JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Evaluation of climate change Impact on stream flow of Mille watershed

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

Abdela Yimer

March, 2018
Jimma, Ethiopia

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Advisor: Dr.Ing. Kassa Tadele

Co-advisor: Mr. Fayera Gudu

March, 2018

Jimma, Ethiopia

DECLARATION

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

Abdela Yimer	___________________	________________
Candidate	signature	date

We, the undersigned, certify that we have read and here by recommend for the acceptance by the Jimma University a dissertation entitled: **Evaluation of climate change impact on stream flow of Mille watershed** in partial fulfillment for the requirements for the degree of Master of Science in Hydraulic Engineering.

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APPROVAL PAGE

This thesis entitled "**Evaluation of climate change impact on stream flow of Mille watershed"** has been approved by the examiners and chair holder in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering.

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ABSTRACT

Climate change manifests itself primarily through changes in average temperature and precipitation, which affects in overall flow magnitude. This study evaluated the impact of climate change on stream flow of Mille watershed, which is situated in the North-East part of Ethiopia. Climate change is likely to affect the hydrology of the watershed. The study aims to assess the change of climate variables (precipitation and temperature) and stream flow of the study area. Different materials and methods were used to arrive at the stated objectives. Downscaled future climate projections of precipitation and temperature were developed from 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 stations and areal rainfall over the catchment was determined. In this study, the period 1976-2005 was used as the baseline period, while 2041-2070 (2050's) and 2071-2100 (2080's) as the middle-future and the far-future respectively. As temperature projected the climate would become warmer for both scenarios in the future. The future projection of climate variable showed an increasing in minimum temperature by 1.4°C and 1.3°C for RCP4.5 and 1.5°C and 1.8°C for RCP8.5 in 2050's and 2080's respectively. As Rainfall 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 2050's but it become rise by 4.64% in 2080's. The Soil and Water Assessment Tool (SWAT) model was calibrated and validated for stream flow simulation. The climate change variables used an input to SWAT model to simulate the future stream flow. 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 period of 2050's and 2080's respectively. Results of this study are expected to arouse the 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 polices.

Key words: Climate Change, Hydrology, Mille, RCPs, SWAT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

a.m.s.l	above mean sea level
Arc GIS	Aeronautical Reconnaissance Coverage Geographic Information Systems
AR4	Fourth Assessment report
AR5	Fifth Assessment Report
CMIP3	Coupled Model Inter Comparison Project Phase three
CMIP5	Coupled Model Inter comparison Project phase five
CN	Curve Number
CORDEX	Coordinated Regional Climate Downscaling Experiment
CO_2	Carbon di Oxide
CV	Coefficient of Variance
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ENSO	El Nino Southern Oscillation
FAO	Food and Agricultural Organization
GCMs	Global circulation Models
GHGs	Green House Gases
GP	Grid Point
HadGEM1-ES	Hadley Global Environment Model 1 - Earth System
HadGEM2-ES	Hadley Global Environment Model 2 - Earth System
HRU	Hydrologic Response Unit
IPCC	Intergovernmental panel on climate change
IWMI	International Water Management Institute
LULC	Land Use and Land Cover
MWIE	Ministry of Water, Irrigation and Electricity
NMA	National Metrology Agency
RCA4	Ross by Centre Regional Atmospheric Climate Model
RCM	Regional climate modeling
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
SCS	Soil Conservation Service
SRES	Special Report on Emission Scenario
SUFI-2	Sequential Uncertainty Fitting Procedure Version 2

SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil and Water Assessment Tool- Calibration and Uncertainty Programs
UK	United Kingdom
UNDP	United Nation Development Program
UNEP	United Nation Environment Program
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WXGEN	Weather Generator
95PPU	95% Prediction Uncertainty

1 INTRODUCTION

1.1 Background

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 change in climate is different from other fluctuations that occur without any forcing at all. Climate variability without forcing 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 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 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 gases 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 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 of water resources. Non climatic 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 having 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).

With respect to hydrology, climate change can cause significant impacts on water resources by resulting changes in the hydrological cycle. For example, the changes on temperature and precipitation can have a direct consequence on the quantity of evapotranspiration and on runoff component. Consequently, the spatial and temporal availability of water resource can be significantly changes 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, Agriculture, water supply, hydropower production, economic and social infrastructure, health and biodiversity are the sector primarily affected with stronger secondary downstream impact to all sectors of the economy and the society (IPCC, 2014).

Despite the fact that the impact of different climate change scenarios projected at global scale, the exact type and the magnitude of the impact at catchment scale is not investigated in most part of the world (Andrew et al., 2010). Hence, identifying local impacts of climate change at catchment level is quite important. The Mille watershed is one of the source of Awash River basin and its water resources is 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 stream flow of 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 in order 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 characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time.

1.2. Statement of the Problem

Climate change affects human kind in several ways. Drought and flood are among the main effect 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 flood, landslide, avalanche 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 ground water (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 (IPCC2014).

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 water resource of lake Tana is highly vulnerable to climate change and the runoff may become much more seasonal and as a result small streams may completely dry up for the part of the year, this will become reason for a drying of wetlands, small springs and wells which are source of water supply to the rural community. The impacts of climate change in precipitation and temperature has produced a significant change on runoff in the basin (Conway et al., 1993)

The Awash River basin would be significantly affected by the changed climate; that is considerable water deficit is projected and the global warming would result general increase in dryness, which would decrease water availability (Kinfe, 1999)

Climate change has to lead to change in the natural drought cycle which is impacting on local people of the watershed. The Mille River is now decreasing from time to time due to climate change. The changing climate is changing the way of some pastoralists.

Therefore, more detail and reliable information is needed for running future water resource development. It is possible by evaluating future stream flow situation and climate change impact of socioeconomic activities on water resource of 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 stream flow of Mille watershed.

1.3.2 Specific Objectives

- To assess the change of climate variables (precipitation and temperature) in the watershed.
- Evaluate the impact of climate change on future stream flow of the study area.

1.4 Research question

1. What is the general climate variables of RCP output of precipitation, maximum and minimum temperature for the baseline period and for the future period?
2. What will be the impact of climate change on the stream flow of the watershed?

1.5. Significance of the study

By investigating the impact of climate change on hydrology and availability of water, it is possible to increase agricultural productivity, utilize water resource and conserve natural resource in proper way. This study will provide valuable climate information with the new plausible emission scenario to farmer communities, designers, policy and decision makers, and other respective stakeholders. Policy and decision makers can implement their proposed ideas using the information. Comparison of historical and future projection climate data can help for planning on adaptation and mitigation policies and strategies. So this study has an interesting insight to such advantageous climatic information and decisions.

2. LITERATURE REVIEW

2.1 Over View of Climate Change

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It may be due to natural internal processes or external forcing‘s such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use and also it could be due to natural climate variability or anthropogenic forcing (e.g., greenhouse gases), or a combination of the two (IPCC, 2014 A).

Nowadays there is strong scientific evidence that indicates the average temperature of Earth surface is increasing due to greenhouse gas emissions. Global Warming and precipitation are expected to vary considerably from region to region. Average change in climate, changes in frequency and intensity of extreme weather events are likely to have major impacts on natural and human systems (Alerts et al., 2004)

In these days the awareness of the effect of climate change due to human activities has been accelerating. Climate change and variability has many significant effects on the hydrological cycle and thus also on hydrology and water resources system. The Intergovernmental panel on climate change has addressed this realization (Solomon, 2007).

Greenhouse gasses have played a great role in changing the climate change at global as well as regional level. The release of these gases to the atmosphere has been disturbing the normal composition of the atmosphere (Luqman et al., 2014)

These scenarios were run by different institutions using climate or circulation models. The outputs from these models have uncertain change signals. The most recent scientific assessment by the Intergovernmental Panel on Climate Change (IPCC) concludes that, since the late 19^{th} century, human induced Emissions of gases such as carbon dioxide (CO_2) that trap heat in the atmosphere in the manner of a greenhouse have contributed to an increase in global mean surface air temperatures of about 0.3 to 0.7^{o}C. Moreover, based on the IPCC’s mid-range scenario of future greenhouse gas emissions and aerosols and their best estimate of climate sensitivity, a further increase of 2^{o}C is expected by the year 2100 (IPCC, 2013).

2.2 GCMs/CMIP5 Climate Models

Global climate models (GCMs) are complex, computer based, mathematical representations of the Earth‘s climate based on fundamental scientific principles. Many different climate processes are represented in the global climate models. Precipitation, wind, cloudiness, the ocean currents, air and water temperatures, the amount and type of vegetation, the concentration of greenhouse gases (GHGs) and atmospheric aerosols (fine particles), these and other Global climate models are the principal tools used by climate scientists to quantitatively explore potential future climates, globally and regionally (IPCC, 2013).

Climate modeling groups from around the world, the World Climate Research Programmer's (WCRP) Working Group on Coupled Modeling (WGCM), with input from the International Geosphere-Biosphere program's (IGBP); Analysis, Integration and modeling of the Earth System (AIMES) project, agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of the Coupled Model Inter-comparison Project CMIP5 (Taylor et al., 2012).

The WGCM‘s endorsement of CMIP5 followed a planning stage involving extensive community input (Meehl and Hibbard, 2007) that led to a consensus proposal to perform a suite of climate simulations that focus on major gaps in understanding of past and future climate changes. In the experiments collected under CMIP5, both models and scenario have changed with respect to CMIP3 making a comparison with earlier results and the scientific literature they generated.

The set of models used in AR4 (the CMIP3 models) have been superseded by the new CMIP5 models and the SRES scenarios have been replaced by four RCPs. The archive of model simulations began being populated by mid-2011 and continued to grow during the writing of AR5 (Hibbard et al., 2007).

At global to sub-continental spatial scales the CMIP5 models do well in their simulation of both surface temperature and precipitation, and have clearly improved over CMIP3 (IPCC, 2013). The four CMIP5 scenario runs, which provide a range of simulated climate futures (characterizing the next few decades to centuries), can be used as the basis for exploring climate change impacts and policy issues of considerable interest and relevance to society.

2.3 Climate Change Scenarios

Climate scenarios are plausible representations of future climate conditions (temperature, precipitation and other climatological phenomena).These scenarios provide plausible descriptions of how the future might unfold in several key areas-socioeconomic, technological and environmental conditions, emissions of greenhouse gases and aerosols, and climate (Moss, 2010).

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). Along with information on other related conditions such as land use and land cover, emissions scenarios provide inputs to climate models.

Table 2. 1: History of climate scenarios (Source (Bjornaes, 2015))

Year	Name	Used in IPCC
1990	SA90	First assessment report
1992	IS92	Second assessment report
2000	SRES-Special Report on Emission Scenario	Third and fourth assessment report.
2009	RCP-Representative Concentration Pathway	Fifth assessment report

2.3.1 Representative Concentration Pathways (RCPs)

RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHGs) concentrations (Bjornaes, 2015). In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level that is of interest but also the trajectory that is taken over time to reach that outcome.

The words concentration pathway are meant to emphasize that these RCPs are not the final new, fully integrated scenarios (i.e. they are not a complete package of socio-economic, emission and climate projections), but instead are internally consistent sets of projections of the components of radiative forcing that are used in subsequent phases (Detlfe et al., 2011).

Anthropogenic climate change is driven by a number of factors, all of which contribute to radiative forcing of the climate system. The RCPs need to model all of these factors so that they are internally consistent. The radiative forcing factors include the full suite of GHGs, aerosols, chemically active gases, and land use (IPCC, 2008).

A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Inter-comparison Project Phase 5 (CMIP5) of the World Climate Research Program. A large number of comprehensive climate models and ESMs have participated in CMIP5, whose results form the core of the climate system projections (IPCC, 2013).Four RCPs pathways named according to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m2, by the end of 2100.

RCP 8.5:- High Emissions. This RCP is consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time.

RCP6:- Intermediate Emissions This RCP is developed by the National Institute for Environmental Studies in Japan. Radiative forcing is stabilized shortly after year 2100, which is consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions.

RCP 4.5:-Intermediate Emissions. This RCP is developed by the Pacific Northwest National Laboratory in the US. Here radiative forcing is stabilized shortly after year 2100, consistent with a future with relatively ambitious emissions reductions.

RCP2.6:-Low Emissions. This RCP is developed by Netherlands Environmental Assessment Agency. Here radiative forcing reaches 3.0 W/m2 before it returns to 2.6 W/m2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time.

Table 2. 2: Overview of Representative concentration pathways (Vanvuuren, 2011)

scenarios	Description	Publication- IA Model
RCP8.5	Rising radiative forcing leading to 8.5 w/m2 in 2100	(Riahi et al.,2007)-MESSAGE
RCP6	Stabilization without overshoot pathway to $6W/m^2$ stabilization after 2100	(Fujino et al.,2006) and (Hijioka et al.,2008) - AIM
RCP4.5	Stabilization without overshoot pathway to $4.5W/m^2$ stabilization after 2100	(Clarke et al.,2007)- GCAM
RCP3-PD2	Peak in radiative-forcing at $3W/^2$ before 2100 and decline.	(VanVuuren etal.,2006)-IMAGE

**MESSAGE, Model for Energy Supply Strategy Alternatives and their General Environmental Impact, International Institute for Applied Systems Analysis, Austria; AIM, Asia-Pacific Integrated Model, National Institute for Environmental Studies, Japan;*
GCAM, Global Change Assessment Model, Pacific Northwest National Laboratory, USA (previously referred to as MiniCAM); IMAGE, Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency, The Netherlands.

In all RCPs, atmospheric CO2 concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of $CO_2$to the atmosphere during the 21st century (IPCC, 2013).The RCP spans a range of radiative forcing from 2.6 to 8.5 W/m^2 and represents various possible climate outcomes.

2.4 Climate Model data and analysis

A climate model used to understand how the climate system works, and how the various components interact with each other. It used to simulate the present day climate, the recent past climate, and the climates of different pale climate epochs. It can have used to simulate the future statistical state of the atmosphere a decade or a century into the future, but does not predict the local weather on particular days (Sahilu and Nigussie, 2015).

Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. There are different kinds of climate models that range from simple energy balance models to complex system models (Randall et al., 2007).

2.4.1 HADGEM2-ES climate model

The HadGEM2-ES is a global climate model of earth system category developed by the Hadley Centre of UK metrology office. The resolution is about 1.875 degrees in longitude and 1.275 degrees in latitude, and 38 levels in the atmosphere. It has dynamic vegetation scheme with carbon cycle representation. The model supports the fifth phase of the Climate Model Inter-comparison Project (CMIP5) (Jones et al., 2011).

The Hadley Centre Global Environmental Model version 2 (HadGEM2) families of models has been designed for the specific purpose of simulating and understanding the centennial scale evolution of climate including biogeochemical feedbacks. The Earth system configuration is the first in the Met Office Hadley Centre to run without the need for flux corrections. The previous Hadley Centre climate model (HadGEM1) (Jones et al., 2006) did not include biogeochemical feedbacks, and the previous carbon cycle model in the Hadley Centre (HadCM3LC) (Cox et al., 2000) used artificial correction terms to the ocean heat fluxes to keep the model state from drifting.

The HadGEM2 Earth system model (HadGEM2-ES) comprises underlying physical atmosphere and ocean components with the addition of schemes to characterise aspects of the Earth system. The particular Earth system components that have been added to create the HadGEM2 Earth system model discussed in this paper are the terrestrial and oceanic ecosystems, and tropospheric chemistry (Collins et al., 2011)

In terms of bias, CV and RMSE, the HADGEM2-ES model performed best at upper Blue Nile River basin. Bias indicates the systematic error in rainfall amount. RMSE has the same unit as the observed variable making its interpretation relatively easy. CV for both the gauged and RCM simulated rainfall amounts to evaluate how well the rainfall variability by the network stations is captured and represented by the RCMs (Alemseged and Tom, 2015).

2.4.2 Climate Data Downscaling

Global Climate Models (GCMs) outputs are often characterized by biases and coarse resolution that limit their direct application for basin level hydrological modeling. “Downscaling” is the process of taking native-scale global climate model (GCM) results of global climate responses to changing global atmospheric composition and post processing those through additional statistical or dynamical models to create a set of results at finer spatial scale that is more meaningful in the context of local and regional impacts(IPCC, 2008).

The dynamical method typically uses the output of regional climate models which are driven by global models at the boundary of the regional model‘s domain. The output from this method is still at a coarser scale compared to what is required locally. Statistical downscaling overcomes this challenge. The statistical methods are based on statistical relationships that link the large-scale atmospheric variables with local/regional climate variables (Wilby, 2002)

The World climate research program (WCRP) recently formed the Task Force on Regional climate downscaling (TFRCD) Coordinated Regional Climate Downscaling Experiment (CORDEX) aims to create a framework for evaluating and comparing the range of dynamical and statistical RCD techniques in use around the world (Flippo and Giorgi ,2009).

The general aim of CORDEX is, for a range of limited-area regions, to downscale a number of GCM climate scenarios/predictions derived from the CMIP5 set of integrations. Its initial focus on Africa (50-km grid spacing) that first Africa is especially vulnerable climate change, both because of the dependence of many vital sectors on climate variability (e.g. agriculture, water management, healthy) and because of the relatively low adaptive capacity of its economies (Flippo and Giorgi ,2009)

Dynamically downscaled CMIP5 products are grid projections: Each climate projection‘s output interpolated from the source model‘s native spatial resolution to a common coarse-resolution grid. The common resolution used for the CMIP3 analysis was 2º; for CMIP5, it was 1º (Levi et al., 2013). They should be viewed as close approximations of uncorrected global climate simulation results over the domain. All regional model simulations should span the period 1951-2100 in orderto include a recent historical period, plus the entire 21st century. For many groups, however, it may prove computationally to demanding to run CORDEX simulations for this entire time span (Flippo and Giorgi, 2009).

2.4.3 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). Major causes of these errors, as identified by (IPCC, 2007) are:

- Lack of computational power to study hydrological processes at a micro scale
- Limitations in our knowledge about few climate processes for example, in the representation and behavior of clouds

- The inability to depict physical processes accurately in climate models.

The nonlinear bias correction method corrects both mean and coefficient of variation. The method, however, resulted in unrealistic corrected dry month rainfall amounts for the study area (Leander and Buishand, 2007).

2.4.4 Defining the Baseline Climate

Baseline climate information is important to characterize the prevailing conditions and its thorough analysis is valuable to examine the possible impacts of climate change on a particular exposure unit. It can have used as a reference with which the results of any climate change studies compared. The choice of baseline period often governed by availability of the required climate data. According to World Meteorological Organization (WMO), the baseline period also called reference period generally corresponds to the current 30 years' normal period.

A 30-year period used by WMO to define the average climate of a site or region, and scenarios of climate change generally based on 30-year means. Most impact assessments seek to determine the effect of climate change with respect to the present, and therefore recent baseline periods such as 1961 to 1990 are usually in favor. A further attraction of using 1961 to 1990 is that observational climate data coverage and availability are generally better for this period compared to earlier ones (IPCC, 2001).

2.5 Climate change in Africa and Ethiopia

Subsistence rain-fed cultivation by farmers in the Ethiopian highlands exposed to variability in daily rainfall and soil moisture and National water supply in Egypt exposed to interdecadal variability in Nile flows due to climate change and variability (Conway, 2005).

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).

Warming projections under medium scenarios indicate that extensive areas of Africa will exceed 2°C by the last 2 decades of this century relative to the late 20th century mean annual temperature and all of Africa under high emission scenarios (IPCC, 2014B). Under a high Representative Concentration Pathway (RCP), that extended could occur by mid-century across much of Africa and reach between 3°C and 6°C by the end of the century.

Increases in mean annual temperature over all land areas are very likely in the mid- and late 21st-century periods for RCP2.6 and RCP8.5. Ensemble mean changes in mean annual temperature exceed 2°C above the late 20th-century baseline over most land areas of the continent in the mid-21st century for RCP8.5, and exceed 4°Cover most land areas in the late 21st century for RCP8.5. (IPCC, 2014 B).

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, Agriculture, water supply, hydropower production, economic and social infrastructure, health and biodiversity are the sector primarily affected with stronger secondary downstream impact to all sectors of the economy and the society (IPCC, 2014).

2.6 Hydrological Models

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The one objective of the watershed hydrologic modeling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena (Lenhart et al., 2002). On the basis of process description, the hydrological models can be classified in to three main categories (Cunderlik, 2003).

Lumped models Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models.

Distributed models Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often unavailable) data. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

Semi-distributed models Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold, et al., 1993), HEC-HMS (HEC, 2005), HBV (Bergström, 1992), are considered as semi-distributed models.

Hydrologic models can be further divided into event-driven models, continuous process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff-events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003).

Generally for this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models.

2.6.1 Hydrological Model Selection Criteria

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-depended (and therefore subjective). Among the various project-dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 2003).

- Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as long-term sequence of flow and sediment yield?),
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?)
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?)
- Price (Does the investment appear to be worthwhile for the objectives of the project?)

2.7 Introduction to SWAT Model

The SWAT (Soil and Water Assessment Tool) watershed model is one of the most recent models developed at the USDA-ARS (Arnold et al., 1998) during the early 1970's. SWAT model is semi-distributed physically based can continuously simulate stream flow, erosion/sedimentation, or nutrient loss in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch et al., 2005).

