the observed data for the base period. Therefore it is plausible to use RCPs data output for future prediction for the catchment.

4.2 Future projection of climate change

In this study 0.44° 0.44° grid resolution of bias corrected RCM model outputs based on RCP 4.5 and RCP8.5 emission scenario used for analysis. Projected future scenarios have been divided in to two successive periods of 30 years based on WMO recommendations (IPCC, 2001). Therefore, period from 1976-2005 taken as a base period and two future periods considered for impacts investigation of 2050`s (2041-2070) and 2080`s (2071-2100).

4.2.1 Future projection of Climate Impacts on Precipitation

The average annually and monthly precipitation result showed in figure 4.4 and 4.5. Characterizations at three different periods were made, historical (1976-2005), middle-term (2041-2070) and long-term (2071-2100).

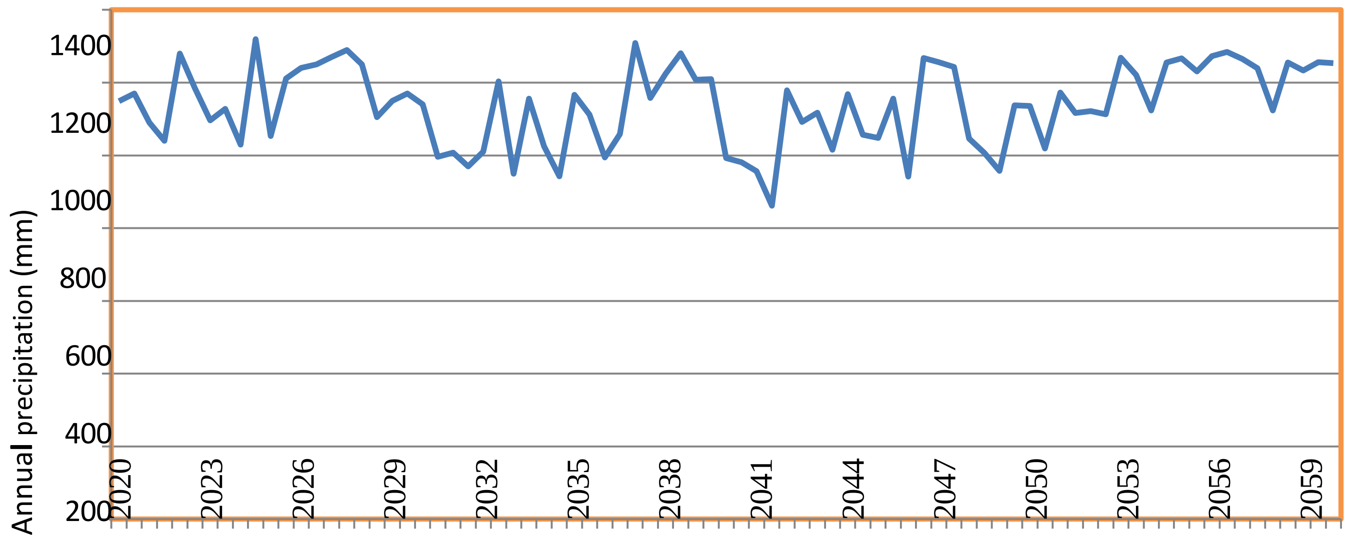


Figure 4.0 4: Changes in average annual precipitation of RCP4.5 for 2050's and 2080's

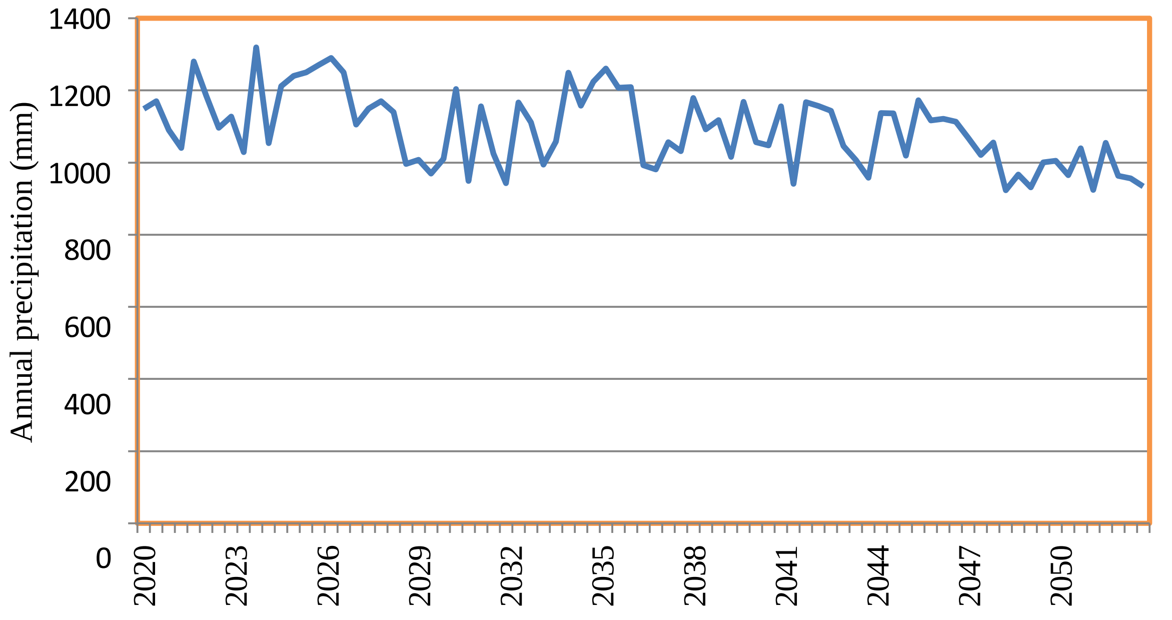


Figure 4. 5: Changes in average annual precipitation of RCP8.5 for 2050's and 2080's

The result indicates, under low-medium scenarios (RCP4.5), the catchment annual precipitation will decreased up to 3.87% in 2050's and increased up to 4.64% in 2080's, while under high emission scenario (RCP8.5), the catchment precipitation will decrease up to 8.05% and 8.73% in 2050‘s and 2080‘s respectively.

Changes in precipitation in monthly values are also plotted in fig 4.6. The mean monthly precipitation will decrease in most dry season and July for both scenarios. During June and August (rainy season) precipitation will have a slight increase in 2050‘s for RCP4.5 and there will be a slight increase in mean precipitation during April (small rainy month) in 2080‘s for RCP8.5.

