STREAMFLOW RESPONSE TO CLIMATE CHANGE ON TIKUR WUHA SUB-WATERSHED, RIFT VALLEY BASIN, ETHIOPIA

M.Sc. THESIS

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HAWASSA, ETHIOPIA

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STREAMFLOW RESPONSE TO CLIMATE CHANGE ON TIKUR WUHA SUB-WATERSHED, RIFT VALLEY BASIN, ETHIOPIA

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APPROVAL SHEET

As Thesis research advisor, we hereby certify that we have read and evaluated this thesis prepared under our guidance by BROOK LEGESE entitled

"Streamflow response to climate change on Tikur Wuha Sub-Watershed, Rift Valley Basin, Ethiopia"

We recommend that it be submitted as fulfillment of the thesis requirement.

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As member of the Board of Examiners of the final open defense by Brook Legese, have read and evaluated his thesis entitled ***"Streamflow response to climate change on Tikur Wuha Sub-Watershed, Rift Valley Basin, Ethiopia"*** and examined the candidate. Therefore, I certify that the thesis is accepted in partial fulfillment of the requirement for the Degree of Master of Science in Water Resources Engineering and Management.

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External Examiner	Signature	Date

DEDICATION

This work is dedicated to my beloved Mother, Kibe Tefera.

Mom, you are the reason for being who I am.

DECLARATION

I, ***Brook Legese Dadhi***, declare that the thesis which I hereby submit for the "***Degree of Master of Science In Water Resource Engineering And Management At The University of Hawassa"*** is my own work and has not previously been submitted and will not be submitted by me for a degree at this or any other institution. To the best of my knowledge and belief, except as acknowledged in the text, the thesis does not contain any written work presented by other persons whether pictures, graphs or data or any other. I also declare that I have complied with the rules, requirements, procedures, and policy of the university.

Student signature: ________________________

Date: May 2018.

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LIST OF ACRONYMS

AOGCM……...Atmosphere-Ocean General Circulation Models

ArcSWAT……SWAT Integrated with ArcGIS

CMhyd………. Climate Model data for hydrologic modeling

CMIP5………...Coupled Model Inter-comparison Project Phase 5

CORDEX……. Coordinated Regional Downscaling Experiment

DEM…………. Digital Elevation Model

GCM…………. General Circulation Model

GIS…………..... Geographic Information System

HRU………..…Hydrological Response Units

IPCC………..…Intergovernmental Panel on Climate Change

ITCZ………..…Inter Tropical Convergence Zone

MAE………..…Mean Absolute Error

m.a.s.l.……….…meters above sea level

MOA……..…...Ministry of Agriculture, Ethiopia

MWIE…………Ministry of Water Irrigation and Energy, Ethiopia

NMSA……..…National Meteorological Services Agency, Ethiopia

RCM………..…Regional Climate Model

RCP……………Representative Concentration Pathway

RE…………..…Relative Error

RMSE………..…Root Mean Square Error

SCS……………Soil Conservation System

SRES………..…Special Report on Emission Scenarios

SWAT……….…The Soil and Water Assessment Tool

SWAT- CUP……Soil and Water Assessment Tool- Calibration and Uncertainty prediction

WGEN……….…Weather Generator

WMO…………...World Meteorological Organization

ABSTRACT

Climate changes alter regional hydrologic conditions and results in a variety of impacts on water resource systems. Such hydrologic changes will affect almost every aspect of human well-being. Simulation models of watershed hydrology and water quality are extensively used for water resources planning and management. This study aims to assess the streamflow response to Climate Change on Tikur Wuha Sub-watershed, Rift Valley Basin of Ethiopia. In the study the daily hydro-meteorological data values for the baseline period of 1981-2005 were used. Historical Representative Concentration Pathway (RCP) data along with observed data of precipitation and temperature were used for extraction and bias correction using CMhyd tool. After evaluation of bias correction methods using residual plot, and RMSE, MAE and RE, the downscaled climate data such as, RCP4.5 and RCP8.5 scenarios was used for the future period assessment. Soil Water Assessment Tool (SWAT) models were used to assess the streamflow response to Climate Change. Calibration and validation of the model output were performed by comparing simulated streamflow with corresponding measurements from the Tikur Wuha outlet for the periods of 1992-2001 for calibration and 2002-2005 for validation using SWAT-CUP(SUFI-2). The model calibration and validation results shows a good agreement with the observed flow with the coefficient of determination 0.79 and 0.86, and a Nash Sutcliffe efficiency was 0.56 and 0.64, respectively. The result of projected temperature reveals a systematic increase in all future time periods for both RCP 4.5 and RCP 8.5 scenarios, and for all considered period whereas the projected result of precipitation was inconsistent throughout all future time periods and for both RCP 4.5 and RCP 8.5 scenarios. The dynamically downscaled daily climate variables (precipitation and temperature) were used to simulate future projections of streamflow. Streamflow projections for future time periods showed that mean annual streamflow may increase by 15.43, 23.48, and 25.42% in 2020s, 2050s, and 2080s, respectively, from the baseline period for RCP 4.5 scenario, whereas for RCP 8.5 scenario, it will be expected to increase by 29.58, 34.20, and 38.72% in 2020s, 2050s, and 2080s, respectively. The model simulations considered only future climate change scenarios assuming all spatial data constant. Therefore, future study need to consider impact of land use/cover change on the sub-watershed for future sustainable development plan.

Keywords;

Climate Change, Climate Projection, Streamflow, RCPs, CMhyd, SWAT, SWAT-CUP

INTRODUCTION

1.1 Back ground and justification of the study

Climate change refers to any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer time periods. Weather is the state of the atmosphere at a given time whilst climate is the average weather over a period of time (Thorpe, 2005).

The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report has shown an increase of 0.85°C in the global mean temperature since 1880 until 2012 (Stocker, T. ed., 2014). These changes in global temperature have been accompanied by changes in climate in different ways (Feng et al. 2014). Many regions have experienced changes in precipitation leading to the frequent occurrence of floods (Min et al. 2008) and droughts (Dai 2011, 2013). These changes in the climate system will have a strong impact on local and regional hydrological regimes in many regions of the world (Dibike and Coulibaly 2005, Hu et al. 2013). The IPCC also has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase 1.4 – 5.8°C by the end of the 21st century (IPCC, 2007).

The impacts of climate change on society and natural resources depend on the response of hydrological cycle to global warming (Marvel and Bonfils, 2013). So, while discussing hydrological regimes, it is extremely important to note the very basics of the hydrological cycle from where all the hydrological components derive. The hydrological cycle comprises different processes such as precipitation, infiltration, percolation, runoff, and evapotranspiration through which water moves continuously from ocean to atmosphere and makes a cycle. While the precipitation is considered as a driver of the hydrological cycle, the increases in temperature lead to an intensification of this cycle. Thus, the change in climate affects all these processes involved in hydrological cycle making it one of the primary causes of hydrological change (Marvel and Bonfils, 2013; Bhuvandas et al., 2014).

The IPCC finding indicates that developing countries, such as Ethiopia will be more vulnerable to climate change. Because of the less flexibility to adjust the economic structure and is largely dependent on agriculture, the impact of climate change has far reach implication in Ethiopia. Increased industrial activity and excessive deforestation during the last century and a half have increased the concentration of carbon dioxide in Earth's atmosphere. This has, in turn, initiated large-scale atmospheric processes resulting in a change of global temperature and precipitation (among other variables). Changes in Earth's climate system can disrupt the delicate balance of hydrologic cycle and can eventually lead to increased occurrence of extreme events (such as flood, droughts, heat waves, summer and ice storms, etc.) (Bernstein, et al, 2008).

Hence, there is a need to quantify and assess the future scenarios of climate change and its impact on water resources of the country in general and the basin in particular, because the country's future development relies on this resource. Therefore, researching in the area of climate change on TikurWuha sub-watershed, in particular, is very vital. Hence, this study addresses the general projection of the future climate variables such as Precipitation and Temperature: Maximum and Minimum, compared to the observed condition and the possible future potential impacts of climate change on the streamflow of Tikur Wuha sub-watershed at regional-scale with a Regional Climate Model Outputs, RCPs.

1.2 Statement of the problem

Unlike most of the rift valley lakes, lake Hawassa is a closed and fresh lake (Tenalem, 1998). Closed lakes are very dependent on the balance of inflows and evaporation, and are very sensitive to change in climate variability, whether driven by nature or human interventions. This also means that they are very important indicators of climate change and can provide records of hydroclimatic variability over a large area (Kilkus, 1998; Obolkin and Potemkin, 1998). Small closed lakes are most vulnerable to a change; there are indications that even relatively small change in inputs can produce large fluctuation in water level and salinity in small closed lakes in Western North America (Laird et al, 1996).

A dike has been constructed to protect the town; however, the continued increase in the Lake level has threatened to overtop the dike even after repeated heightening. The major cause of the continued rise of the Lake is not clearly known (WMO, 2003). But there is no volcanic activity at present except for the existence of geothermal activities, which have little or no role in changing the level of the rift lakes (Tenalem Ayenew, 2007).

Yemaneh (2004) study on water balance of lake Hawassa shows an increased trend of lake Awassa water level. The study assesses the catchment as the whole not specific to Tikur wuha sub-watershed. However, the study had recommended that further study is needed specific to Tikur wuha sub-watershed with respect to change in climate. There have been few studies performed utilizing CMIP3 GCM under SRES scenarios for climate change impact studies in Tikur Wuha Sub-Watershed. Which include a studies done by Diriba (2015) using only one GCM model(HadCM3) of the IPCC fourth assessment report(AR4); under three SRES emission scenarios (A1B, A2 & B1) and the study concluded that the river flow will increase at the end of 2099 and had recommended further studies has to carry out using ensemble of GCM output.

However, Studies performed at the regional scale, which is based on the IPCC fifth assessment report(AR5) to investigate the future changes of hydrologic regimes, and water resources availability under climate change in Tikur Wuha Sub-watershed with respect to RCPs are still limited. Therefore, studies that fill these gaps and provide information are very important. So, this research was focused on using a dynamically downscaled ensemble of 20 GCMs models..

Having the above mentioned and other related problems, it is imperative to understand the impact of future climate change on Tikur Wuha River. The hydrological model Soil and Water Assessment Tool (SWAT) with SWAT-CUP linked SUFI-2 uncertainty analysis has been used in this study to assess climate changes impacts on the hydrology of Tikur Wuha sub-watershed, Ethiopia.

1.3 Objectives of the study

- The general objective of the research is to assess the impact of climate change on Streamflow of Tikur Wuha Sub-Watershed.

The specific objectives of the study are:

- To project future change in precipitation and temperature for three window periods (i.e. the 2020s, 2050s, 2080s) compared with a baseline period (i.e. 1981-2005).
- To quantify the possible impacts of the climate change on streamflow using SWAT hydrological model.

1.4 Research questions

- ✓ Do downscaled RCPs have a significant bias compared to the observable data's?
- ✓ What is the likely change in temperature and precipitation in the year 2010-2099 against a baseline period of 1981-2005?
- ✓ How much will the stream flow likely change in the future (2010-2099) compared to the baseline period (1981-2005)?

1.5 The significance of the Research

The contribution of this research is to address valuable information on the projected climate variables and to evaluate future streamflow using a recent technique of regional climate models under the two scenarios (RCP 4.5 and RCP 8.5). These will help to devise a policy framework incorporating the appropriate adaptations and mitigation measures to preserve water resource of Tikur Wuha sub-watershed in light of future climate change scenarios. Moreover, assessing the impact of climate change on Tikur Wuha River will help to maintain the sustainability of the lake Hawassa, manage water resources in the sub-watershed and combat the potential damage that could be caused as a result of flooding or drought.

1.6 Limitation of the Research

In this study, the impact of climate change was assessed by assuming the land use/cover will remain the same for the future. But, in the real world, the land use/cover is dynamic due to natural and human influences. Moreover, the RCP scenarios were developed only for the three climatic variables: maximum temperature, minimum temperature, and precipitation values. The rest of the climate variables were assumed to be constant. Even though, WMO recommends that the ideal baseline period is 30 years, due to unavailability of data this study had used 25 years' data as a baseline (1981-2005).

2. Literature Review

2.1. Climate change observations and drivers

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.

The Intergovernmental Panel on Climate Change report in (IPCC, 2007) strongly confirmed that climate change due to human activities is happening and that its consequences are likely to be serious. Further, it broadly confirmed the findings of the UK Stern Review that the consequences of climate change under business-as-usual scenarios are likely to be far more expensive than efforts to limit climate change by reducing greenhouse gas emissions (Stern, 2006). It also pointed out that stabilizing concentrations of carbon dioxide equivalent (treating all greenhouse gases as if they were carbon dioxide) at 450 ppm still leaves more than 50% chance of global warming greater than 2°C relative to preindustrial conditions, and possibly as high as 3°C.

Climate observations from direct measurements and remote sensing platforms reveal unequivocal warming of the climate system. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (IPCC, 2013). The global average surface temperature increased by 0.85°C over the period 1880 to 2012. For the longest period when the calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951). For other latitudes area-averaged long-term positive or negative trends have low confidence. The global mean sea level rose by 0.19 m between 1901 and 2010.

Greenhouse gases emitted by human activities are believed to be the major causes of global warming. The atmospheric concentrations of these gases that include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased since 1750. In 2011 the concentrations of these greenhouse gases were 391 ppm, 1803 ppb, and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC, 2013).

Climate change is caused by natural and anthropogenic substances and processes that alter the energy budget. The strength of drivers is quantified as Radiative Forcing (RF) in units of Watts per square meter ($W m^{-2}$). RF is the change in energy flux caused by a driver and can be positive or negative. Positive RF leads to surface warming, negative RF leads to surface cooling. The RF can be reported based on the concentration changes of each substance or the level of emission from different sources. The emission-based RF provides a more direct link to human activities. The total radiative forcing is positive with the largest contribution coming from the increase in the atmospheric concentration of CO_2.

2.2. Climate models in climate change studies

Climate models, class of computer-driven models, are defined as a mathematical representation of the climate system based on physical, biological and chemical principles (Goosse et al., 2010) and they are the primary tools available for investigating the response of the climate system to various forces (IPCC, 2013; Flato et al., 2013). Many climate models have been developed to understand the level of climate change in response to the emission of greenhouse gases (GHG). The population size and lifestyle including energy and land use are the main drivers of anthropogenic GHG emissions and the representative concentration pathways (RCPs) are projections of GHG concentrations based on these factors. The RCP2.6 is for the strict mitigation scenario, RCP4.5 and RCP6.0 are for two intermediate mitigation scenarios and RCP8.5 is for very high GHG emissions (IPCC, 2014).

Knowing how temperature and precipitation are projected to change in the future on average is not very useful to decision-makers planning for specific types of impact studies of climate change on agriculture or water supply (Girvetz et al., 2012). But climate models that can be used to create more useful climate metrics and impact modeling results are needed, which in turn will be used directly to inform the development of climate adaptation responses for weather forecasting, understanding climate and projecting climate change. There are wide ranges of climate models identified by IPCC for impact assessment studies (IPCC, 2000; IPCC, 2007; IPCC, 2013). But, there is no single model which is appropriate for all purposes. Models used in climate research vary from simple energy balance models to complex earth system models (ESMs) (Goosse et al., 2010; Flato et al., 2013). The following are climate models evaluated in the IPCC 's Fifth Assessment Report (AR5).

2.2.1. Atmosphere-Ocean General Circulation Models

Atmosphere-Ocean General Circulation Models (AOGCMs) are developed to simulate the present climate and also used as a major tool for projections of future climate change using different emission scenarios. Global climate model information can be enhanced to better represent the conditions we know to have occurred in specific places by using historically observed local climate information from weather stations (Girvetz et al., 2012). But to assess the hydrological impacts of climate change at the watershed and the regional scale, the GCM outputs cannot be used directly due to the mismatch in the spatial resolution between the GCMs and hydrological models (Hashmi et al., 2009). Outputs from many GCMs are available in the public domain for academics and research, mainly in the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset of the World Climate Research Programs (WCRPs). CMIP5 is meant to provide a framework for coordinated climate change experiments for the IPPC AR5 and beyond and it promotes a standard set of model simulations in order to provide projections of future climate change on two-time scales, near-term (out to about 2035) and long-term (out to 2100 and beyond).

Most of these GCMs have spatial resolutions that are usually no higher than 70–120 km (Solomon, 2007, D'onofrio et al.,2013). But to properly predict impacts of climate change and variability it needs information on a spatial scale in the order of 10km, but global climate models (GCMs) rarely have a spatial resolution finer than the order of 100km. This mismatch in spatial resolution creates the gap between the information available from GCMs and that needed to inform climate change adaptation strategies. This is mainly true for models that can benefit from higher spatial resolutions than global models provide. The best example is hydrological simulations, which are sensitive to elevation, local soil properties, topography, and slope orientation, and so on (Pierce et al., 2014).

2.2.2. Earth System Models

Earth System Models (ESMs) are the current state-of-the-art models, which are expanded on Atmosphere-Ocean General Circulation Models (AOGCMs) by incorporating the biogeochemical cycles (Flato et al., 2013). Adding biological and chemical components to a climate model due to the strong interactions associated with climate with the assumption that climate system is not only driven by physical processes specifically, the concentrations of major greenhouse gases are not only affected by man-made emissions but are also involved in chemical reactions and interactions with the biological components of the Earth system.

So, ESM is developed with the aim of quantifying feedback on climate through the Earth system interactions.

2.2.3. Earth System Models of Intermediate Complexity

In some instances, more focused modeling systems aim to answer specific scientific questions concerning long-term climate change and climate sensitivity, or for developing large model ensembles, and for these projects lower resolution models called Earth System Models of Intermediate Complexity (EMICs) are used. Intermediate-complexity models are models which describe the dynamics of the atmosphere and/or ocean in less detail than conventional General Circulation Models (Flato et al., 2013).

2.2.4. Regional Climate Models (RCMs)

Regional Climate Models (RCMs) or limited-area models use large-scale and lateral boundary conditions and sea surface temperatures (SST) from GCMs to produce higher resolution outputs (Fowler et al., 2007). They have a higher spatial resolution in the order of 10-50 kms. The higher resolution of RCMs compared to GCMs makes it possible to realistically simulate regional climate features such as orographic precipitation, extreme events, and regional scale climate anomalies, or non-linear effects (Fowler et al., 2007). The use of RCMs gained the higher interest of scholars in recent years and the ability of RCMs to reproduce the present-day climate has substantially improved (Van Roosmalen et al., 2010).

Unfortunately, using an RCM provides additional uncertainty to that inherent in GCM output because RCMs are subject to systematic biases when comparing simulated meteorological variables for the current climate to observations and these biases can affect hydrological simulations considerably (Van Roosmalen et al., 2010). There has now been much assessment of the ability of RCMs to simulate climate variables, particularly those relevant to hydrological impact studies (Hagemann et al., 2004; Leung et al., 2004; Fowler et al., 2007). RCMs are used to dynamically downscale global model simulations for some particular geographical region to provide more detailed information, but they require considerable computing resources and are expensive to run (Flato et al., 2013).

2.3. Climate Model downscaling

Global climate models (GCMs) are typically run at coarse spatial resolutions and result in a mismatch between available climate change projections and the scale of interest to most applications (Brown et al, 2008). Climate downscaling techniques are used to bridge the spatial and temporal resolution gaps between what climate modelers are currently able to provide and what impact assessors require (Wilby & Dawson, 2007a). There are two main types of downscaling techniques- ***Dynamical downscaling and Statistical downscaling.***

Dynamical downscaling seeks to couple large-scale climate dynamics and local climate features. It does so by utilizing higher resolution regional climate models (RCMs) that respond to the output of GCMs. The GCM output is provided as boundary conditions, which are the values at the edges of the spatial domain of the RCM. Horizontal resolution for most RCMs is in the order of tens of kilometers which could capture important orographic and physical geography details to the simulations. In terms of temporal resolution, RCMs are usually most skillful at monthly or coarser timescales (Brown et al, 2008).

Statistical downscaling consists of modeling the relationship between GCM output and observations to produce results that are used as inputs to sector models or for direct use in decision making. The general principle is to form empirical relationships between predictors and historically observed values, then apply the empirical relationship to future projections. Statistical models are simpler in nature, significantly easier to construct and manage, and require much less computational time than dynamical downscaling. The consensus of model intercomparison studies is that dynamical and statistical methods have comparable skill at estimating surface weather variables under present climate conditions (Wilby and Dawson, 2007b). The general approach to GCM downscaling is illustrated in Fig. 2.1 and summary of the advantages and disadvantages statistical and dynamic downscaling methods are shown in Table 2.1.

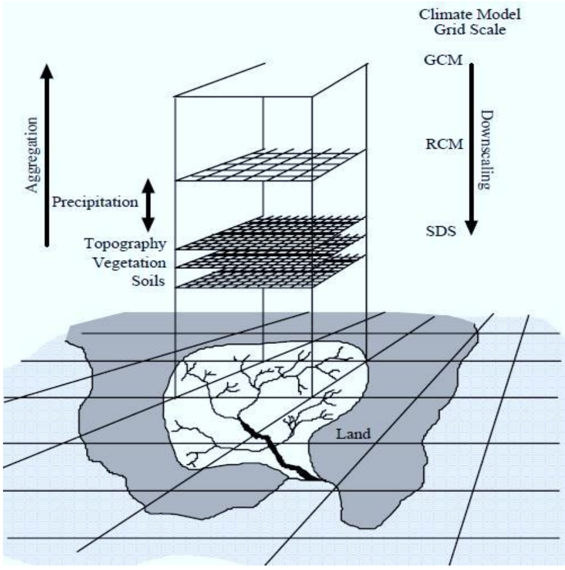

Figure 2. 1 A schematic illustrating the general approach to downscaling *(Wilby and Dawson, 2007b).*

Table 2. 1 Advantages and disadvantages of the climate downscaling techniques(Wilby and Dawson, 2007b).

	Statistical downscaling	Dynamical downscaling
Advantages	• Comparatively cheap and computationally efficient • Can provide point-scale climatic variables from GCM-scale output • Can be used to derive variables not available from RCMs • Easily transferable to other regions • Based on standard and accepted statistical procedures • Able to directly incorporate observations into method	• Produces responses based on physically consistent processes • Produces finer resolution information from GCM-scale output that can resolve atmospheric processes on a smaller scale
Disadvantages	• Require long and reliable observed historical data series for calibration • Dependent upon choice of predictors • Non-stationarity in the predictor-predictand relationship • Climate system feedbacks not included • Dependent on GCM boundary forcing; affected by biases in underlying GCM • Domain size, climatic region and season affects downscaling skill	• Computationally intensive • Limited number of scenario ensembles available • Strongly dependent on GCM boundary forcing

2.4. Climate Scenarios

Socio-economic and emission scenarios provide plausible descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emission of greenhouse gases and air pollutants (Van Vuuren et al. 2011). These future scenarios of forcing agents (e.g., greenhouse gases and aerosols) are fed into the climate models as input, and the output of these climate models is further used in climate change analysis and hence, the assessment of impacts, adaptation, and mitigation. Several sets of scenarios including the IS92 scenarios (Legegett et al. 1992), the scenarios from the Special Report on Emission Scenarios (SRES) (Nakicenovic & Swart, 2000) and, more recently, the Representative Concentration Pathways (RCP) (van Vuuren et al. 2011) are used in climate research.