The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed. In SWAT model, the impacts of spatial heterogeneity in topography, land use and soil are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics (Neitsch et al., 2005).

The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al., 2005). Major hydrologic processes that can be simulated by the this model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998).

2.7.1 Hydrological Component of SWAT

SWAT splits hydrological simulations of a watershed in to two major phases: the land phase and the routing phase. The land phase of the hydrological cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub watershed. While the routing phase considers the movement of water, sediment and agricultural chemicals through the channel network to the watershed outlet. The land phase of the hydrologic cycle is modeled in SWAT based on the water balance equation (Neitsch, et. al, 2005)

$$SW_t = SW_o + \sum_{t=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{sep} - Q_{gw} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots 2.1$$

Where SWt is the final soil water content (mm), SW_o is the initial water content (mm), t is the time (days), P_{day} is the amount of precipitation on day i (mm), Qs_{urf} is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm). W_{seep} is the amount of water entering the zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm)

2.7.1.1 Surface Runoff Volume

SWAT uses the concept that surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. Based on this assumption, SWAT uses two methods for estimating surface runoff: the Soil Conservation Service Curve Number (SCS-CN) technique (USDA Soil Conservation Service, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911).

The SCS curve number method is less data intensive than Green & Ampt infiltration method. Hence, the SCS curve number was used to calculate surface run off in the watershed since available spatial data is limited. In the Soil Conservation Service (SCS) curve number method often called the Curve-Number (CN) method, land use and soil characteristics are lumped into a single parameter (White et al., 2008).

The initial value for CN is assigned by the user for each HRU then SWAT calculates the lower and upper limit. For this calculation, SWAT uses a soil classification based on the Natural Resource Conservation Services (NRCS).This classifies soil into four hydrologic groups (a soil group has similar runoff potential under similar storm and cover condition based on infiltration characteristics of the soil (Neitsch et al., 2005)). After this classification the model defines three antecedent moisture conditions to determine the appropriate CN for each day using the CN-AMC (Curve Number Antecedent Soil Moisture Condition) distribution based on the moisture content of the soil calculated by the model (Neitsch et al., 2005).This daily CN is then used to determine a theoretical capacity S (retention parameter) that can be infiltrated.

$$S = 25.4\left[\frac{1000}{CN} - 10\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

The empirical model used to estimate direct runoff from storm is the SCS runoff equation.

$$Q_{surf} = \frac{\left(P_{day} - I_a\right)^2}{\left(p_{day} - I_a + S\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where Q_{surf} is the daily surface runoff in millimeters (mm), P_{day} is the daily Precipitation (mm), Ia is the initial abstraction which is commonly approximated as 0.2S and S is the retention parameter. Equation above becomes.

$$Q_{surf} = \frac{\left(p_{day} - 0.2S\right)^2}{\left(P_{day} + 0.8S\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified in to four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively.

2.7.2 SWAT-CUP

The SWAT-CUP program is linked to four algorithms to run calibration and validation in SWAT models. These includes

i. Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 1992)
ii. The Sequential Uncertainty Fitting (SUFI-2) (Abbaspour et al., 2007) method
iii. The Parameter Solution (Van Griensven et al., 2006) and
iv. The Bayesian inference which is based on the Markov Chain Monte Carlo (MCMC) method.

SUFI-2 algorithm, in particular, is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources (e.g., data, model and etc.) (Yang et al., 2008). It can perform parameter sensitivity analysis to identify those parameters that contributed the most to the output variance due to input comprehensive description on the SUFI-2 algorithm can be found in (Abbaspour et al., 1997).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical Location

Mille catchment is one of the largest sub-catchment in lower-Awash basin found in the Amhara and Afar regional state. The area lies between 11^{o}10’-11^{o}45’ North Latitude and 39^{o}35’- 40^{o}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 drained by the Mille River, which flows part of the North Wollo and South Wollo of Amhara region as well as administrative zone of 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 join the Awash River.

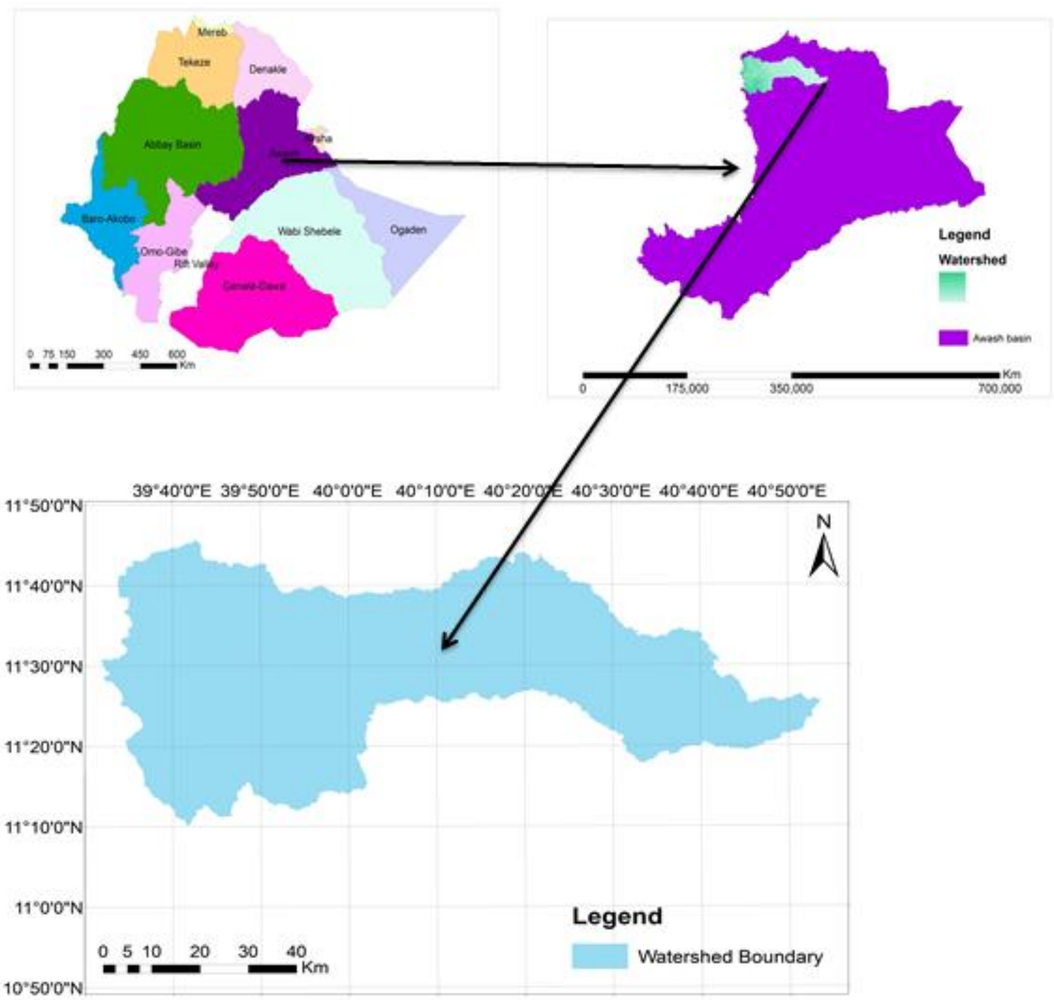

Figure 3.1: Location of the Study area

3.1.2. Topography

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

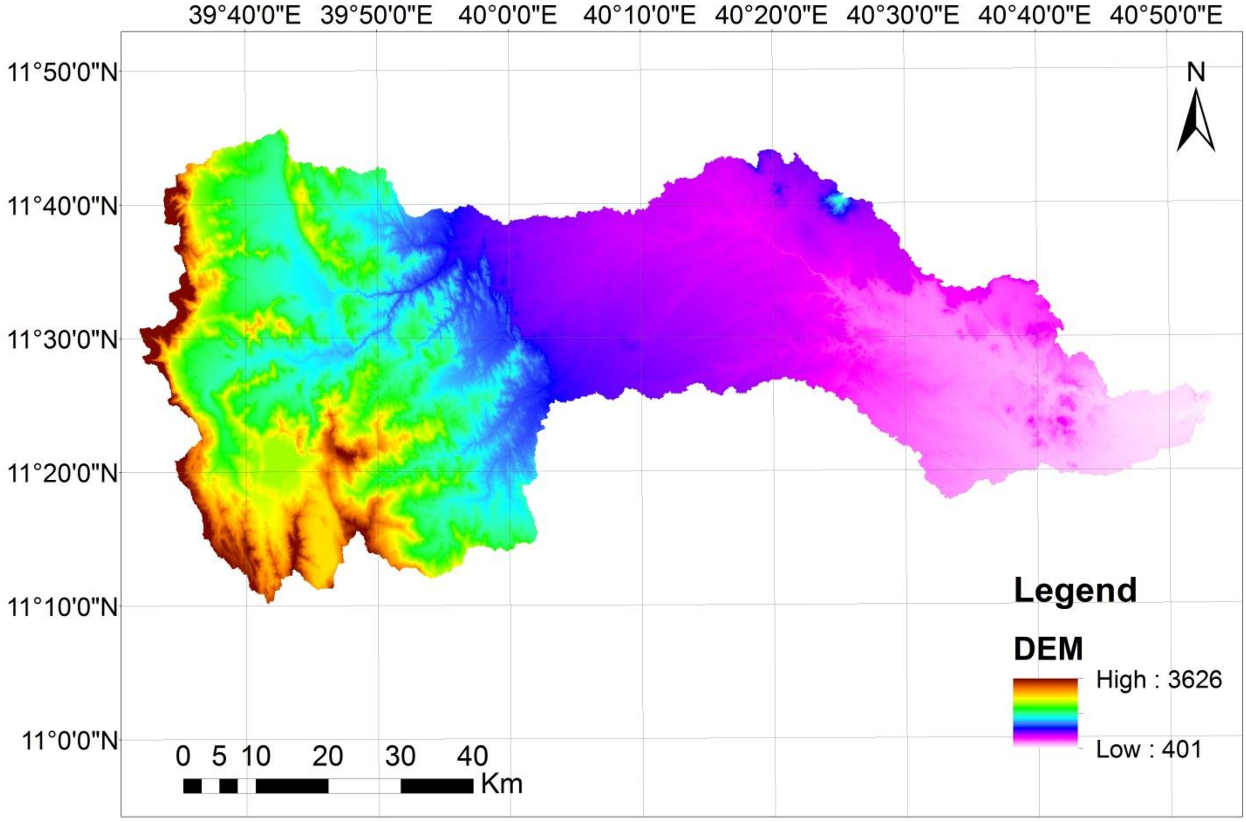

Figure 3. 2: Digital Elevation Model (DEM) of Mille watershed.

3.1.3. Climate and Hydrology

3.1.3.1 Climate

The climate of the Mille catchment varies from semi-humid subtropical over the western part to semi-arid on some part of 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).

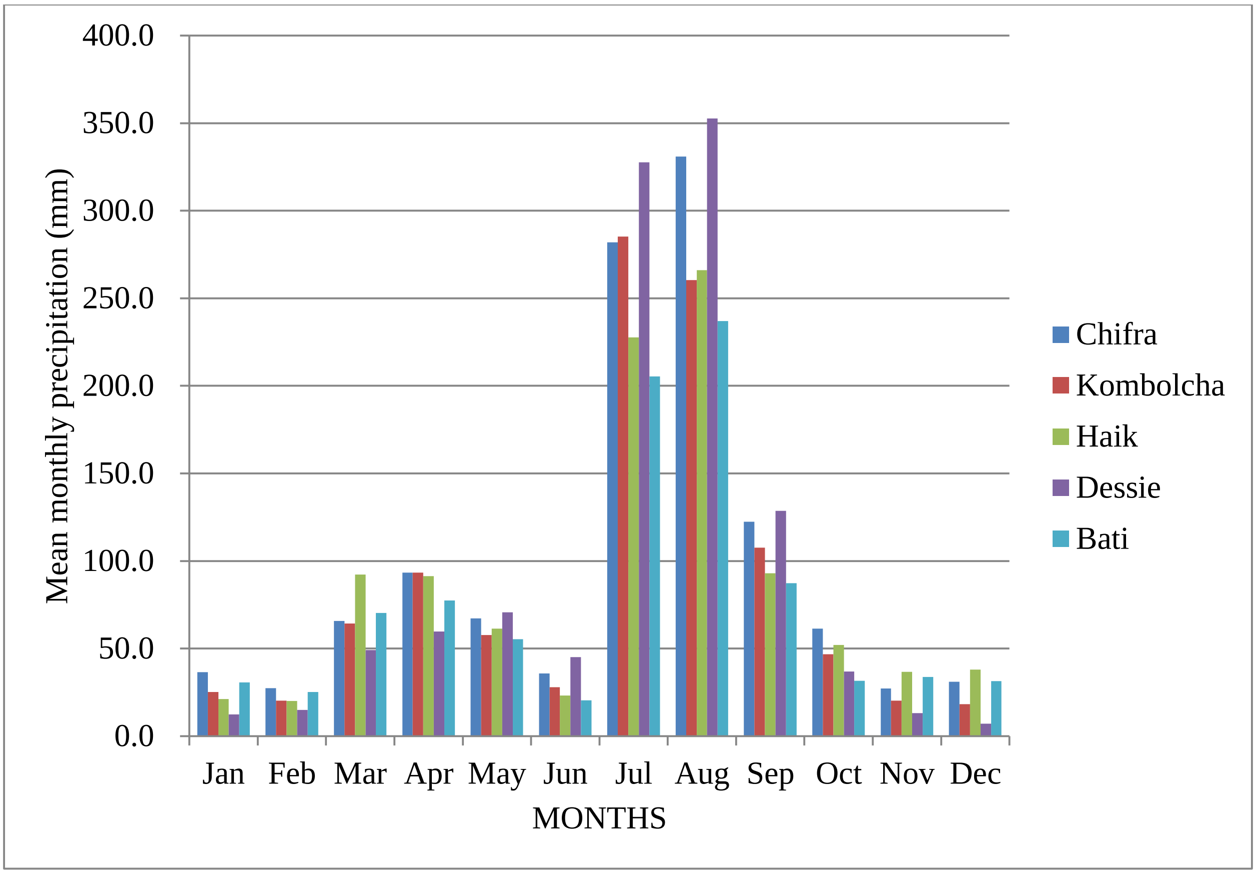

Figure 3. 3: Mean monthly Rainfall pattern of selected stations (1989-2016)

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.

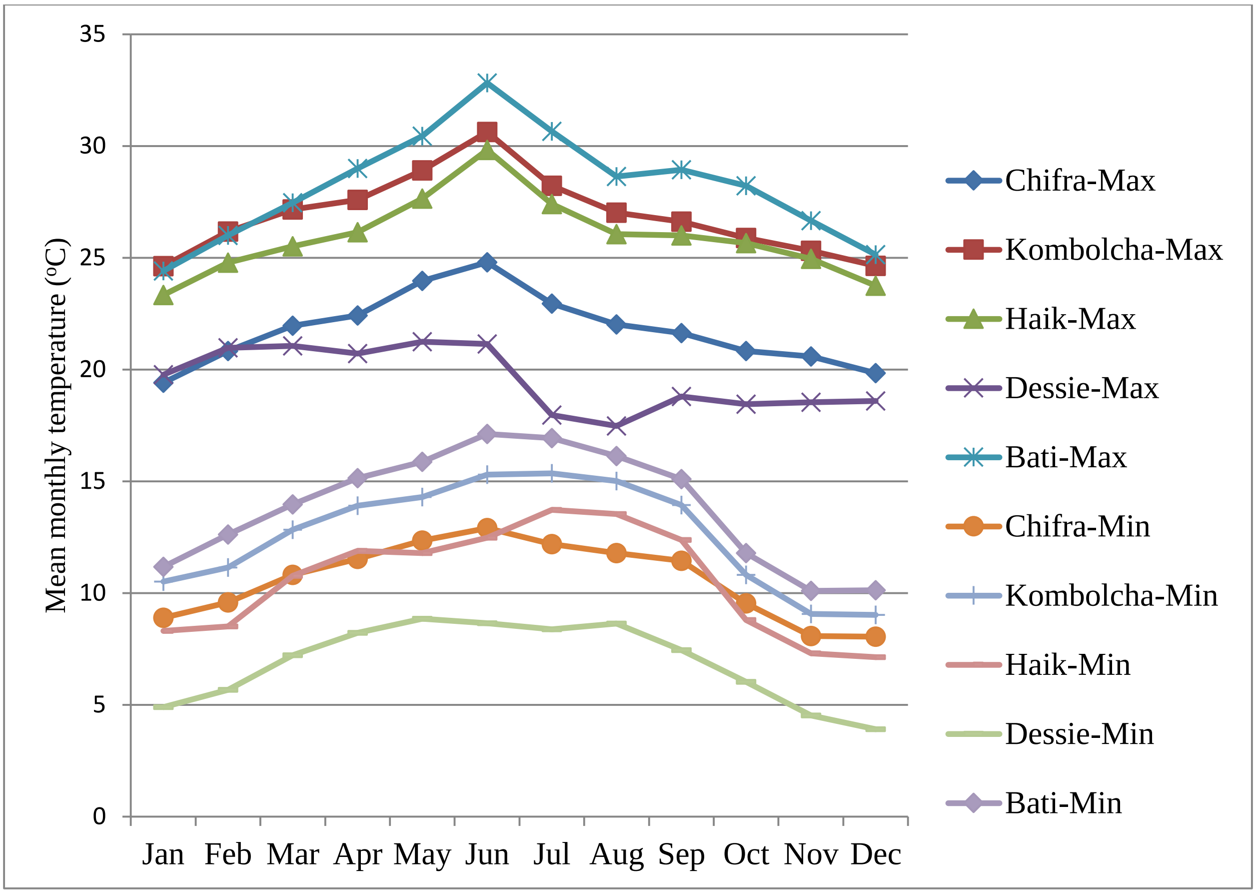

Figure 3.4: Mean monthly maximum and minimum temperature of selected stations (1989-2016)

3.1.3.2 Hydrology

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

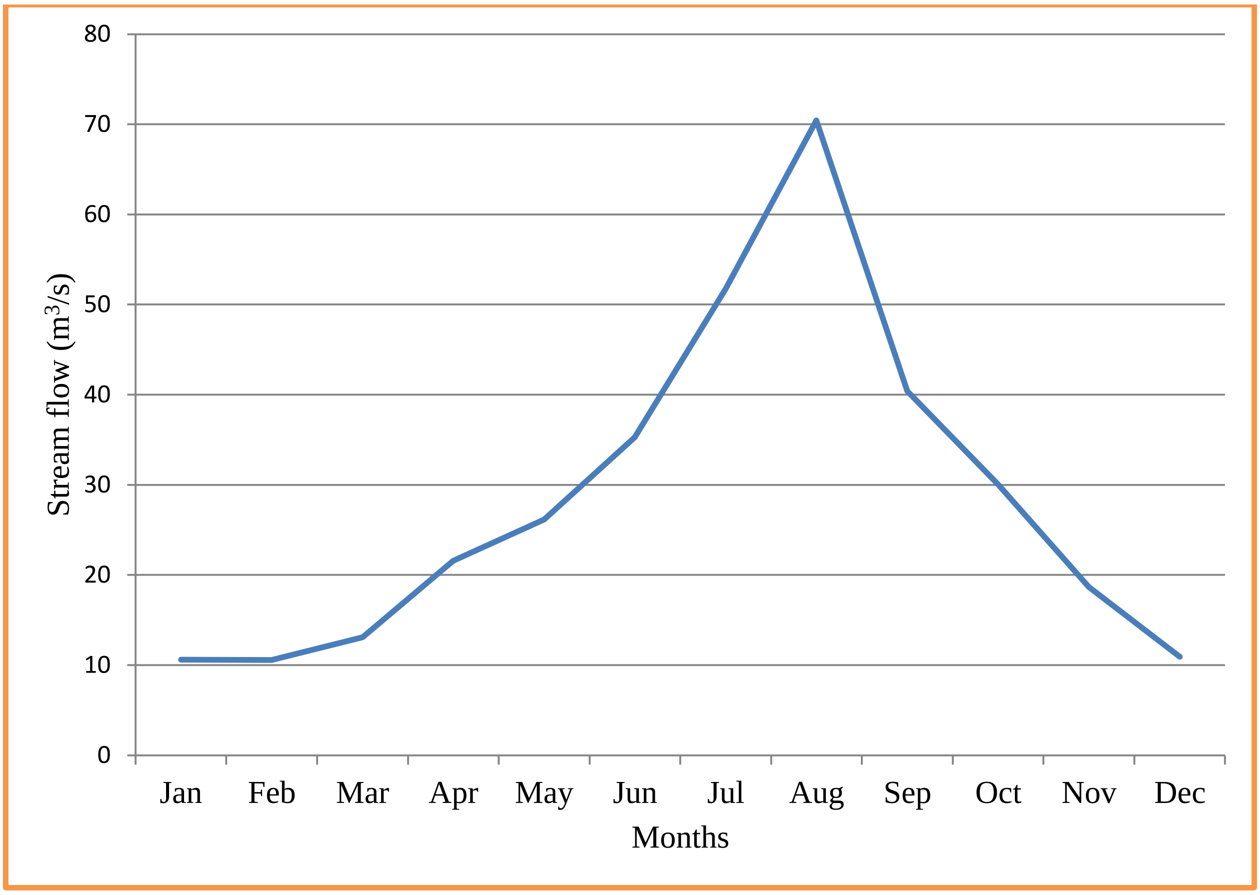

Figure 3. 5: Average monthly flow of Mille River

3.1.4 Land use/ land cover and soil

According to Ethiopian Mapping Agency (EMA) GIS data based land cover of the 2004 year classification, the land use land cover of the Mille watershed is mostly dominated by crop (Agricultural) land and shrub land (figure 3.6).