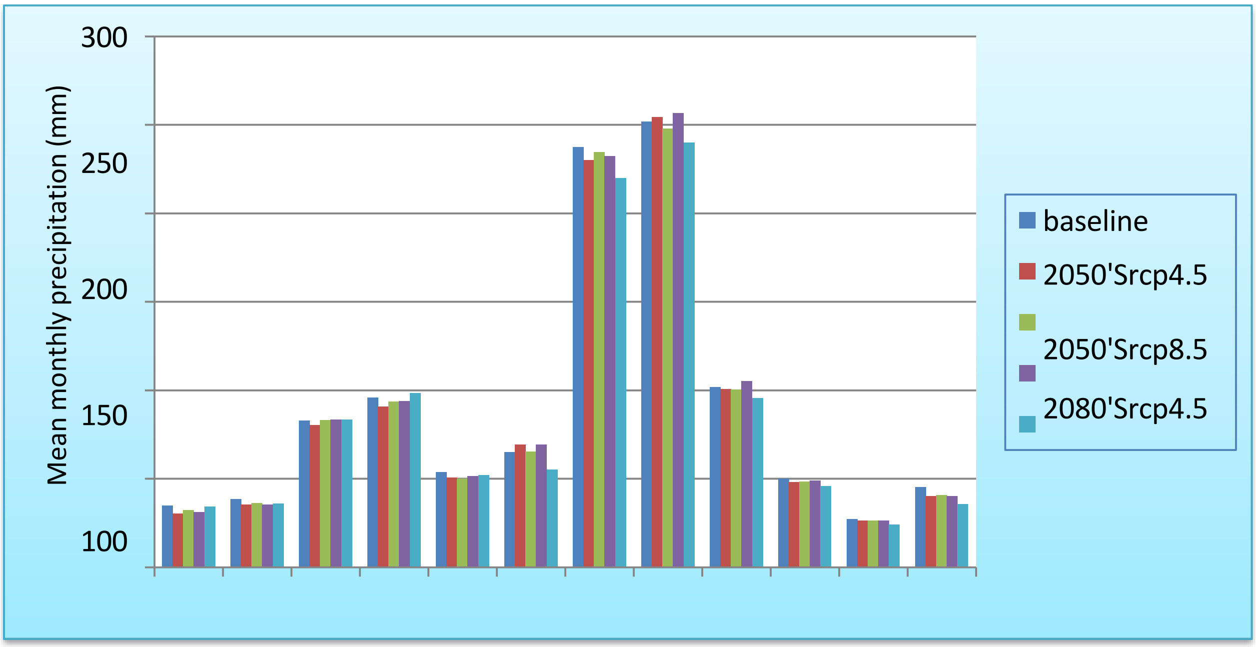


Figure 4.6: Comparison of areal mean monthly precipitation of base line (1976-2005) with two future scenarios RCP4.5 and RCP8.5 (2050s and 2080s).

For these two future horizons, expected changes in precipitation characteristics are unclear. (Beyene et al., 2007) report a 24% increase in precipitation projection in late 21st century (2070-2099) using 11 GCMs, while (Elshamy et al., 2009) report almost no expected change in precipitation considering the ensemble mean of 17GCMs. Generally there is no consensus among the GCMs on the direction and magnitude of precipitation change at basin-wide or sub-basin scale within the upper Blue Nile River basin (e.g Setegn et al., 2011; Taye et al., 2011; Enyew et al., 2014).

4.2.2 Future Projection of Climate Impacts on Minimum Temperature

For minimum temperature, the result has been computed for baseline and two future periods to demonstrate the change in temperature under two emissions (RCP4.5 and RCP8.5). Generally the result showed that, there will be an increasing in minimum temperature for both middle-future and far-future periods in two scenarios. The average minimum temperature increased by up to 1.4^{o}c in 2050‘s and 1.3^{o}c in 2080‘s under RCP4.5 scenario; for RCP8.5, the average minimum temperature increases by 1.5^{o}c and 1.8^{o}c in 2050‘s and 2080‘s respectively.

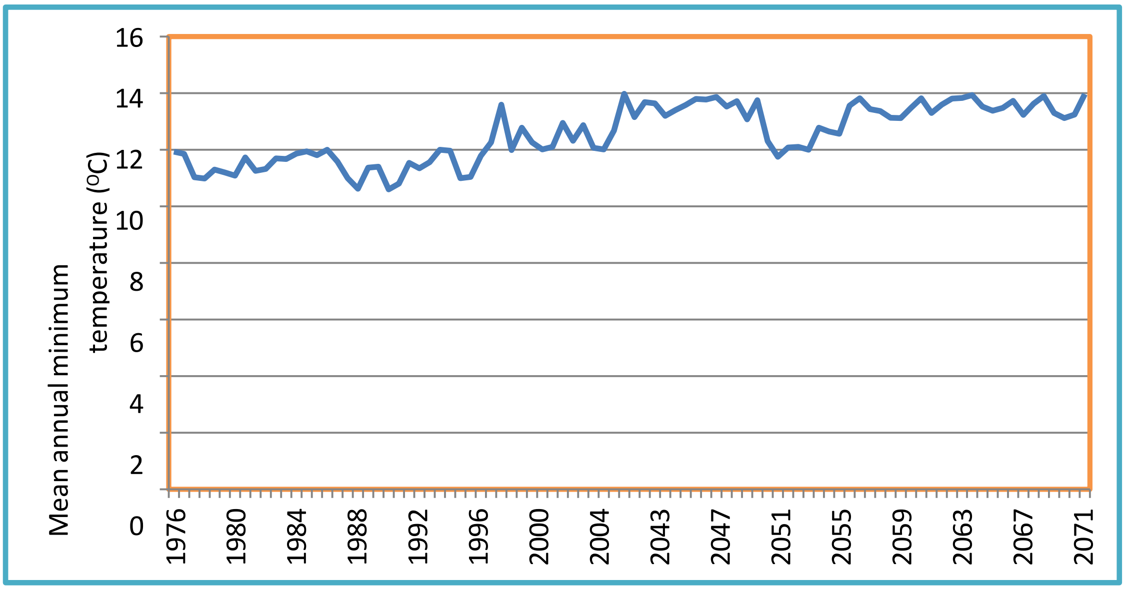


Figure 4. 7: Comparison of annual minimum temperature of base line with future results of RCP4.5 scenario.