2.4.1. RCP – Emission scenarios

Among the research community, recently there has been an increasing interest in scenarios that explicitly explore the impact of different climate-policies in addition to the **no-climate-policy** scenarios such as SRES (Moss et al. 2010). The need for new scenarios prompted the IPCC to request scientific communities to develop a new set of scenarios for the assessment of future climate change. Therefore, a set of new scenarios is constructed containing emission, concentration and land-use trajectories referred to as "**R**epresentative **C**oncentration **P**athways" (RCPs). In its name, the word "representative" signifies that each of the RCPs represents a larger set of scenarios in the literature. This implies that this set of RCPs should be compatible with the full range of emission scenarios (with and without climate policy) available in the current scientific literature.

The word "concentration pathway" emphasizes 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 for the input to climate models. The word "concentration" also emphasizes that instead of emissions, concentrations are used as the primary product of the RCPs, designed as input to climate models. Four RCPs scenarios named according to radiative forcing target level for 2100 are presented here below. Comparison of CO_2 concentrations obtained by SRES and RCP emission scenarios are indicated in Fig. 2.2.

RCP2.6: This scenario has also been referred to as RCP3PD representing the radiative forcing trajectory which goes to a peak level of 3 W/m^2 (~490 ppm CO_2 eq) before 2100, followed by a decline (PD=Peak-Decline). The selected pathway declines to 2.6 W/m2 by 2100 (Van Vuuren et al., 2007). It aims at limiting the increase of global mean temperature to 2°C above the pre-industrial period.

RCP4.5: This scenario describes the stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100 (Clarke et al. 2007). RCP4.5 corresponds to that category scenario in AR4 which contains the far majority of the scenarios assessed.

RCP6: This scenario is also similar to RCP4.5, with stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100 (Fujino et al. 2006). The number of mitigation scenarios leading to 6 W/m^2 in the literature is relatively low, however, at the same time, many baseline scenarios (no climate policy) correspond to this forcing level.

RCP8.5: This scenario corresponds to the rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100 (Riahi et al. 2007). It corresponds to a scenario with no-climate-policy baseline and comparatively high greenhouse gas emissions.

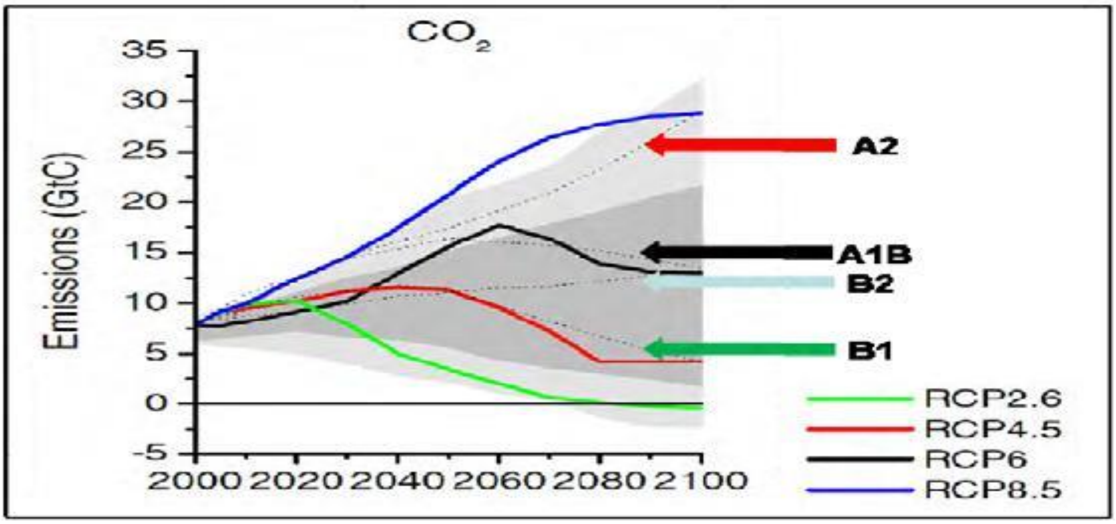

Figure 2. 2 Comparison of the SRES and RCP emission scenarios *(Van Vuuren et al., 2011)*

2.5. Climate change projections

Due to the inherent uncertainty of the climate system and the inevitable existence of model errors, the multi-model ensemble is the recommended approach for climate change projections. IPCC has used several models in its coupled model inter-comparison projects (e.g. CMIP3, CMIP5) to make the various projections. There are also regional model inter-comparison projects, like the Co-ordinated Regional Climate Downscaling Experiment (CORDEX).The CORDEX project[1] is an initiative of the World Climate Research Program (WCRP) performed with the intention of producing an ensemble of high-resolution climate change projections by dynamically downscaling GCM simulations from Coupled Model Inter-comparison Project Phase 5 (CMIP5) data archive (Jones *et al.*, 2011).

The major aims of the CORDEX initiative are to provide a quality controlled dataset of downscaled information, coordinated model evaluation framework, and an interface to the applicants of the climate simulations for further climate change impact, adaptation, and mitigation studies (Giorgi *et al.*, 2009). Recent analyses in relation to CORDEX simulations over Africa can be found in Nikulin *et al.* (2012), Hernández-Díaz *et al.* (2013). Nikulin *et al.* (2012) evaluate the ability often RCMs over Africa and conclude that all RCMs simulate the seasonal mean and annual cycle quite accurately. Likewise, it is verified that the mean of multi-model outputs does better than individual simulation.

Hernández-Díaz *et al.* (2013) strengthen the achievement of Nikulin *et al.* (2012). They successfully reproduce the overall features of geographical and seasonal distribution over most Africa. In their report, CORDEX simulations succeed in reproducing the average distribution of precipitation and its large geographical differences.

The fifth assessment report of IPCC provided global and regional climate projections for the new RCP scenarios under CMIP5. Limited validation studies indicated good agreement with observations (Chaturvedi et al, 2012). Figure 2.3 indicates projections for temperature and precipitation in East Africa.

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1 (http://wcrp-cordex.ipsl.jussieu.fr/)

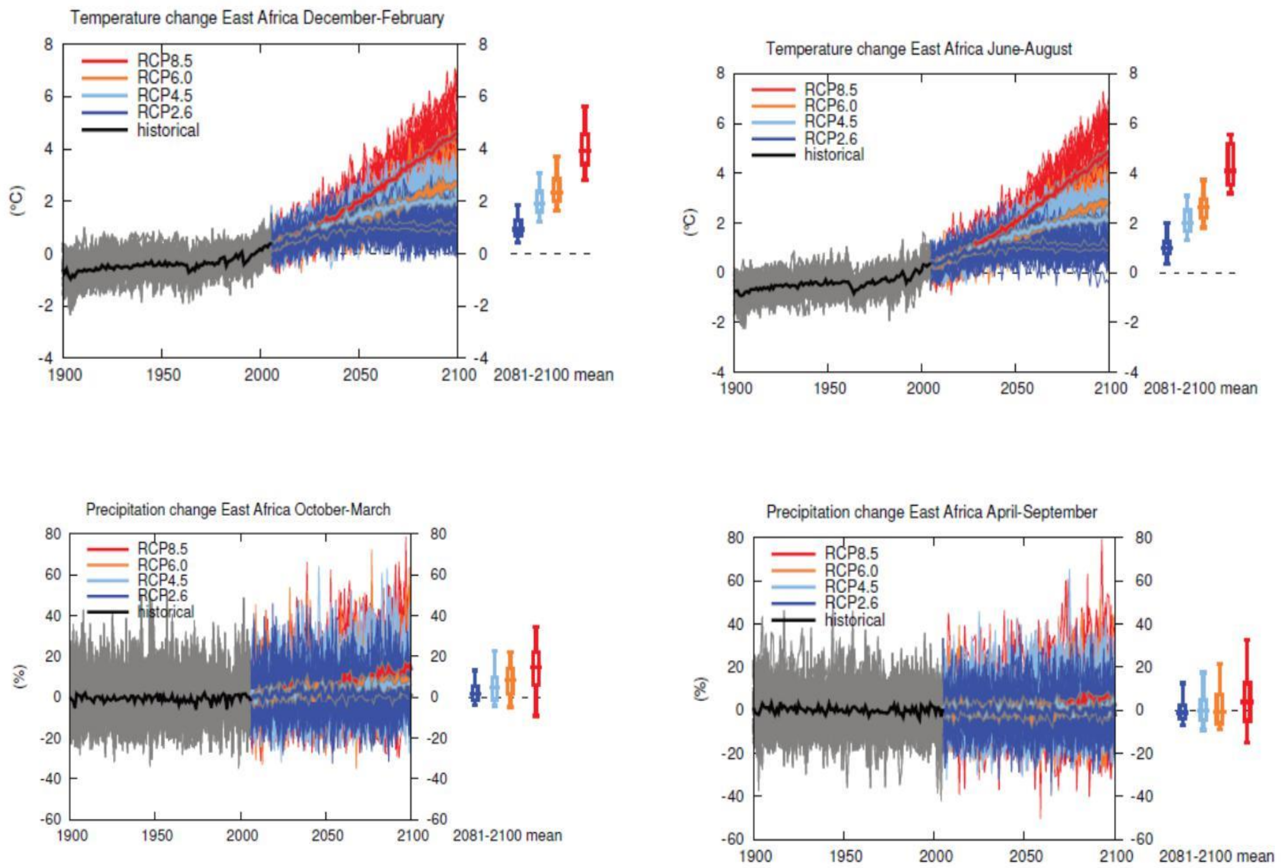


Figure 2. 3 Temperature and Precipitation projections for East Africa

2.6. Climate Change Impact on Hydrology

The Global Climate Model (GCM) suggests the increasing of Greenhouse concentration and it in turns cause changes at global and regional levels (Wilby and Dawson,2007a). Total anthropogenic Green House Gases (GHG) emissions have risen more rapidly from 2000 to 2010 in comparison to the past three decades and it was considered as the highest emissions in human history that reached 49 gigatonnes CO2- equivalents/year (IPCC, 2014). On the other hand, Trenberth et al., 2000 stated that due to doubling CO2 emission, the hydrological cycle is enhanced by 10% and it bringing increased evaporation and rainfall globally.

Climate models developed to simulate present climate and predict future climate change. On the other hand, hydrological models establish a framework to understand and investigate the relationship between climate and water resources (Xu, 1999). The GCM attempts to incorporate the atmospheric circulation, oceanic circulation, land surface process, sea ice and other processes of biogeochemical cycles (Trenberth et al., 2000).

Sirak, 2015 as cited Birsan et al., 2005 noted that human-induced climate change coupled with changes in physiographic characteristics of the catchments could alter the stream flow. To quantify key factors of human development impact on GHG emissions and their mitigation responses, scenarios are developed that depend on plausible futures (IPCC, 2014).

Solomon, 2016 stated that due to climate change 2/3 of world population become more vulnerable to availability and use of water. More particular it will cause a significant impact on the hydrological system of arid and semiarid Africa where water resource occurrence sensitively affected by climate variability, especially due to rainfall. Solomon, 2016 also describes Impact of climate change in Ethiopia Rivers and lakes diminish in size and small streams are dry up in a country considered as water tower of East Africa.

2.6.1. Coupling RCM and Hydrological Model

The CORDEX -RCM outputs represent daily average values at the model resolution (~50 km) rather than the local values that make them not to be used directly in hydrological models. Moreover, the RCM outputs are reported to have inherent systematic biases due to their imperfect conceptualization, discretization and spatial averaging within grid cells. (Graham et al. 2007a) Therefore, in order to use the RCM outputs in the SWAT model further correction was made on precipitation and temperature data

Teutschbein and Seibert (2012) provided a recent review on the use of RCMs for hydrological models. They recommend that a bias correction is necessary for using the outputs in any hydrological models as RCMs are susceptible to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. These biases are typically due to the occurrence of too many wet days with low-intensity rain or incorrect estimation of extreme temperature in RCM simulations.

2.7. Hydrologic Simulation Models

2.7.1. Classification of Hydrologic Models

Hydrological modeling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling (Lenhart et al. 2002).

There are many classification schemes of hydrologic models, such as short-term vs. long-term, small-scale vs. large scale, forecasting vs. predicting, physical vs. mathematical, continuous vs. discrete, descriptive vs. conceptual, lumped vs. distributed, and deterministic vs. stochastic models. Classifications are generally based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle (Zeray 2006).

Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow. These models can be classified as either theoretical or empirical models. A theoretical model includes a set of general laws or theoretical principles. If all the governing physical laws were well known and could be described by equations of mathematical physics, the model would be physically based. However, all existing theoretical models simplify the physical system and often include obviously empirical components, so they are considered conceptual models. An empirical model omits the general laws and is, in reality, a representation of data (Zeray 2006). Physically based models are based on our understanding of the physics of the hydrological processes which control catchment response and use physically based equations to describe these processes. Generally, physically based models are used to simulate a wide range of complex aspects (Lenhart *et al.* 2002).

The stochastic vs. deterministic classification of models depends on the character of the results obtained. If one or more of the variables in a mathematical model are regarded as random variables having distributions in probability, then the model is stochastic. If all the variables are considered to be free from random variation the model is deterministic. Using long data series, process-based deterministic models can compute the great number of calculations required to describe the complexity of a system. They can provide reliable information on the behavior of the system (Zeray 2006).

Deterministic hydrologic models can be classified into three main categories (Cunderlik 2003):

1. **Lumped Models**: parameters of lumped 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. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve a certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. Lumped models are not 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 (Beven 2000).

2. **Semi-distributed Models**: parameters of semi-distributed models are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. There are two main types of semi-distributed models: kinematic wave theory (KW) models and probability distributed (PD) models. The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven 2000). In the PD models, spatial resolution is accounted for by using probability distributions of input parameters across the basin. The main advantage of semi-distributed models is their more physically based structure than that of lumped models, and their less input data demand than fully distributed models.

3. **Distributed Models**: parameters of distributed models are 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 amounts of data for parameterization in each grid cell. However, the governing physical processes are modeled in detail and hence can provide the highest degree of accuracy.

2.7.2. Hydrologic Model Selection Criteria

There are numerous criteria which can be used for choosing the right hydrologic model. These criteria are always projected dependent since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for GUI, computer operation system, input/output management, and structure, or users add on expansibility. Among the various project-depended selection criteria, there are four main common, fundamental ones that must be always considered (Cunderlik 2003):

1. Required model outputs important for the needed purpose and therefore to be estimated by the model – does the model predict the variables required by the project such as peak flow, event volume, and hydrograph, long-term flows, etc?
2. Hydrologic processes that need to be modeled to estimate the desired outputs adequately – is the model capable of simulating regulated reservoir operation, snow accumulation and melt, single event or continuous processes, etc?
3. Availability of input data – can all the inputs required by the model be provided within the time and cost constraints of the project?
4. Price – does the investment appear to be worthwhile for the objectives of the project?

For the project needing to assess the potential impacts of climate change on a wide range of hydrological processes and existing water management practices, the following hydrologic model outputs are required (Cunderlik 2003):

❖ Simulated flow peaks (stage, discharge), volumes and hydrographs at the outlets of sub-basins, and in the profiles of special interest within the main basin,

❖ Simulated long flow sequences for water budget and drought analysis primarily for the main basin, preferably also for the individual sub-basins,

❖ Simulated extend of flood areas for different precipitation events and various antecedent basin conditions.

2.8. Approach to Climate Change Impact Study on Water Resources

Findings of the IPCC 2001, strongly suggests that water resource responds to global warming in ways that will negatively impact the water availability and water supplies. The climate change has also the potential to deteriorate the surface water quality due to increased evapotranspiration, lower flows and rivers becoming warmer, making the management of water treatment works and subsequent compliance with the drinking water quality regulations more challenging. Consequently, it is quite essential to identify the level of impact on such resources. Nawaz and Adeloye [no date] used the following diagram (Fig. 2.4) in determining climate change impact on water resources.

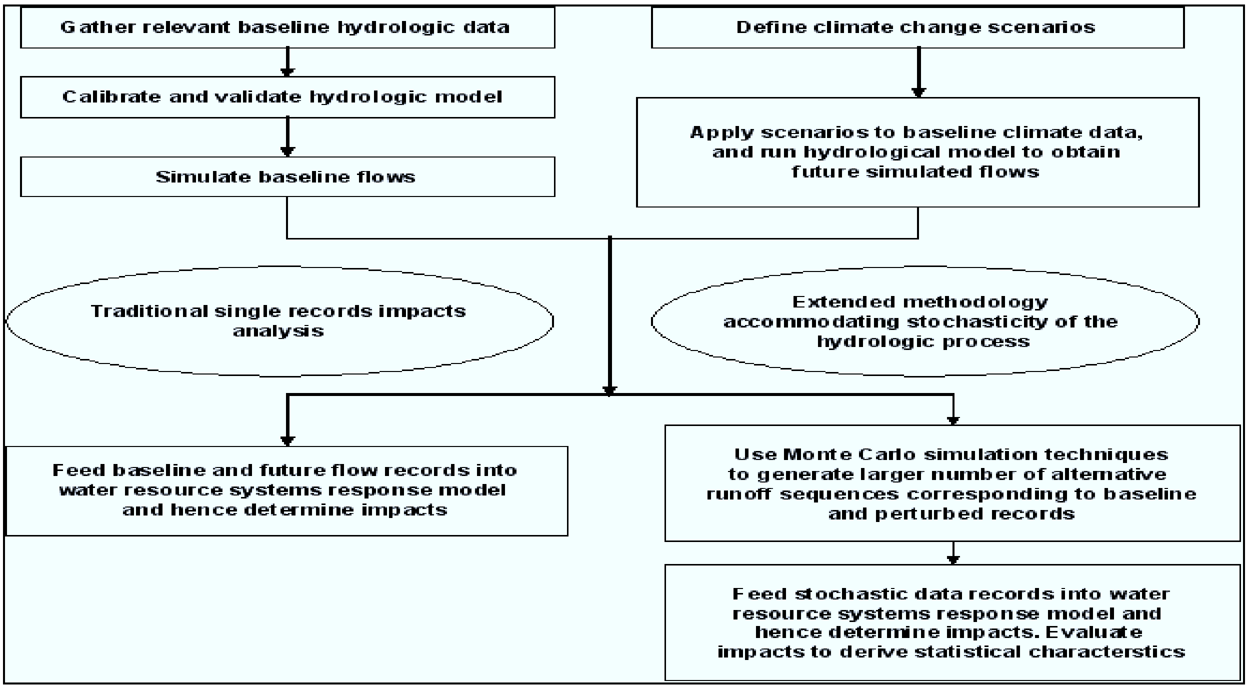


Figure 2. 4 Deterministic and stochastic methodologies for climate change water resources impacts assessment *(Nawaz and Adeloye [no date])*

In identifying the impacts, it is important to have credible results from the model chain GCM - downscaling - hydrologic model, and hence, the following two factors are very important to achieve the credibility (Bürger *et al.* 2005):

❖ Present water resources climate should be reproducible from present atmospheric climate via downscaling and hydrologic modeling;

- Simulated future trends of water resources climate should be as consistent as possible with a given global climate projection.

2.9. Bias-Correction Method

Often, outputs of regional climate models cannot be directly used for impact assessment as the computed variables may differ systematically from the observed ones. Bias correction is therefore applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables. Bias correction factors are computed from the statistics of observed and simulated variables.

2.9.1. CMhyd for extraction and bias correction

Watershed models are often used to simulate the impact of future climate conditions on hydrologic processes. However, Teutschbein and Seibert (2012) state that simulations of temperature and precipitation often show significant biases due to systematic model errors or discretization and spatial averaging within grid cells, which hampers the use of simulated climate data as direct input data for hydrological models.

Bias correction procedures are used to minimize the discrepancy between observed and simulated climate variables on a daily time step so that hydrological simulations are driven by corrected simulated climate data match simulations using observed climate data reasonably well. CMhyd is a tool that can be used to extract and bias-correct data obtained from global and regional climate models. It is highly recommended to apply an ensemble approach, i.e. to use bias-corrected data provided by several climate models and downscaling methods (Teutschbein and Seibert, 2010, 2012).

2.9.1.1. Processing framework of CMhyd

CMhyd was designed to provide simulated climate data that can be considered representative of the location of the gauges used in a watershed model setup. Therefore, climate model data should be extracted and bias corrected for each of the gauge locations.

Bias correction procedures employ a transformation algorithm for adjusting climate model output. The underlying idea is to identify biases between observed and simulated historical climate variables to parametrize a bias correction algorithm that is used to correct simulated historical climate data (Hendrik, R.,2016).

Bias correction methods are assumed to be stationary, i.e. the correction algorithm and its parametrization for current climate conditions are assumed to be valid for future conditions as well. Thus, the same correction algorithm is applied to the future climate data. However, it is unknown how well a bias correction method performs for conditions different from those used for parametrization. A good performance during the evaluation period does not guarantee a good performance under changed future conditions. Teutschbein and Seibert (2012) provide a detailed discussion and state that a method that performs well for current conditions is likely to perform better for changed conditions than a method that already performs poorly for current conditions.

2.10. SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

Distributed watershed models are increasingly being used to support decisions about alternative management strategies in the areas of land use change, climate change, and pollution control and water allocation. For this reason, it is important that these models pass through a careful calibration and uncertainty analysis. Furthermore, as calibration model parameters are always conditional in nature the meaning of a calibrated model, its domain of use and its uncertainty should be clear to both the analyst and the decision maker. Large-scale distributed models are particularly difficult to calibrate and to interpret the calibration because of large model uncertainty, input uncertainty, and parameter nonuniqueness. To perform calibration and uncertainty analysis, in recent years many procedures have become available(Abbaspour,2007). For this study, the hydrologic simulator SWAT under the same platform, SWAT-CUP (SWAT Calibration Uncertainty Procedures) was used.

2.11. Case study related to the study

- **Hydrological Response to Climate Change of the Upper Blue Nile River Basin: Based on IPCC Fifth Assessment Report (AR5)** (Gebre SL, Ludwig F,(2015)

In order to understand the future impacts of climate change, they assessed the hydrological response of climate change of four catchments (Gilgel Abay, Gumer, Ribb, and Megech) of the upper Blue Nile River basin using new emission scenarios based on IPCC fifth assessment report (AR5). Five biased corrected 50 km by 50 km resolution GCMs (Global Circulation Model) output of RCP 4.5 and RCP 8.5 emission scenarios is used. The future projection period was divided into two future horizons of 2030`s (2035-2064) and 2070`s (2071-2100). The Hydrologic Engineering Center-Hydrological Modelling System (HEC-HMS) was calibrated and validated for streamflow simulation. All the five GCMs projection showed that, maximum and minimum temperature increases in all months and seasons in the upper Blue Nile basin. They suggested that change in magnitude in

RCP 8.5 emission is more than RCP 4.5 scenario. There is considerable average monthly and seasonal precipitation change variability in magnitude and direction. Their study showed that runoff is expected to increase in the future, at 2030`s average annual runoff projection change may increase up to +55.7% for RCP 4.5 and up to +74.8% for RCP 8.5 scenarios. At 2070`s average annual runoff percentage change increase by +73.5% and by +127.4% for RCP 4.5 and RCP 8.5 emission scenarios, respectively.