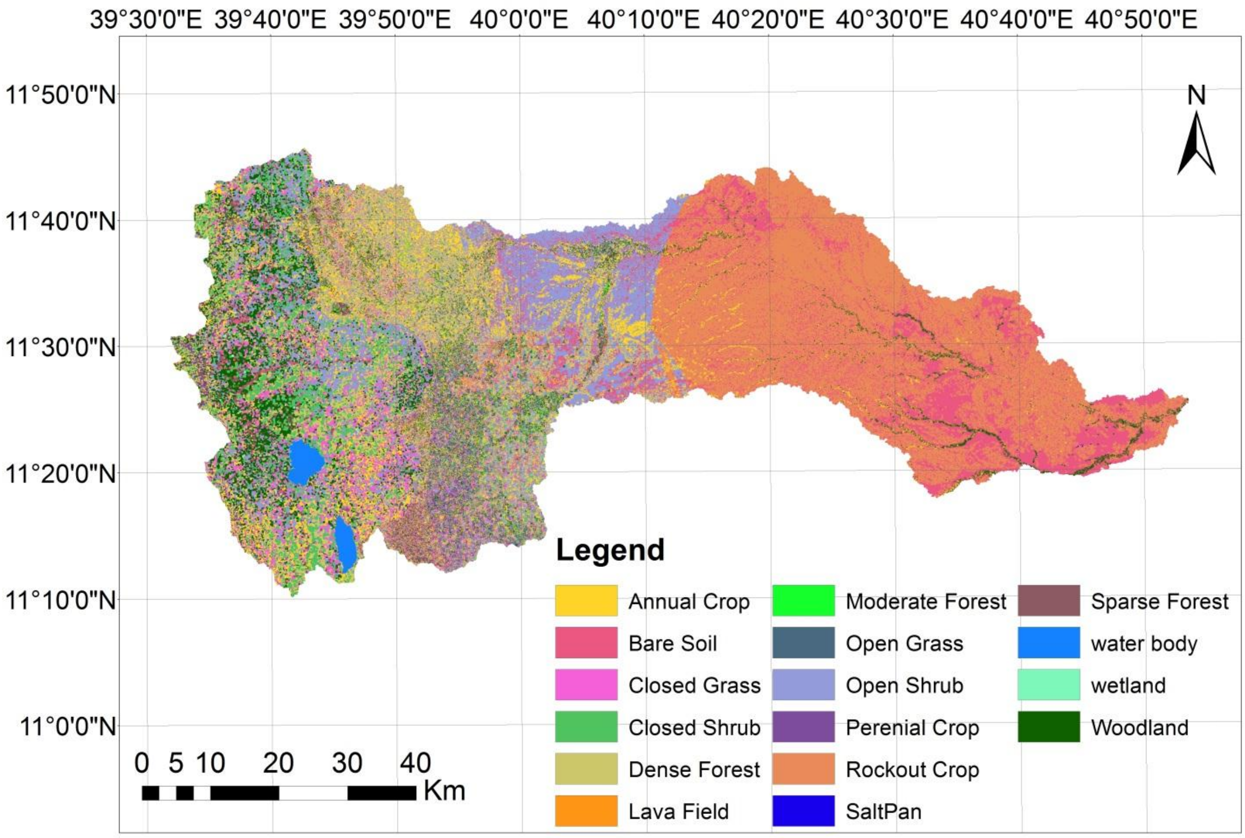

Figure 3.6: Land use and land cover of Mille watershed.

According to FAO soil classification the most widespread and predominantly available soil types in the study area are calcic xerosols, Eutric cambsols, Eutric gleysols and Lithosols. (Figure 3.7)

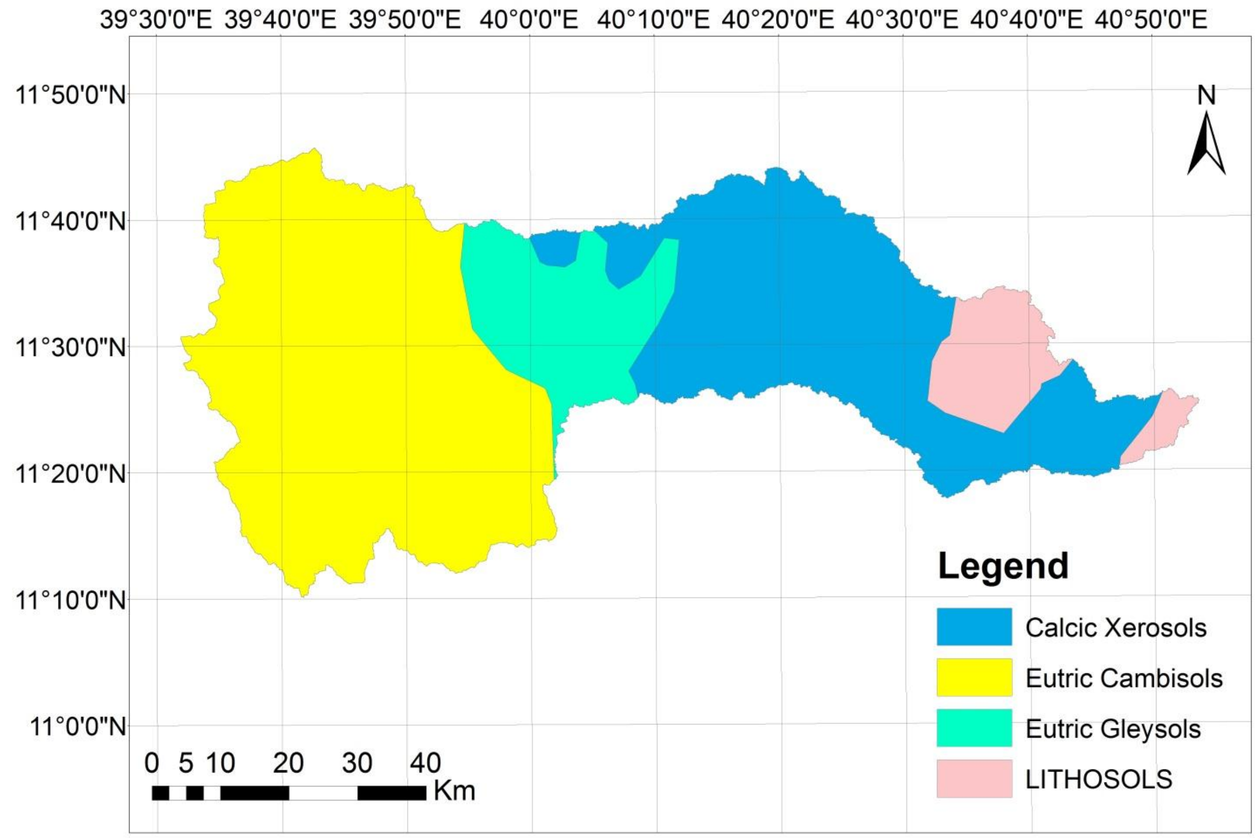

Figure 3.7: Soil types of Mille watershed

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

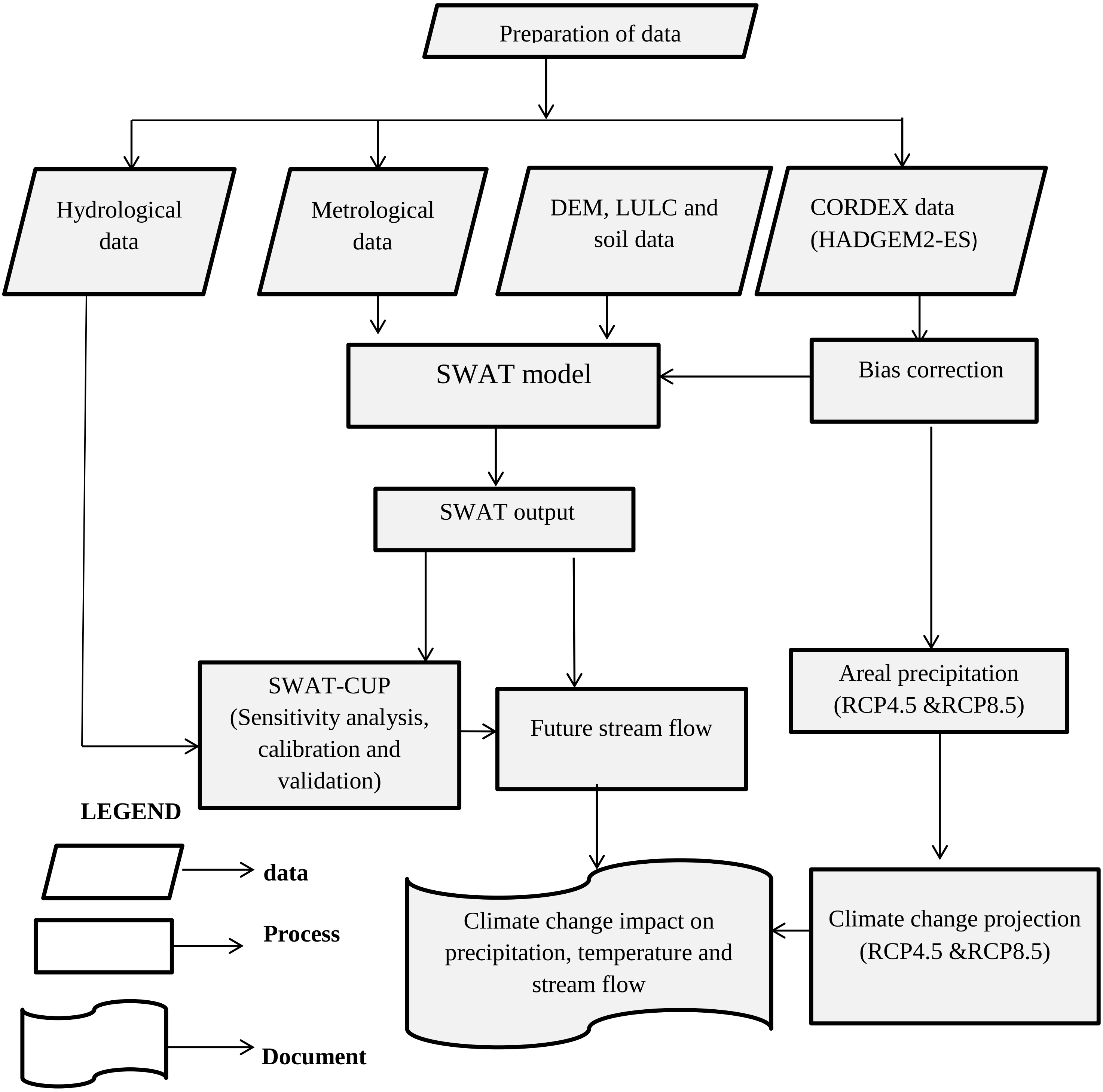

Figure 3.8: Overall flowchart used in the study

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

SN^o	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. Estimating Missing data

3.4.1.1 Estimating Missing Precipitation

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 we use the rainfall data for any analysis. The surrounding stations located within the catchment help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations.

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

$$Px = \frac{1}{n}\left[p_1 + p_2 + \cdots p_m\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where P_1, P_2. . . .. ….P_m are the precipitations of index stations and

P_x 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 (Subramanya, 2008):

$$Px = \frac{Nx}{n}\left[\frac{P1}{N1} + \frac{P2}{N2} + \cdots \frac{Pn}{Nn}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [3.2]$$

Where P1, P2 . . . Pn are the rainfall data of index stations,

N1, N2 . . . Nn the normal annual rainfall of index stations,

Px and Nx the corresponding values for the missing station x in question and

n is the number of stations surrounding the station x.

Table 3.4: Percent of missing precipitation and filling methods in the selected stations.

SN°	Stations	% of missing	Filling method
1	Kombolcha	2.81	Arithmetic mean
2	Haik	9.13	Arithmetic mean
3	Dessie	18.56	Normal Ratio
4	Chifra	21.62	Normal Ratio
5	Bati	3.2	Arithmetic mean

3.4.1.1 Estimating Missing Temperature

Failure of any thermometer or absence of observer from a station causes short break in the record of temperature at the station. The gaps should be estimated first before we use the temperature data for any analysis. The surrounding stations located within the catchment help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations. In this study Arithmetic mean method were used.

3.4.2. 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.

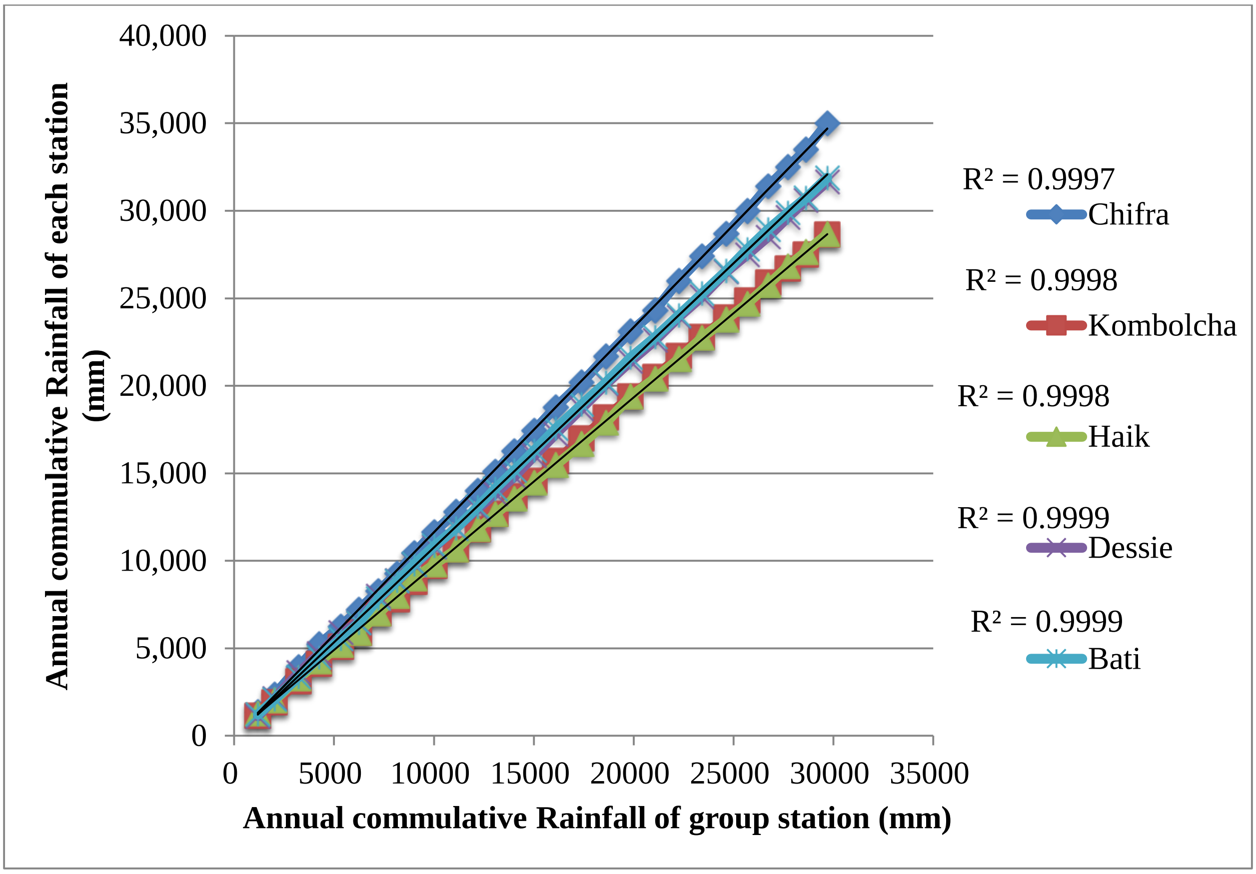

Figure 3. 9: Rainfall consistency checking result of selected meteorological stations

3.4.3. 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.

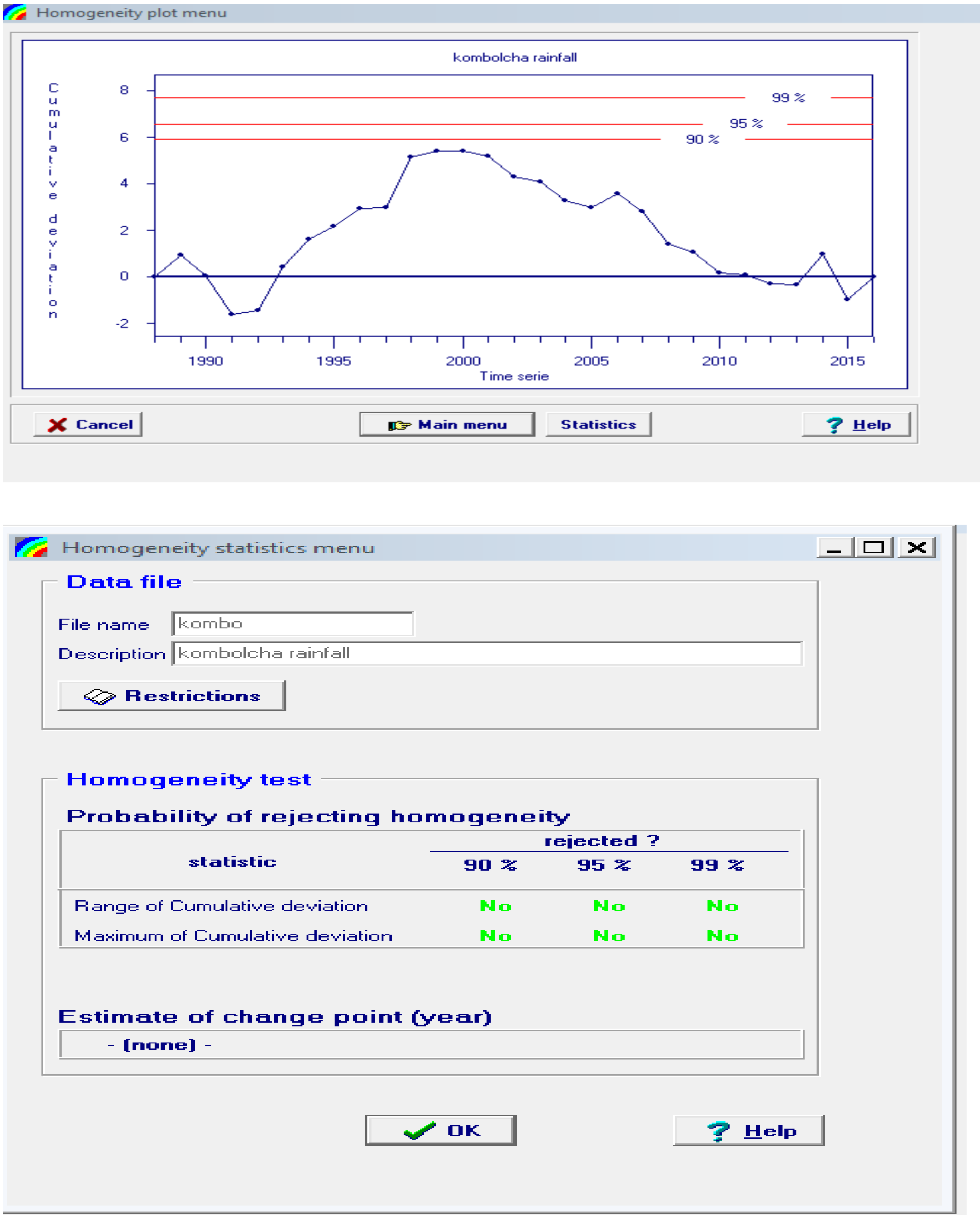

Figure 3.10: Cumulative deviation and probability of rejecting homogeneity test result of annual Rainfall at Kombolcha gauging station

3.4.5 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.

3.4.5.1 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.