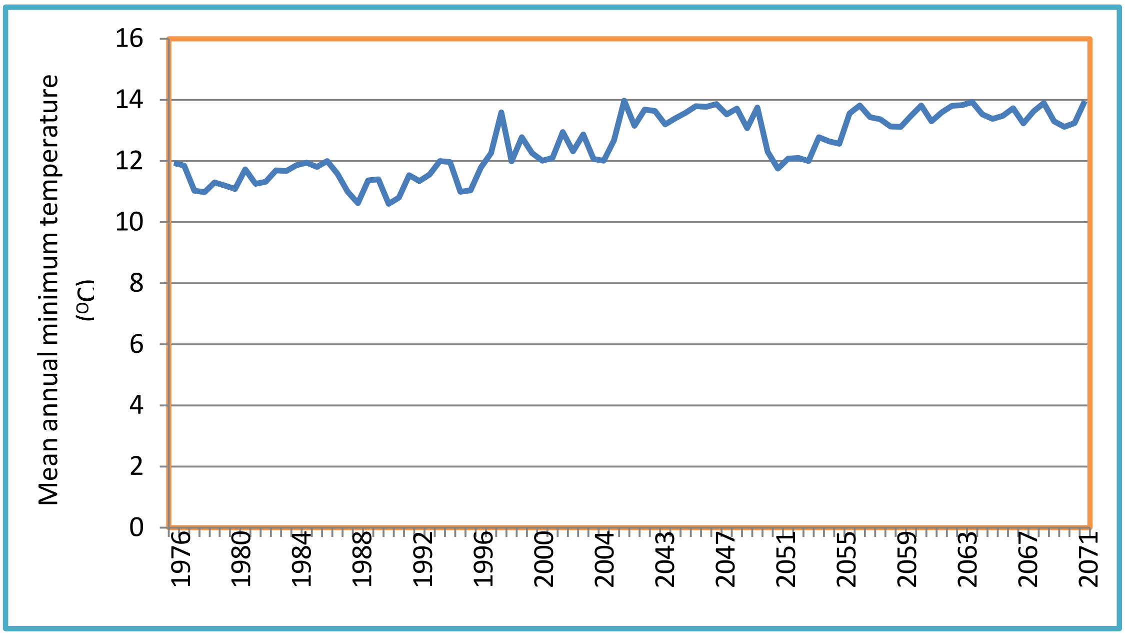


Figure 4. 8: Comparison of annual minimum temperature of base line with future results of RCP8.5 scenario.

Figure 4.9 shows the comparison of arithmetic average monthly minimum temperature at Mille catchment. It showed that both the base line and projected minimum temperature goes to the lowest value during the months of January, February, November and December.

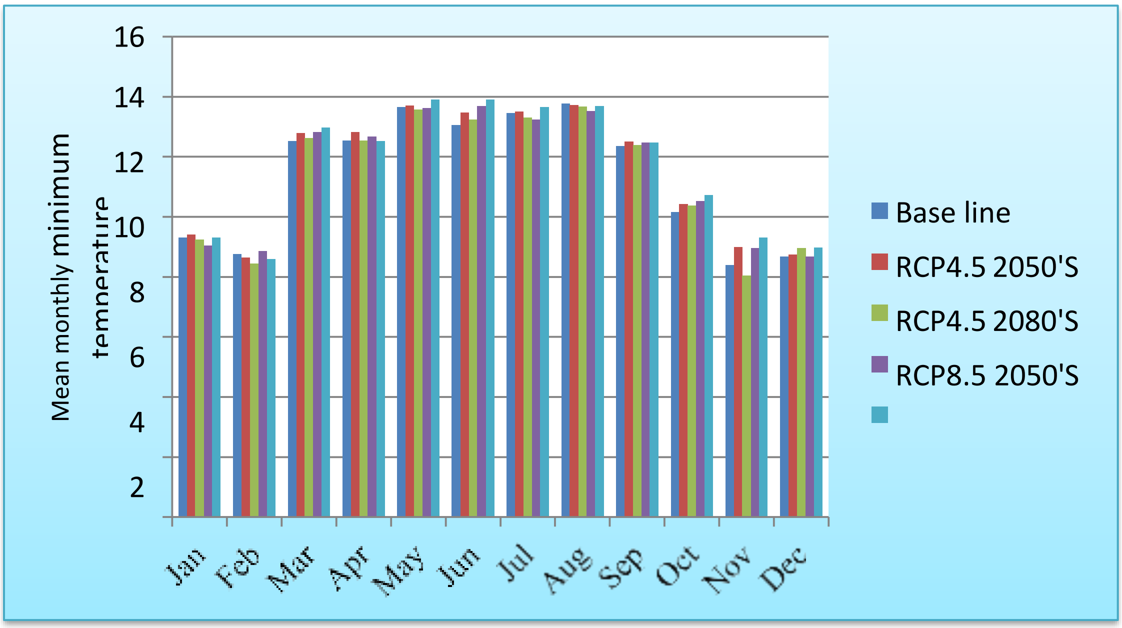


Figure 4. 9: Comparison of mean minimum temperatures of base line with future results of RCP4.5 and RCP8.5 scenarios.

Most studies project shows a clear increase in temperature by the end of the 21st century. The minimum temperature result of (Abdo et al., 2009) was an increasing trend in all future time horizons for both A2 and B2 scenarios. In 2050s the increment will be 2.2°C and 1.7°C for A2 and B2 scenario respectively. For the 2080s periods the average annual minimum temperature will be increased by 3.7°C and 2.7°C for A2 and B2 scenario respectively. The differences in the result exist because they used SRES of AR4, but this study used RCPs of AR5. The average annual minimum temperature projection result (Gebre et al., 2015), there will increase in both horizon (2030‘s and 2070‘s) periods and high maximum change predicted at the end of 21st century for RCP8.5 emission scenario

4.2.3 Future Projection of Climate Impacts on Maximum Temperature

Like minimum temperature, the maximum temperature result has been computed for base line and two future periods to demonstrate the change in temperature. This enables to estimate the changing climate under these two emissions in comparison with the base line. The projected maximum temperature result shows that, there will be an increasing in the middle-future and in the far-future period for both scenarios. For RCP 4.5 the average maximum temperature increased by up to 1.2°c and 1.3°c in 2050s and 2080‘s respectively. For RCP8.5, increases by 1.6°c and 1.7°c in 2050‘s and 2080‘s respectively.