- **Modeling the potential impacts of climate change on the hydrology of the Bago River Basin, Myanmar** (Sangam Shrestha & Aung Ye Htut, 2016)

This study aims to investigate the potential impacts of climate change on the hydrology of the Bago River Basin (BRB) in Myanmar. Two scenarios from the Representative Concentration Pathways (RCPs): RCP4.5 and RCP8.5 recommended by the Intergovernmental Panel on Climate Change, Fifth Assessment Report (IPCC AR5) were used to project climate change scenarios for the 2020s, 2050s, and 2080s. In their study Six General Circulation Models from the Coupled Model Inter-comparison Project Phase, 5 was selected to project the climate change scenarios in the basin. An increase of average temperature by 1.5°C and 3°C was observed under RCP4.5 and 8.5 in future periods respectively. Similarly, average annual precipitation shows a distinct increase in all three periods with the highest increase for the 2050s. A well-calibrated and validated Soil and Water Assessment Tool was used to simulate the climate change impact on future stream flows in the basin. Their results show the changes in the monthly, seasonal and annual stream flows as compared to baseline period due to the impact of climate change in the basin. The monthly streamflows are projected to increase from May to September in future.

The average streamflow changes in the winter season are projected to be higher in comparison to other seasons during 2010–2099. Similarly, the annual and rainy season stream flows are projected to increase approximately 40% and 29% in the whole basin, respectively, while the summer seasonal flows are decreased by 21%.

- **Climate Modeling of the Impact of Climate Change on Sugarcane and Cotton for Project on 'a Climate Resilient Production of Cotton and Sugar in Ethiopia' (Geremew Sahilu and Agizew Nigussie,2015)**

Based on the result they obtained inter-annual pattern of rainfall in the Central Rift Valley for both bias-corrected and uncorrected projection does not show a distinct trend. However, the monthly and seasonal distribution when observed for the near (the 2020s), medium (2050s) and long-term (2090s) period considering various scenarios show changes. On the other hand, the inter-annual trend in the case of Northwest lowlands shows a decrease with that of RCP8.5 showing more pronounced decrease.

They also suggested that monthly and seasonal distribution of Central Rift Valley region for bias uncorrected version shows a decrease of rainfall in the rainy seasons of Belg (43%) and Kiremt (8%) in the 2090s and for bias corrected projection the values are: Belg (25%) and Kiremt (3%) for RCP8.5. In Northwestern Lowlands the decrease in the 2090s for the same scenario is Belg (50%) and Kiremt (26%) for bias uncorrected Belg (29%) and Kiremt (16%) for bias corrected projection.

In the Bega, the increase for RCP8.5 in the 2090s is (97%) and (18%), and (113%) and (33%) for bias uncorrected and corrected projections in the Central Rift Valley and Northwestern Lowlands respectively. Then, they conclude that there will be less rainfall in rainy seasons and more in the drier periods.

Moreover, their study revealed that the change in rainfall quantity in whichever direction becomes significant when one moves from the near-term period (the 2020s) to the long-term (2090s) and from RCP2.6 to RCP8.5. However, in some cases, the finding of the research for bias corrected shows variability - a decrease or increase in one period – 2050s and an opposite trend in the next, 2090s. The other important finding this study is a delay in the beginning and exit of the rainy season showing a shift of season particularly a drier June and extension of the rainy period to October and November.

- **Impact Assessment of Climate and Land Use Change On Tikur Wuha River (Diriba Shuma 2015)**.

In this study, He used the Statistical Down-Scaling Model (SDSM) to derive local-scale information from global climate scenarios generated by GCMs. Among four scenario families of Special Report on Emissions Scenarios (SRES), three of them (A1B, A2, and B1,) scenarios were used in this study. After calibration and validation, He used the downscaling model for computing future temperature and precipitation pattern. Then, the downscaled future precipitation was used in the hydrologic model to assess the impact of future climate change. The assessment showed that average mean flow increased in the future periods considered (2015 - 2035, 2040 - 2050 and 2080-2099). Finally, He concluded that downscaled data resulted in an increase in the mean annual flow by a minimum of 20.05 % and a maximum of 51.67 % during time periods and three of emission scenarios considered.

3. Materials And Methods

3.1. Description Of The Study Area

3.1.1. Location

Tikur Wiha sub-watershed is part of Lake Hawassa watershed. It is located in central rift valley in central Ethiopia. It lies between (6^0 49'-7^0 11'N and 38^0 28'- 38^0 43'E) at 275Km south of Addis Ababa (Fig. 3.1). It has elevation ranging between 1680 m.a.s. l at the outlet of Tikurwuha River into the lake and 2940 ma.s.l at Kululu ridge South East of the sub-watershed. It is the only perennial river that supplies water to the lake Hawassa. The sub-watershed is accessible through Addis-Moyale road at Westside, Shashemane-Wondo-Wondo Mazoria road at the middle and Hogiso-Guguma-Koffele road at the Eastern side of the watershed. The total area of the sub-watershed is 670.25 km^2. The sub-watershed is characterized by flat-lying topography with small hills and ridges at the escarpment.

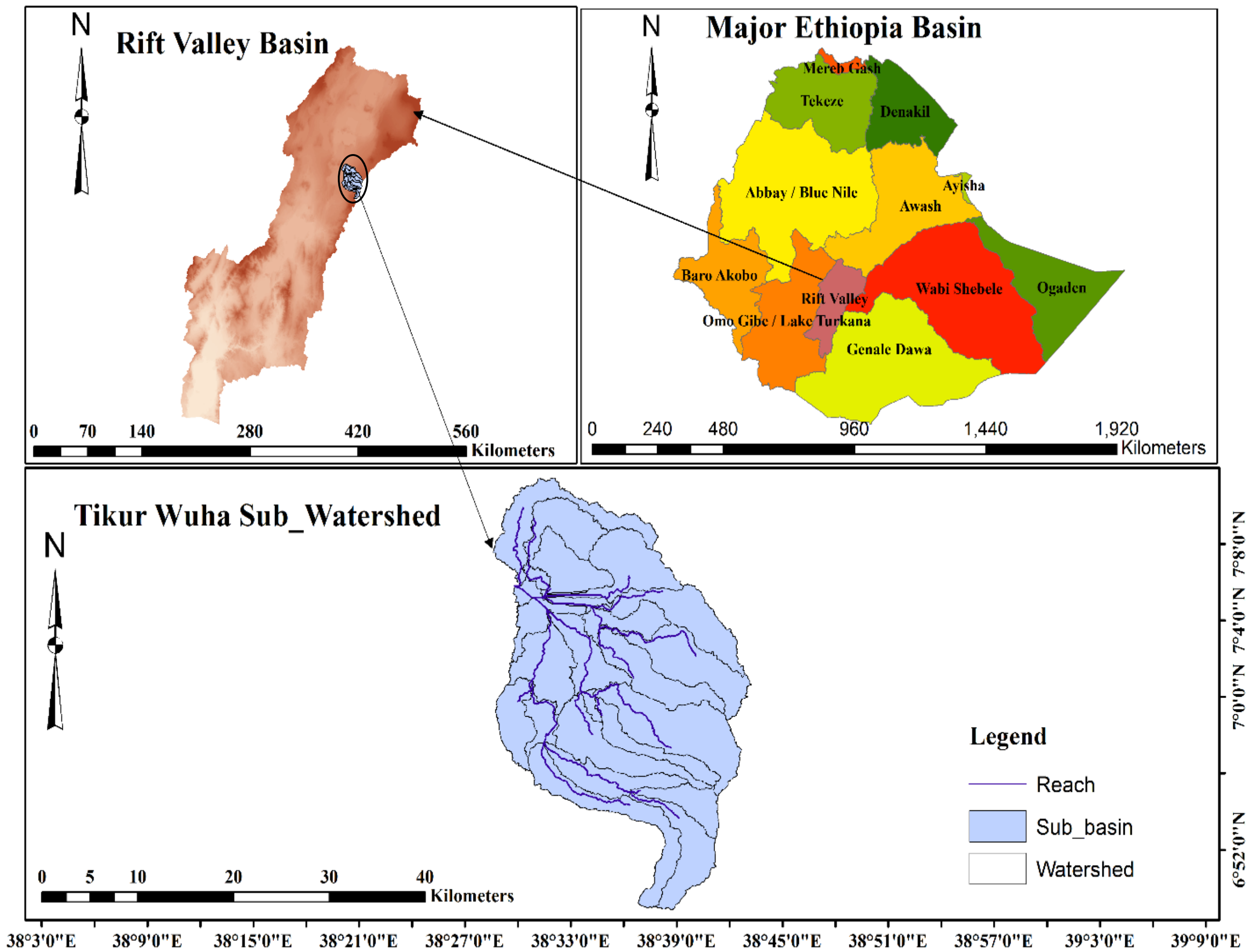


Figure 3. 1 Map of the study area

3.1.2. Climate

The mountains and high plateaus of Ethiopia greatly influence the climate. In Ethiopia, three seasons can be distinguished based upon the distribution of rainfall (Belete, 2013). The distribution of rainfall in four different rain gauge stations was plotted in Fig. 3.2. The locations of the rain gauges are presented in Appendix 2. The precipitation in the southern plateau region (Haisawita) is higher compared to the region in the North (Shashemene).

According to Legesse et al.,2003, Hawassa watershed is characterized by three main seasons. The long rainy season in the summer from June-September is known locally as Kiremt and is primarily controlled by the seasonal migration of the Inter-tropical convergence zone(ITCZ), which lies to the North of Ethiopia at this period. The wet period locally named as Kiremt represents 50-70% of the mean annual total rainfall. The dry period locally named as the Bega extend between October and February when the ITCZ lies to the South of Ethiopia (Legesse et al.,2004).

The "small rain" season locally named as Belg extends from March to May, represents about 20-30% of the annual rainfall. The climate in the area varies from dry to sub-humid according to the Thorn Thwaite's system of defining climate or moisture regions(Dessie,1995). Generally, as computed from the long-term climate data (1981-2005), the mean annual precipitation in the Tikur Wuha Sub-watershed reaches 75.79 mm and the max. and min. annual temperature ranges from 9.63°C-14.10°C to 24.03°C-29.41°C, for minimum and maximum temperature respectively.

3.1.3. Land Cover/Land Use

The humid escarpment in the North-Eastern part (Wendo Genet area) comprises a patch of wet Montane evergreen Forest together with Agro-ecosystem rich with Coffee, Enset, and various Fruit Plants. The Shallo and Cheleleka Swamps also lie at the foot of this escarpment extending to the East. In addition, irrigated vegetation cultivation and Eucalyptus plantations practiced around the mouse of Tikur Wuha River. Dense woodland and trees around the Lake used to support a variety of Wild Life. Now, however, they are degraded due to their conversion to different land uses i.e Farmland, Settlements etc (Diriba,2015).

3.1.4. Soil

The soil of the Awassa sub-basin are primarily deep, medium and fine textured Chromic and Haplic luvisols in the south and east on a rolling to hilly topography with mixed perennial and annual cultivation. In the center of sub-basin extending into the Wendo Koshe hills, the soils are Chromic and Eutric Cambisols, moderately deep to deep and medium textured with poorly drained, fine-textured Vertic Cambisols in the Chelelaka wetlands. To the North and West side of the Lake, the soil is moderately deep to deep, well to excessively drained Vitric Andosols, with small areas of very shallow Leptosols (Diriba,2015).

3.2. Data Availability

3.2.1. Meteorological datas

Required long year daily precipitation data were collected from four meteorological stations such as Hawassa, Shashamene, Haisawita and Wendo Genet (Fig. 3.2). Daily maximum and minimum temperature data were collected from Hawassa station (Fig. 3.3). Other weather elements (wind speed, sunshine hour, Relative Humidity) were also obtained from Hawassa Station which is a synoptic station of the study area. The historical weather data for above three station were obtained from National Meteorological Service Agency (NMSA) from the year1981 to 2005.

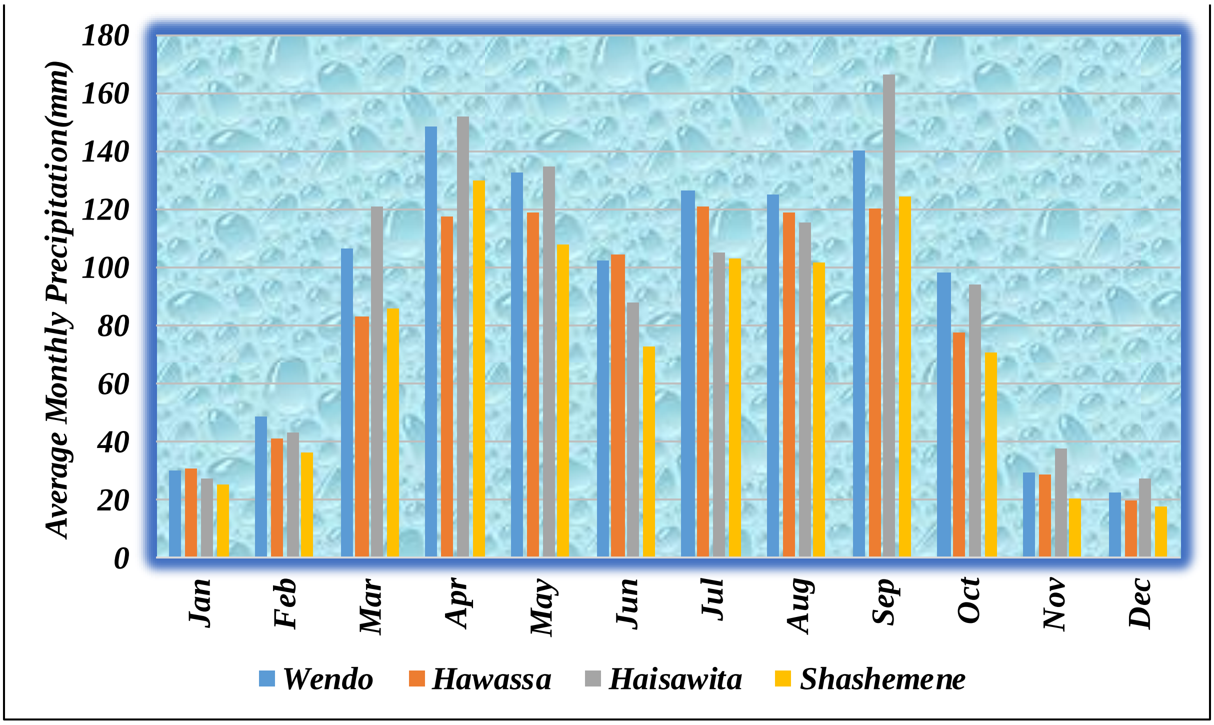


Figure 3. 2 Long-term average monthly precipitation of the selected stations from 1981-2005

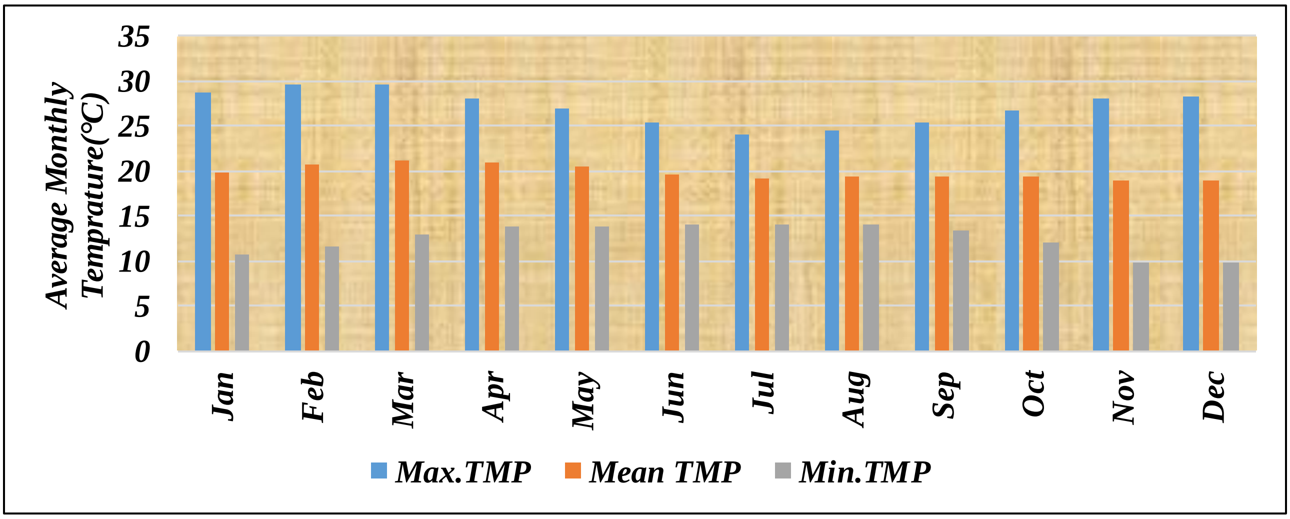


Figure 3. 3 *Long-term average monthly maximum, mean and minimum temperature from 1981-2005.*

3.2.2. Hydrological Data

Streamflow was used for calibrating and validating the SWAT model simulation. Daily streamflow data were obtained from Ministry of Water Irrigation and Energy (MWIE) for Tikur Wuha River outlet near Hawassa bridge from 1981 to 2005(Figure 3.4). Even though, there exist two gauging stations (at bridge and Dato) on Tikur Wuha River the study considered only the gauging station existed at the outlet of the River which is the gauging station near Hawassa bridge.

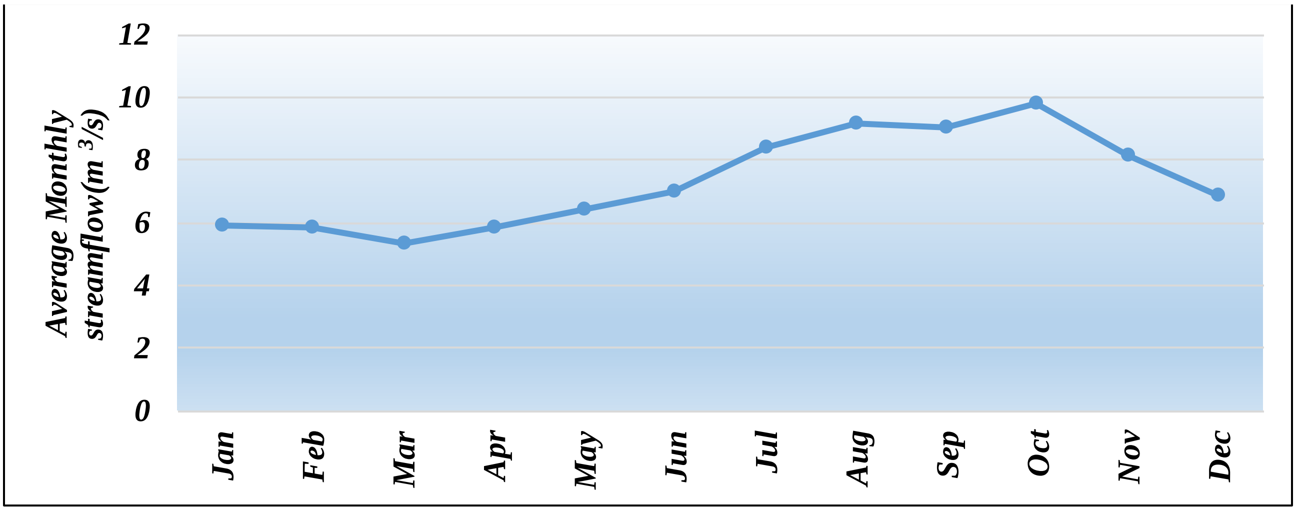


Figure 3. 4 Long-term mean monthly streamflow (1981-2005)

3.2.3. Spatial Data

Digital elevation model (DEM), land use/land cover, and soil are the three spatial data inputs required by SWAT model. DEM describes the elevation of any point in a given area at a specific spatial resolution as a digital file. DEM is one of the essential inputs required by SWAT:
(1) to delineate the watershed into a number of sub-watersheds or sub-basins and (2) to analyze the drainage pattern of the watershed, slope, stream length, width of the channel within the watershed. The DEM was obtained from Rift valley office with a resolution of 30 m by 30 m.

The land use /cover map of the study area was clipped from raster file of the land use of Ethiopia (2000) with a resolution of 30 m × 30m, which has a scale of 1: 250,000 was taken from rift valley office. Soil map of the study area was clipped from soil shapefile which was taken from MoWIE with a resolution of 30m*30m and has a scale of 1: 250,000.

3.2.4. Climate Scenario(RCPs) Data

The Intergovernmental Panel for Climate Change (IPCC) has published projections of future climate change scenarios in a series of reports. There was a fundamental change between the fourth and fifth assessment reports (AR4 and AR5) (Stocker TF, et al. (2013), Moss RH, et al. (2010, Caldwell PV, (2012)) and in order to reflect such differences as well as model variability, the study looked at two future scenarios. The first scenario considers what the future climate will be under conditions with a representative concentration path (RCP) that assumes radiative forcing will reach at 8.5 W/m^2 in 2100 (RCP8.5), which is the extreme climate scenario; the second medium-low stabilization scenario assumes that radiative forcing will stabilize at 4.5 W/m^2 in 2100 (RCP4.5)

The ensemble of 20 GCMs of Dynamically Downscaled rainfall, and minimum and maximum temperatures for the period 1951-2100 have been obtained from CORDEX-Ethiopia dataset(IWMI). The data correspond to three RCP scenarios- RCP2.6, RCP4.5, and RCP8.5. Because these two scenarios have the first priority by CMIP5 projection and the most preferable by CORDEX project, this study was considered only, RCP 4.5 and RCP 8.5 forced scenarios from 2010 to 2099 for four climate stations, and extracted to the same climate stations which were used for SWAT model simulations (Table 1).

3.2.5. Materials Used

Table 3. 1 Materials used in the study

	Name	Description and purpose
Soft-wares and Tools	Microsoft Office Word 2016	* To organize and assemble hydro-metrological data To present results and check uncertainty.
	Microsoft Office Excel 2016	* a tool used for Preparing, describing, visualizing and analyzing hydro-metrological data
	Arc GIS 10.1	* GIS software used for spatial analysis of hydrological and physical parameters.
	SWAT 2012	* A GIS interface of soil and water assessment tool used for simulation.
	SWAT-CUP	* A sensitivity analysis program interface of SWAT and used for calibration, sensitivity analysis, Uncertainty measure and Validation.
	CMhyd	*A climate data analysis tool which is used to extract and bias-correct data obtained from Global and Regional climate models.
	PCPstata	For weather generator data preparation
	DEW02	For weather generator data preparation
	RAINBOW	For hydro-meteorological data homogeneity test
	XLSTAT	*Is an EXCEL add-in tool and used for Preparing, describing, visualizing and analyzing hydro-metrological data
Data's	DEM(30m*30m)	* Digital Elevation Model (30m*30m) spatial resolution for stream delineation.
	Soil map(MoWIE)	*The soil map of the study area is taken from the soil Maps prepared by MoWIE. *An input data for SWAT model simulation.
	CORDEX_Ethiopia_RCPs dataset(IWMI)	*Coordinated Regional Climate Downscaling Experiment. It is used to obtain a downscaled historical and future climate data for Ethiopia and then extracted to Tikur Wuha.
	Meteorological Data	* Rainfall, Temperature, Solar Radiation, Wind speed, and Relative Humidity. * It is used as an input data for SWAT simulation.
	Hydrological Data	* Streamflow data, for the purpose of the model Calibration and Validation.
	Physiographic Data	* Soil and Land Use/Land cover data to create Hydrologic Response Units and simulate the model.