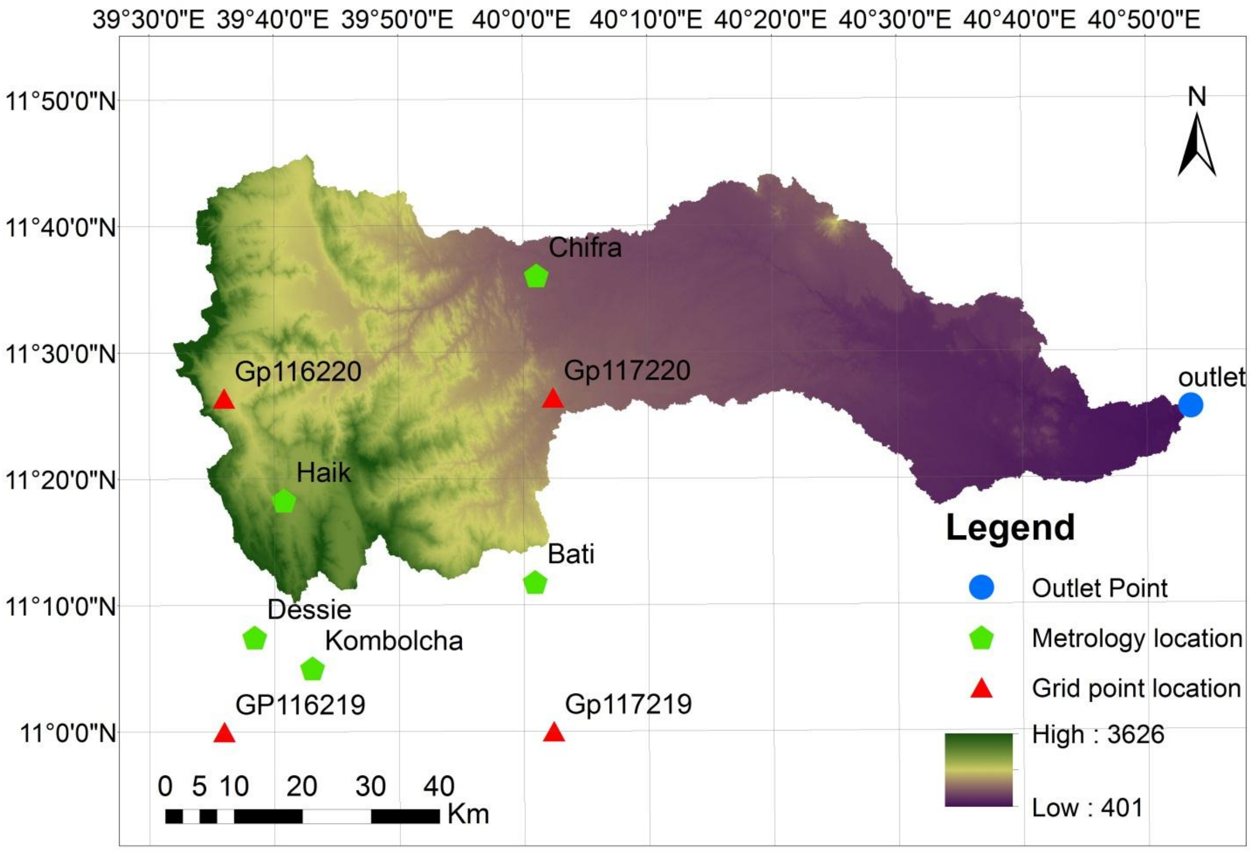

Figure 3.11: Mille catchment selected meteorological stations with RCP grid points and hydro gauged station locations.

3.4.5.2 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:

$$P^{*} = aP^{b} \text{..} 3.3$$

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:

$$T^* = \bar{T}_{obs} + \frac{\sigma(T_{obs})}{\sigma(T_{unc})}(T - \bar{T}_{unc}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots .3.5$$

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.

3.4.5.3 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).

$$\overline{P} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i} = \frac{[(P_1A_1)+(P_2A_2)+\cdots+(P_nA_n)]}{[A_1+A_2+\cdots A_n]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

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).

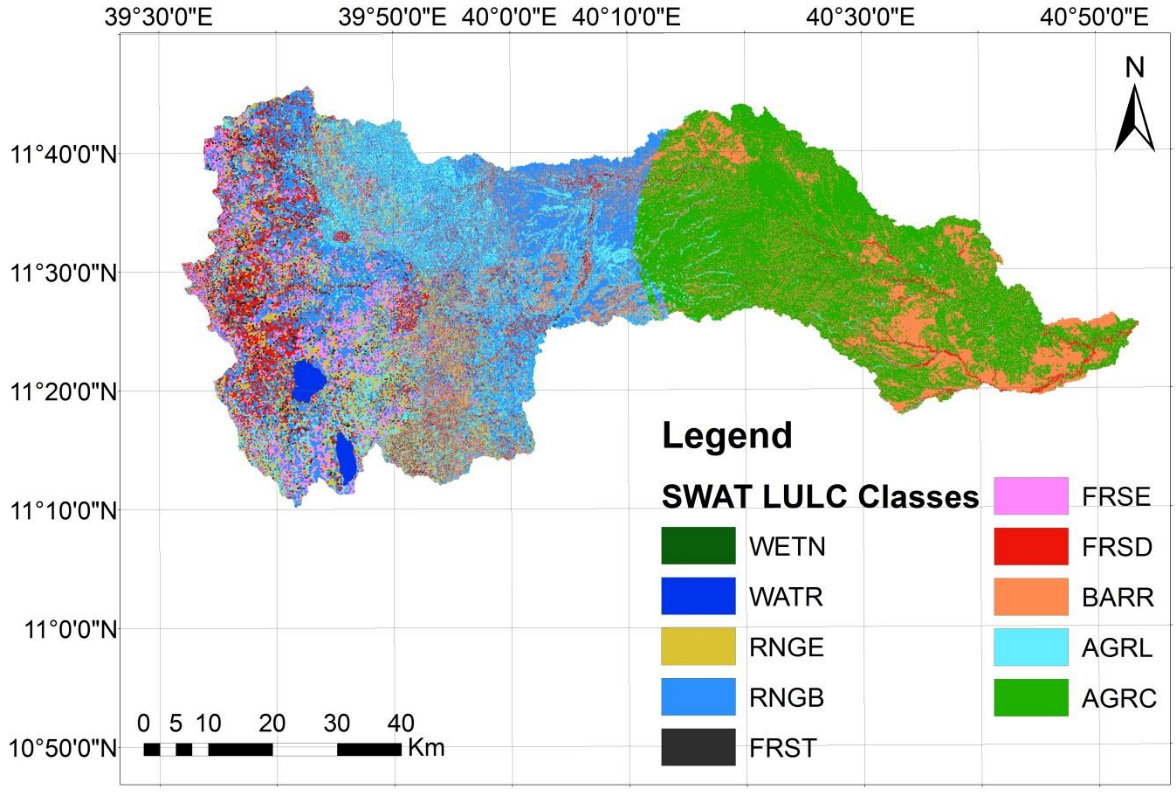

Figure 3. 12: Land use classification of the watershed according to SWAT classification

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). 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).

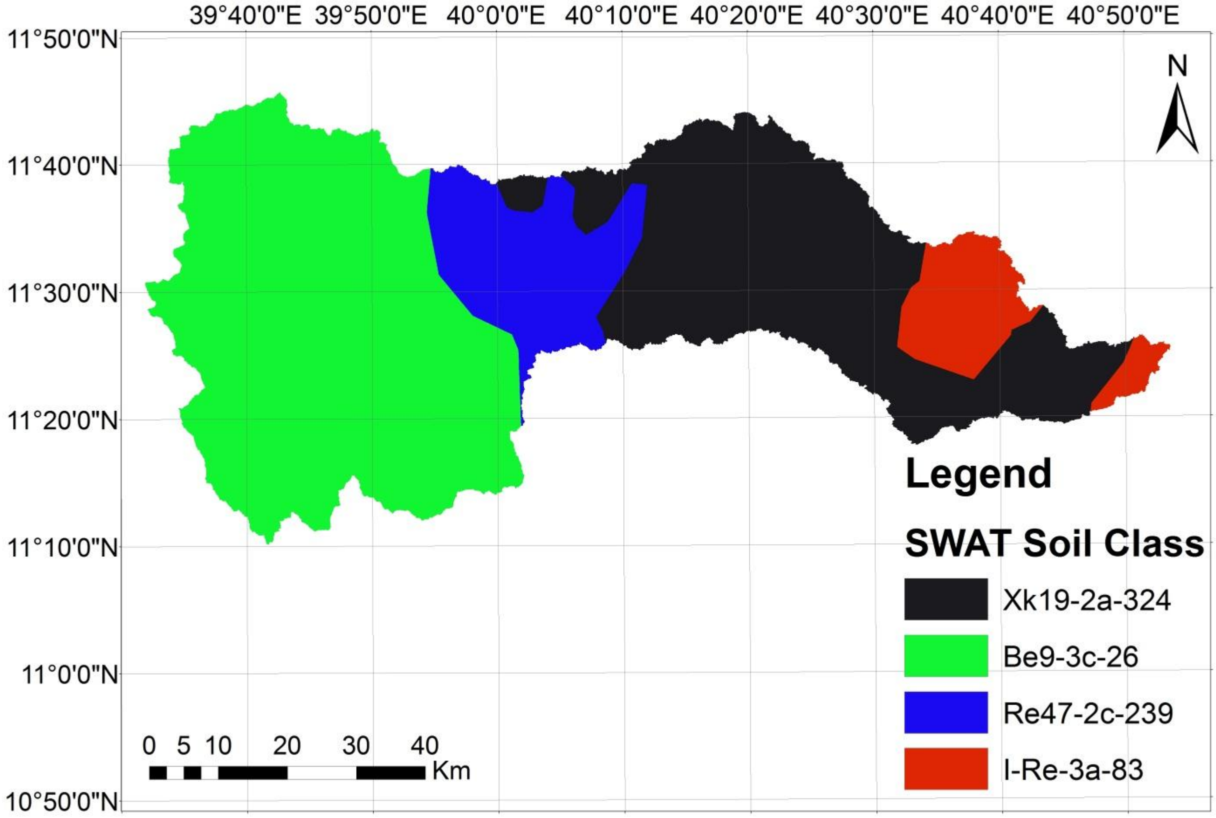

Figure 3. 13: Soil map of Mille watershed according to SWAT classification

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% (Table 3.6).

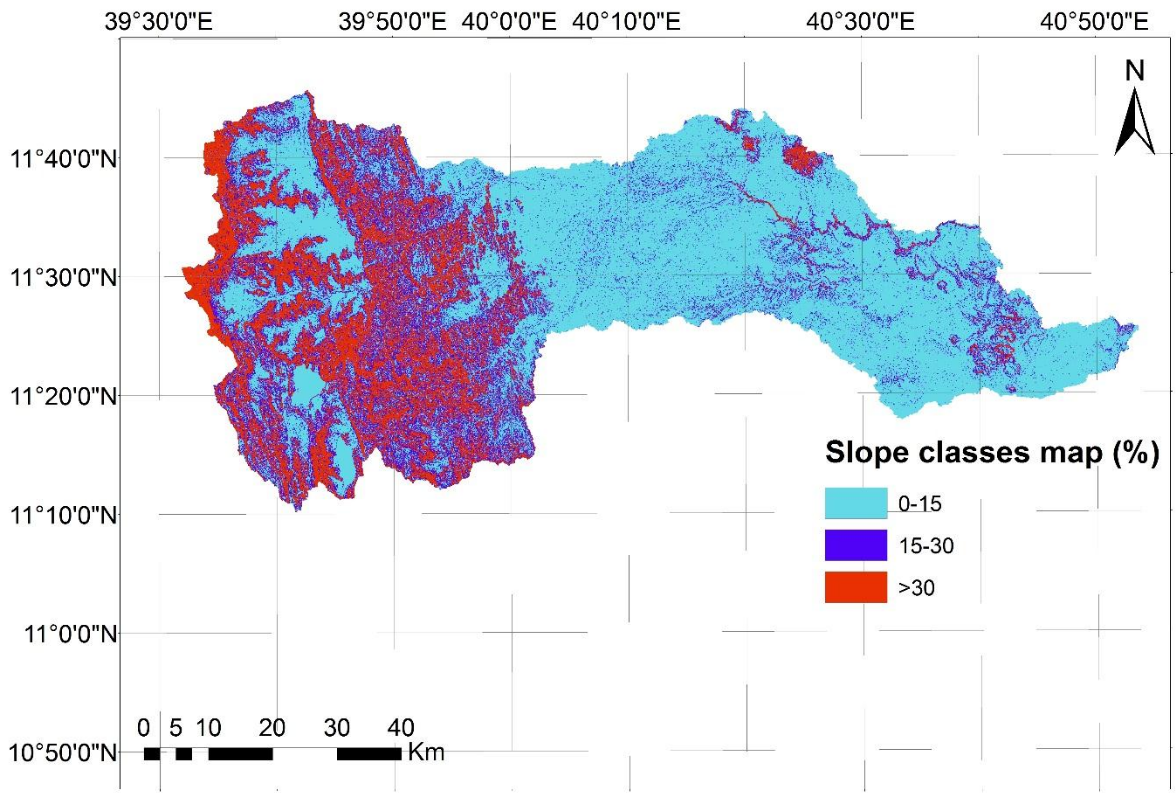

Figure 3. 14: SWAT slope classes of the watershed.

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	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.

3.5.3 Weather Data Definition

The weather generator was developed for U.S. The WXGEN weather generator was provided with all the necessary statistical information from the meteorological records of the watershed. The WXGEN model was provided using pcpSTAT.exe and dew02.exe (which include humidity data) based on Kombolcha and Bati meteorological data's as input information. The parameters needed for the weather generator are listed (Appendix 4). Daily solar radiation was calculated from the daily sunshine hour data using the Penman-Monteith method which is simple empirical formulae that relates short-wave radiation with other physical factors, such as extraterrestrial radiation, optical air mass, and turbidity, water vapor content of the air, the amount and type of cloud cover (Persuad et al., 1997).

$$R_s = \left[a_s + b_s \frac{n}{N}\right] R_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

R_s ….. Solar or shortwave radiation [MJ m^{-2} day^{-1}],

n ….. Actual duration of sunshine [hour],

N ….. Maximum possible duration of sunshine or daylight hours [hour],

n/N ….. Relative sunshine duration

R_a …… Extraterrestrial radiation [MJ m^{-2} day^{-1}],

a_s …… Regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0), a_s+b_s fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

Other meteorological data (daily precipitation, daily minimum and maximum air temperature, daily relative humidity, daily solar radiation and daily wind speed) including the corresponding location table were prepared according to the SWAT format and integrated into the model using the weather data input wizard.

3.6 SWAT model Sensitivity Analysis, Calibration and Validation

3.6.1. Sensitivity Analysis

The aim of the sensitivity analysis is to estimate the rate of change in the output of a model with respect to changes in watersheds that result in a clear difference in hydrologic sensitivity (Reungsang et.al, 2005). Sensitivity analysis were conducted for the Mille watershed hydrology to determine the parameters needed to improve simulation results and thus to better understand the behavior of the hydrologic system and to evaluate the applicability of the model.

Sensitivity analysis from SUFI-2 provided partial information about the sensitivity of the objective function to model parameters. Different water-related parameters (global parameters), with absolute minimum and maximum ranges in the SWAT model documents were selected to do sensitivity analysis separately. Then see the sensitivity ranking, and checking there stat. 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).

3.6.2 Calibration and Validation

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.

The SWAT model was calibrated and validated for stream flow at the outlet of the watershed. Monthly discharge records from 1993 to 2007 were used for calibration and validation (from 1993-2001 for calibration and from 2002-2007 for validation). For this study SWAT Calibration and Uncertainty Procedures (SWAT-CUP) free software was selected to do sensitivity analysis, calibration and validation.

3.6.3 Statistical model performance indicators

Model evaluation is an essential measure to verify the performance of the model. In this study, two model evaluation methods were used in order to evaluate the model's performance relative to the observed data; Coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) have been used.

Coefficient of determination (R^2): Is the index of correlation of measured and simulated values. The value of R^2 ranges from 0 to 1. The more the value of R^2 approaches 1, the better is the performance of the model and the values of R^2 less than 0.5 indicate a poor performance of the model.

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - O_{ave})(P_i - P_{ave})}{\left[\sum_{i=1}^{n}(O_i - O_{ave})^2 \sum_{i=1}^{n}(P_i - P_{ave})^2\right]^{0.5}}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

Where:

Oi= Observed stream flow

Pi= Predicted/Simulated Stream flow

O_{ave}= Average observed Stream flow

P_{ave}= Average Simulated Stream flow

n = number of observation

Nash-Sutcliffe Efficiency (NSE): NSE is the normalized statistics which measures the relative magnitude of the residual variance as compared to measured data variance. Similar to R^2, the more the NSE approaches 1, the better will be the model performance and vice versa.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{ave})^2} \ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

3.7 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.

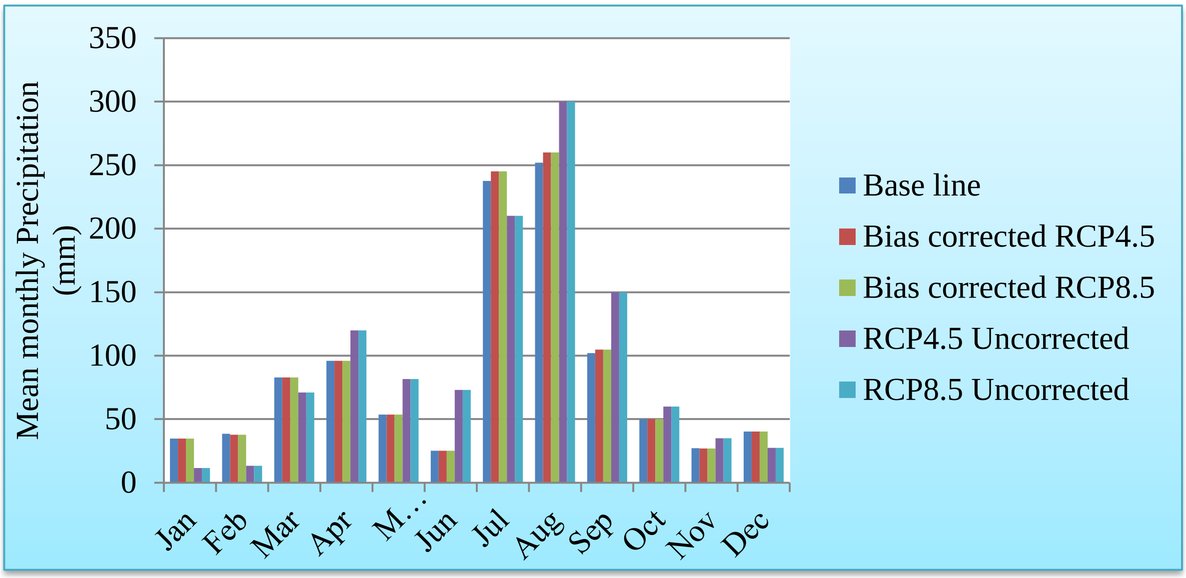

Figure 4. 1**:** Comparisons between monthly Precipitation bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed

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.

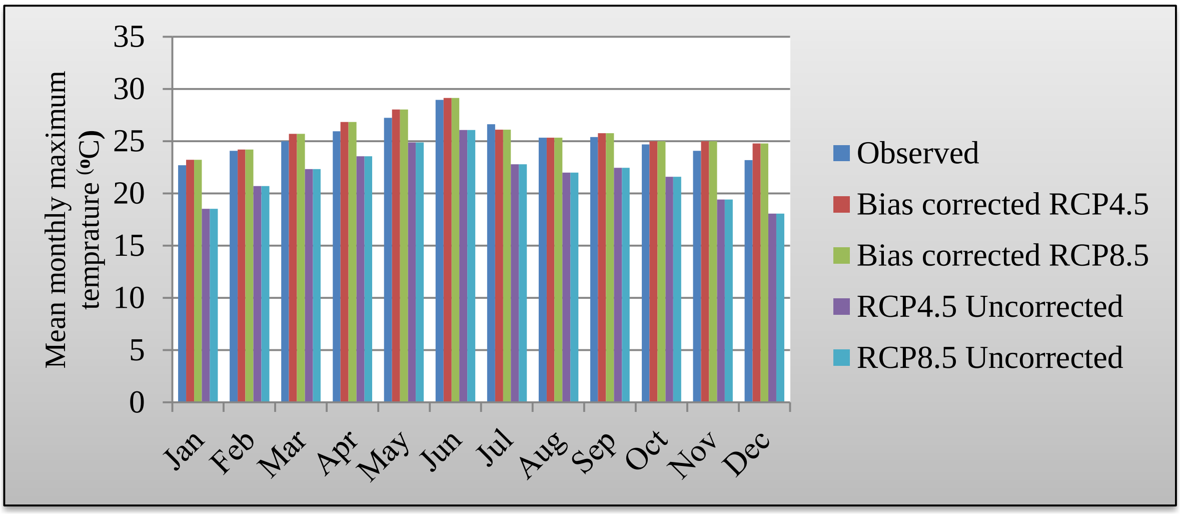

Figure 4. 2: Comparisons between monthly maximum temperature bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed.

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.