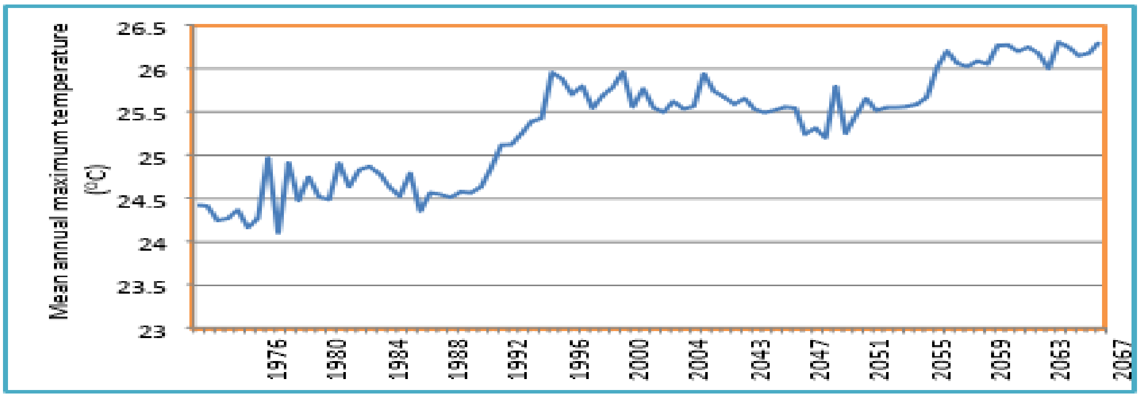


Figure 4.10: Comparison of annual maximum temperature of the baseline with future results

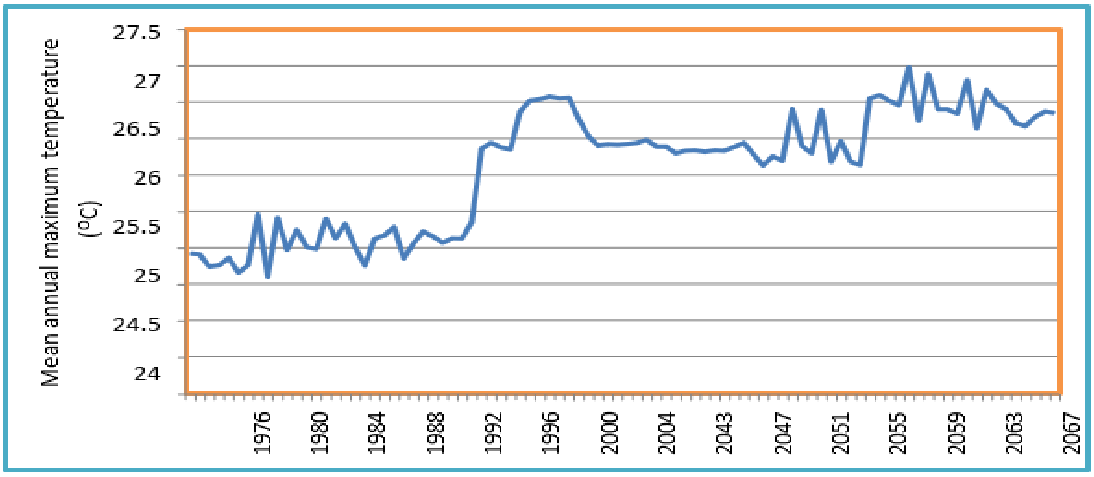


Figure 4.11: Comparison of annual maximum temperature of the baseline with future results

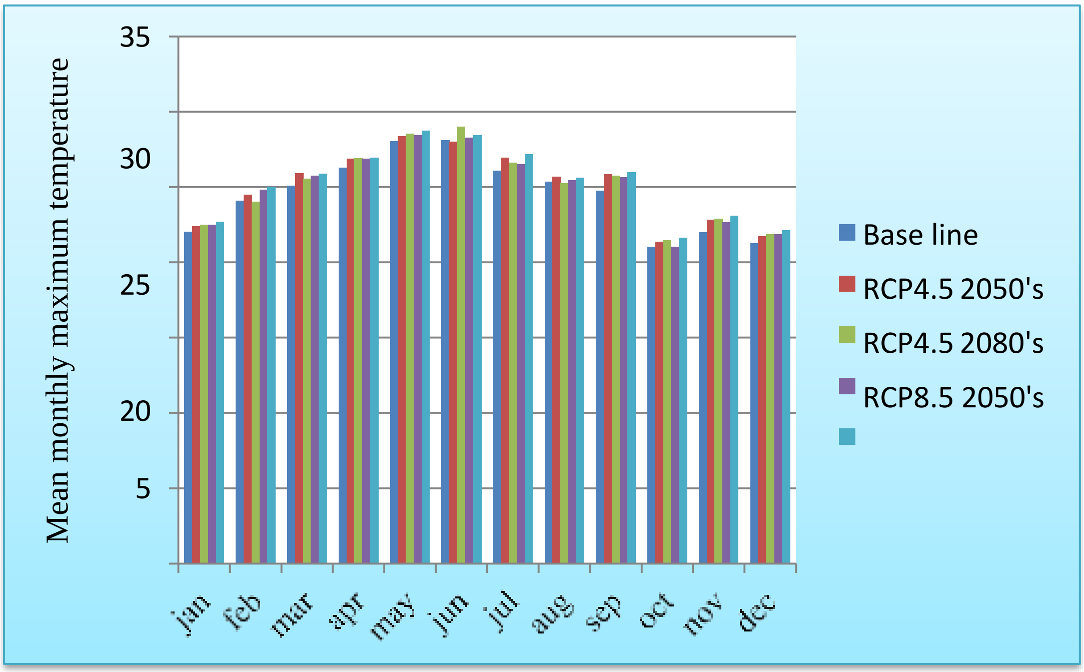


Figure 4.12: Comparison of mean maximum temperatures of the base line with future results of RCP4.5 and RCP8.5 scenarios.

Most studies project shows a clear increase in temperature by the end of the 21st century. Over the Awash River Basin, a temperature increase of 2.4 and 3.0°C, respectively (Kinfe, 1999). The difference in the result occurred; since he used the GCM climate model which has lower resolution. The projected temperature in 2020s indicates that maximum temperature will rise by 0.6ºC. In 2050s the increment will be 1.4ºC and 1.1ºC for A2 and B2 scenario respectively. In 2080s the annual maximum temperature will be increased by 2.5ºC and 1.8ºC for A2 and B2 scenario respectively (Abdo et al., 2009). The average annual maximum and minimum temperature projection results showed that temperature will increase in both future horizon periods (2050‘s and 2080‘s). High maximum change predicted at the end of 21st century for RCP 8.5 emission scenario (Gebre et al., 2015).