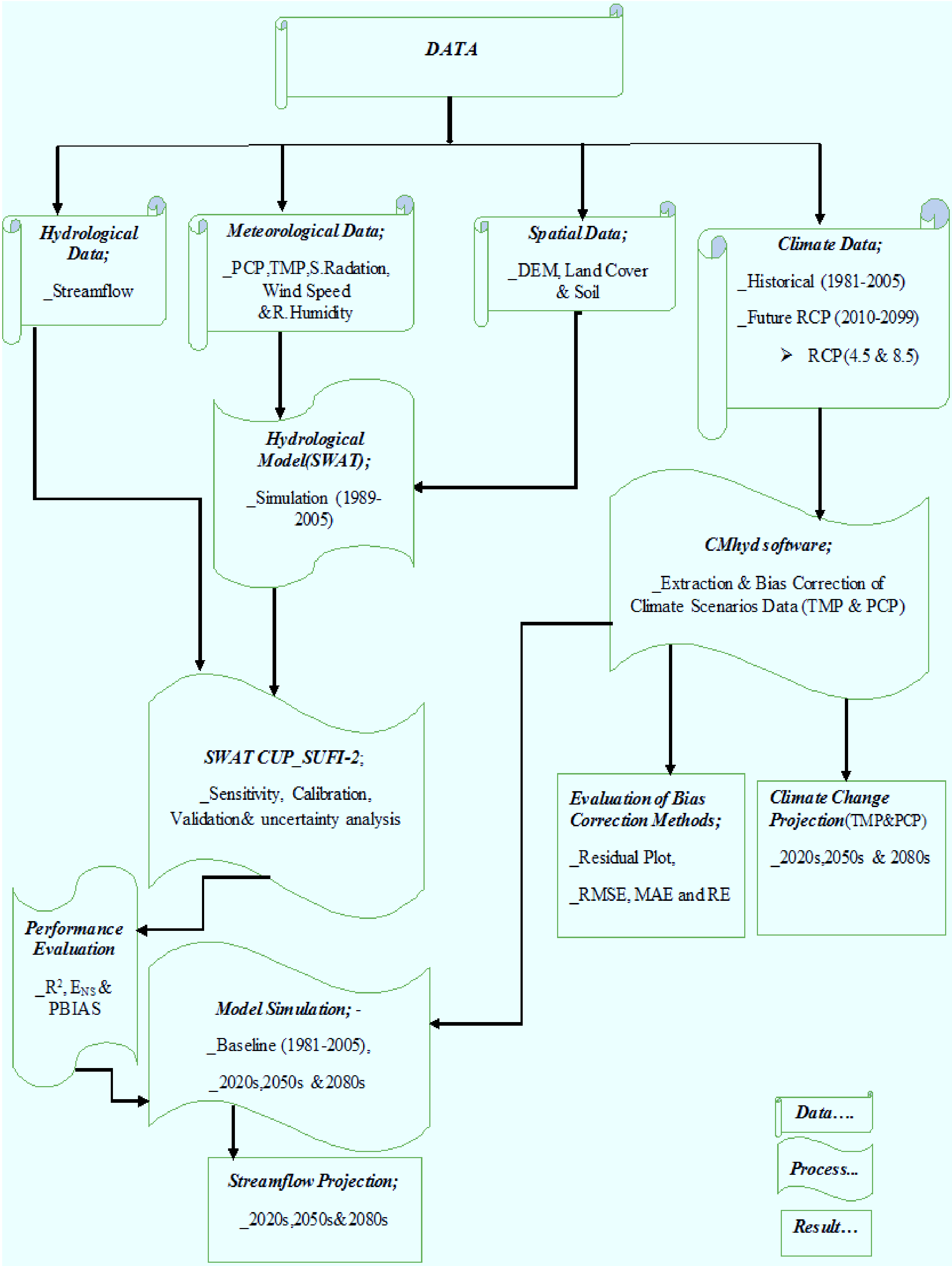


Figure 3. 5 Flow chart of the study

3.3. Data Analysis

3.3.1 Hydro-Meteorological Data

Filling of Missed Data

There are a number of methods provided to fill the missing records of daily precipitation data. Among those methods, the Arithmetic average method is applied if the average annual rainfall station to be filled is within 10% gap of annual rainfall of the adjoining stations. The station with missed data is filled in an estimate of simple average calculations of nearby stations.

Unlike the arithmetic method, the Normal ration method is applied when the percentage gap between the station to be filled and the adjoining station's annual rainfall is more than 10%. The station missed data is filled by estimating the rainfall with a weighted average of adjoining stations. The adjoining stations are weighted by the ratio of average annual rainfall of the station to be filled and by the adjoining stations.

The distance power method, on the other hand, estimates the missed data weighting by reciprocating the distance (to some power) between the station to be filled and adjoining stations. But this method does not consider spatial distribution of variables and is not recommended if the stations are close. Considering easiness and the percentage gap of the annual average rainfall between the station to be filled and the adjoining stations are greater than 10%, in this study the Normal Ratio Method was selected to fill the missed records. The method works based on a general formula (Eq.1).

$$\mathbf{P} = \frac{N_X}{M}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \cdots + \frac{P_M}{N_M}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (1)}$$

Where: M…………. Total number of stations considered

Nx…………. Average annual rainfall of station at the missing data

N1, N2, N3…. Nm……. Average annual rainfall at the adjoining stations

The missed record of observed Temperature values was estimated by multiple regressions using XLSTAT through filling from its neighboring stations. For the others missing weather variables, a negative (-99.0) was inserted. This value tells SWAT to generate weather data for that missed value.

3.3.2. Precipitation Data Quality/Consistency Checking

Consistency test

The consistency of time series data analyzed based on the theory that a plot of two cumulative quantities that are measured for the same time period should be a straight line and their proportionality remain unchanged which is represented by the slope. To check the consistency of data, the double mass curve was used. In this study station of Haisawita, Wendo Genet and Shashemane were needed slope adjustment and adjusted accordingly (Fig. 3.6).

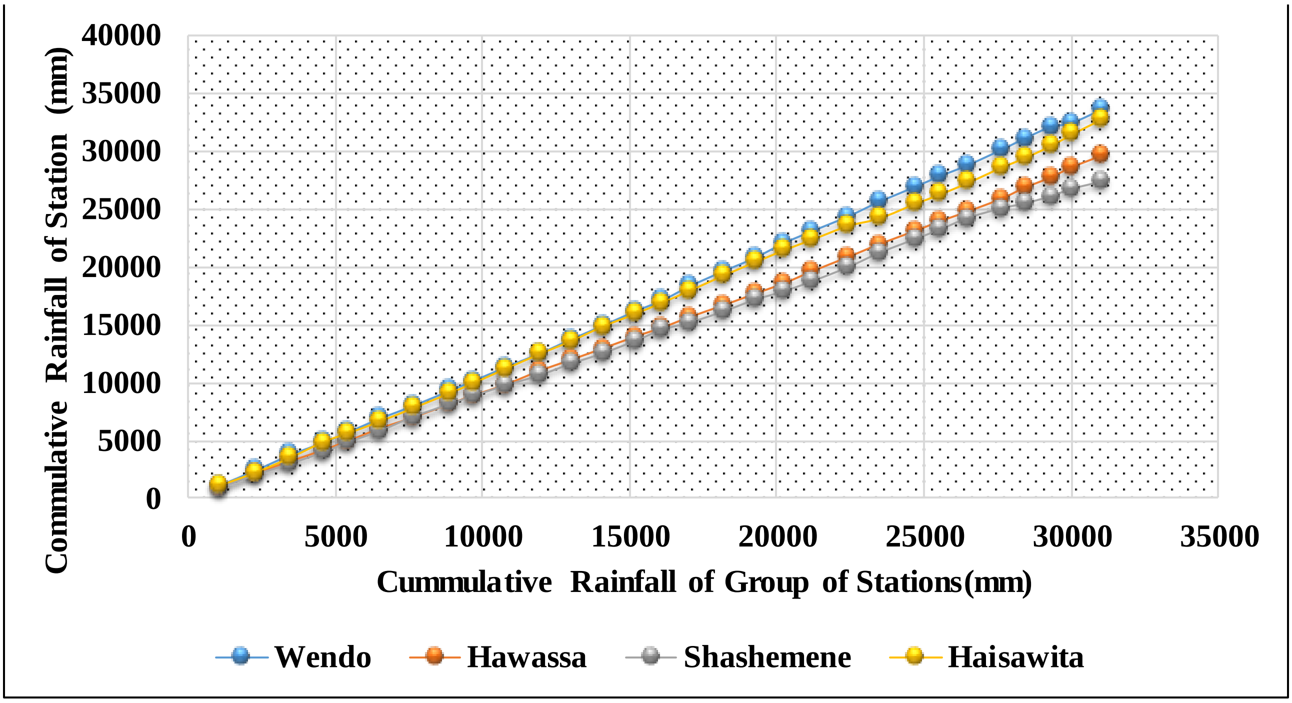


Figure 3. 6 Consistency test of precipitation data using the Double mass curve

Homogeneity test

Nonhomogeneous data series for climate change impact assessment may amplify real climate variations. The collected data said to be homogeneous if the measurements have been consistently done by the same method, with the same instrumentation, at the same time and place, and in the same environment. The homogeneity test was evaluated using RAINBOW software for this study by means of frequency analysis since it's one of the methods designed to study the homogeneity of hydro-meteorological datasets (Raes, D.,2016). The restriction of homogeneity assures that the observations are from the same population. One of the tests of homogeneity is based on the cumulative deviations from the mean using:

$S_K=\sum_{i=1}^{k}(X_{i-}\ \overline{X})$..........K=1,....., n ....Eq.(2)

Where; Xi is time series data records from X1, X2, X3; and $\bar{X}$ mean of the data. The initial value of S (k=0) and last value S (k=n) are equal to zero.

For a homogeneous record, one may expect that the SK‟s fluctuates around zero since there is no systematic pattern in the deviations of the S_K "s from their mean value. If the cumulative deviation crosses one of the horizontal lines the homogeneity of the data is rejected with respectively 90, 95 and 99% probability. The probabilities of rejecting the homogeneity of the datasets were evaluated for this study using the Homogeneity statistics menu. Homogeneity test was done after several trials for precipitation stations used in the study and the result is available under Appendix(Fig.3.7.)

3.4. Estimation of Areal Precipitation

The daily areal precipitation was computed using Thiesson Polygon method. Rainfall varies in intensity and duration from place to place, hence the rainfall recorded by each rain gauge station should be weighted according to the area it is assumed to represent. This method is useful for areas which is not much rugged rather plain and also the rain gauge stations are few compared to the size. The Thiessen polygon coverage of the area was prepared for both grid-based RCP data and observed station data (Fig. 3.7).

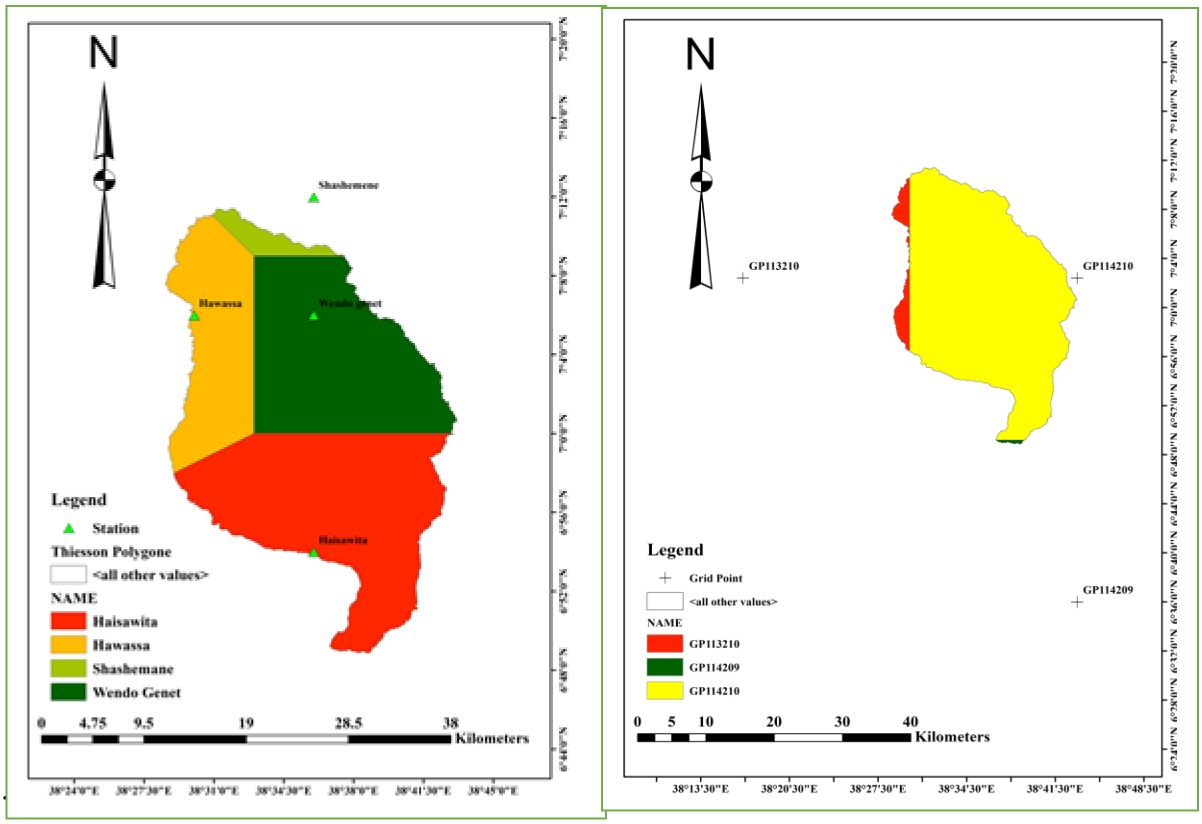
(a)  (b)

Figure 3. 7 Thiessen polygons of (a) observed meteorological stations and (b) RCPs grid points of the CORDEX_Ethiopia dataset

Table 3. 2 Meteorological Stations and their Corresponding Area

No	Meteorological stations	Area(Km^2)	% of Area Coverage
1	Hawassa	136.88	20.42
2	Shashemane	19.14	2.85
3	Wendo Genet	232.19	34.64
4	Haisawita	282.04	42.08
Total		670.25	100

Table 3. 3 CORDEX_Ethiopia Gridpoint and their Corresponding Area

No	RCPs Grid Points	Area(Km^2)	% of Area Coverage
1	GP113210	28.4	4.24
2	GP114210	640.24	95.52
3	GP114209	1.61	0.24
Total		670.25	100

3.5. RCP Bias Correction using CMhyd

Often, the downscaled RCPs data cannot be directly used for impact assessment as the computed variables may differ systematically from the observed ones. Bias correction is therefore applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables.

Bias correction is all about identifying the biases between the observed and simulated historical climate variables to parameterize a bias correction algorithm for the simulated historical climate data. The correction algorithm and its parameterization for current climate conditions are assumed to be valid for future conditions as well (Fig. 3.9). In CMhyd, there are about 8 bias correction methods. Among these methods, based on Teutschbein and Seibert (2010, 2012) recommendation this study was used the distribution mapping and variance scaling for the precipitation and temperature bias correction of RCPs data, respectively.

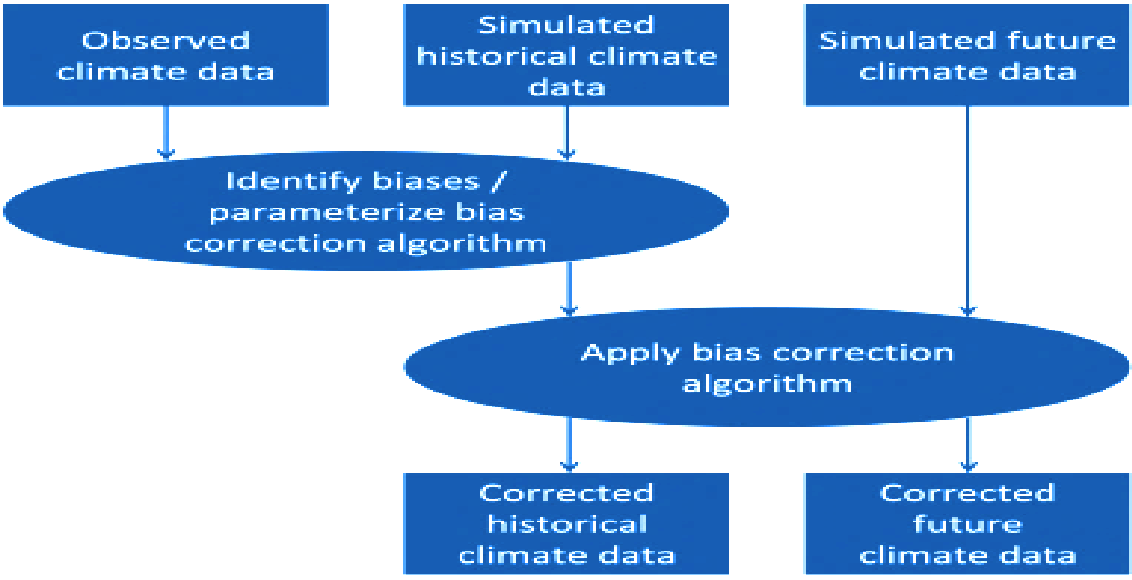


Figure 3. 7 Bias correction framework of CMhyd (Source: RAINBOW user manual,2016)

3.5.1. Bias Correction Performance Evaluation

The performance of the bias correction method will be evaluated using the root means square error (RMSE), the mean absolute error (MAE) and the Relative Error (RE) (Shamarokh A, 2012). These were calculated using the following equations.

RMSE = $\sqrt{\frac{\sum_{i}^{N}(Y_s - Y_o))^2}{N}}$……………………………………………………***Eq.(3)***

MAE= $^{1}/_{N} \sum_{i=1}^{N} |Y_s - Y_o|$…………………………………………………… ***Eq.(4)***

RE = $\frac{^{1}/_{N} \sum_{i=1}^{N}(Y_s - Y_O)}{Y_{mean}}$……………………………………………………***Eq.(5)***

Where Y_O is the observed value at time step i, Y_s is simulated value at time step i, Y_{mean} is the mean of observed values, and N is the number of observations.

3.6. SWAT Hydrological Model selection

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

For instance, SWAT model applicability and performance was checked in Lake Tana Basin and gave satisfactory results (Setegn et al. 2010). Mengistu and Sorteberg (2012) used the SWAT model to investigate the sensitivity of SWAT simulated streamflow to climatic changes within the Eastern Nile River basin. Based on the previous experiences of SWAT model obtained in Ethiopia and the above reasons the SWAT model is preferred for this study. The description of the model, model inputs, and model setup are discussed in detail in the subsequent sections.

3.7. Hydrological component of SWAT

The simulation of the hydrology of a watershed in SWAT is done with two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet.

3.7.1. The land phase of the hydrological cycle

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

$$SW_t = SW_0 + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw}) \text{ ………………} Eq.\ (6)$$

In which SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapo-transpiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

Using the above equation, the soil moisture content for the given area is simulated. Since the soil moisture storage is the main concern of this study, the brief description of some of the key model components is provided in this thesis. Soil water may follow different paths of movement: vertically upward (plant uptake), vertically downward (percolation), or laterally-contributing to stream flow. The vertical movement as plant uptake removes the largest portion of water that enters the soil profile.

The amount of soil water is usually measured in terms of water content as a percentage by volume or mass, or as soil water potential, this soil water content is highly depending on the water balance values given in Equation 6. Mostly, taking the precipitation as a source of soil water content and reduction of runoff, actual evapotranspiration, and groundwater from precipitation is result in the availability of water in the soil. Therefore, SWAT model revealed quantitatively the value of soil water content (SW) depends on the above water balance values.

However, water content does not necessarily describe the availability of the water to the plants, indicates how the water moves within the soil profile. The only information provided by water content is the relative amount of water in the soil. Soil water dynamics can be thought of as comparable to a sponge. When a sponge is saturated by soaking it in water when it is lifted out of the water, any excess water will drop off it. This is equivalent to drainage from the macropores in the soil. Once the sponge has stopped dripping it is at field capacity.

When the sponge is squeezed it is easy to get the first half of the water out. This first squeeze is equivalent to draining the sponge to the stress point and the water is removed like the RAWC (readily available water-holding capacity). Squeezing the second half of the sponge out is much harder. This is like draining the sponge to the permanent wilting point. The total water squeezed out of the sponge from when it stopped dripping is the TAWC (Total Available Water-Holding Capacity). But no matter how hard the sponge is squeezed there is no way to get all the water out of it. The water left is the equivalent to the hygroscopic water found in soil.

This sponge analogy is similar to how plant roots find getting moisture from the soil. From field capacity to the stress point it is easy to get the water. From the stress point to the permanent wilting point plants find it much harder to draw water from the soil and their growth is stunted. Below the permanent wilting point, no further water can be removed and the plant dies.

Percolation is the downward movement of water in the soil. SWAT calculates percolation for each soil layer in the profile. Water is allowed to percolate if only the water content exceeds the field capacity of that layer (Neitsch et al., 2005).

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure and the Green &

Ampt infiltration method. Using daily or sub-daily rain-fall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. In this study, the SCS curve number method was used to estimate surface runoff because of the unavailability of sub-daily data for Green & Ampt method.

Lateral flow is common in areas with high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturated zone stored above this layer. This is called a perched water table, which is the source of water for lateral subsurface flow. SWAT incorporates a kinematic storage model for subsurface flow (Neitsch et al., 2005).

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

$$q_{peak} = \frac{\alpha_{to} * Q_{surf} * Area}{3.6 * t_{conc}} \qquad \textbf{\textit{Eq. (7)}}$$

Where: q_{peak} is the peak runoff rate (m^3/s), α_{tc} is the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm), Area is the sub-basin area (km^2), t_{conc} is the time of concentration (hr), and 3.6 is a conversion factor.

Potential evapotranspiration- there are many methods that are developed to estimate potential evapotranspiration (PET). Three methods are incorporated into SWAT: The Penman-Monteith method, the Priestley-Taylor method, and the Hargreaves method. However, the methods vary based on climatic variables required for calculation.

The temperature-based method uses only temperature and day length; the radiation based method uses net radiation and air temperature and some other formula like Penman requires a combination of the above net radiation, air temperature, wind speed, and relative humidity.

The FAO Penman_Monteith method is recommended as the sole ET_0 method for determining reference evapotranspiration when the standard meteorological variables including air temperature, relative humidity, and sunshine hours are available (Allen RG, et al., 1998). In this study, the potential evapotranspiration for the study area was computed by FAO Penman-Monteith method.

$$ET_0 = \frac{0.408\Delta(R_n - G)}{\Delta + Y(1+0.34U_2} + \frac{Y}{\Delta + Y(1+0.34U_2)*}\frac{900U_2(e_s - e_a)}{(T+273)} \ldots\ldots\ldots\ldots\ldots Eq.\ (8)$$

Where; ET_0 = Reference Evapotranspiration, mm/day, R_n = Net radiation, MJm-2day-1, G= Soil heat flux, MJm-2 day-1, e_s= Saturated vapor pressure, KPa, e_a= Actual vapor pressure, KPa, e_s-e_a= Saturated vapor pressure deficit, KPa, Δ= Slope of the saturation vapor pressure temperature relationship, KPa°C, Y= Psychometric constant, KPaC-1, U_2= Wind speed, ms^{-1} and T = Mean daily air temperature at 2m height (°C).