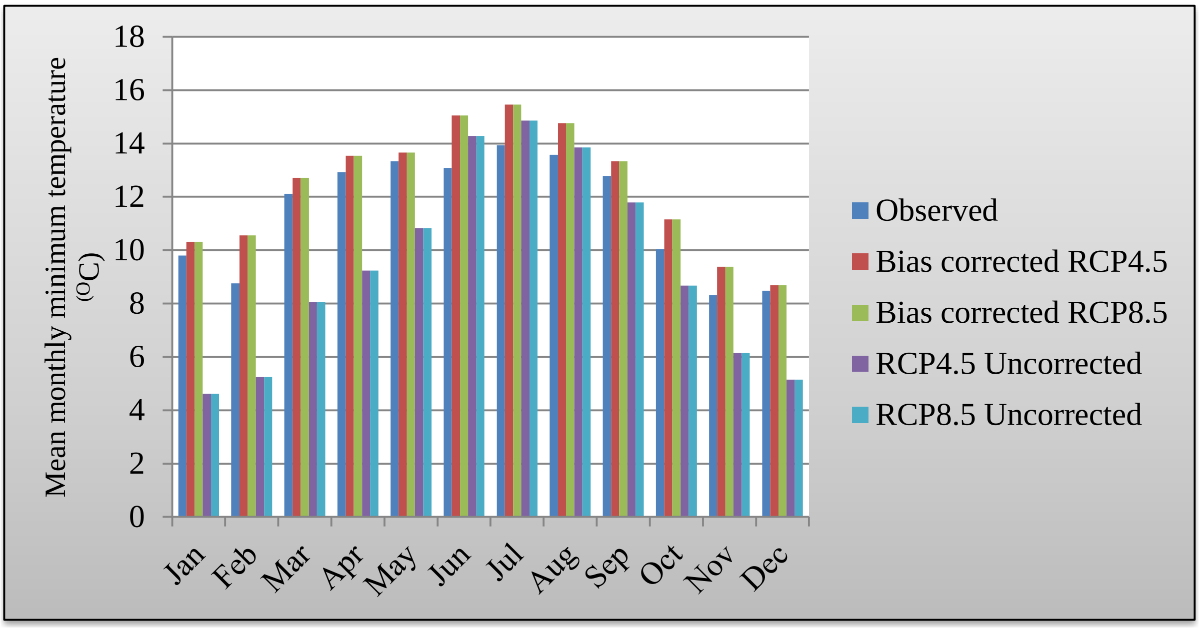

Figure 4.3: Comparisons between monthly minimum temperature bias corrected, uncorrected of two scenarios (RCP 4.5 and RCP8.5) and the observed.

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).

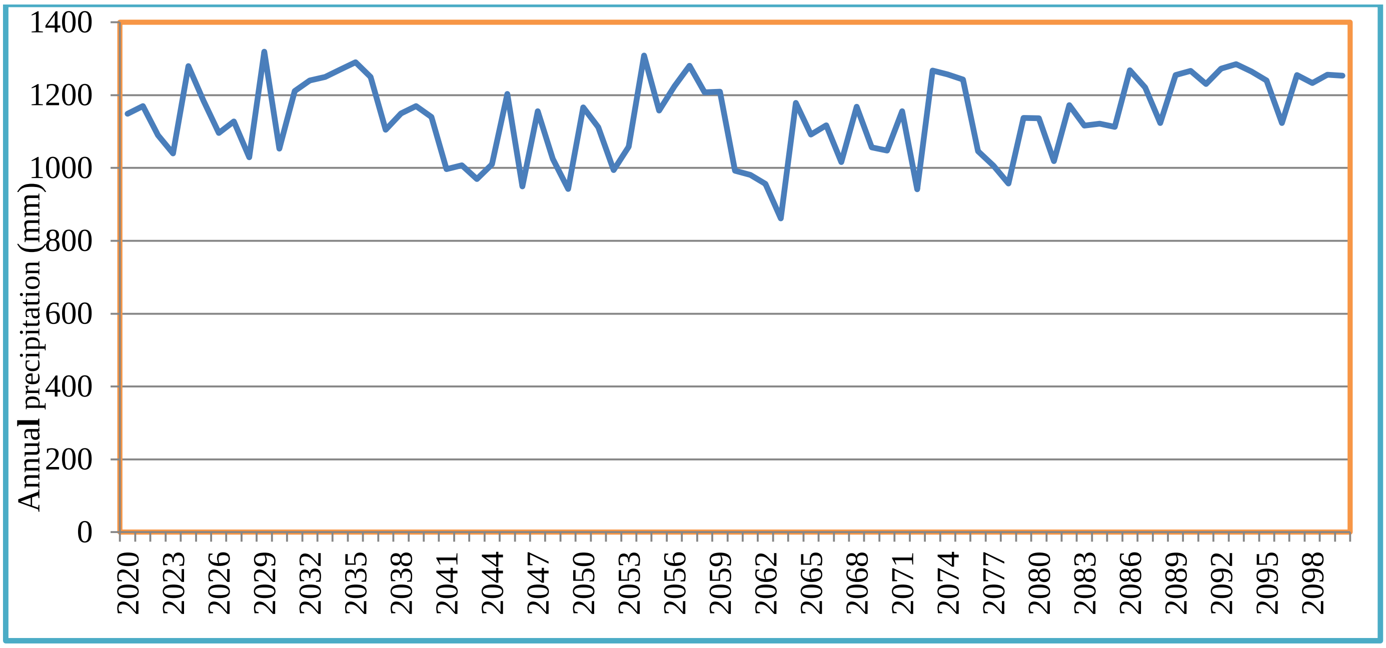

Figure 4. 4: Changes in average annual precipitation of RCP4.5 for 2050's and 2080's

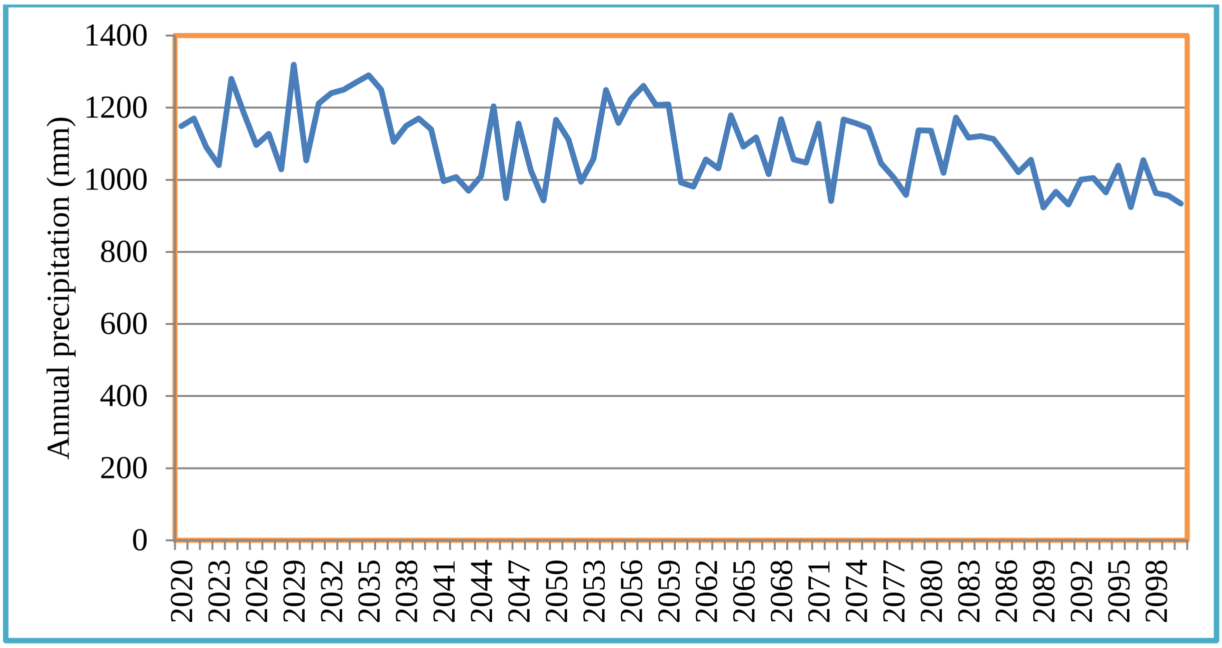

Figure 4. 5: Changes in average annual precipitation of RCP8.5 for 2050's and 2080's

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.

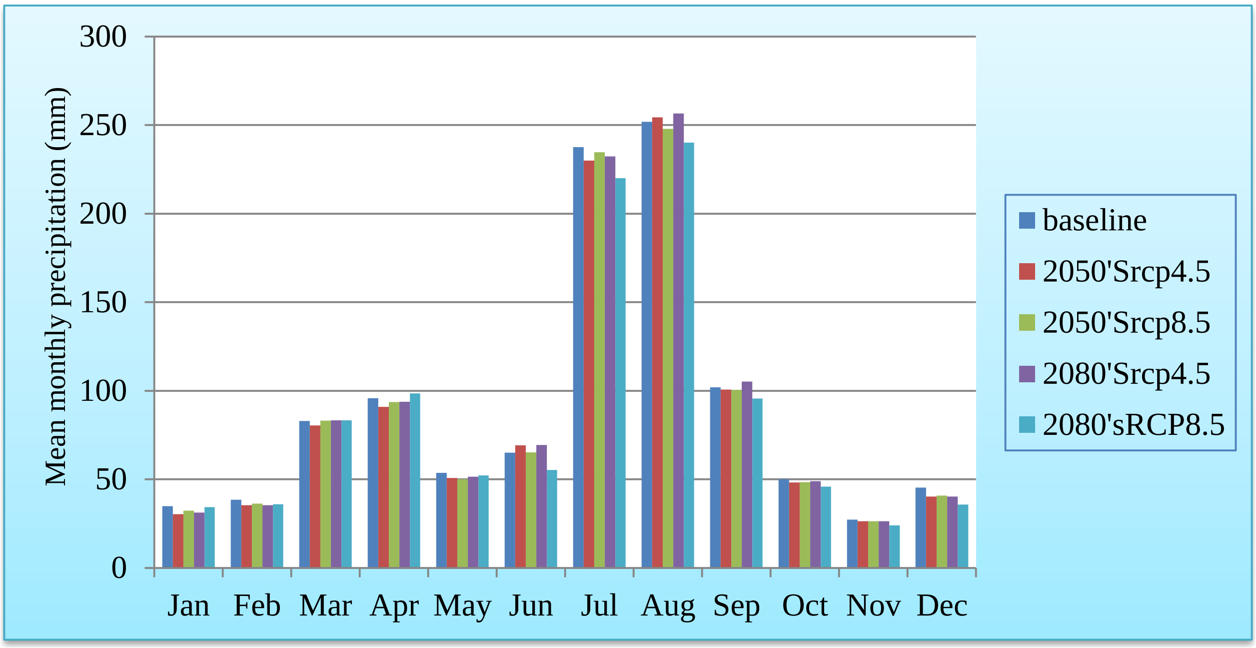

Figure 4.6: Comparison of areal mean monthly precipitation of base line (1976-2005) with two future scenarios RCP4.5 and RCP8.5 (2050s and 2080s).

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.

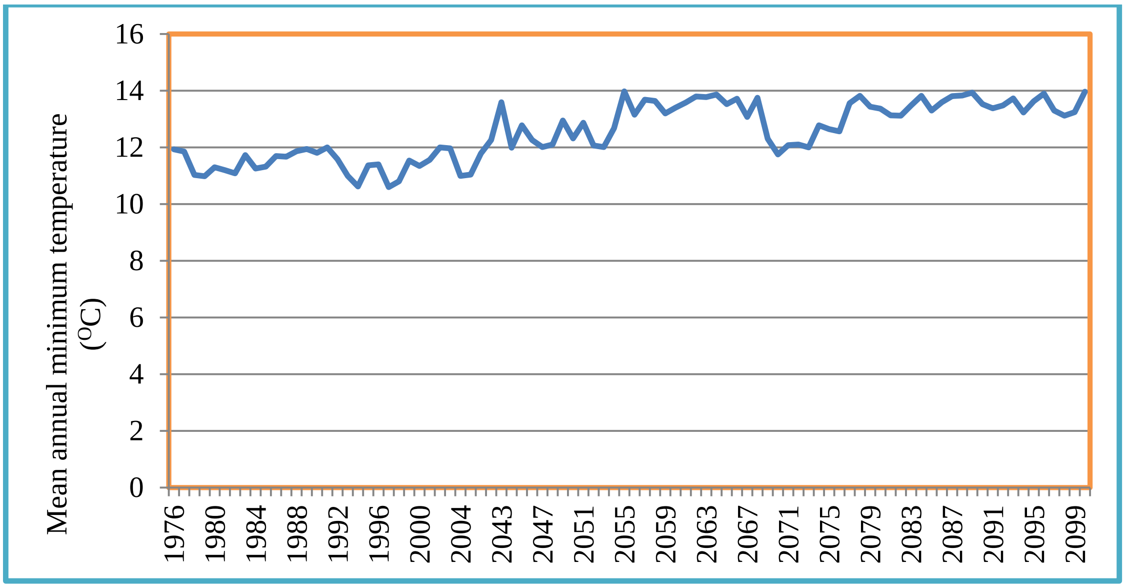

Figure 4. 7: Comparison of annual minimum temperature of base line with future results of RCP4.5 scenario.

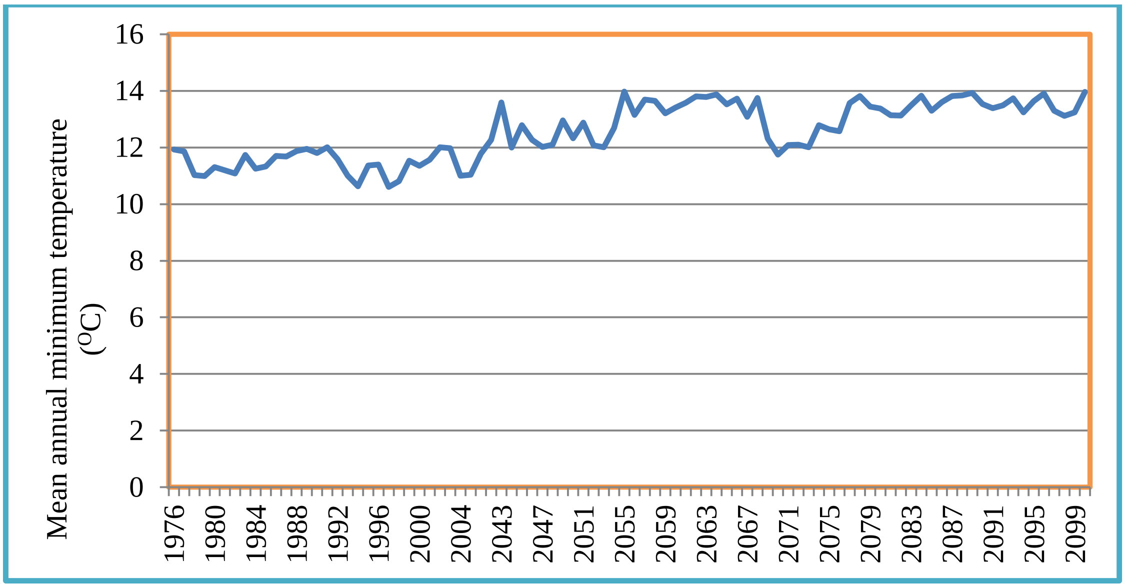

Figure 4. 8: Comparison of annual minimum temperature of base line with future results of RCP8.5 scenario.

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.

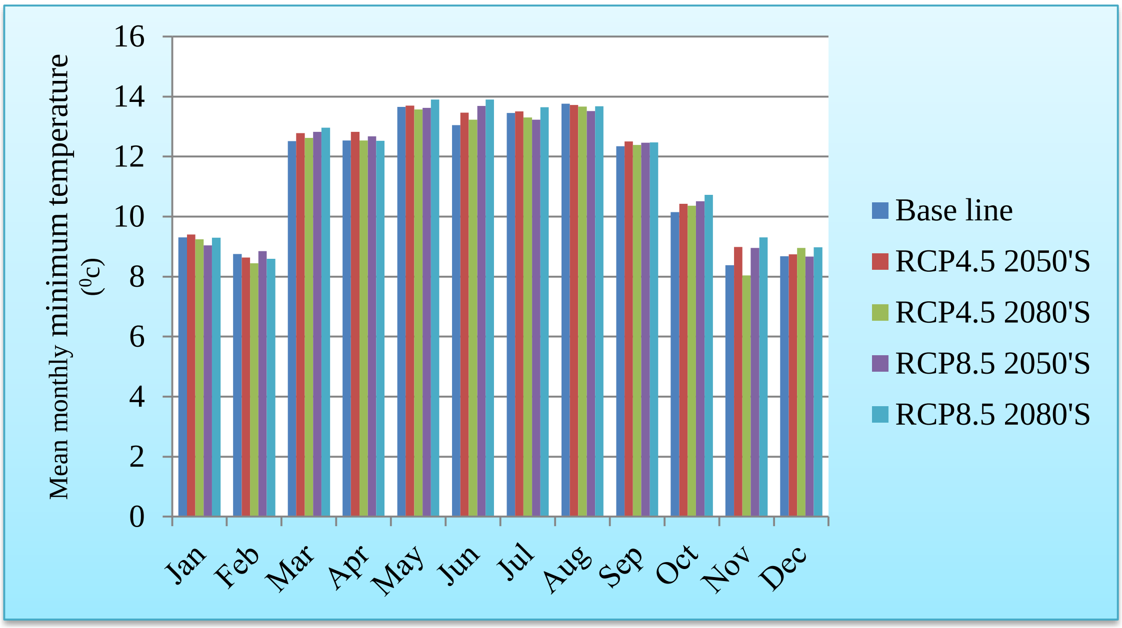

Figure 4. 9: Comparison of mean minimum temperatures of base line with future results of RCP4.5 and RCP8.5 scenarios.

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.

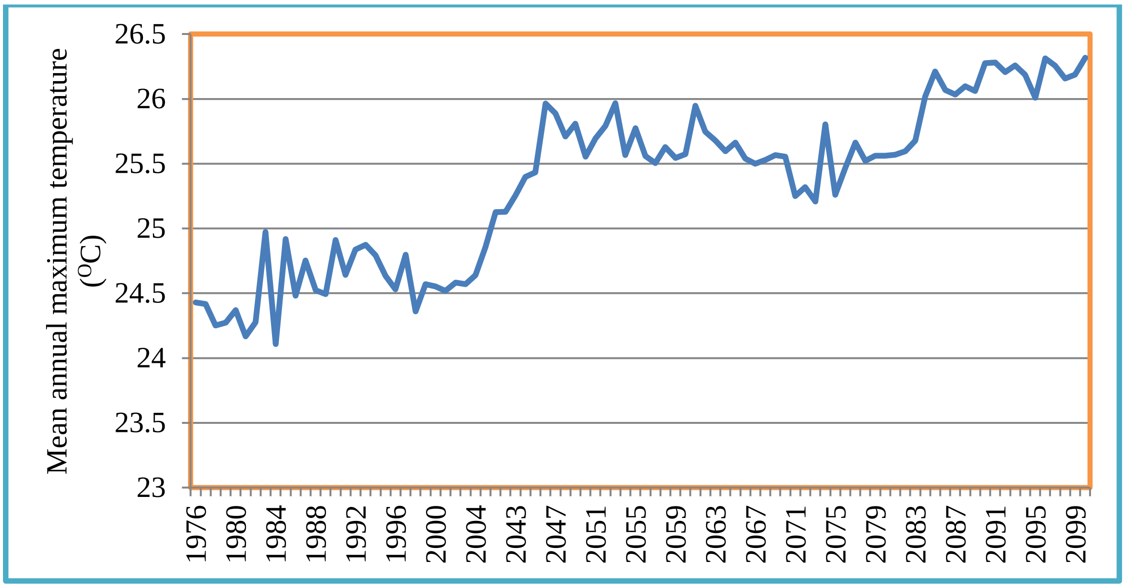

Figure 4.10: Comparison of annual maximum temperature of the baseline with future results of RCP4.5 scenario

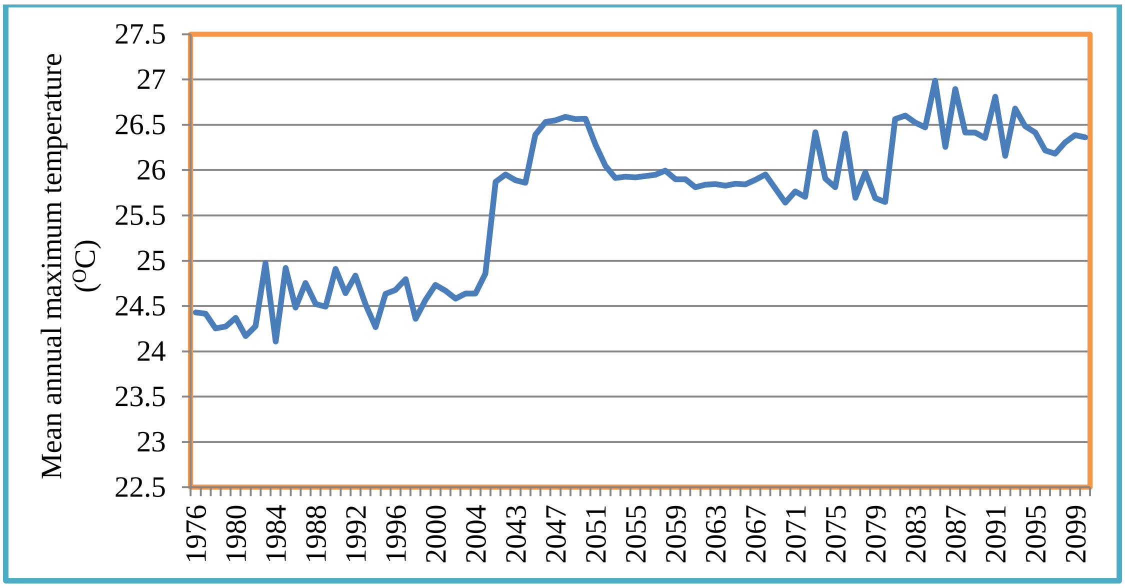

Figure 4.11: Comparison of annual maximum temperature of the baseline with future results of RCP8.5 scenario.