Table 4.1: Changes in precipitation and temperature in the future periods of 2041-2070 and 2071-2100 relative to the baseline period of 1976-2005

Projected period	Precipitation change (%)		Maximum temperature change (^{o}c)		Minimum temperature change (^{o}c)	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2041-2070	-3.87	-8.05	1.2	1.6	1.4	1.5
2071-2100	4.64	-8.73	1.3	1.7	1.3	1.8

4.3 SWAT Model Sensitivity Analysis, Calibration and Validation

4.3.1 Sensitivity Analysis

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive. Sensitivity analysis from SUFI-2 provided partial information about the sensitivity of the objective function to model parameters. In the study, 13 water-related parameters (global parameters), with absolute minimum and maximum ranges in the SWAT model documents were selected to do sensitivity analysis. The sensitivity ranking, a t stat provides a measure of sensitivity (larger absolute values are more sensitive), and p values determine the significance of the sensitivity (a value close to zero has more significance).

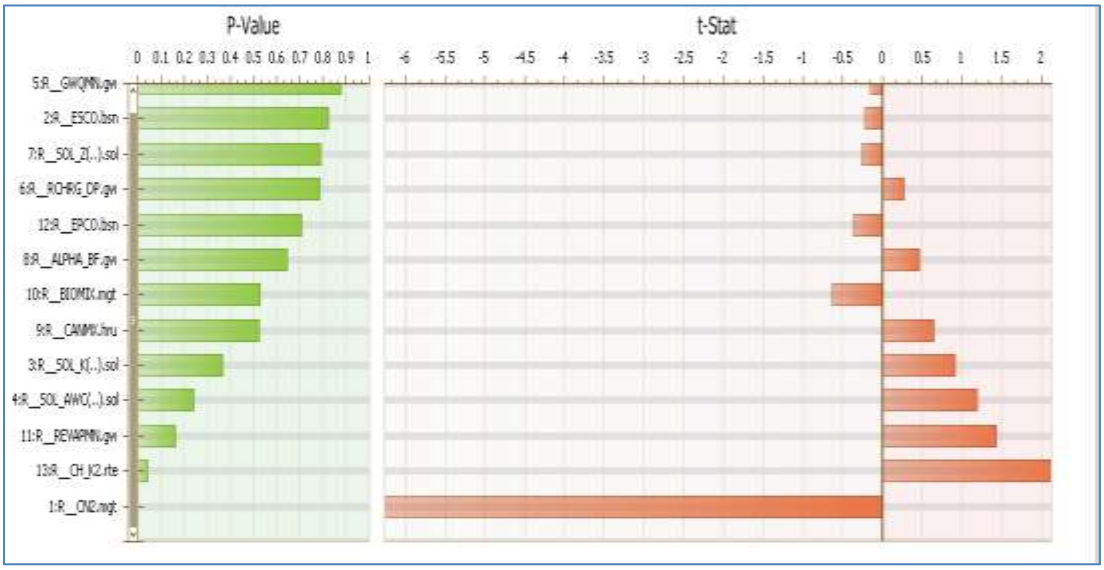


Figure 4.13: Sensitivity analysis of flow

Table 4. 2: Flow sensitive parameters and fitted values

SN^{O}	Sensitive Parameters	Description	Lower bound	Upper bound	Fitted value	Sensitivity rank
1	CN2	Initial SCS runoff curve number for moisture condition II	-25%	25%	-0.0125	1
2	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr.)	0	150	106.25	2
3	REVAPMN	Threshold depth of water in shallow aquifer for revap or percolation to the deep aquifer	0	500	429.167	3
4	SOL_AWC	Soil available water capacity(mm Water/mm soil)	-25%	25%	0.220833	4
5	SOL_K	Saturated Hydraulic conductivity [mm/hr.]	-25%	25%	0.220833	5
6	CANMX	Maximum canopy storage	0	10	5.0833	6
7	BIOMIX	Biological mixing efficiency	0	1	0.658333	7
8	ALPHA_BF	Base flow recession	0	1	0.45833	8
9	EPCO	Plant uptake compensation factor	0	1	0.108333	9
10	RCHRG_DP	Deep aquifer percolation fraction	0	1	0.05833	10
11	SOL_Z	Soil depth [mm]	-25%	25%	-0.1875	11
12	ESCO	Soil evaporation compensation factor	0	1	0.94167	12
13	GWQMN	Threshold depth of water in the shallow aquifer require for return flow`	0	5000	3375	13

The most sensitive parameter was found to be CN2 (Initial SCS runoff curve number for moisture condition II), followed by effective hydraulic conductivity in main channel (CH_K2), REVAPMN (Threshold depth of water in shallow aquifer for revap or percolation to the deep aquifer) etc.

4.3.2 Model calibration and validation

Model calibration followed sensitivity analysis by considering those parameters. Calibration involves testing the model with known input and output data in order to adjust some parameters, while validation involves comparison of the model results with an independent dataset during calibration without any further adjustment of the calibration parameters. Model calibration and validation using SUFI-2 Al-algorithm, flow predictions were calibrated using 1993 to 2001 and validated using 2002 to 2007 monthly flow data.

After calibrating for flow simulation was executed and the hydrographs are well captured. The agreement between the measurement and simulation is generally very good, which are verified by NSE and R^2 and an acceptable result were obtained according to the model evaluation guideline (Moriasi et al., 2007). The results of these tests illustrated that the monthly coefficient of determination and Nash- Sutcliffe coefficient was 0.92 and 0.90 for calibration period, 0.86 and 0.81 for validation period.

The calibration and validation period of the model was fifteen years from 1993 to 2007 (Figure 4.14) and (Figure 4.15) respectively. The result of calibration and validation for monthly flow hydrograph showed that there is a good agreement between the measured and simulated monthly flows.