Groundwater the simulation of groundwater is partitioned into two aquifer systems i.e. an unconfined aquifer (shallow) and a deep-confined aquifer in each sub-basin. The unconfined aquifer contributes to flow in the main channel or reach of the subbasin. Water that enters the deep aquifer is assumed to contribute to streamflow outside the watershed (Arnold et al., 1993). The water balance for a shallow aquifer is calculated with Eq. (9).

$$aq_{sh,i} = aq_{sh,i-1} + W_{rechrg} + Q_{gw} - W_{deep} - W_{pump,sh} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Eq. (9)}$$

Where: $aq_{sh,i}$ is the amount of water stored in the shallow aquifer on day i (mm), $aq_{sh,i-1}$ is the amount of water stored in the shallow aquifer on day i-1 (mm), W_{rchrg} is the amount of recharge entering the aquifer on day i (mm), Q_{gw} is the groundwater flow, or base flow, into the main channel on day i (mm), W_{deep} is the amount of water percolating from the shallow aquifer into the deep aquifer on day i (mm), and $W_{pump,sh}$ is the amount of water removed from the shallow aquifer by pumping on day i (mm).

3.7.2 Routing phase of the hydrological cycle

The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. As an optional process, the change in channel dimensions with time due to downcutting and widening is also included.

The rate and velocity of flow are calculated by using the Manning's equation. The main channels or reaches are assumed to have a trapezoidal shape by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskinghum methods. Both are variations of the kinematic wave model. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model.

The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskinghum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In the latter method, when a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave recedes, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length.

The variable storage method was adopted. The method was developed by (Williams, 1969) and used in the ROTO (Arnold et al., 1995) model. Storage routing is based on the continuity equation:

$$\Delta V_{strored} = V_{in} - V_{out} \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (10)}$$

Where: V_{in} is the volume of inflow during the time step (m^3 water), V_{out} is the volume of outflow during the time step (m^3 water), and V_{stored} is the change in volume of storage during the time step (m^3 water). Detail of the equation was available in SWAT manual.

3.8. Watershed Delineation

The watershed delineation was carried out through automatic delineation procedure based on a Digital Elevation Model (DEM). The ArcSWAT interface proposes the minimum, maximum, and suggested size of the sub-basin area (in hectare) to define the minimum drainage area required to form the origin of a stream. Generally, the smaller the threshold area, the more detailed are the drainage networks and the larger number of sub-basins and HRUs. However, this needs more processing time and space. As a result, an optimum size of a watershed that compromises both were selected. Dilnesaw (2006), did a sensitivity analysis of the threshold area on SWAT model performance and found that the optimum threshold area that can be used for the delineation procedure is ±1/3 of the suggested threshold area. Therefore, a threshold area of +1/3 of that suggested by the model was used.

The watershed is divided into 27sub-basins and the total area of the delineated basin is reported by the delineator as 67025.6432 ha(670.25Km^2) while the delineated basin and its 27 sub-basins are depicted in Fig. 3.10.

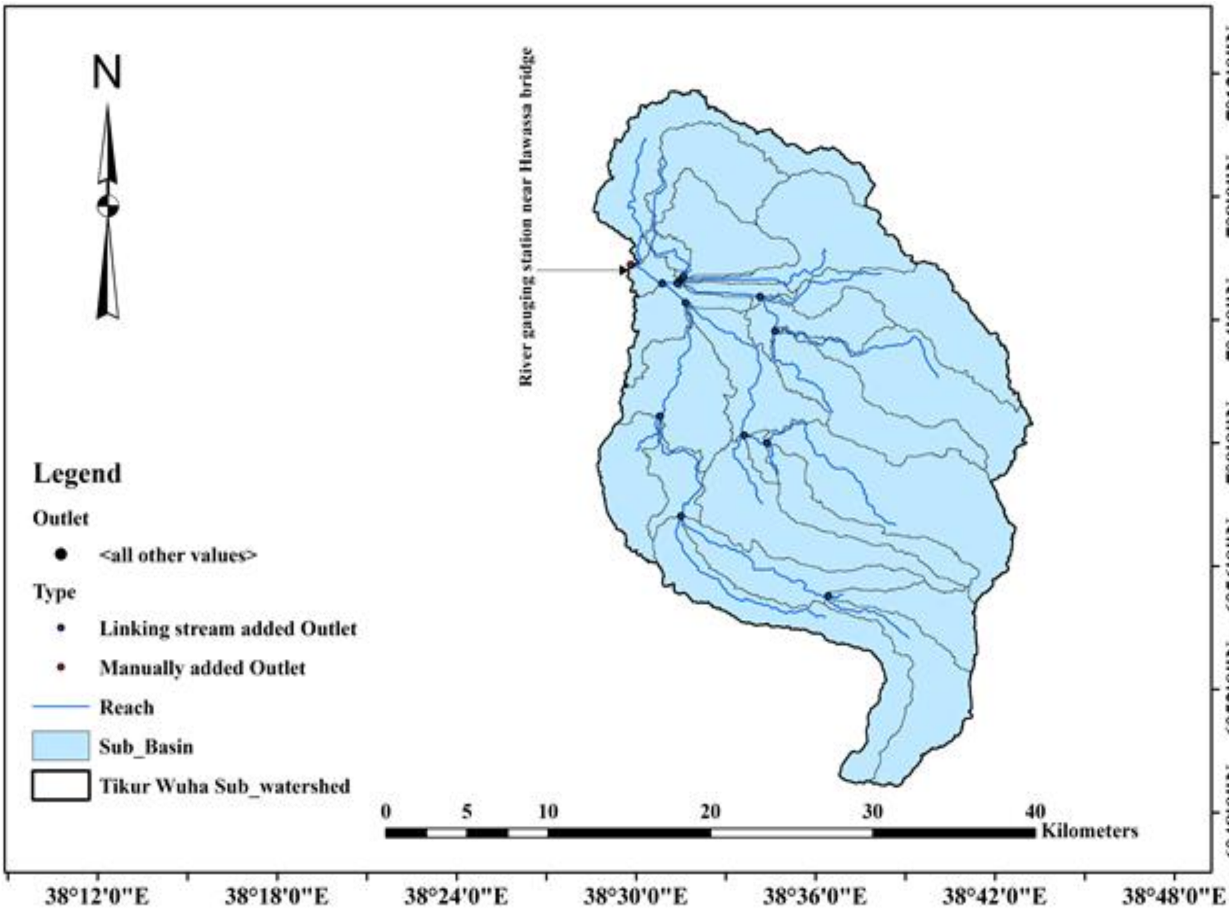


Figure 3. 8 Delineated sub-catchment of Tikur Wuha and its 27 sub-basins

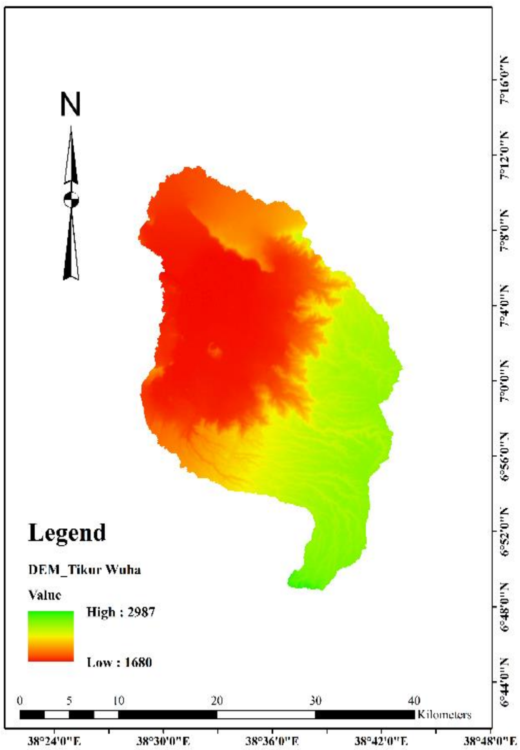


Figure 3. 9 DEM of Tikur Wuha Sub-watershed

3.9. SWAT Model data input and preparation

3.9.1. Model Inputs

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

3.9.2. Spatial Data Projection

ArcSWAT requires all data to be in the same projection before any GIS processing can take place (Table 3.4). The UTM projection was chosen as it is commonly used for larger areas in GIS.The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Subbasin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

Table 3. 4 Transverse Mercator projection parameters used in the study

Projection	**Traverse Mercator**
Projected coordinate system	Adindan _UTM_Zone_37N
datum	GCS_Adindan
False Easting	D_Adindan Prime Meridian:0
False Northing	500000.000
Central Meridian	0.000
Scale Factor	39.000
Latitude of Origin	0.9996
Linear Unit	Meter(1.000)

3.9.3. Weather Generator

Lack of full and realistic long period climatic data is the problem of developing countries, particularly in Ethiopia. Weather generators solve this problem by generating data having the same statistical properties as the actual one (Danuso 2002). SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation (which was converted from a sunshine hour), relative humidity and wind speed. The climatic data collected from the available meteorological stations in the study area may have; however, too many missing data. As SWAT has a built-in weather generator called WGEN (Richardson *et al.*, 1984) that is used to fill the gaps, all the missing values filled with a missing data identifier, -99.

The weather generator first is independently generating precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed will be generated independently. For the sake of data generation, weather parameters were developed using PCPstata and dew point temperature calculator (DEW02) (Liersch, 2003), which were downloaded from the SWAT website.

PCPsata calculates statistical parameters of daily precipitation data used by the weather generator of SWAT model. The DEW programs read daily values of relative humidity, and maximum and minimum temperature values and calculate monthly average dew point temperatures. Other parameters which were not estimated by PCPstata and DEW02 was calculated using Excel built-in Tool-Pivot.

Furthermore, the maximum half hour rainfall in the entire period of record for a month has been assumed to be 1/3 of the maximum daily rainfall in a month (Srinivasan,2013). But, in this study as precipitation and temperature missing value was already done using Normal ratio and multiple regression methods, respectively, weather generator was used to fill the rest climatic variables (Table 7.3).

3.9.4. Land Use/Cover

Land use/cover is one of the most important factors that affect surface erosion, runoff, and evapotranspiration in a watershed. As previously mentioned, the land use/cover map (2000) of the study area was obtained from Rift valley office which has 30m*30m resolution and 1: 250,000 scale.

As shown in table 3.5, the watershed is composed of six land use types: Montane Evergreen Forest (2.27%), Crop Land (77.89%), Deciduous Woodland (3.64%), Deciduous Shrubland with sparse trees (10.330%), Wet Land (5.52%), Cropland with Open Woody Vegetation's (0.38%). This justifies the dominance of agricultural land uses in the Sub-watershed. However, SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces. Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model (Fig. 3.12) (Table 3.5).

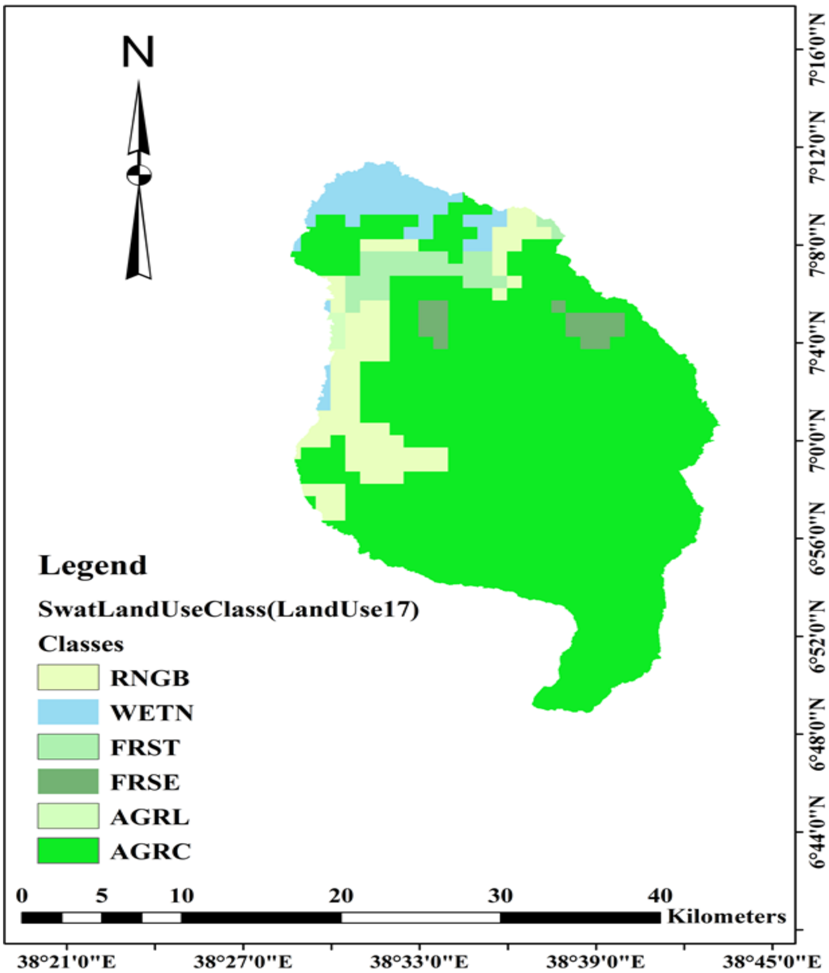


Figure 3. 10 Land Use/Cover Map of the Study Area(source: Rift Valley office,2000)

Table 3. 5 Land use/cover types as redefined by SWAT Code

No	Original Land Use	Redefined Land Use According To SWAT Database	SWAT Code
1	Montane Evergreen Forest	Forest Evergreen	FRSE
2	Crop Land	Agricultural Land Close Grown	AGRC
3	Deciduous Woodland	Mixed Forest	FRST
4	Deciduous Shrub Land	Range Brush	RNGB
5	Wet Land	Wet Land Non-Forested	WETN
6	Crop Land With Open Woody Vegetation	Agricultural Land Generic	AGRL

Table 3. 6 Land cover types as redefined by SWAT Code and their corresponding area coverage

No	Redefined Land Use According To SWAT Database	SWAT Code	Area(Km^2)	% of Area In The Sub-watershed
1	Forest Evergreen	FRSE	15.2	2.27
2	Agricultural Land Close Grown	AGRC	52.2	77.89
3	Mixed Forest	FRST	24.39	3.64
4	Range Brush	RNGB	69.05	10.3
5	Wet Land Non-Forested	WETN	36.98	5.52
6	Agricultural Land Generic	AGRL	25.74	0.38
Total			670.25	100

3.9.5 Soil

The spatial distribution of different soil types is one of the very important factors affecting the overall hydrology of a watershed. SWAT model basically needs the soil data in defining lumped land areas, HRUs. SWAT soil database needs all physical and chemical properties of each soil types in the sub-watershed.

As mentioned before, Soil map of the study area was obtained from MoWIE which has 30m*30m resolution and 1: 250,000. In order to integrate the soil map within the SWAT model, it was necessary to make a User Soil Database. In this database, all types of soils in the study area were represented and coupled with their characteristics.

Even though the soil map is clipped to the extent of the study area from a soil map of Ethiopia(MoWIE), the Physio-Chemical properties of each soil type were adopted from the one already prepared by Rift valley office, which was intentionally prepared for SWAT purpose.

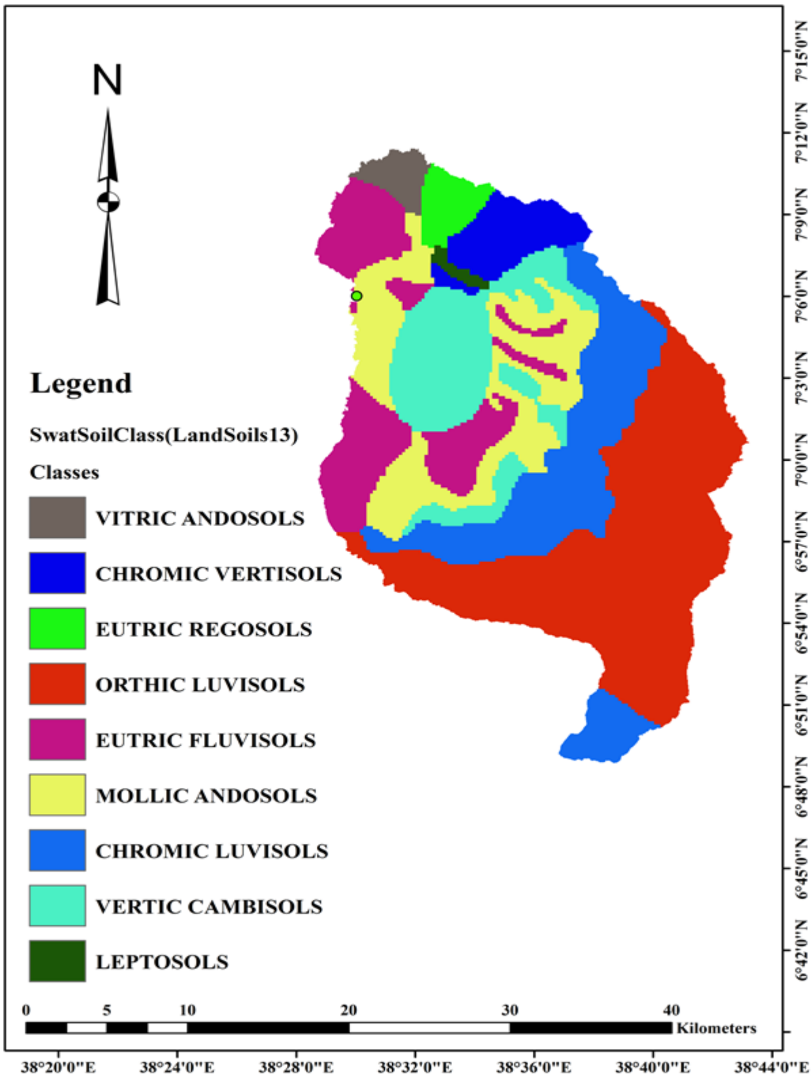


Figure 3. 11 Soil map of the study area(source: MoWIE)

Table 3. 7 Soil types of the study area with their aerial coverage

No	Soil Type	Area(Km^2)	% of Area In The Sub Catchment
1	VITRIC ANDOSOLS	13.84	2.07
2	CHROMIC VERTISOLS	17.70	2.64
3	EUTRIC REGOSOLS	17.84	2.66
4	ORTHIC LUVISOLS	232.47	34.68
5	EUTRIC FLUVISOLS	83.42	12.45
6	MOLLIC ANDOSOLS	83.99	12.53
7	CHROMIC LUVISOLS	134.98	20.14
8	LEPTOSOLS	2.59	0.39
9	VERTIC CAMBISOLS	83.37	12.44
Total		670.25	100

As shown above, (Fig. 3.13) (Table 3.7), Nine soil type are identified. Orithic luvisols and Chromic Luvisols are the major soil type covering 34.68% and 20.14% of the overall sub-watershed area, respectively. The rest of the study area is covered by Vitric Andosols, Eutric Regosols, Eutric Fluvisols, Mollic Andosols, Chromic Vertisols, Leptosols and Vertic Cambisols

3.9.6. **HRU Definition**

The HRU definition was performed through the HRU analysis Manu that requires the land use/land cover, the soil, and slope of the catchment. There are three options available in ArcSWAT for the definition of HRUs (Neitsch et al., 2005). This study has adopted the method that considers the spatial variability of the processes and the datasets were prepared in spatial format and linked to the ArcSWAT. Based on the soil, land cover and slope data, the definition of HRU were performed that assigns a unique value to each unit in the subbasin.

As the SWAT manual recommends, the study was considered four classes of the slope, 0-5%, 5-10%, 10-15% and ≥15% (Fig. 3.14). The multiple HRU definition criteria were then performed for most applications the default settings for land use threshold (20%) and soil threshold (10%) and slope threshold (20%) for the slope of individual sub-basin area (ArcSWAT, 2012). Overall, there were 128 HRUs defined in the entire watershed within 27 subbasin.

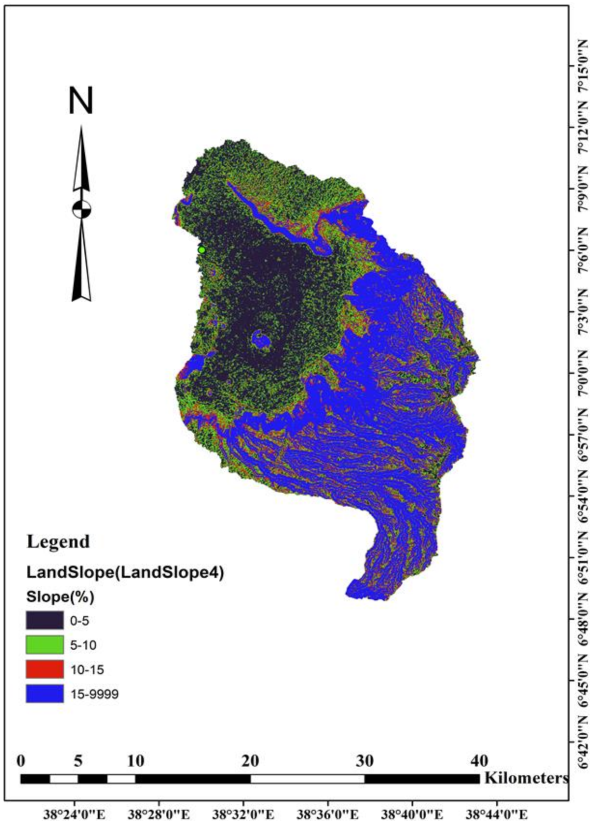


Figure 3. 12 Slope classes of the study area used in HRU definition

3.9.7. **Sensitivity Analysis**

A sensitivity analysis was used as a screening tool for reducing the number of parameters to be adjusted during calibration. The sensitivity of different parameters is impacted by topography, geomorphology of the landscape, size of the watershed, land-use variations and human impacts. To identify sensitive parameter, the model was run for both warm-up period (from 1st January,1989 to30-December,1991and Calibration from 1st January,1992 to 30 December 2001).

3.9.8. **Calibration**

Physically based semi-distributed model SWAT generally have a large number of parameters which are not directly measurable and must, therefore, be estimated through model calibration, i.e. by fitting the simulated outputs of the model to the observed outputs of the watershed by adjusting the model parameters. A measure of the fit between the simulated and observed outputs is called calibration. The goal of calibration is to find those values for the model parameters that minimize (Maximize) the specified calibration criterion. As per Refsgard and Storm, 1996, three types of calibration procedures can be differentiated:

1. Trial-and-error, manual parameter adjustment;

2. Automatic, numerical parameter optimization;

3. A combination of (1) and (2)

Manual calibration alone is very tedious, time-consuming, and requires some experience of the user. For this reason, automated calibration methods are increasingly being used. In this study, the SWAT model calibration and validation were performed using automated calibration and validation developed in SWAT Calibration and Uncertainty Program (SWAT-CUP). Sequential Uncertainty Fitting version 2 (SUFI-2) algorithms were selected in SWAT-CUP that finds out the most favorable model parameters within the uncertainty ranges of 95% after incorporating the possible parameters ranges. The streamflow data from 1992-2001 was used for calibration.

3.9.9. **Validation**

Validation is the process of testing model performance of the calibrated model parameter set against an independent set of measured data without further adjustment of parameters used during calibration. The model was validated using datasets from 2002 to 2005. The statistical criteria used during the calibration procedure were also checked here to make sure that the simulated streamflow is still within the accuracy limits.

3.9.10. **SWAT Model Performance Evaluation**

The performance of a model must be evaluated on the extent of its accuracy, consistency, and adaptability (Goswami et al., 2005). The model simulation was evaluated using efficiency criteria such as coefficient of determination, R^2, Nash and Sutcliff (NS), and percent of bias PBIAS.