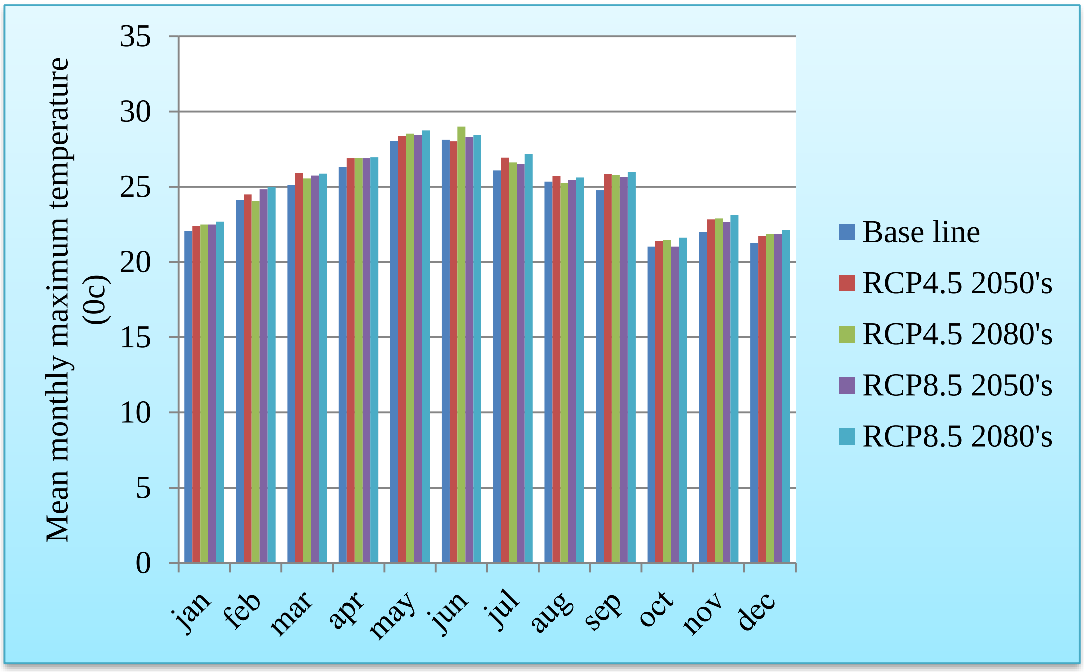

Figure 4.12: Comparison of mean maximum temperatures of the base line with future results of RCP4.5 and RCP8.5 scenarios.

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 0.6°C. In 2050s the increment will be 1.4°C and 1.1°C for A2 and B2 scenario respectively. In 2080s the annual maximum temperature will be increased by 2.5°C and 1.8°C 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).

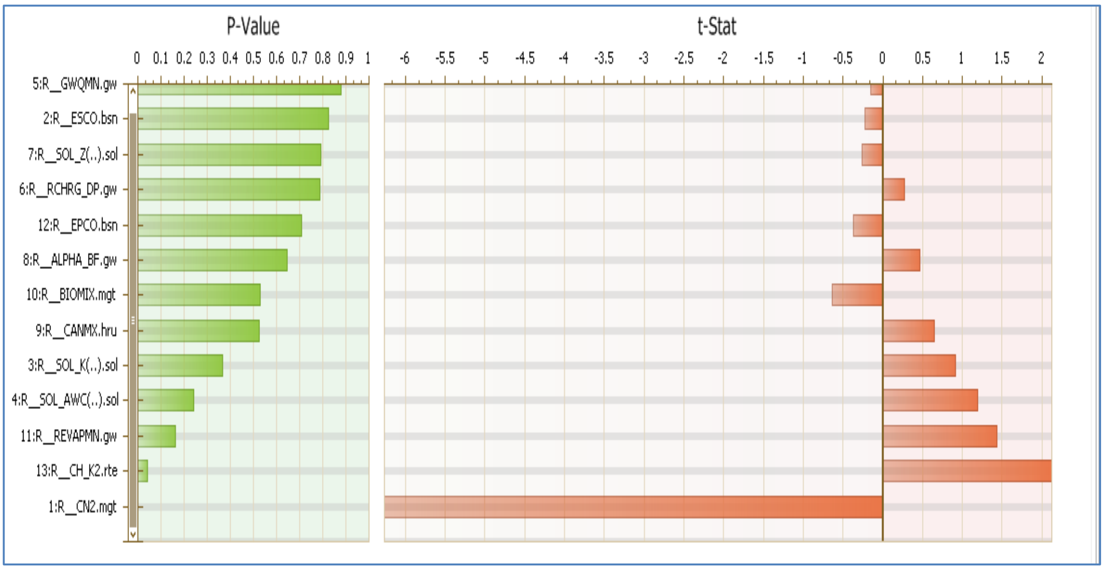

Figure 4.13: Sensitivity analysis of flow

Table 4. 2: Flow sensitive parameters and fitted values

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

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.

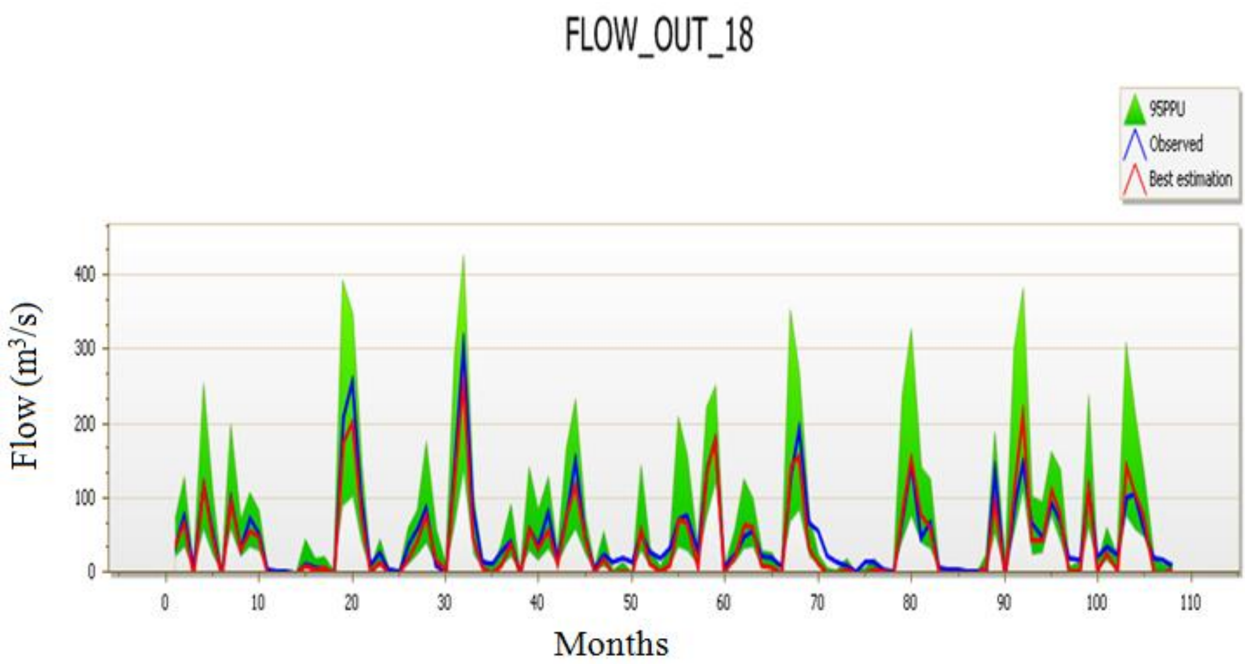

Figure 4.14: Hydrograph of the observed and simulated flow from the watershed for the calibration period on a monthly basis (1993-2001)

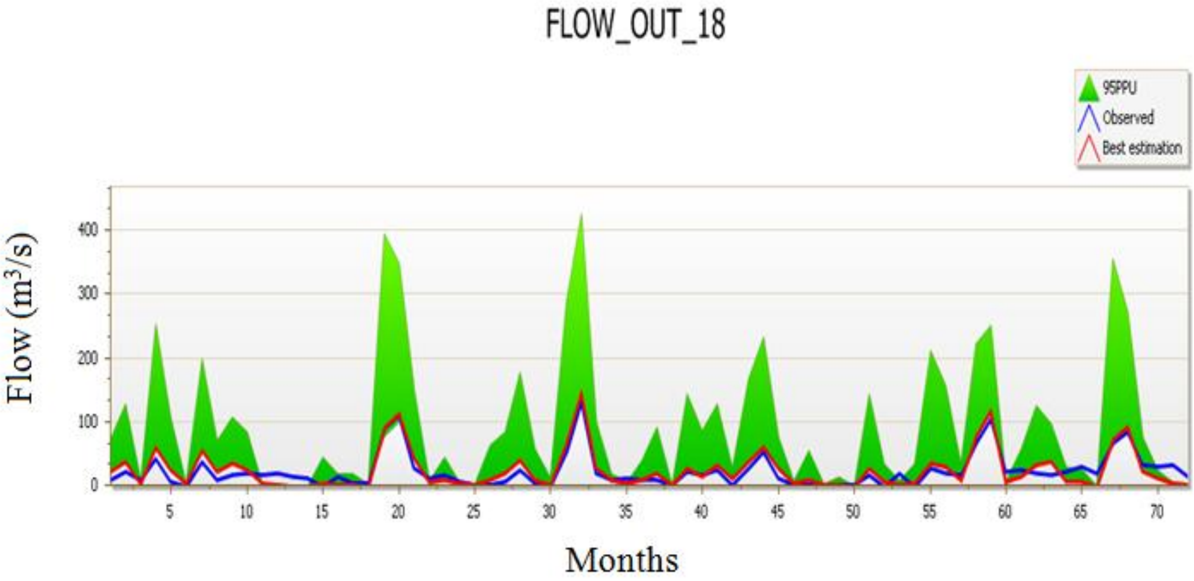

Figure 4.15: Hydrograph of the observed and simulated flow from the watershed for the validation period on a monthly basis (2002-2007)

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

4.4. 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.

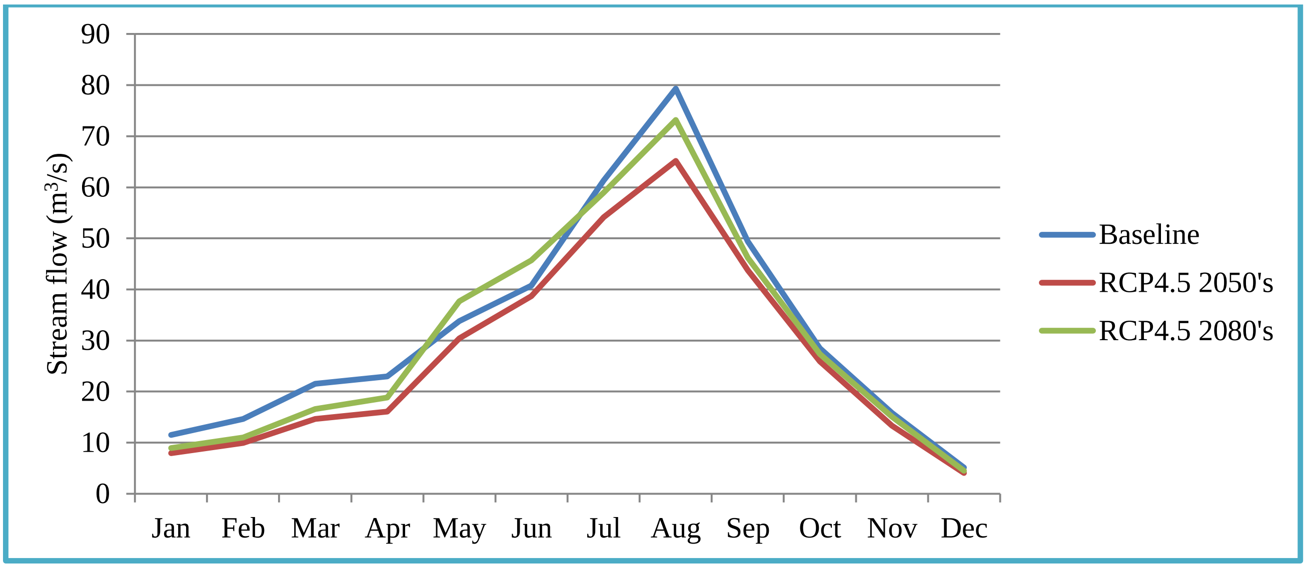

Figure 4.16: Comparison of mean monthly stream flow for the future periods 2041-2070 and 2071-2100 relative to the baseline period under RCP4.5.

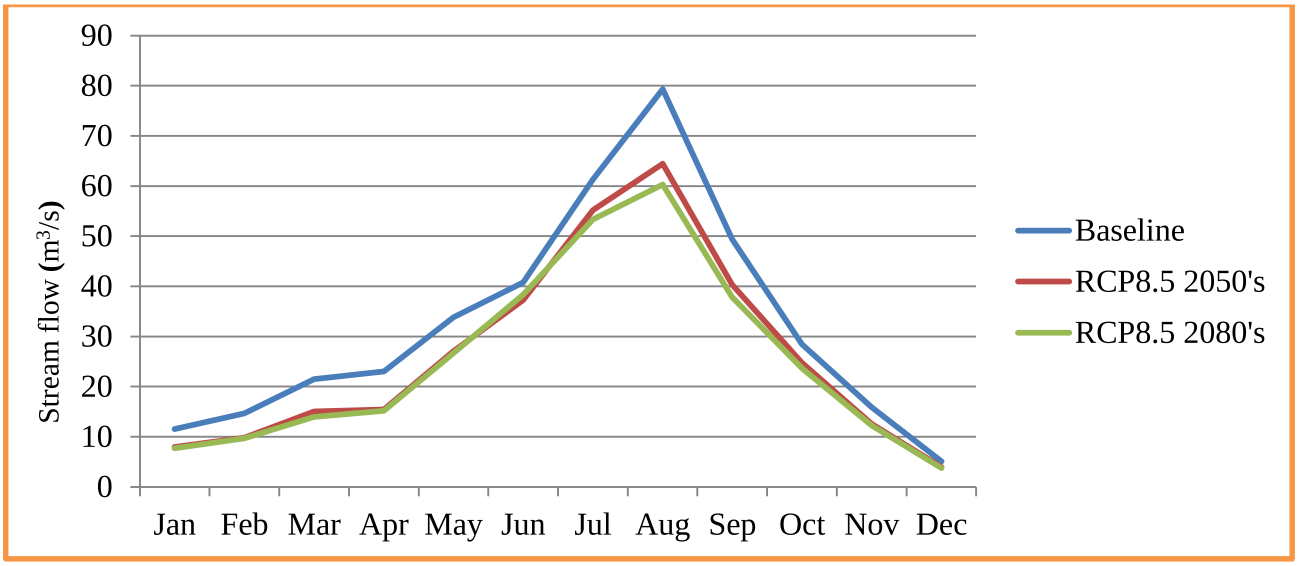

Figure 4.17: Comparison of mean monthly stream flow for the future periods 2041-2070 and 2071-2100 relative to the baseline period under RCP8.5 scenario.

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

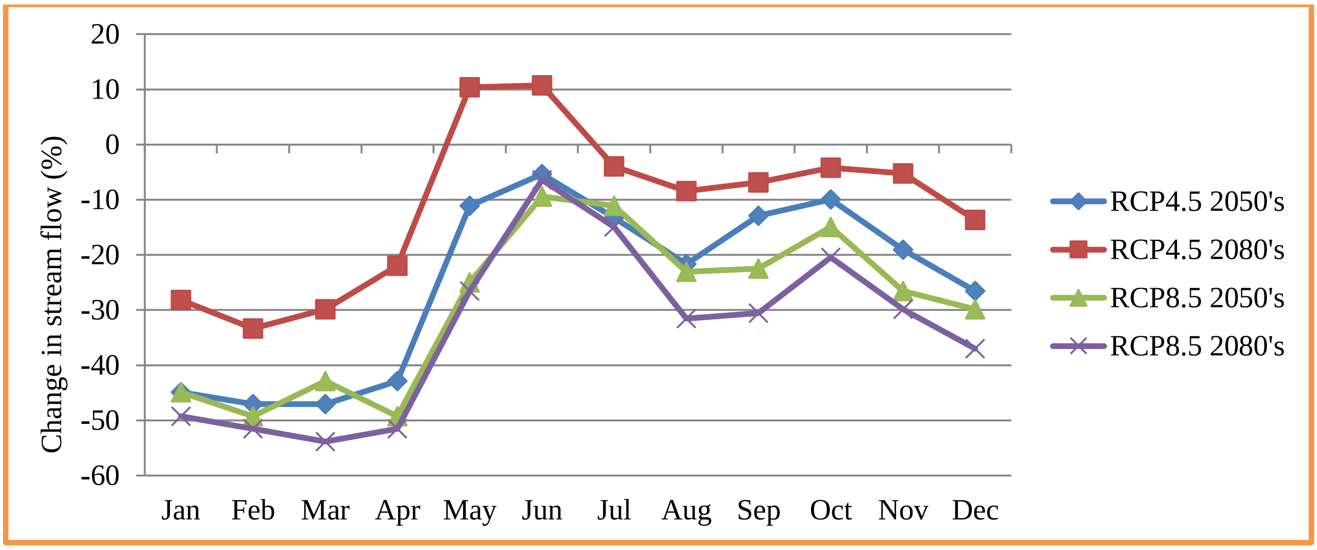

Figure 4.18 : Relative percentage change in mean monthly stream flow projection for 2050's (2041-2070) and 2080's (2071-2100) under RCP4.5 and RCP8.5 as compared to the baseline period (1976-2005) for Mille catchment

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.

4.5 uncertainties in the study

The uncertainties which arise from hydrological model, the impact of climate change has done only considering the changes in the precipitation, maximum and minimum temperature. However, in real world, other climatic variables and land use will also change.

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 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.