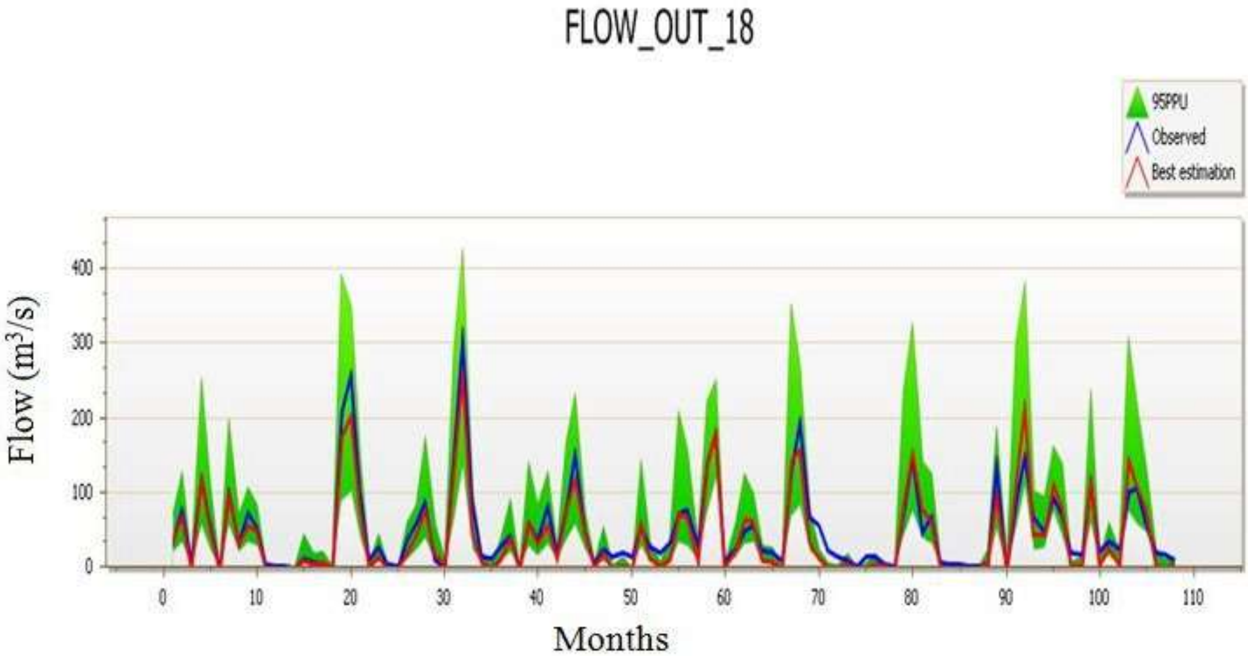


Figure 4.14: Hydrograph of the observed and simulated flow from the watershed for the calibration period on a monthly basis (1993-2001)

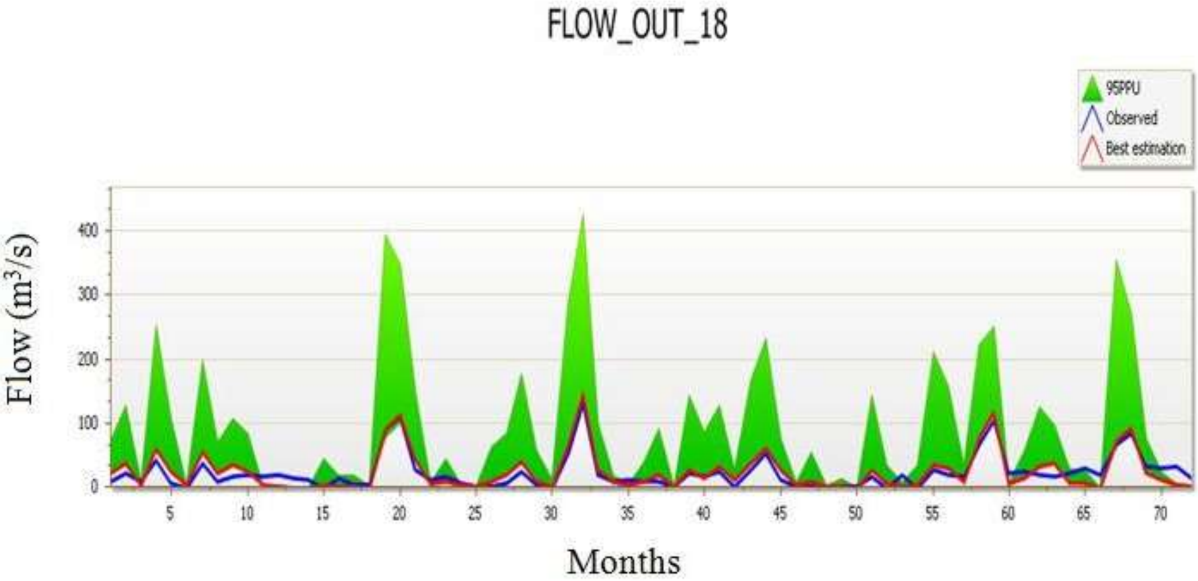


Figure 4.15: Hydrograph of the observed and simulated flow from the watershed for the validation period on a monthly basis (2002-2007)

Table 4. 3: Monthly model evaluation statistics for flow in the Catchment

Performance measure	Calibration (1993-2001)	Validation (2002-2007)
Coefficient of determination (R^2)	0.92	0.86
Nash Sutcliff efficiency (NSE)	O.90	0.81

4.3.3 Impact of future Climate Change on stream flow

The impact of climate change on stream flow predicted on Mille catchment based on the changes in temperature and precipitation projected under RCP 4.5 and RCP 8.5 scenarios. Therefore, after calibrating the hydrological models with the observed record, the next step is the simulation of river flows in the catchment by using the bias corrected precipitation, maximum and minimum temperature as input to hydrological models. Based on this, stream flow impact of the Mille River analyzed with respect to three 30 years period of baseline (1976-2005), 2050‘s (2041-2070) and 2080‘s (2071-2100) and the hydrological model re-run for each case. The SWAT simulation of the 1976-2005 period used as a base period against the future period of which the climate impact assessed.