The coefficient of correlation (R^2);

$$\boldsymbol{R^2} = \left(\frac{\sum_{i=1}^{n}(Q_{obs} - \bar{Q}_{obs})^2 - \sum(Q_{sim} - \bar{Q}_{sim})^2}{\sum(Q_{obs} - Q_{sim})^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (11)}$$

Where; Q_{obs}=observed discharge, Q_{sim}=Simulated discharge,$\bar{Q}_{obs}$=mean of observed discharge, $\bar{Q}_{sim}$=mean of simulated discharge

R^2 indicates how the simulated data value correlated to the observed data. The range of R^2 extends from 0(unacceptable) to 1(best).

Nash-Sutcliffe efficiency(E_{NS});

$$E_{NS}=1 - \frac{\sum(Q_{obs}-Q_{sim})^2}{\sum(Q_{obs}-\bar{Q}_{obs})} \text{..Eq.(12)}$$

Where; Q_{obs}=observed discharge, Q_{sim}=simulated discharge, $\bar{Q}_{obs}$=mean of observed discharge

Nash-Sutcliffe efficiency can range from -∞ to 1.an efficiency of E_{NS}=1 Corresponding to a perfect match of modeled discharge to the observed data. The closer the model results to 1 the more accurate the model is.

Percent of bias(PBIAS);

The percent bias (% bias) over a specified period with the total day is calculated from measured and simulated values of the quantity in each model time step as:

$$PBIAS = \frac{\sum(Q_{obs}-Q_{sim})}{\sum Q_{obs}} * 100 \text{ .... Eq. (13)}$$

Where: Q_{sim} is the simulated value, Q_{obs} is the observed value

A value close to 0% is best for PBIAS. A negative value indicates model overestimation and a positive value indicate model underestimation.

4. Results and Discussion

4.1. RCPs Bias Correction

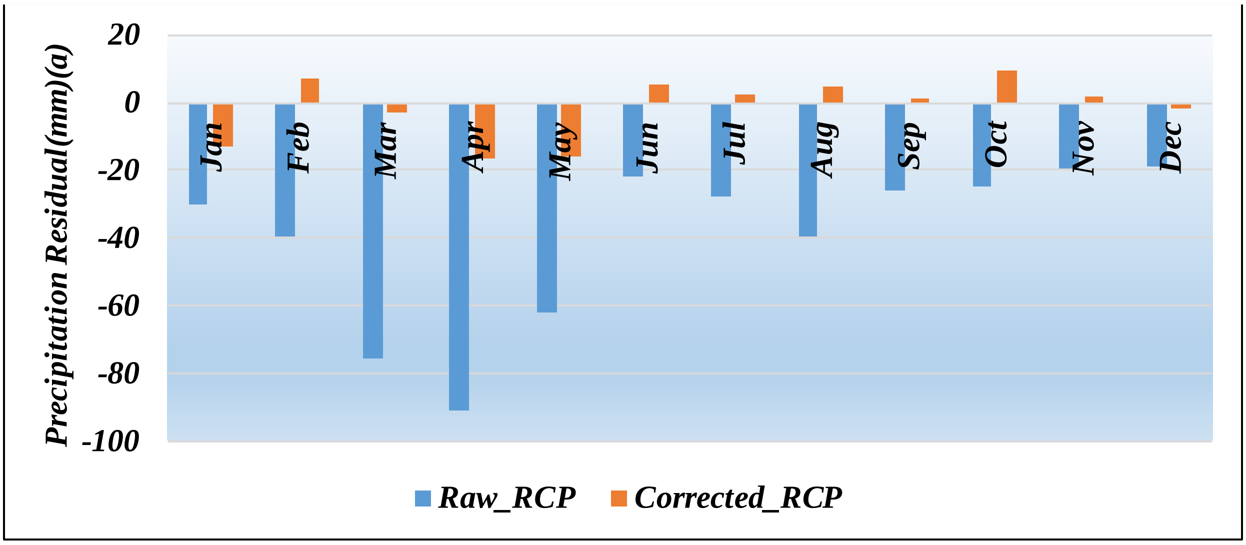
In this study, the bias correction method was applied to correct systematic bias of raw climatic variables: precipitation for four meteorological stations (Hawassa, Shashemene, Wendo Genet and Haisawita), and maximum and minimum temperature for Hawassa station.

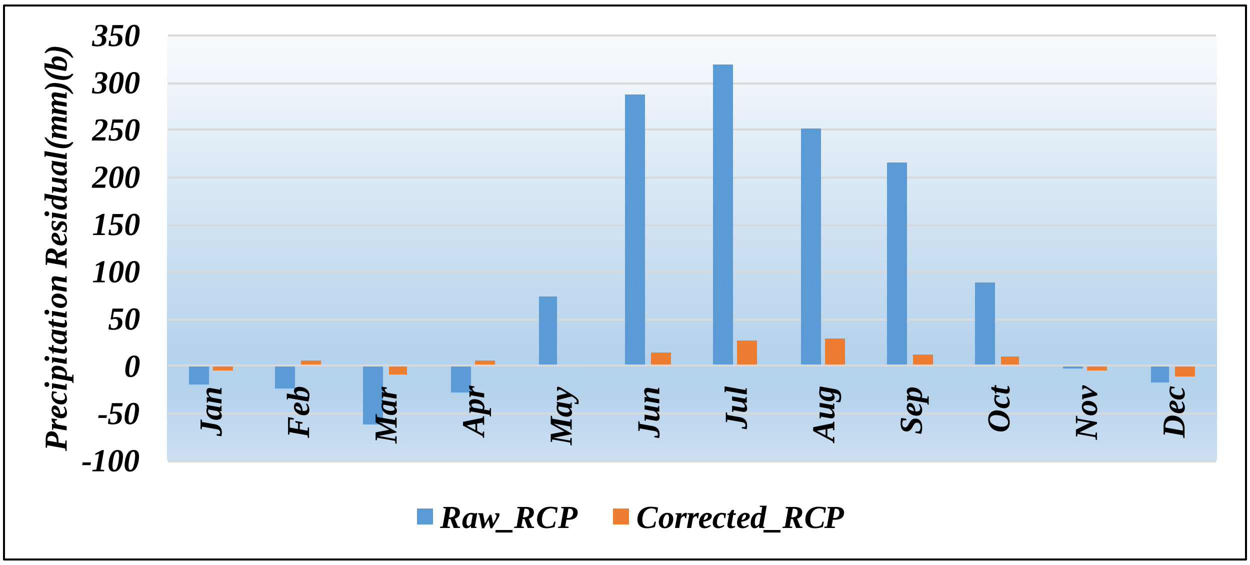
The results of the bias correction methods were evaluated using residual plots (the difference between the simulated and observed values) of precipitation and temperature in terms of mean. Furthermore, Standard model performance statistics tests were carried out by computing the root mean square error (RMSE), the mean absolute error (MAE) and the relative error (RE). The result obtained for historical period from both residual plot and performance statistical test was discussed briefly in the sections here below.

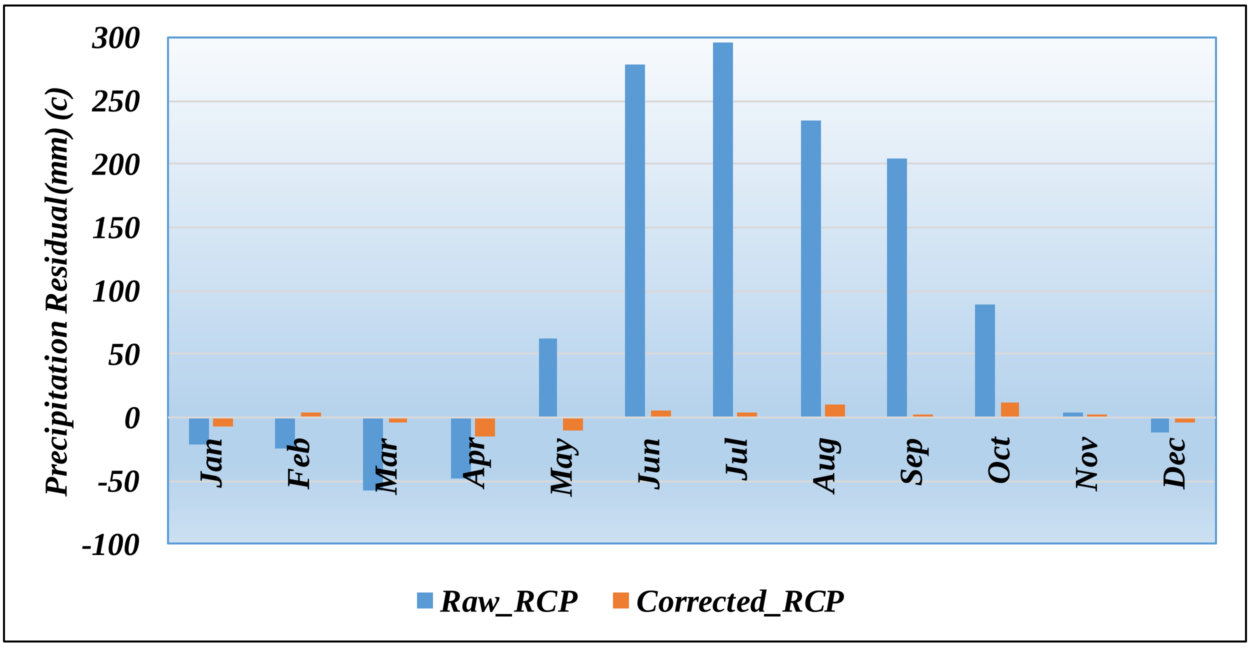
4.1.1. Precipitation

A significant improvement was achieved by applying bias correction method on RCPs since the bias-corrected results provided smaller monthly mean bias values than the raw RCPs results (Fig. 4.1). In other words, the bias-corrected results are closer to the observed values than the raw RCPs results at the four stations.

The mean monthly residuals of raw precipitation at Hawassa station was between -90.78mm and -18.63 mm and after bias correction, the residuals were between -16.25 mm and +9.28 mm (Fig. 4.1a).The mean monthly residuals of raw precipitation at Haiswaita station was between -62.56 and 319.07 mm and after bias correction, the residuals were between -10.13mm and +28.93 mm(Fig. 4.1b).The mean monthly residuals of raw precipitation at Shashemene station was between -57.76 mm and +295.21 mm and after bias correction, the residuals are between -14.45 mm and +11.25 mm(Fig. 4.1c).The mean monthly residual of raw precipitation at Wendo Genet station was between -78.62 mm and +272.03 mm and after bias correction, the residual was between -34.70 mm and -7.68 mm (Fig.4.1d). These results showed that significant improvement was achieved after bias correction.


Precipitation Residual(mm)(a)
20
0
-20
-40
-60
-80
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Raw_RCP
Corrected_RCP


Precipitation Residual(mm)(b)
350
300
250
200
150
100
50
0
-50
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Raw_RCP
Corrected_RCP


Precipitation Residual(mm) (c)
300
250
200
150
100
50
0
-50
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Raw_RCP
Corrected_RCP

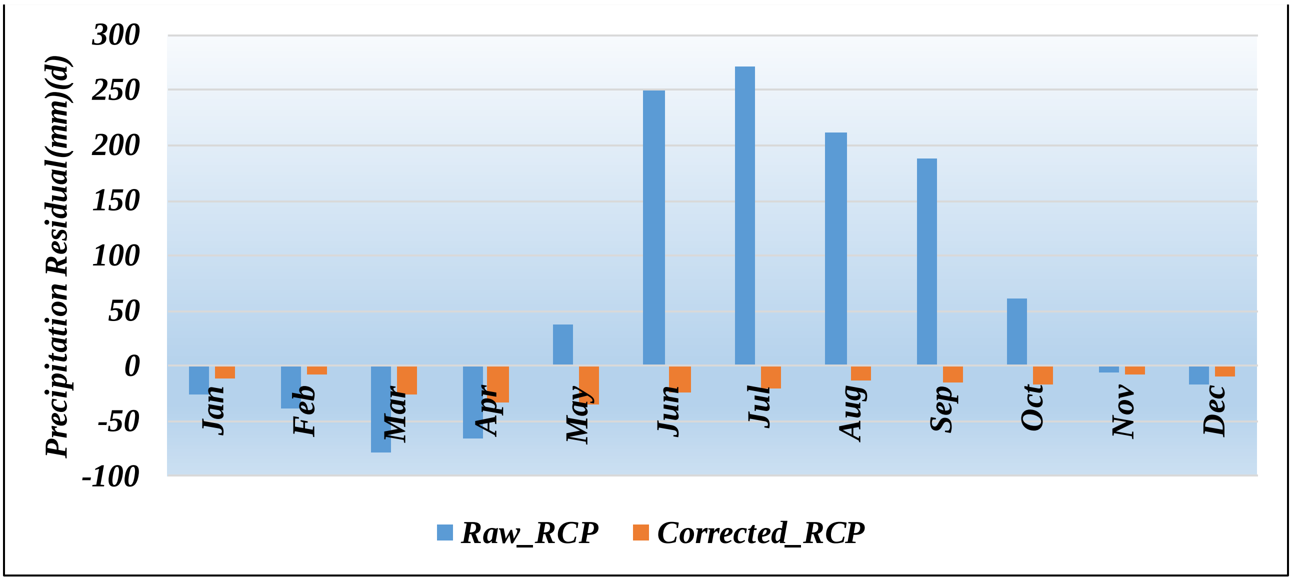


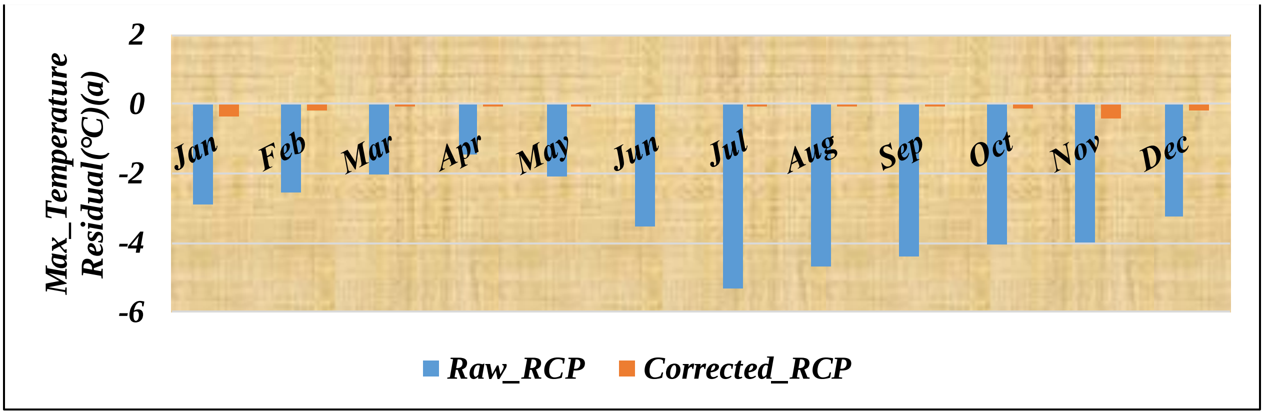
Figure 4. 1 Mean monthly residuals plot of raw RCPs and corrected RCPs (1981-2005) for a)Hawassa b) Haisawita c)Shashemene and d)Wendo Genet stations

4.1.2. Maximum and Minimum Temperature

The bias-corrected mean monthly maximum temperature and a minimum temperature of Hawassa station were compared with the raw mean monthly maximum temperature and minimum temperature using residual plots (Fig. 4.2).

It was found that while the raw mean daily maximum temperature residuals are between -5.3°C and -1.46°C, after bias correction the range is between -0.39°C and +0.06°C in terms of mean (Fig 4.2a), whereas the mean monthly residual plots of raw mean monthly minimum temperature residual were between -2.09°C and +1.86°C, after bias correction the range was between -0.14°C and +0.24°C in terms of mean (Fig 4.2b).

The bias-corrected results show that the corrected RCPs provided fewer errors than the raw RCP results. Moreover, it can be seen that the models' performance statistics (RMSE, MAE, and RE) for precipitation, maximum temperature, and minimum temperature was good (Table 4.1).



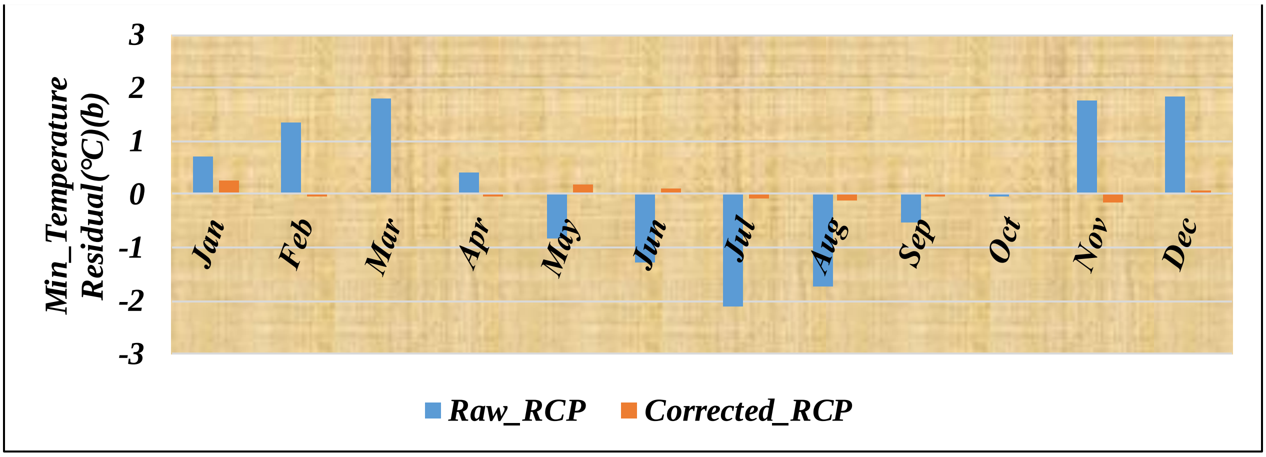


Figure 4. 2 Mean monthly residuals temperature of raw RCPs and corrected RCPs (1981-2005) for Hawassa station a) Maximum Temperature and b) Minimum Temperature

Table 4. 1 Performance statistical test of bias correction method

Station	Evaluation	Precipitation		Max. Temperature		Min. Temperature	
		Raw	*Bias-corrected*	*Raw*	*Bias-corrected*	*Raw*	*Bias-corrected*
Hawassa	**RMSE**	*45.69*	*8.61*	*3.53*	*0.17*	*1.37*	*0.12*
	MAE	*39.63*	*6.80*	*3.35*	*0.13*	*1.21*	*0.09*
	RE	*-0.48*	*-0.018*	*-0.12*	*-0.0044*	*0.01*	*0.0016*
Shashemene	**RMSE**	*152.85*	*7.62*	-	-	-	-
	MAE	*110.97*	*6.49*	-	-	-	-
	RE	*1.12*	*-0.0025*	-	-	-	-
Wendo - Genet	**RMSE**	*139.84*	*20.09*	-	-	-	-
	MAE	*104.20*	*18.04*	-	-	-	-
	RE	*0.71*	*-0.1949*	-	-	-	-
Haisawita	**RMSE**	*161.84*	*14.01*	-	-	-	-
	MAE	*115.71*	*11.19*	-	-	-	-
	RE	*1.33*	*0.0987*	-	-	-	-

4.2. Future climate projection

The respective mean monthly, seasonal, and annual changes from the base period (1981-2005) for both the RCP 4.5 and RCP 8.5 scenarios were calculated in relative percentage change for precipitation and in absolute change for maximum and minimum temperatures (in degree centigrade). The mean seasonal change was carried out considering the main season of the sub-watershed namely; Kiremt- main rainy season (Jun, July, August, and September); Bega-dry season (October, November, December, January and February) and Belg-less rainy season (March, April and May). The changes for each of these climate variables are discussed in the section here below.

4.2.1. Precipitation Scenarios

As per the projected precipitation, in the 2020s the RCP 4.5 scenario showed mean monthly precipitation increase up to 78.03% in the month of July and RCP 8.5 showed an increase up to 101.45% in the month of July. In the 2020s, mean seasonal precipitation under RCP 4.5 and RCP 8.5 scenario may increase by 72.49% and 88.87% during the Kiremt season. But there will be a decrement during the Bega season by 8.21% for RCP 4.5 and 4.59 for RCP 8.5, and Belg season by 20.92% and 15.35% for RCP 4.5 and RCP 8.5 scenarios respectively. The overall effect in the 2020s may be an increment of mean annual precipitation by 15.51% in the RCP 4.5 scenario and by 23.87% in the RCP 8.5 scenario (Fig. 4.3)

In the 2050s, the increment in mean monthly precipitation may reach up to 69.87% during June in the RCP 4.5 scenario and 139.94% during November in the RCP 8.5 scenario. In the 2050s, mean seasonal precipitation under RCP 4.5 and RCP 8.5 scenario may increase by 57.49% and 84.12% during the Kiremt season and by 7.12% and 24.28% during the Bega. But there will be a decrement during Belg season by 20.87% and 34.59% for RCP 4.5 and RCP 8.5 scenarios respectively. The overall effect in the 2050s may be an increment of mean annual precipitation by 16.91% in the RCP4.5scenario and 29.51% in the RCP 8.5 scenario (Fig. 4.3)

In the 2080s, the increment in monthly mean precipitation may reach up to 109.67% during July in the RCP 4.5 scenario and 123.03% during Oct in the RCP 8.5 scenario. In the 2080s, mean seasonal precipitation under RCP 4.5 and RCP 8.5 scenario may increase by 59.53% and 88.91% during the Kiremt season. But the decrement during the Balg season for both scenarios will be expected to reach 37.25% and 26.85% for RCP 4.5 and RCP 8.5 scenarios. In the 2080s the RCP 4.5 and RCP 8.5 scenarios showed an increment in mean annual precipitation by 18.27% and 33.01% respectively(Fig.4.3). The detail projected change in mean precipitation for each scenario and time period is available on Table 4.2.

In the case of mean monthly precipitation projection, there was no clear increment and decrement in precipitation. This result was similar to a study done on Central Rift Valley and Northwestern Lowlands by Geremew and Agizew (2015). Their study shows that Considering the bias-corrected projection, the increase of rainfall in months of the dry season or decrease in other is not as clear as that of bias uncorrected projections when seen from a monthly perspective. It is also consistent with a study done on Hare watershed in Rift Valley by Menna (2017), show that the mean monthly projection change in rainfall is not uniform; instead, it differs from time to time.