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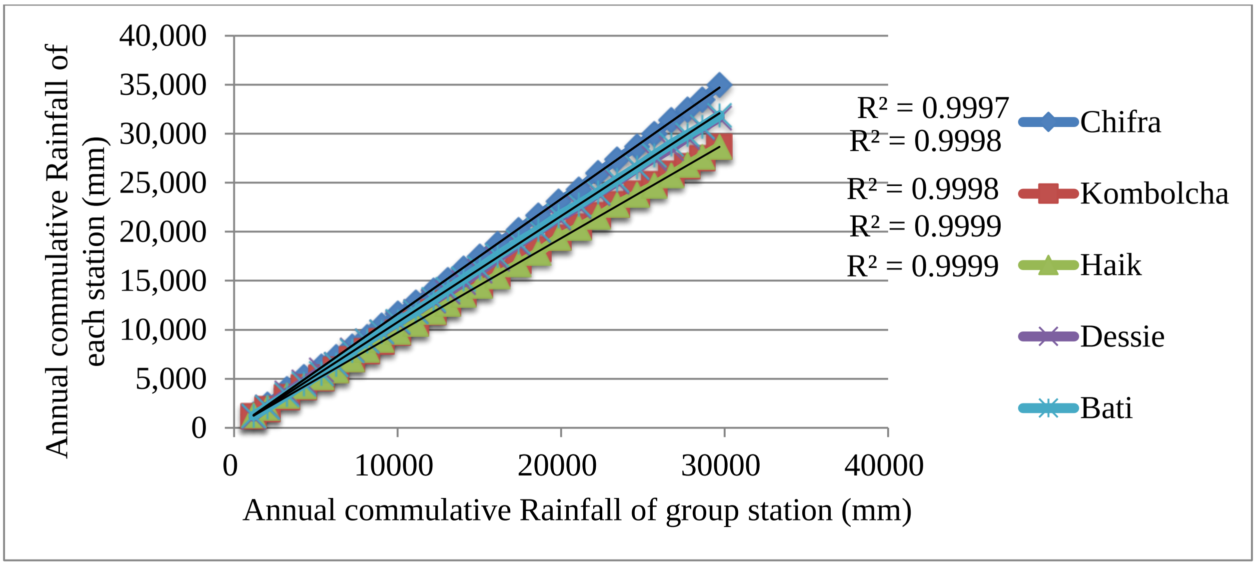
APPENDIXES

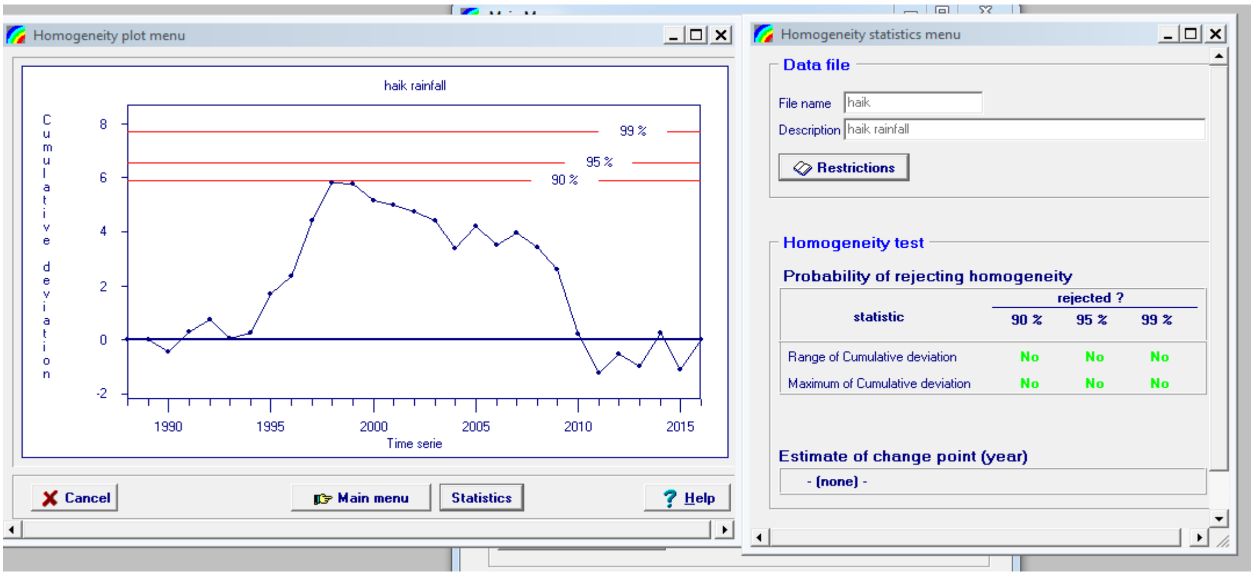
Appendix 1: Summary of data availability and missing rainfall data (1989-2016)

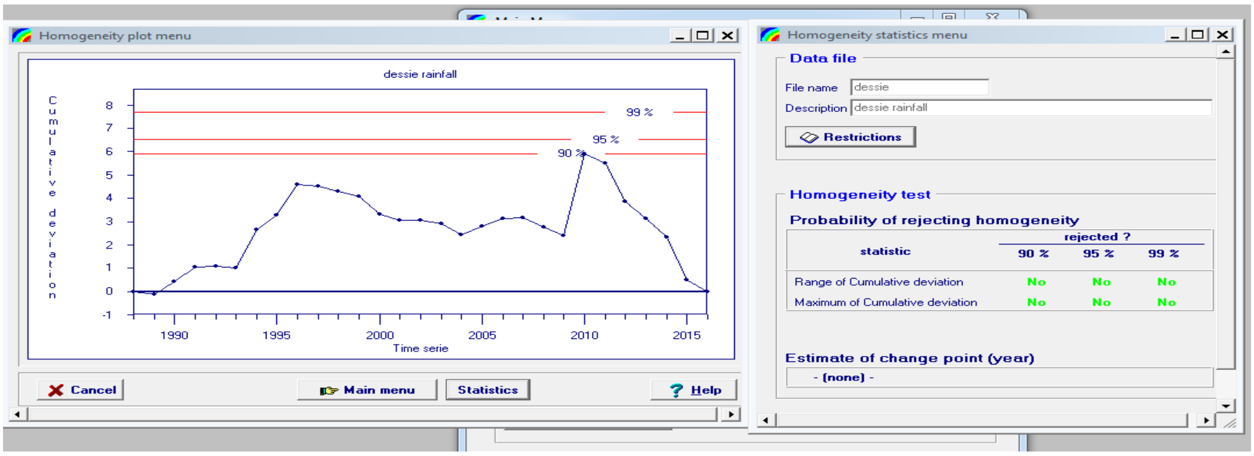
Stations data	Longitude (º)	Latitude (º)	Altitude (m.a.s.l)	Data availability	% of missing Rainfall
kombolcha	39.7576	11.0839	1857	1989-2016	2.81
Haik	39.6802	11.3053	1985	1989-2016	10.13
Dessie	39.6406	11.1246	2250	1989-2016	18.56
Chifra	40.0182	11.6012	1650	1989-2016	21.62
Bati	40.0154	11.1967	1640	1989-2016	3.2

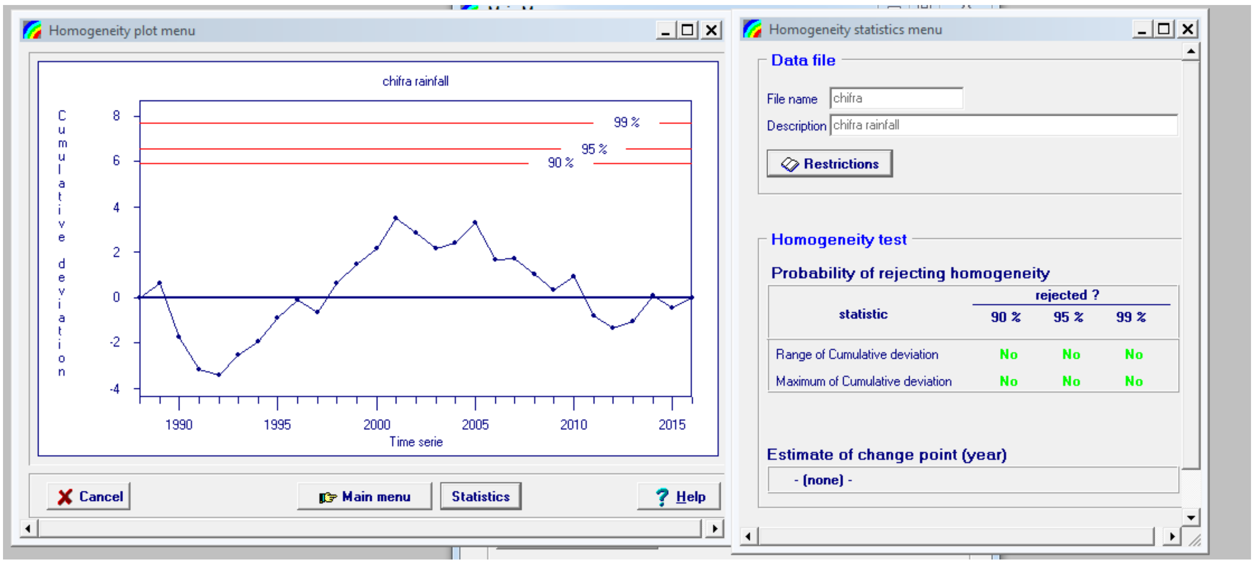
Appendix 2: Consistency test of Rainfall of selected metrological station.

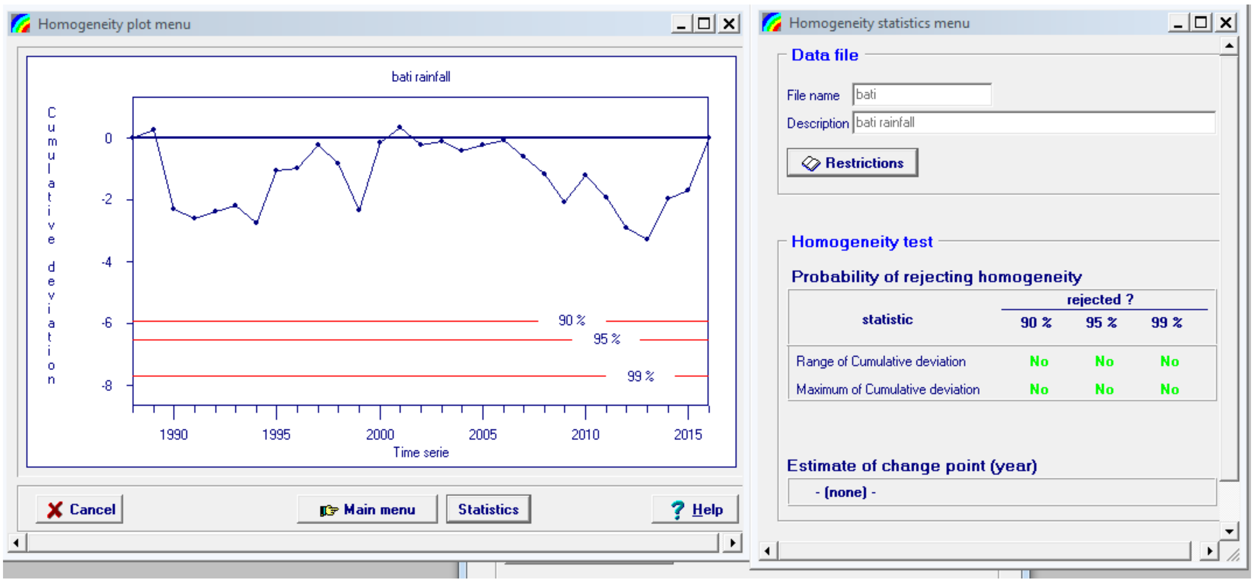


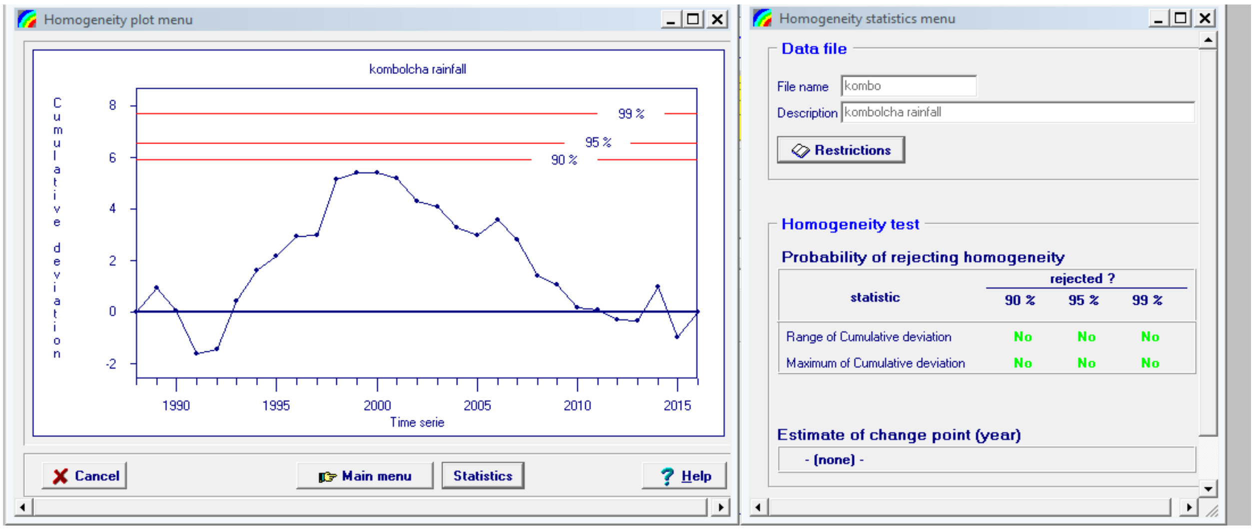
Appendix 3: Homogeneity test of Rainfall of selected station








Homogeneity plot menu
bati rainfall
Cumulative deviation
0
-2
-4
-6
-8
90 %
95 %
99 %
1990
1995
2000
2005
2010
2015
Time serie
Cancel
Main menu
Statistics
Help
Homogeneity statistics menu
Data file
File name bati
Description bati rainfall
Restrictions
Homogeneity test
Probability of rejecting homogeneity
rejected ?
statistic 90 % 95 % 99 %
Range of Cumulative deviation No No No
Maximum of Cumulative deviation No No No
Estimate of change point (year)
- (none) -


Homogeneity plot menu
kombolcha rainfall
Cumulative deviation
8
6
4
2
0
-2
99 %
95 %
90 %
1990
1995
2000
2005
2010
2015
Time serie
Cancel
Main menu
Statistics
Help
Homogeneity statistics menu
Data file
File name kombo
Description kombolcha rainfall
Restrictions
Homogeneity test
Probability of rejecting homogeneity
rejected ?
statistic 90 % 95 % 99 %
Range of Cumulative deviation No No No
Maximum of Cumulative deviation No No No
Estimate of change point (year)
- (none) -

Appendix 4**:** Weather generator (WGEN) parameters used by the SWAT Model

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

Appendixes 5 mean monthly future Rainfall of Bati station under RCP4.5

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2020	2.06	2.9	3.25	6	0.05	0.04	4.96	3.34	1.67	0.13	0.01	0.64
2021	1.32	0.2	0.48	0.02	3.29	0.93	4.54	4.08	0.52	0.15	0	0.01
2022	1.07	5.69	0.17	0.49	0.24	0.49	5.48	0.25	1.32	0.22	0.05	5.75
2023	4.89	0.03	7.23	6.27	0.16	0.65	9.11	4.81	0.87	0.53	0.15	0
2024	0.54	0	0	1.28	0	0.51	7.37	5.31	4.57	0.27	2.99	3.94
2025	4.77	6	2.59	3.03	2.77	0.66	0.7	6.96	2	0.69	2.24	6.69
2026	2.28	0	0	1.76	0.26	0.71	4.7	8.95	1.48	0.02	0	0.02
2027	0.41	0.23	0.05	1.07	0.47	1.87	8.3	10.08	1.01	0.01	0	0
2028	0.09	0	0	1.34	0.06	2.31	11.2	5.35	1.8	0	0.03	0.88
2029	0.6	0.06	0	4.23	4.35	0.79	2.15	4.2	3.46	2.86	0.1	0.14
2030	0.8	5.76	5.06	2.21	0.12	0.26	3.26	3.51	0.96	2.32	1.72	0.75
2031	1.33	6.03	0	0	0.83	1.57	6.9	12.84	7.15	0	0.63	0
2032	0.47	12.71	0	7.33	0	0	8.76	5.09	1.72	0.01	0.35	0.02
2033	9.78	7.33	1.32	8.06	0.06	0.38	3.91	3.21	3.11	0.36	0	1.3
2034	1.74	0.25	2.38	9.08	3.29	0.2	1.55	4.85	2.59	0.51	0.18	5.71

2035	1.08	2.77	0	4.69	2.61	0	0.88	2.57	0.41	1.64	0.44	0.23
2036	0.25	0.1	0	11.27	0.06	0	6.81	3.47	7.34	1.27	0	1.54
2037	4.93	0	0	2.99	2.63	0.54	8.84	7.09	0.48	1.39	0.4	0.01
2038	0.03	0.56	0.83	0.41	0.27	0.15	10.3	5.67	12.92	0.59	0.9	0.71
2039	1.78	4.25	0.17	10.93	10.77	0.32	7.04	5.87	9.57	6.17	2.53	1.55
2040	0.42	0.15	0	1.04	1.51	1.23	8.05	2.65	1.76	0.88	0.07	0.22
2041	0.18	1.08	5	0.35	0	0	7.6	6.55	2.08	0.73	1.17	0.31
2042	0.37	1.25	0	0.7	3.08	0.69	5.97	1.83	4.03	1.31	1.83	0.05
2043	6.38	0.34	0.55	0.42	0	0.11	3.26	7.8	0.17	2.82	0.14	0.03
2044	0.21	1.47	0	0	0.05	1.21	5.23	7.63	0.83	0	0.39	0.39
2045	0.09	0.61	4.7	0.38	5.43	0.52	6.45	7.81	5.4	0.89	0.95	1.67
2046	0.14	1.13	5.3	2.05	0.19	0	2.7	2.83	5.78	1.26	0.89	0.3
2047	0.91	4.44	1.13	4.05	3.05	0.33	0.08	9.83	4.19	0.11	0.09	1.18
2048	0.89	3.46	2.56	1.19	0.9	0	5.43	5.96	6.57	0.68	0	1.6
2049	0.9	0	0	4.58	0.3	0.68	3.82	5.81	6.11	0.65	0.56	0
2050	0	5.46	0	0.07	0	0.38	8.6	3.69	0.91	0.18	0.31	1.26
2051	0.03	0.09	2.19	4.78	0.27	0.39	2.19	5.66	4.33	0.29	0.08	4.2
2052	0.35	0	0.43	1.79	0.82	0.17	1.03	3.5	2.66	0.17	3.09	0.01
2053	5.76	0.06	6.86	0.35	0.03	0.66	2.8	1.82	0.68	0.69	0.09	15.03
2054	1.32	0.12	0	0.14	1.34	1	5.46	4.59	1.66	5.29	0	3.58
2055	1.49	0.11	1.43	0.45	0.24	0.17	3.4	3.93	3.95	0.89	3.2	6.72
2056	1.62	8.69	0.05	0.96	0.67	0.36	5.61	9.1	6.71	0.4	0	0.61
2057	2.72	0	0	0.23	1.51	0.56	2.83	6.95	1.47	0.25	0.35	1.38
2058	1.98	0.21	1.01	0.11	0.57	0.05	4.81	2.01	3.15	1.3	1.06	0
2059	2.45	0.11	3.35	2.04	0	0.85	5.6	10.04	2.31	2.44	2.46	1.9
2060	0.91	0.33	0.5	0.11	0.2	0.51	3.27	5.49	0.43	0	0.16	0.42
2061	0.03	0	0.54	4.53	0.92	0.67	1.65	9.88	2.33	10.97	0.26	0.12
2062	0	3.88	0	0.15	0.06	0.09	2.06	5.36	4.07	2.06	3.95	2.53
2063	1.36	0.22	8.93	0.48	0	0.39	0	2.7	1.56	3.8	22.84	0.37
2064	5.05	0.1	8.48	0	0	1.11	4.54	6.39	1.01	0.18	0.63	0.51
2065	0.43	1.08	0	0	0	0.09	4.36	2.4	2.61	0	0.11	0.58
2066	0	7.03	5.23	0.44	0	0.52	7.92	4.73	2.77	0.5	0.03	3.4
2067	3.04	0.63	0	0	1.41	2.14	2.36	11.16	0.45	0.46	0	0.01
2068	0.15	1.24	5	4.48	0.05	0.14	0.69	6.22	2.11	0.58	1.95	0.92
2069	0.26	0	5.94	13.09	3.85	0	0.85	10.02	5.7	4.72	7.79	12.91
2070	1.57	0.23	0	0.06	0	1.8	9.57	4.96	4.95	0.05	0.06	0.78
2071	0.98	0.45	0	0	0.11	3.13	6.52	4.86	4.71	0.16	0.37	3.5
2072	1.3	0	0	1.72	1.8	2.31	14.1	3.63	0.04	0.18	0	0.23
2073	1.3	1.18	4.09	11.83	0	0.12	9.11	4.78	3.07	1.1	0.14	0.29
2074	3.04	1.77	2.93	9.88	0.4	0	5.2	5.26	0.92	0.15	0.3	2.24
2075	0.27	3.38	0	0.62	0.45	0	1.59	6.98	4.87	0.64	0.15	7.97
2076	0.15	0	0.77	0	2.68	4.04	15.5	4.88	1.69	0.28	0.01	0
2077	0.52	5.48	0.73	0	0.28	0.87	4.81	7.43	3.89	0.09	0	2.86
2078	4.03	0	1.27	2.62	0	0.62	1.55	9.88	4.4	0.44	0.13	0.06

2079	1.47	0.12	0	0.16	0.32	1.87	3.02	5.09	1.76	0.61	0.57	5.85
2080	2.54	0	10	0	1.07	0.64	2.06	1.25	2.59	4.66	20.15	6.27
2081	2.71	0.58	7.91	6.81	0.22	0	0.61	2.03	4.28	1.28	4.43	5.75
2082	0.18	0	0	0.02	1.5	0.39	2.9	8.8	0.47	0.05	0.01	0.71
2083	2.41	0.77	0	0	2.06	0.84	4.51	7.66	2.06	0.19	0.04	1.29
2084	0.81	0	9.24	6.3	0.64	0.75	6.61	3.99	1.68	0.22	1.35	0
2085	0.23	0.03	1.29	0	0	0.52	8.48	8.24	0.7	0.29	0	3.04
2086	0	0	0	2.25	0.09	0.04	3.78	2.14	7.7	4.65	0.38	0.6
2087	4.83	4.51	0	6.84	0.53	0.09	6.27	2.74	1.83	0.44	2.84	1.71
2088	1	0.1	1.69	0	0	0	5.36	7.37	1.14	1.6	0.55	0.4
2089	0	0	1.13	0.44	4.32	0.71	3.58	2.48	0.59	2.02	0.17	0.07
2090	2.34	0	0.12	0	0.17	0.14	0.57	2.04	1.09	8.36	10.63	0
2091	2.84	0.21	2.89	9.08	0	0.37	8.87	2.34	0.62	0.08	0.09	9.76
2092	2.85	0	2.46	2.98	1.23	0.46	10.6	10.15	2.32	2.36	0.83	0.7
2093	2.5	1.54	5.84	0.04	0.64	0.36	1.41	5.03	2.8	0	0.93	0
2094	1.44	0.62	6.05	0.88	0.25	0	3.47	13.66	1.07	2.67	1.63	0.28
2095	2.65	0.56	8.89	0.45	3.65	0.52	2.03	11.79	0.84	4.41	3.19	0.01
2096	0.33	0.48	0.71	0	0.5	1.13	1.32	8.35	8.69	0	0	4.2
2097	6.16	0.87	1.14	1.94	0	0.47	9.6	17.61	0.9	0	0.15	3.87
2098	0	0	0	0.21	1.62	1.86	12.4	5.87	2.31	0.82	0.1	2.32
2099	1.18	0.47	0.98	2.72	0.08	0.78	6.98	7.99	2.16	0.27	1.34	0.3
2100	1.86	4.51	0	1.46	2.79	0.28	2.35	1.8	3.57	0.73	0	0