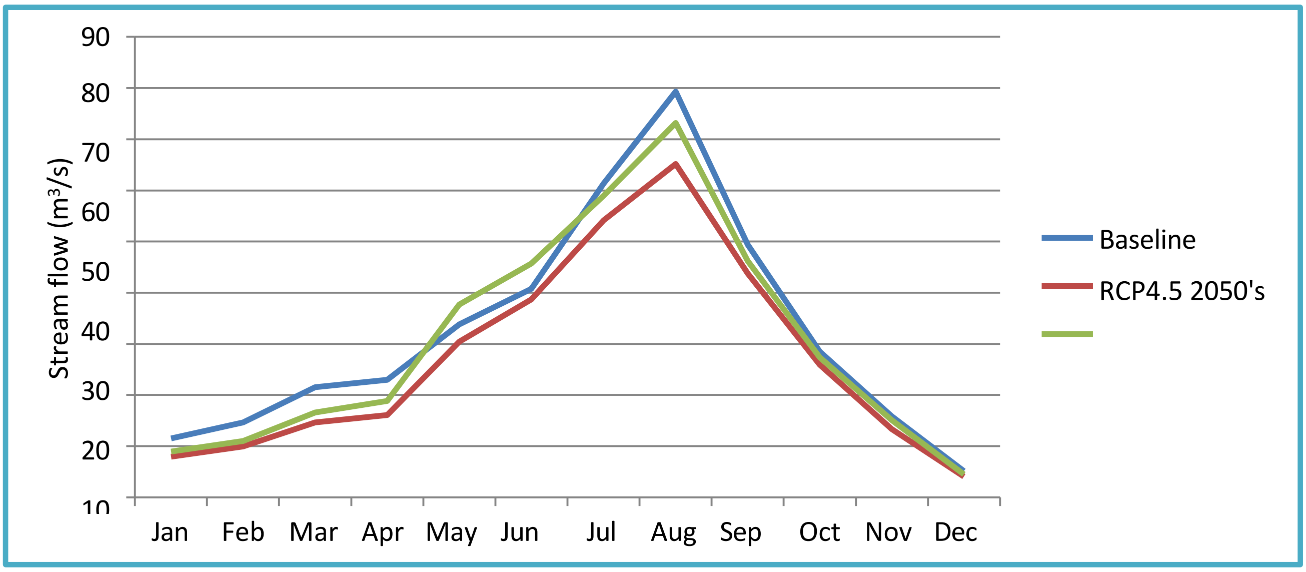


Figure 4.16: Comparison of mean monthly stream flow for the future periods 2041-2070 and 2071-2100 relative to the baseline period under RCP4.5.

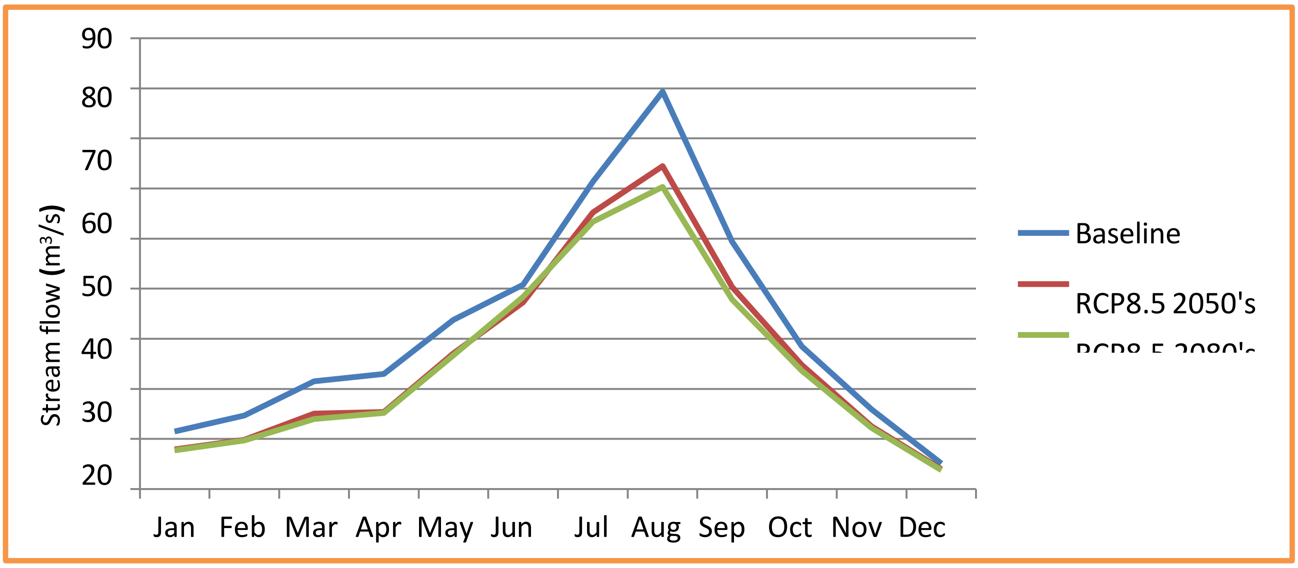


Figure 4.17: Comparison of mean monthly stream flow for the future periods 2041-2070 and 2071-2100 relative to the baseline period under RCP8.5 scenario.

The simulation results for two future time horizons are summarized in Table 4.4 and Figures 4.16 and 4.17. As it is shown in table, the variation in mean annual stream flow is moderate. The mean annual stream flow will be reduced by 6.37% and 13.9% in 2050s for RCP4.5 and RCP8.5 scenario respectively, while mean annual stream flow will be increased by 5.8% for RCP4.5 in 2080‘s, as a result slight increases will happen in monthly stream flow during May and June under this scenario by 10.5% and 10.71% respectively due to the increase in precipitation.

In the main rainy season (July-September) the stream flow will be reduced by 3.9% - 21.68% for RCP4.5 and 11.1% - 30.5% for RCP8.5. With respect to individual months, there will be large reductions in February, March and April by 51.5%, 53.8% and 51.5% respectively in 2080‘s under RCP8.5.

Table 4. 4: Changes in simulated stream flow under RCP4.5 and RCP8.5 for the period of 2041-2070 and 2071-2100.

Projected period	Stream flow change (%)	
	RCP4.5	RCP8.5
2041-2070 (middle-future)	-6.37	-13.9
2071-2100 (far-future)	5.8	-26.3