The result of this study, in the case of seasonal projection, was also in line with the study done by Menna (2017), which states that rainfall projection of Kiremt and the Bega shows increasing for the two emission scenarios whereas Belg projection shows a decreasing mean monthly rainfall for both RCP 4.5 and RCP 8.5 scenarios. Also, Geremew and Agizew (2015) study shows that monthly and seasonal distribution of precipitation in Central Rift Valley region for bias uncorrected version shows a decrease of rainfall in the rainy seasons of Belg (43%) and Kiremt (8%) in the 2090s and for bias corrected projection the values are: Belg (25%) and Kiremt (3%) for RCP8.5. Furthermore, the drying of Belg is consistent with the declining rainfall that occurred during the second half of the 20th century and which is projected to continue into the future in the East Africa region, particularly in Ethiopia (Muluneh et al.2015; Muluneh et al.,2016; Funk et al.2008; Williams & Funk 2011; Lyon & DeWitt, 2012)

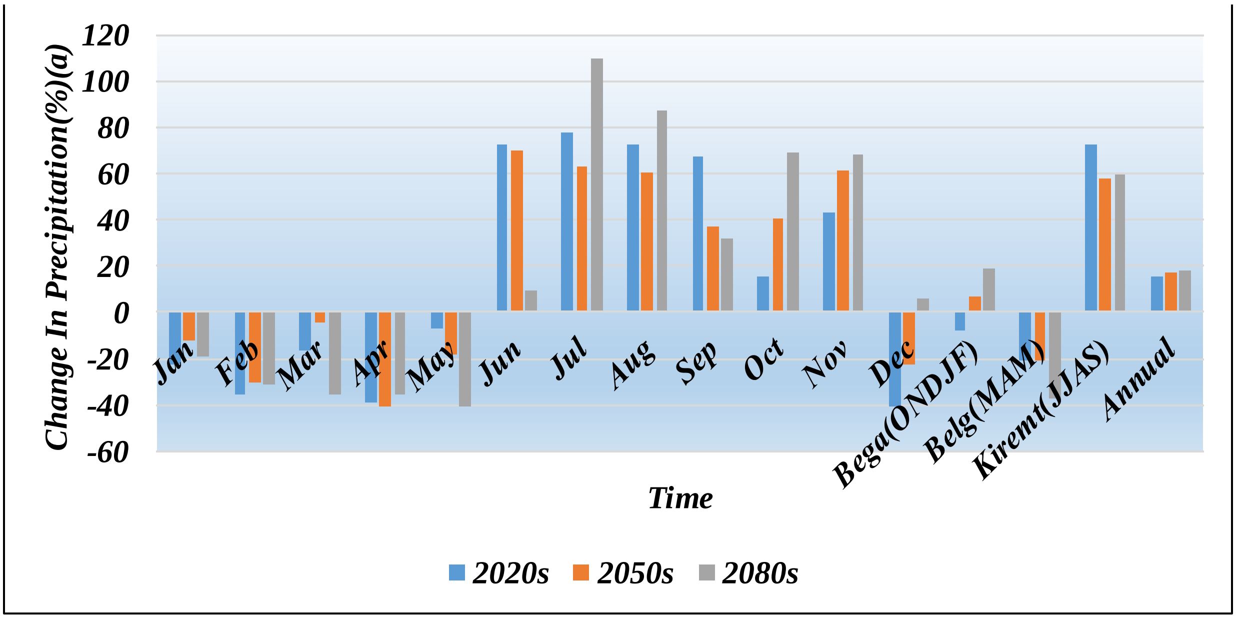
But the result obtained in the current study was in contrast to the study done in the similar area by Diriba (2015) which showed that Tikur wuha sub-watershed could experience reduced precipitation for period 2050s and 2080s during the main rainy season. In contrary, in the current study, there may be a decrement of precipitation during the small rainy season (Belg) whereas the projected precipitation during the main rainy season(Kiremt) will be increased for both scenarios and all future window periods. Kiremt(main rainy season) and Belg(small rainy season) are the cropping season in Ethiopia. Hence, this study can give us an insight into the possible impact of climate change on the agriculture in the study area.

The mean annual precipitation for the Tikur Wuha will progressively increase within and between the three periods. This result is in agreement with IPCC 5^{th} assessment report that explain CMIP5 projects likely increase in the mean annual precipitation over areas of central and east Africa in the mid-21^{st} century for RCP 8.5 and over east Africa by the end of 21^{st} century that will have a wetter climate with more intense wet season and less severe drought (Niang et al., 2014).

Moreover, the study done by Getahun (2017), on Bilate watershed, Rift Valley, through using 20 GCMs from CMIP5 bias-corrected under three future time slices, near-term (2010-2039), mid-century (2040-2069) and end-century (2070-2099) shows that rainfall will increase in mean annual under all-time slices and emissions pathways.

Table 4. 2 Mean precipitation change result for both scenarios (in %) by monthly, seasonal and annual basis

Months	***RCP4.5 Scenario***			***RCP8.5 Scenario***		
	2020s	***2050s***	***2080s***	***2020s***	***2050s***	***2080s***
Jan	-22.81	-12.46	-18.94	-33.69	-38.29	-21.54
Feb	-35.91	-30.78	-31.21	-42.98	-33.34	-33.44
Mar	-16.41	-4.15	-35.38	-33.30	-43.93	-41.79
Apr	-38.94	-40.47	-35.46	-26.49	-20.06	-37.24
May	-7.42	-18.00	-40.91	13.74	-39.79	-1.53
Jun	72.12	69.87	9.57	84.88	79.97	83.42
Jul	78.03	62.80	109.67	101.45	95.42	113.41
Aug	72.56	60.04	87.21	88.24	83.67	78.11
Sep	67.26	37.27	31.68	80.93	77.42	80.71
Oct	15.76	40.55	69.38	48.71	84.18	123.03
Nov	42.84	61.12	67.83	-13.21	139.94	64.40
Dec	-40.94	-22.85	5.75	18.20	-31.11	-11.46
Bega(ONDJF)	-8.21	7.12	18.56	-4.59	24.28	24.20
Belg(MAM)	-20.92	-20.87	-37.25	-15.35	-34.59	-26.85
Kiremt(JJAS)	72.49	57.49	59.53	88.87	84.12	88.91
Annual	15.51	16.91	18.27	23.87	29.51	33.01



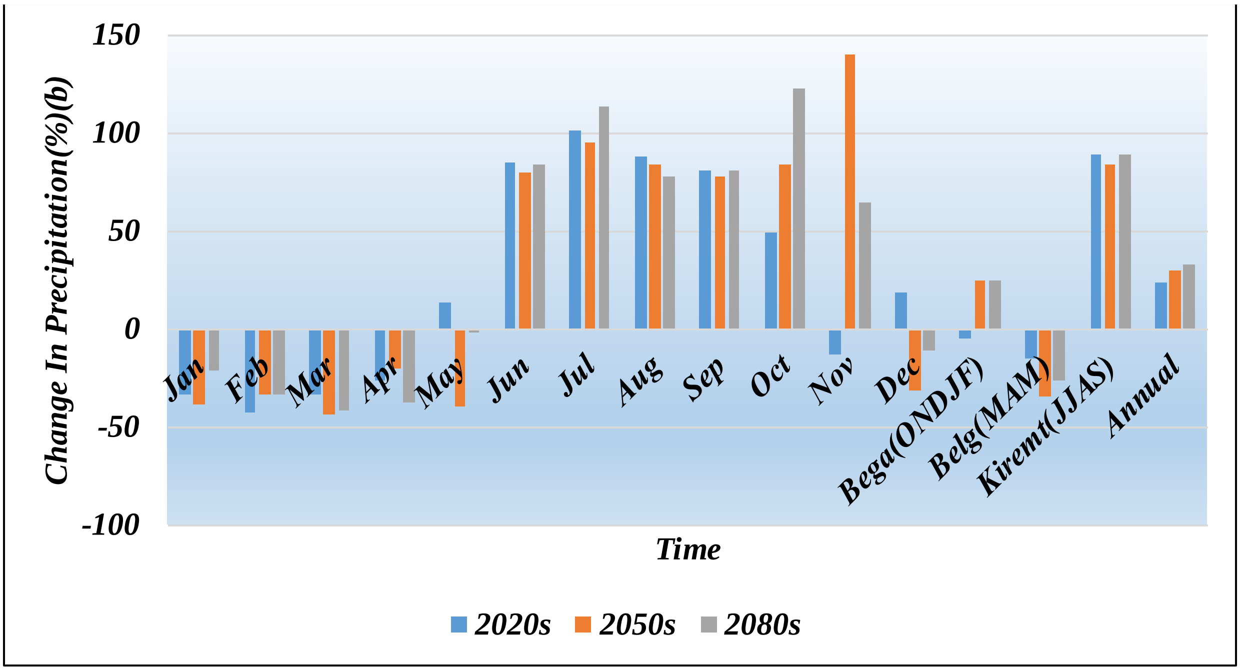


Figure 4. 3 Relative percentage change of areal precipitation of monthly, seasonal, and annual for (a) RCP 4.5 and (b) RCP 8.5 scenarios

4.2.2. Maximum Temperature Scenarios

The projected maximum temperature shows an increment for all months in all future time horizons and for both RCP 4.5 and RCP 8.5 scenarios. Increasing maximum temperature showed more variation at the monthly time step with a range from 1.43°C to 2.27°C in the 2020s, 2.40°C to 3.53°C in 2050s and 2.89°C to 5.44°C in 2080s for both RCP 4.5 and RCP 8.5 scenario respectively, in terms of mean (Fig. 4.5).

The mean seasonal maximum temperature in the 2020s will be increased by 1.12°C and 1.79°C during Belg for RCP 4.5 and RCP 8.5 scenarios, respectively. For the 2050s periods, the mean seasonal maximum temperature will be increased by 2.20°C and 3.24°C during Belg for RCP 4.5 and RCP 8.5 scenarios respectively. For the 2080s periods, the mean seasonal maximum temperature will be increased by 2.69°C and 5.15°C during Belg for RCP 4.5 and RCP 8.5 scenario respectively (Fig. 4.5). The increment in Temperature during Belg do have an effect through exacerbating evapotranspiration in the sub-watershed.

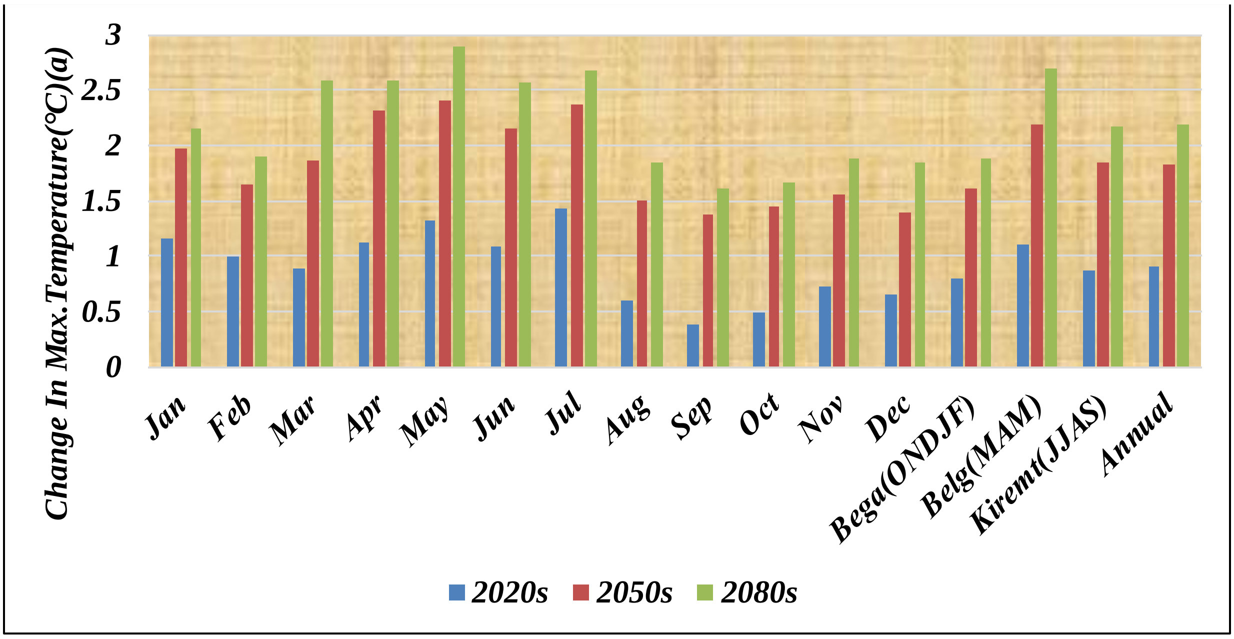
The mean annual maximum temperature in the 2020s will be increased by 0.91°C and 1.48°C for RCP4.5and RCP8.5 scenarios, respectively. For the 2050s periods, the mean annual maximum temperature will be increased by 1.84°C and 2.78°C for RCP4.5 and RCP8.5 Scenario respectively.

For the 2080s periods, the mean annual maximum temperature will be increased by 2.19°C and 4.43°C for RCP 4.5and RCP 8.5 emission scenario respectively (Fig. 4.5). The detail projected change in mean maximum temperature for each scenario and the time period is available in Table 4.3.

Generally, as compared for both scenarios the increment in maximum temperature for RCP 8.5 scenario is more pronounced than RCP 4.5 scenario because RCP8.5scenario represents a high emission scenario which produces more CO_2 concentration than the RCP 4.5 scenario which represents a medium-low emission scenario.

Table 4. 3 mean Maximum Temperature change (in °C) for both scenarios by monthly, seasonal & annual basis

MONTH	***MAXIMUM TEMPERATURE***					
	RCP4.5 Scenario			***RCP8.5 Scenario***		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
Jan	*1.16*	*1.98*	*2.16*	*1.62*	*2.62*	*4.32*
Feb	*1.00*	*1.64*	*1.90*	*1.19*	*2.63*	*4.30*
Mar	*0.90*	*1.87*	*2.59*	*1.41*	*2.78*	*4.69*
Apr	*1.13*	*2.32*	*2.59*	*1.84*	*3.41*	*5.44*
May	*1.32*	*2.40*	*2.90*	*2.11*	*3.53*	*5.33*
Jun	*1.08*	*2.15*	*2.58*	*2.27*	*3.53*	*5.10*
Jul	*1.43*	*2.38*	*2.68*	*2.03*	*3.43*	*5.06*
Aug	*0.61*	*1.51*	*1.86*	*1.05*	*2.30*	*3.80*
Sep	*0.38*	*1.38*	*1.61*	*1.12*	*2.39*	*3.87*
Oct	*0.49*	*1.45*	*1.67*	*0.74*	*2.11*	*3.86*
Nov	*0.74*	*1.56*	*1.88*	*1.22*	*2.38*	*3.80*
Dec	*0.66*	*1.40*	*1.85*	*1.21*	*2.30*	*3.56*
Bega(ONDJF)	*0.81*	*1.61*	*1.89*	*1.20*	*2.41*	*3.97*
Belg(MAM)	*1.12*	*2.20*	*2.69*	*1.79*	*3.24*	*5.15*
Kiremt(JJAS)	*0.76*	*1.60*	*1.89*	*1.62*	*2.91*	*4.46*
Annual	*0.91*	*1.84*	*2.19*	*1.48*	*2.78*	*4.43*



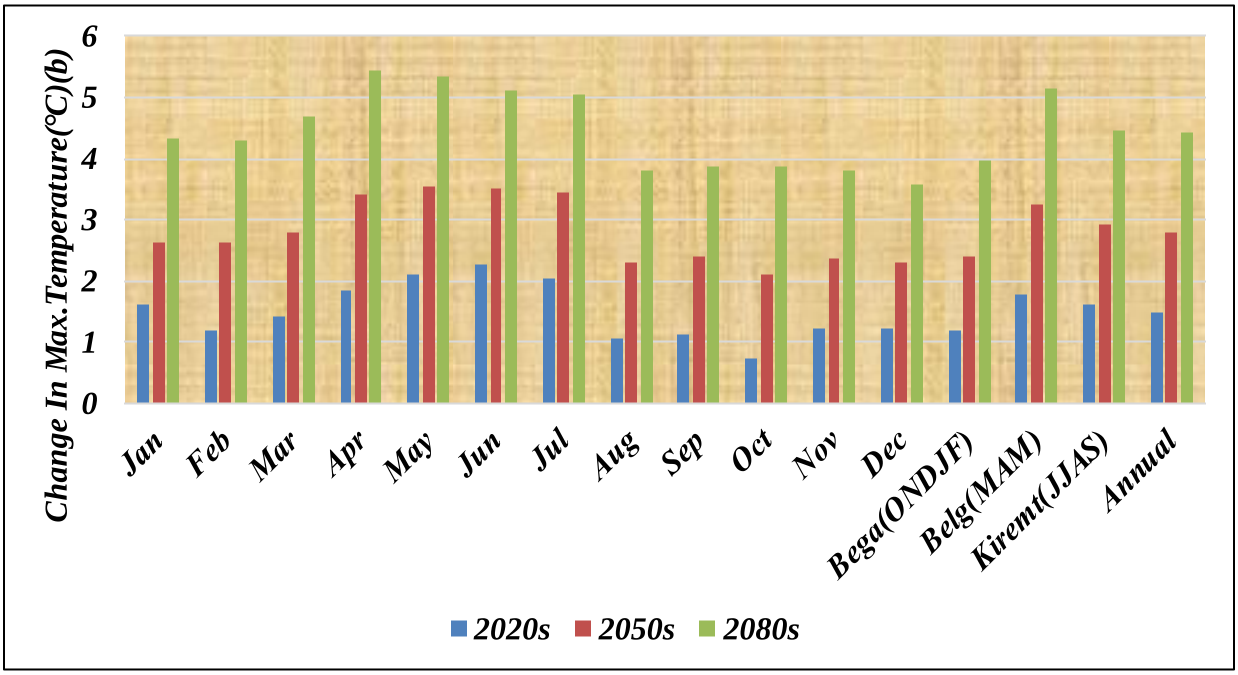


Figure 4. 4 Absolute change in Max. Temperature for both scenario;(a) RCP 4.5 & (b) RCP 8.5(°C).

4.2.3. Minimum Temperature Scenarios

The projected minimum temperature shows an increment for all months in all future time horizons for both RCP 4.5 and RCP 8.5 scenarios. Increasing minimum temperature showed more variation at the monthly time step with a range from 1.71°C to 2.40°C in the 2020s, 2.40°C to 3.13°C in 2050s and 2.78°C to 5.90°C in 2080s for both RCP 4.5 and RCP 8.5 scenario in terms of mean (Fig. 4.6).

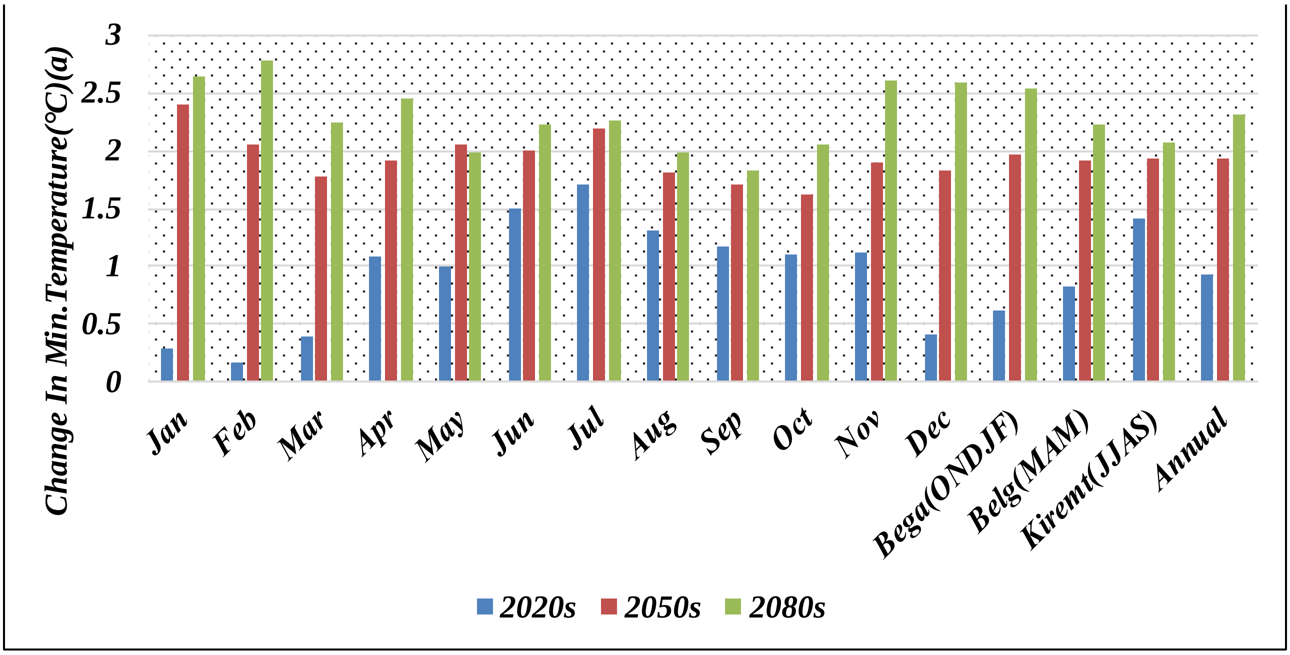
The mean seasonal minimum temperature in the 2020s will be increased by 1.42°C during Kiremt and 1.59 °C during Belg for RCP 4.5 and RCP 8.5 scenario respectively. For the 2050s periods, the mean seasonal minimum temperature will be increased by 1.96°C during Bega and 2.87°C during Belg for RCP4.5 and RCP8.5 scenarios respectively. For the 2080s periods, the mean seasonal minimum temperature will be increased by 2.54°C and 5.18°C during the Bega for RCP 4.5 and RCP 8.5 Scenario respectively (Fig. 4.6).

The mean annual minimum temperature in the 2020s will be increased by 0.94°C and 1.50°C for RCP 4.5 and RCP 8.5 scenario respectively. For the 2050s periods, the mean annual minimum temperature will be increased by 1.94°C and 2.85°C for RCP4.5 and RCP 8.5 scenario respectively. For the 2080s periods, the mean annual minimum temperature will be increased by 2.31°C and 4.64°C for RCP 4.5and RCP 8.5 scenario respectively (Fig. 4.5). The detailed change in mean minimum temperature for each scenario and the time period is available in Table4.4.

As comparing RCP 4.5 and RCP 8.5 scenarios the variation of mean minimum temperature for RCP8.5 scenarios has more pronounced than the RCP 4.5 scenario.