Appendix 6. Mean monthly future minimum temperature of kombolcha station under RCP8.5

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2020	8.98	7.81	11.33	13.09	12.75	15.18	15.76	15.21	13.12	13.33	9.47	10.44
2021	10.06	9.44	10.18	13.14	14.01	15.64	16.46	16.07	14.37	12.45	11.13	8.55
2022	9.78	9.33	10.65	11.76	12.9	16.51	15.33	15.19	14.61	10.52	11.03	8.27
2023	9.62	8.72	11.85	12.76	13.07	14.59	15.61	15.5	14.28	12.12	9.64	10.45
2024	8.62	9.69	9.06	12.56	13.91	14.59	15.21	15.35	14.71	12.73	11.79	10.61
2025	8.64	11.02	12.27	11.36	15.08	17.16	15.57	15.74	14.5	12.79	12.29	9.06
2026	10.26	11.01	12.36	12.32	13.79	13.87	16.75	15.61	14.36	11.08	11.49	12.12
2027	10.62	9.5	11.51	12.79	14.15	17.65	16.21	15.92	14.91	13.43	11.42	8.65
2028	8.57	7.87	10.17	13.01	13.49	16.54	15.54	15.52	14.11	10.4	11.41	10.98
2029	8.9	7.81	11.48	10.41	11.88	14.55	15.34	15.41	14.94	13.08	12.05	8.88
2030	8.21	9.2	11.28	11.23	15.4	16.16	15.64	15.82	14.97	11.85	10.39	9.41
2031	6.92	7.34	9.54	11.75	13.7	15.99	15.52	15.37	14.49	10.25	8.84	9.03
2032	7.5	10.12	12.1	13.12	11.71	14.88	15.6	15.58	13.23	10.85	9.35	8.5
2033	8.48	8.11	13.6	13.7	14.15	15.7	15.17	15.8	15.13	12.32	10.89	10.41
2034	13.11	11.02	12.72	14.59	13.25	16.29	16.19	15.91	15.45	13.11	10.93	11.58
2035	9.72	9.72	13.11	12.94	14.1	15.21	15.91	15.97	15.87	13.94	11.19	7.82
2036	9.44	11.88	9.74	10.92	12.98	14.85	15.87	15.63	15.04	12.12	10.03	9.63

2037	7.29	8.32	10.45	12.77	12.86	15.07	15.83	15.8	15.26	12.64	11.14	11.09
2038	10.09	9.31	10.29	12.28	13.89	15.79	16.29	16.02	15.27	11.71	9.64	9.82
2039	11.25	9.04	11.28	14.01	13.5	16.58	16.4	15.94	15.02	12.58	10.3	7.95
2040	9.77	8.71	11.14	12.61	13.96	15.57	16.07	15.81	14.56	12.83	10.67	9
2041	8.06	9.75	11.06	13.41	13.89	15.13	16.27	16.01	14.84	13.36	10.3	9.21
2042	9.29	10.47	13.43	11.64	13.61	17.93	15.89	15.45	13.99	11.86	11.52	10.73
2043	8.87	13.19	14.27	14.25	15.48	16.83	18.35	16.66	15.93	14.73	12.18	12.47
2044	10.85	8.87	11.32	11.79	13.93	15.7	16.04	16.13	15.57	14.22	10.56	8.23
2045	9	9.1	11.15	13	14.26	16.88	15.71	16.05	14.46	12.02	9.44	9.99
2046	10.32	10.02	10.65	12.33	13.54	18.25	16.24	15.97	14.58	12.62	10.91	12.19
2047	7.3	9.78	11.31	13.43	14.5	15.76	16.52	16.17	15.44	11.81	12.81	9.46
2048	9.06	11.67	10.56	13.09	15.23	15.45	16.2	16.1	14.97	14.22	9.67	9.02
2049	9.44	7.86	11.54	12.72	15.04	16.82	15.59	15.72	14.34	13.46	11.99	8.8
2050	8.77	10.74	9.77	13.17	12.97	16.19	15.13	14.13	13.49	10.5	12.45	9.67
2051	8.54	10.72	9.73	10.66	12.72	15.27	15.33	14.65	13.13	12.03	9.82	7.44
2052	8.28	8.62	8.9	12.7	13.35	15.94	15.08	14.9	13.69	11.28	10.83	8.4
2053	8.2	6.98	9.11	12.9	12.96	14.11	14.85	15.12	13.92	11.88	12	8.54
2054	10.67	11.21	9.4	14.33	12.68	14.16	15.18	15.17	14.56	12.55	9.81	9.37
2055	12.47	11.4	10.85	12.75	12.42	15.95	16.17	14.76	14.62	12.58	10.52	9.96
2056	8.5	8.46	10.33	13.14	14.55	13.54	14.93	15.08	14.91	11.79	9.61	9.46
2057	7.12	7.29	10.31	11.19	13.57	14.61	15.57	14.3	14.27	11.13	10.12	8.72
2058	7.68	8.02	10.08	10.32	13.03	14.97	15.23	14.46	13.59	10.32	10.1	8.8
2059	8.32	11.61	10.47	12.77	12.31	14.5	15.67	15.38	13.18	10.49	11.1	8.53
2060	7.81	10.38	12	11.12	14.3	16.53	15.28	14.69	14.15	11.93	10.57	7.76
2061	8.9	8.02	11.01	12.24	14.25	17	15.09	15.01	14.26	12.75	10.3	10.53
2062	9.08	11.15	11.72	12.91	11	15.33	16.06	15.18	13.97	12.86	10.88	10.91
2063	8.16	9.34	9.64	12.95	13.79	14.81	15.55	15.16	14.72	13.48	11.35	11.92
2064	8.88	11.04	11.03	12.41	14.15	14.88	15.79	15.52	14.02	14.01	10.59	10.32
2065	8.77	9.44	10.28	13.21	13.35	14.95	15.55	14.96	13.72	13.43	11.48	8.8
2066	9.09	10.27	10.89	12.3	13.56	15.19	16.21	14.95	14.4	12.72	11.07	8.92
2067	8.17	7.66	10.28	10.93	13.31	14.39	15.32	15.23	14.09	11.81	11.75	9.1
2068	7.81	10.27	9.78	13.48	14.32	16.58	15.87	15.44	14.54	13.15	10.9	9.58
2069	8.81	10.7	11.39	13.82	14.14	15.83	16.06	15.75	15.6	13.76	11.09	8.86
2070	10.01	8.99	10.6	12.01	15.16	16.48	15.52	15.52	15.34	13.32	9.81	9.17
2071	6.6	7.78	8.86	12.19	13.38	15.1	15.55	15.67	13.5	12.06	11.79	9.16
2072	7.81	11.42	11.02	11.74	15.96	17.53	16.15	15.53	15.09	12.91	11.43	9.26
2073	11.02	10.52	14.75	11.9	14.9	16.26	18.29	16.04	14.92	14.5	11.69	11.08
2074	9.24	10.61	11.52	13.28	14.9	16	15.54	15.36	14.31	11.73	11.44	8.33
2075	9.33	8.8	9.03	13.15	13.11	15.2	15.73	15.65	14.46	12.37	12.18	9.02
2076	10.35	8.88	10.65	12.95	15.52	18.25	16.36	15.84	13.64	13.14	13.37	9.73
2077	9.04	9.32	11.48	14.07	13.05	15.67	16.06	16.33	14.95	13.97	12.44	13.58
2078	11.47	12.25	10.68	13.79	14.66	14.66	16.56	16.4	15.34	14.07	11.92	9.84
2079	11.65	11.26	10	11.93	14.19	15.26	16.54	15.92	15.14	13.96	12.74	11.21
2080	7.19	9.94	9.59	10.4	12.16	14.61	14.63	14.31	12.25	11.34	9.16	8.26

2081	8.15	6.27	10.75	12.35	12.34	15.64	16.68	14.84	14.07	12.29	10.01	9.6
2082	9.57	9.27	11.58	9.83	13.33	15.11	15.38	14.91	13.45	13.36	8.86	8.4
2083	8.41	10.19	12.17	11.34	11.83	14.8	16.19	14.82	13.4	12.98	10.9	9.86
2084	9.47	9.66	12.46	13.02	11.82	14.03	15.62	14.78	14.06	12.18	12.4	10.46
2085	8.48	8.45	11.13	12.14	12.51	15.14	15.38	15.12	14.23	11.96	9.26	9.93
2086	11.12	8.14	10.36	11.81	14.51	15.33	15.5	15.01	13.89	11.5	11.92	9.97
2087	8.97	9.42	11.86	9.83	14.58	15.57	15.08	15.2	14.39	12.43	12.76	11.73
2088	7.61	8.85	12.02	12.51	15.6	15.41	16.21	15.14	14.55	12.24	10.63	9.88
2089	10.34	9.75	11.9	14.15	14.26	15.54	15.45	15.76	14.45	12.69	10.96	8.97
2090	8.38	8.44	10.61	11.58	13.42	17.04	15.82	15.11	14.59	11.29	10.7	10.44
2091	7.14	10.35	10.39	13.44	13.59	15.29	15.5	15.11	14.37	12.9	9.17	8.19
2092	8.24	9.33	12.02	12.39	14.68	16.46	15.79	15.28	13.86	12.6	11.12	7.23
2093	9.73	9.81	9.54	12.3	13.77	15.66	15.93	15.41	14.73	11.51	11.58	10.86
2094	10.41	8.69	10.9	14.03	14.46	17.43	17.31	15.26	14.88	12.79	11.43	9.63
2095	7.94	9.02	10.58	12.53	14.21	15.03	15.38	15.2	14.1	13.83	10.95	10.62
2096	9.71	8.61	11.64	13.52	12.83	16.08	15.88	15.62	13.71	11.64	12.38	10.59
2097	10.43	9.75	13.54	13.21	12.48	14.92	15.8	15.8	14.73	14.05	11.5	10.47
2098	8.7	10.23	10.41	13.17	15.93	17.25	16.88	15.83	14.97	13.38	10.25	9.04
2099	9.57	10.87	13.16	12.53	15.77	18.31	15.85	15.27	14.67	12.23	11.27	9.26
2100	7.59	8.42	10.9	12.72	13.36	15.62	16.96	15.77	14.8	13.79	12.14	10.27

Appendixes 7 mean monthly future maximum temperature of Haik station under RCP4.5

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2020	23.53	25.68	27.06	25.27	29.12	29.98	29.08	26.53	26.76	24.86	23.1	21.98
2021	23.04	25.37	27.81	26.85	27.14	30.51	30.39	28.05	27.26	26.67	23.7	23.3
2022	24.5	25.95	27.26	26.14	27.43	28.87	25.33	24.83	24.01	24.6	23.13	22.26
2023	22.66	24.6	28.26	27.73	27.47	28.9	24.17	24.51	26.44	25.06	23.44	23.32
2024	24.35	24.3	27.38	28.41	30.58	29.54	26.52	26.49	25.38	24.35	22.51	22.1
2025	23.42	23.16	26.88	27.26	26.4	30.03	26.94	25.46	26.13	25.06	21.94	21.76
2026	24.19	26.55	27.62	27.71	31.2	29.21	24.84	27.37	26.14	24.86	24.2	23.38
2027	24.45	25.56	26.19	29.27	31.26	30.36	25.71	24.8	26.46	25.33	24.01	23.3
2028	23.48	24.76	27.61	28.45	28.83	28.54	26.46	27.39	26.53	25.12	23.19	24.11
2029	22.75	25.33	27.34	28	31.55	30.66	29.28	26.25	27.21	25.98	23.95	23.41
2030	24.17	25.53	27.33	29.68	31.07	28.61	25.89	25.4	26.28	26.28	24.89	23.62
2031	24.37	24.45	26.22	29.13	26.69	30.66	28.58	25.55	26.31	24.86	24.4	21.94
2032	24.05	26.26	27.05	26.73	29.69	31.56	30.59	28.08	27.26	26.2	24.6	23.98
2033	24.79	25.74	26.91	27.1	28.75	29.55	29.84	27.79	27.85	25.99	25.39	24.02
2034	25.14	26.8	26.28	29.8	30.69	32.04	29.64	25.6	25.97	24.49	23.21	23.39
2035	24.01	25.47	28.19	28.4	30.14	28.1	26.65	26.98	26.02	24.85	23.93	23.8
2036	24.88	26.21	27.03	30.26	31.25	31.32	28.71	27.85	27.74	26.85	24.19	21.53
2037	21.53	24.54	26.25	26.98	28.96	32.84	31.47	27.74	28.44	27.6	26.12	24.97
2038	24.69	26.6	26.09	27.59	31.57	30.19	24.44	26.84	26.49	25.83	25.17	23.11

2039	23.74	26.57	27.7	28.03	30.58	31.94	28.69	26.58	26.47	25.47	24.38	23.45
2040	23.91	25.04	27.84	30.54	31.31	30.84	27.13	25.87	27.43	26.26	25.27	24.19
2041	24.86	25.55	27.58	30.77	30.41	31.21	24.41	24.03	25	25.21	23	23.18
2042	23.41	25.7	27.41	28.78	30.23	28.84	25.28	25.82	26.88	25.31	24.98	22.68
2043	22.16	25.27	26.37	24.86	28.23	31.21	29.77	26.71	27.01	25.96	23.91	24.53
2044	25.28	27.43	28.92	27.17	29.8	31.66	27.84	27.09	27.01	27.01	25.08	22.47
2045	25.16	25.67	26.95	28.1	29.66	31.09	25.92	25.51	25.64	25.2	24.32	24.14
2046	25.64	26.24	29.13	29.15	30.84	30.26	25.28	25.76	27.22	26.95	25.47	23.65
2047	24.87	25.89	28.77	25.19	29.03	30.24	28.5	26.68	28.04	25.53	23.34	22.93
2048	21.33	25.72	27.38	30.2	31.58	28.87	28.01	26.82	26.38	26.05	25.37	24.25
2049	25.32	26.5	27.72	28.17	30	30.82	26.67	27.59	27.74	26.36	24.05	22.88
2050	23.77	24.83	27.71	30.28	31.11	29.45	27.4	27.14	26.21	25.48	24.02	22.87
2051	24.66	26.78	27.43	26.84	29.52	30.46	28.85	26.61	26.7	25.35	25.56	23.26
2052	24.48	26.86	28.35	27.3	29.92	30.81	28.1	27	25.94	24.33	23.05	21.82
2053	21.35	24.67	25.67	29.05	30.5	29.68	28.22	26.76	26.33	25.23	24.78	20.88
2054	22.7	24.94	28.29	29.27	28.99	29.98	29.03	25.35	26.33	24.53	23.82	22.43
2055	22.31	25.57	27.54	26.35	29.97	29.48	27.3	26.27	26.17	24.12	22.69	21.95
2056	22.16	23.01	26.27	28.38	29.31	30.45	24.72	24.41	24.68	24.75	24.14	22.88
2057	22.79	25.38	26.17	28.58	29.53	29.03	27.57	26.4	26.39	25.73	24.74	23.56
2058	23.64	25.25	26.64	28.34	29.9	30.65	29.03	27.41	27.1	25.33	23.87	24.11
2059	23.75	26.3	27.23	27.95	31.53	30.1	27.81	25.5	26.16	24.91	22.09	21.67
2060	23.66	24.82	27.97	28.9	30.61	28.92	27.86	25.98	26.33	26.27	24.75	23.9
2061	25.24	25.53	26.54	27.17	28.68	30.56	29.3	25.34	26.13	22.71	22.15	23.28
2062	24.24	24.25	27.62	29.3	29.91	30.69	29.25	27.27	26.29	25.54	22.66	21.99
2063	23.61	26.22	26.63	28.1	30.72	31.21	30.55	28.55	26.94	26.34	21.13	22.65
2064	22.37	25.57	25.72	29.24	31.35	30.77	27.84	25.36	26.66	26.08	24.41	23.28
2065	23.26	24.8	27.92	29.49	30.78	30.55	27.91	26.74	26.8	25.43	24.99	23.38
2066	24.99	24.28	26.22	28.52	30.59	30.67	27.43	27.1	26.75	25.11	24.42	22.37
2067	23.36	24.77	27.86	29.5	29.57	29.61	27.32	24.43	26.09	24.5	24.12	23.92
2068	24.71	24.98	26.02	26.21	28.22	30.76	29.77	26.44	26.8	25.3	23.28	23.18
2069	23.76	26.41	29.19	25.51	27.52	29.5	28.66	26.86	26.42	24.68	21.85	20.82
2070	22.91	25.33	27.53	29.8	31.2	31.44	28.76	27.34	26.25	25.85	25.41	23.84
2071	23.93	25.28	27.44	30.1	30.33	28.6	24.37	24.54	24.74	24.8	23.72	22.76
2072	23.34	25.44	27.03	28.04	28.05	27.76	25.15	25.96	26.04	25.81	24.56	24.56
2073	23.47	25.05	27.05	24.75	29.2	30.76	26.75	25.53	26.09	25.47	23.57	23.46
2074	23.59	25.26	27.08	25.02	28.55	32	30.72	26.55	28.18	27.1	25.3	24.28
2075	24.62	25.44	27.92	29.33	29.78	32.11	29.14	26.81	26.22	24.45	23.52	22.02
2076	24.05	25.93	27.52	30.25	29.23	26.8	24.18	24.49	26.99	25.1	24.32	24.59
2077	24.39	24.58	26.28	29.12	28.76	28.18	24.65	24.67	26.15	24.81	24.24	22.75
2078	21.58	24.55	25.52	27.52	30.63	31.43	29.01	25.24	25.84	25.01	23.93	24.2
2079	24.96	25.02	28.48	30.79	30.14	31.56	27.54	24.95	26.26	24.47	23.63	22.55
2080	23.42	26.64	26.84	28.66	29.96	31.39	28.94	28.43	27.06	25.97	22.15	21.49
2081	23.39	26.01	27.31	28.11	29.62	32.41	29.36	28.58	26.94	25.13	22.91	20.98
2082	22.78	25.67	28.13	29.85	29.23	31.34	26.64	24.04	26	25.64	24	23.32

2083	23.57	24.54	27.2	29.89	28.61	27.58	25	25.61	26.51	24.67	24.71	23.25
2084	23.54	25.9	24.54	25.76	28.69	28.18	25.84	26.98	25.47	25.33	24.28	22.95
2085	23.74	26.44	25.63	29.5	30.39	31.64	26.74	25.79	26.87	26.18	25.74	23.11
2086	24.31	26.09	28.88	28.15	30.69	32.18	29.25	28.49	26.73	25	24.26	23.31
2087	23.3	24.36	26.95	25.12	29.9	30.85	27.31	24.86	26.36	25.1	23.13	23.15
2088	23.67	26.08	27.25	29.38	30.52	31.49	26.21	25.43	26.28	25.29	23.66	23.29
2089	24.41	25.65	26.53	28.91	28.11	30.26	29	27.32	26.97	24.76	23.48	23.57
2090	23.83	26.48	26.89	29.34	30.99	31.5	30.8	27.27	27.37	23.95	21.71	22.51
2091	22.46	24.9	27.42	24.67	28.41	30.32	27.14	26.74	26.07	24.62	24.1	21.31
2092	22.08	25.13	26.92	26.08	28.74	30.24	26.92	26.03	26.63	24.84	23.36	23.49
2093	22.89	25.16	25.62	28.99	30.28	30.33	27.63	25.36	26.26	25.7	24.67	24.19
2094	23.66	25.42	25.67	26.87	29.09	31.47	29	25.09	26.5	25.71	23.42	23.09
2095	23.54	25.61	26.52	27.37	28.22	29.2	27.93	25.74	26.65	25.59	23.05	22.21
2096	24.12	26.18	27.75	30.08	29.61	28.86	29.83	26.63	25.06	25.66	25.33	23.44
2097	22.57	24.92	26.88	28.75	29.85	30.87	26.38	23.5	26.07	26.3	24.82	22.07
2098	23.64	25.86	26.69	29.45	29.63	28.66	24.77	24.12	26.31	25.8	23.82	22.63
2099	23.45	25.06	26.13	28.93	29.72	28.97	26.65	23.77	26.5	25.61	24.18	24.27
2100	23.63	25.8	28.15	27.83	28.17	30.48	30.96	27.58	26.63	26.32	25.94	25.07