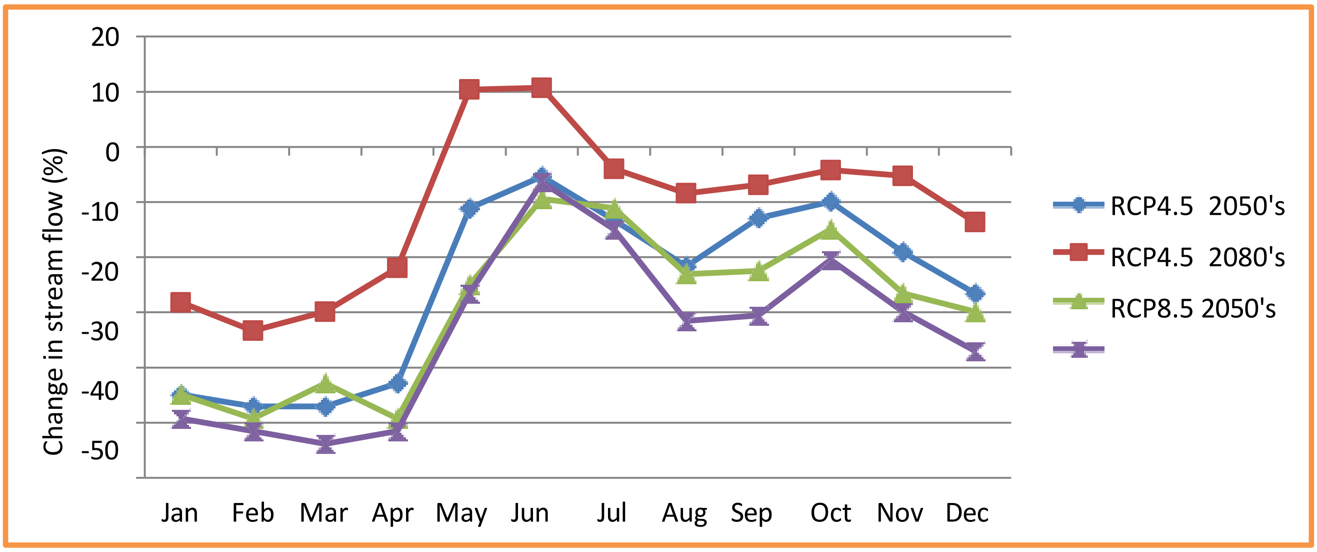


Figure 4.18 : Relative percentage change in mean monthly stream flow projection for 2050‘s (2041-2070) and 2080‘s (2071-2100) under RCP4.5 and RCP8.5 as compared to the baseline period (1976-2005) for Mille catchment

Regarding stream flow (Beyene et al., 2007) reported a project increase in stream flow of 26% for 2010-2039 and a decrease of 10% for 2070-2099 using A2 emission scenarios. (Elshamy et al., 2009) also report reduced prediction of mean annual stream flow by 15% for the 2080‘s compared to the baseline period. The hydrological impact of future change scenarios indicates (Abdo et al., 2009) there will be high monthly variation of stream flow compared to the annual variation. In the main rainy season (June-September) the stream flow will reduce by 11.6% and 10.1% for A2 and B2 scenario respectively in 2080s. July also exhibit a reduction in mean monthly flow where the flow will be reduced by 20% and 16% in the 2080s for A2 and B2 scenario respectively.

The impact of climate change in precipitation and temperature has produced a significant change on stream flow in upper Blue Nile basin (Conway et al., 2011). The different GCMs model resulted different projection response to climate change over the basin. Ecearth and IPSL GCM projected more or less increase in stream flow change whereas HadGEM2-ES projected decrease in average stream flow change for the different of the catchments of the Blue Nile basin (Gebre et al., 2015). According to our study the result shows that, mean monthly and annual stream flow will decrease for most months for both future periods of RCP4.5 and RCP8.5 scenarios. The decrease in stream flow may highly associate to the decrease in precipitation over the catchment. The average stream flow change in magnitude is similar compared to other studies. Results of this study are expected to arouse the serious concern about water resource availability in the Mille watershed under the continuously warming climate.

5. Conclusions and Recommendations

5.1 Conclusions

RCM output under different climate change scenarios (RCP4.5 and RCP8.5) and bias corrections of precipitation and temperature have been analyzed for current and two future time horizons (2041-2070 and 2071-2100) in the catchment.

The projection of precipitation and temperature changes showed different in the two scenarios in both future periods. Under low-medium scenarios (RCP4.5), the catchment annual precipitation will decreased up to 3.87% in 2050‘s and increased up to 4.64% in 2080‘s, while under high emission scenario (RCP8.5), the areal precipitation will decrease up to 8.05% and 8.73% in 2050‘s and 2080‘s respectively.

The average minimum temperature increased by up to 1.4^{o}c in 2050‘s and 1.3^{o}c in 2080‘s under RCP4.5 scenario. On the other hand under RCP8.5, the average minimum temperature increases by 1.5^{o}c and 1.8^{o}c in 2050‘s and 2080‘s respectively.

The projected maximum temperature result shows that, there will be an increasing in maximum temperature in the middle-future and in the far-future period for both scenarios. For RCP 4.5 the average maximum temperature increased by up to 1.2^{o}c and 1.3^{o}c in 2050s and 2080‘s respectively. For RCP8.5, the average maximum temperature will increases by 1.6^{o}c and 1.7^{o}c in 2050‘s and 2080‘s respectively.

The result of hydrological model calibration and validation indicates that the SWAT model simulates the runoff considerably good for the study area. The model performance criterion which is used to evaluate the model result indicates that the coefficient of determination (R^2) and Nash and Sutcliffe efficiency (NSE) are 0.92 and 0.90 for calibration, 0.86 and 0.81 for validation respectively.

The catchment stream flow will have significant changes under predicted changes in precipitation and temperature. The change in stream flow, during in the future period of 2041-2070 and 2071-2100 as compared to the baseline period 1976-2005 range from -6.37% and 5.8% for RCP4.5 and -13.9% and -26.3% for RCP8.5. Results of this study are expected to arouse the serious concern about water resource availability in the Mille watershed under the continuously warming climate.

5.2 Recommendations

Analysis of climate change impact has been done by assessing it_s primarily manifestation of changes in precipitation and temperature data under two scenarios. However, it is more appreciable when considering the change in land use, soil and other climate variables such as (relative humidity, wind speed etc.) as inputs in addition to the change in precipitation and temperature for better understanding of the climate change impact on the catchment.

The outcome of this study is based on single GCMs and two scenarios. However, it is often recommended to apply different GCMs and emission scenarios so as to make comparison between different models as well as to explore a wide range of climate change scenarios that would result in different hydrological impacts. Hence this work should be extended in the future by including different GCMs and emission scenarios.

There is a need to minimize the sensitivity to climate change by making stringent climate polices, strong reforestation and stable co_2 and methane emissions. Moreover, research activities should be intensified in this area in order to explore the impact of climate change on various sectors including water resource.

Acknowlegments
First of all I would like to thank to the almighty of Allah for his never ending gift and his provision to complete this work. I am also grateful to my employer Wollo University for providing me leave during my study. I also thank National Metrology Agency (NMA), Ministry of Water, Irrigation and Electricity (MOWIE), International Water Management Institute (IWMI) and Ethiopian Mapping Agency for providing me data of free charge. I would like to express my appreciation to all my friends for their encouragement, moral support and true friendship. Finally I would like to express my deep gratitude to my mother and my brother.

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