Table 4. 4 Mean Minimum Temperature change (in °C) for both scenarios in monthly, seasonal & annual basis

MONTH	***MINIMUM TEMPERATURE***					
	RCP4.5 Scenario			***RCP8.5 Scenario***		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
Jan	*0.29*	*2.40*	*2.63*	*0.35*	*2.51*	*5.90*
Feb	*0.17*	*2.05*	*2.78*	*0.53*	*2.68*	*5.73*
Mar	*0.39*	*1.77*	*2.25*	*0.84*	*2.54*	*4.73*
Apr	*1.08*	*1.91*	*2.45*	*1.89*	*3.04*	*4.51*
May	*0.99*	*2.06*	*1.99*	*2.04*	*3.04*	*4.41*
Jun	*1.50*	*2.00*	*2.23*	*2.29*	*3.10*	*4.43*
Jul	*1.71*	*2.19*	*2.26*	*2.40*	*3.13*	*4.26*
Aug	*1.32*	*1.81*	*1.99*	*1.99*	*2.84*	*3.73*
Sep	*1.17*	*1.71*	*1.82*	*1.76*	*2.79*	*3.76*
Oct	*1.10*	*1.63*	*2.06*	*1.65*	*2.79*	*4.35*
Nov	*1.11*	*1.90*	*2.61*	*1.46*	*2.98*	*5.04*
Dec	*0.42*	*1.84*	*2.59*	*0.81*	*2.74*	*4.90*
Bega(ONDJF)	*0.62*	*1.96*	*2.54*	*0.96*	*2.74*	*5.18*
Belg(MAM)	*0.82*	*1.92*	*2.23*	*1.59*	*2.87*	*4.55*
Kiremt(JJAS)	*1.42*	*1.93*	*2.08*	*1.07*	*2.76*	*5.05*
Annual	*0.94*	*1.94*	*2.31*	*1.50*	*2.85*	*4.64*



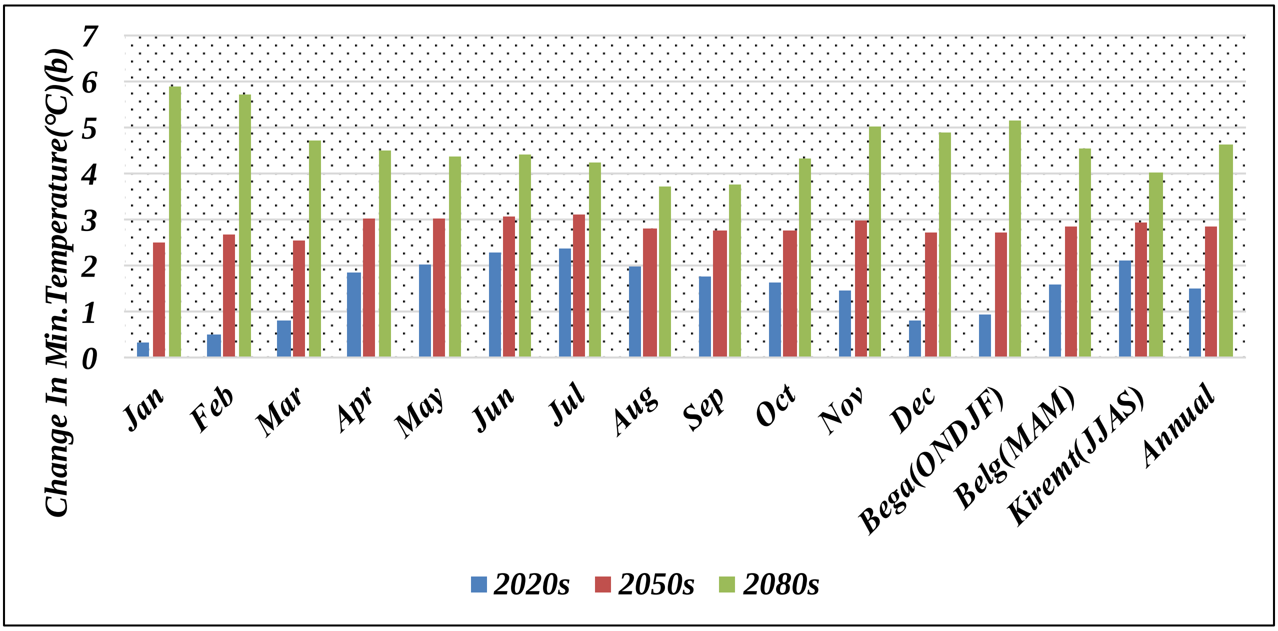


Figure 4. 5 Absolute change in Minimum Temperature (°C) for both (a) RCP4.5 & (b) RCP 8.5

This result was consistent with a study done on Central Rift Valley by Geremew and Agizew (2015), which shows that average annual maximum and minimum temperature projection will increase in both future horizon periods and scenarios. The highest maximum change was predicted at the end of the 21st century for RCP 8.5 emission scenario.

Generally, both scenarios show an increasing projection of minimum and maximum temperature where RCP 8.5 is slight overestimates, compared to RCP 4.5. This result of the increase in minimum and the maximum temperature is in agreement with IPCC 5th Assessment Reports (Niang et al,2014).

The projected increase in both minimum and maximum temperature over the study area will end up in warming, attributed to be the direct effect of a continued increase in CO_2 emission during the 21st century when the CO_2 concentration is projected to be increased above 650ppm (IPCC,2014). This is also in close agreement with the finding that has shown that there will be a warming over East Africa (Waithaka et al,2013).

Besides, the current result was inconsistent both in direction and magnitude with the previous study done in the same study area by Dirba (2015), his result shows that there will be an increment and decrement of both maximum and minimum temperature for all considered scenarios and window periods whereas the current study confirmed that there will be an increment for both variables throughout three window periods and under both scenarios.

4.3. SWAT Model Results

4.3.1. Sensitivity analysis

Sensitivity analysis is a technique of identifying the responsiveness of different parameters involving in the simulation of a hydrological process. For big hydrological models like SWAT, which involves a wide range of data and parameters in the simulation process, calibration is quite a cumbersome task. Hence, sensitivity analysis is a method of minimizing the number of parameters to be used in the calibration step by making use of the most sensitive parameters largely controlling the behavior of the simulated process. This appreciably eases the overall calibration and validation process as well as reduces the time required for it.

Before running the calibration, the sensitivity of the parameters was carried out using the Latin hypercube(LH) method of SWAT-CUP(SUFI-2). This approach combines the advantages of global and local sensitivity analysis methods and can efficiently provide a rank ordering of parameter importance. The sensitivity analysis was performed on twenty-five SWAT model parameters that may have the potential effect on the flow of the River (Fig 4.8). The ranges of parameter variation are based on the SWAT manual (Abbaspour et al, 2004). After sensitivity analysis more sensitive SWAT parameters are identified based on their p-value of statistical significance for the catchment. After setting up the SWAT-CUP using SWAT model outputs and incorporating all input parameters, itration were carried out with SUFI-2 by running 500 simulations and the Sensitivity analysis was done for both the calibration and warming up periods (1989-2001).

Among twenty-five parameters used for the sensitivity analysis, only eleven of them revealed the meaningful effect on the monthly flow simulation of the Tikur Wuha River. Curve number (CNII), soil bulk density (SOL-BD), soil hydraulic conductivity (SOL-K), available water capacity (SOL_AWC), Depth from soil surface to bottom of layer (SOL-Z), soil evaporation compensation factor(ESCO), Channel effective hydraulic conductivity (CH_K2), Biological mixing efficiency (BIOMIX), Manning's "n" value for the main channel (CH-N2), Average slope steepness (HRU-SLP) were relatively high sensitive parameters that significantly affect surface runoff while Groundwater delay (GW_DELAY) and base flow Alpha factor (ALPHA_BF) were other parameters that mainly influence base flow. The selected sensitive parameters with their fitted value are shown in Table 4.5.In the Fig.4.8 the p-value determines the significance of the sensitivity. A value closer to zero denotes more significance.

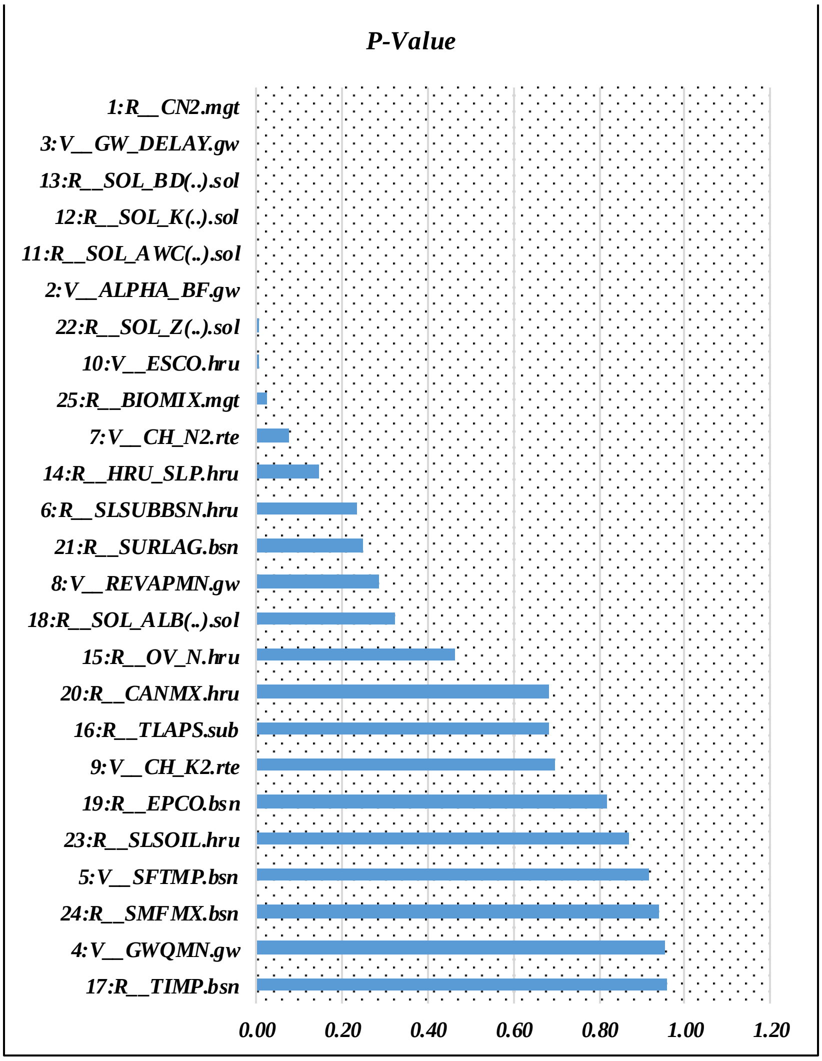


Figure 4. 6 Global sensitivity results according to a p-value of significance using SWAT-CUP

Table 4. 5 Hydrologic calibration parameters values with their fitted value

No.	Parameter	SWAT default		Fitted
		Lower bound	Upper bound	Value
1	r_CN2	35	98	35
2	v_ALPHA_BF	0	1	0.06
3	v_GW_DELAY	0	500	20
4	v_CH_N2	0	1	0.027
5	v_ESCO	0	1	0.68
6	r_SOL_AWC	0	1	0.28
7	r_SOL_K	0	100	9.97
8	r_SOL_BD	0.9	2.5	1.07
9	r_HRU_SLP	0	1	0.039
10	r_SOL_Z	0	3000	130.15
11	v_BIOMIX	0	1	0.2

*Note: *r-sensitive parameter shows default value multiply by 1+ the given fitted value.*
***v-sensitive parameter shows to replace the value by the given fitted value.*

4.3.2. Calibration and Uncertainty Analysis

Flow calibration was performed for a period of ten years from January 1st, 1992 to December 31, 2001, using the sensitive parameters identified. However, flow was simulated for seventeen years from January 1, 1989, to December 31, 2005, within which the first three years was considered as a warm-up period. Flow validation was performed for a period of four years from January 1, 2002, to December 31, 2005.

The parameters were allowed to vary during the calibration process within acceptable ranges until an acceptable fit between the measured and simulated values was obtained; no changes were made to the calibrated parameters during the 4-year of validation. Hydrologic calibration parameters and their fitted values for the gauged stations are shown in Table 4.6.

The calibration and validation results for the gauged station in Table 4.6 shows that there is a good agreement between the monthly simulated and observed flows. The general performance rating of recommended statistics for monthly time step as suggested by (Moriasi et al,2007) indicates R^2>0.6, and E_{NS}>0.5, and PBIAS<±25 suggested by Gupta et al. (1999). Based on this recommendation, the present result shows acceptable performance.

Hence, it is observed that SWAT exhibited a satisfactory performance in representing the hydrological conditions of the Sub-Watershed. It can be seen from the flow hydrographs (Fig. 4.9 and 4.11) that the simulated flows well matched the observed flows except for peak values in the calibration period and low values in the validation period for monthly time steps.

Table 4. 6 Calibration, validation and uncertainty analysis results for Tikur wuha gauged station near Hawassa Bridge

Criteria	**Calibration (1992-2001)**	**Validation (2002-2005)**
R^2	0.79	0.86
E_{NS}	0.54	0.64
PBIAS	-13.9	-11.4
P-factor	0.92	0.67
R-factor	1.52	0.68

Uncertainty analysis was also done using SWAT-CUP linked to SUFI-2 on measured streamflow data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU) and another measure quantifying the strength of a calibration/uncertainty analysis is the R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The results of P-factor and R-factor for monthly discharge are also shown in Table 4.6.

Gauging station at the bridge monthly discharge, 92% of the observed data is bracketed by the 95PPU (P-factor) and the thickness of the 95PPU (R-factor) had a value of 1.52 during calibration, which is a good result. The smaller R-factor value, the smaller the uncertainties and the better is the calibration work. A value close to 1 is highly desirable for R-factor with a *P-factor* also close to 1.

As seen from the calibration and the validation results, it is deduced that the model represented the hydrological characteristics of the sub-watershed at gauging station and can be used as a baseline for further analysis.

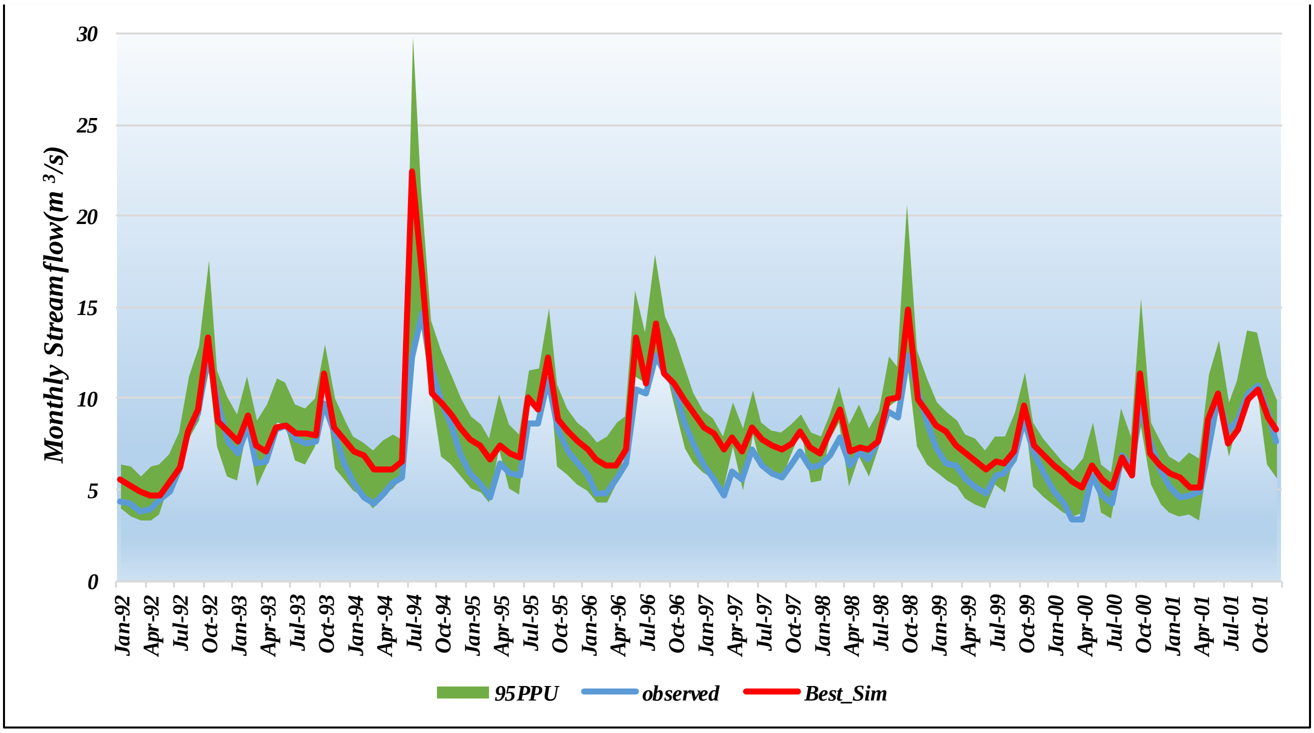


Figure 4. 7 Observed and simulated monthly flow hydrograph during calibration (1992-2001)

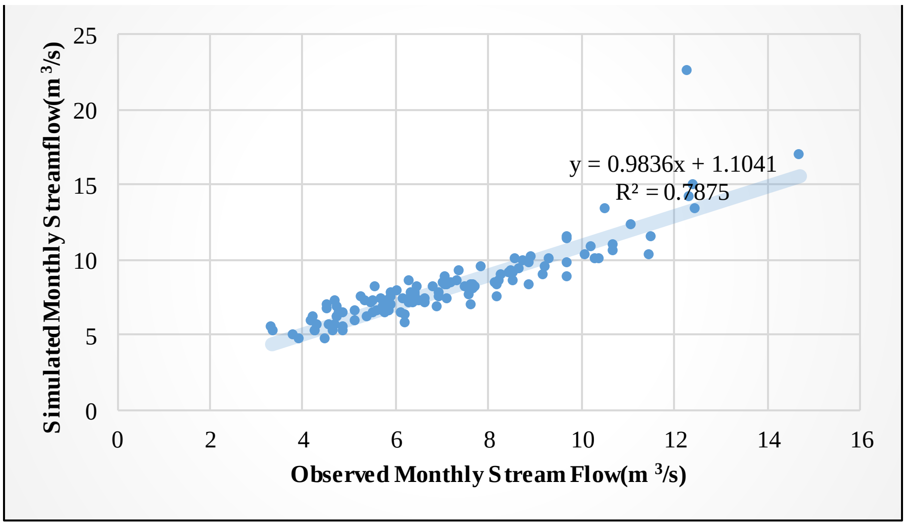


Figure 4. 8 Correlation result during calibration period

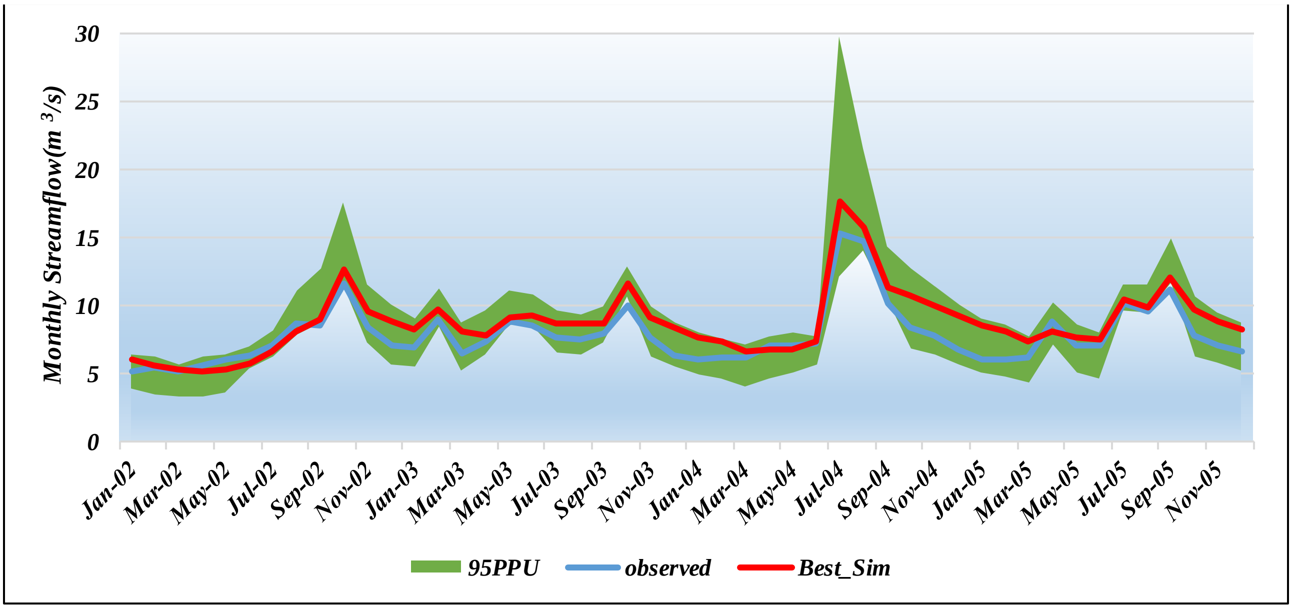


Figure 4. 9 Simulated and observed monthly discharge at the bridge during validation (2002-2005)

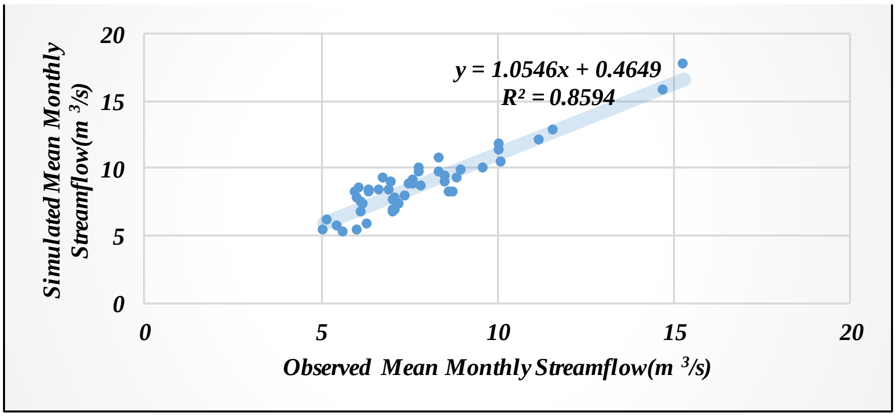


Figure 4. 10 Correlation result during validation period

4.4. Climate Change Impact on the Streamflow

The main objective of downscaling is to generate a reliable estimation of meteorological variables corresponding to given scenario of the future climate so that these meteorological variables will be used as the basis for different types of impact studies. Therefore, after calibration and validation of hydrological models with the historical record, the next step is to simulate river flows in the sub-watershed corresponding to future climate conditions by using the downscaled daily precipitation and temperature into SWAT model. Such simulation helps to identify the hydrological impacts caused by climate change.

The future climate variables that are downscaled precipitation and temperature found as an output from the RCPs and then-then corrected RCPs were given as an input to the SWAT model. Then simulation results corresponding to each of downscaling scenario time period (baseline (1981-2005), the 2020s, 2050s, and 2080s) were analyzed in monthly, seasonal and annual basis.

4.4.1. Climate Change Impact on Monthly Streamflow

Climate change impact on monthly streamflow was analyzed by comparing baseline river flow with the future flows for the 2020s, 2050s, and 2080s.

Increase in streamflow may be observed in months which showed an increase in monthly precipitation. In the 2020s for the RCP4.5 scenarios, the streamflow may show an increment and decrement for the given months. In this period an increment up to 114.8% in the month of July will be expected. In the 2020s for RCP 8.5 scenario, the same effect as the RCP 4.5 scenarios of 2020s may be observed. But the increase in monthly streamflow will be expected to reach up to 152.8% in the month of July.

In the 2050s for both RCP 4.5 and RCP 8.5 scenarios, the increment and decrement of streamflow will be expected. For RCP 4.5 scenarios the monthly change in streamflow may reach up to 109.42% in the month of July whereas for RCP 8.5 scenario the monthly change in streamflow may expect to reach 208.44 % in the month of November.

As in the case of 2020s and 2050s, again in 2080s for both RCP4.5 and RCP8.5 scenarios an increment and decrement in streamflow may be expected in all months in the year. For RCP 4.5 scenarios the monthly change in streamflow may reach up to 140.33% in the month of July whereas for RCP 8.5 scenarios the monthly change in streamflow may be expected to reach up to 188% in the month of October. The mean monthly percentage change of streamflow under both scenarios are available in Table 4.7 and Fig. 4.13.

Table 4. 7 Monthly percentage change (%) in streamflow for both RCP 4.5 and RCP 8.5 Scenarios

Scenario	Period	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP4.5	2020s	-46.7	-71.4	-32.3	-77.7	-15.1	110.7	114.8	108.6	84.5	27.4	59.4	-77.0
	2050s	-27.9	-62.8	-8.1	-74.8	-34.5	92.9	109.4	105.0	70.8	60.4	97.66	-45.9
	2080s	-34.2	-59.3	-69.0	-76.8	-75.3	77.1	140.3	124.0	63.4	75.0	67.8	71.9
RCP8.5	2020s	-65.6	-86.3	-67.6	-53.3	20.6	124.4	152.8	132.8	122.8	74.6	-25.8	25.6
	2050s	-77.2	-67.8	-86.3	-42.3	-80.6	121.6	144.9	125.0	116.4	127.3	208.4	-79.3
	2080s	-44.6	-61.1	-82.0	-74.5	-15.86	122.8	165.1	115.5	122.8	188.0	97.0	-68.7

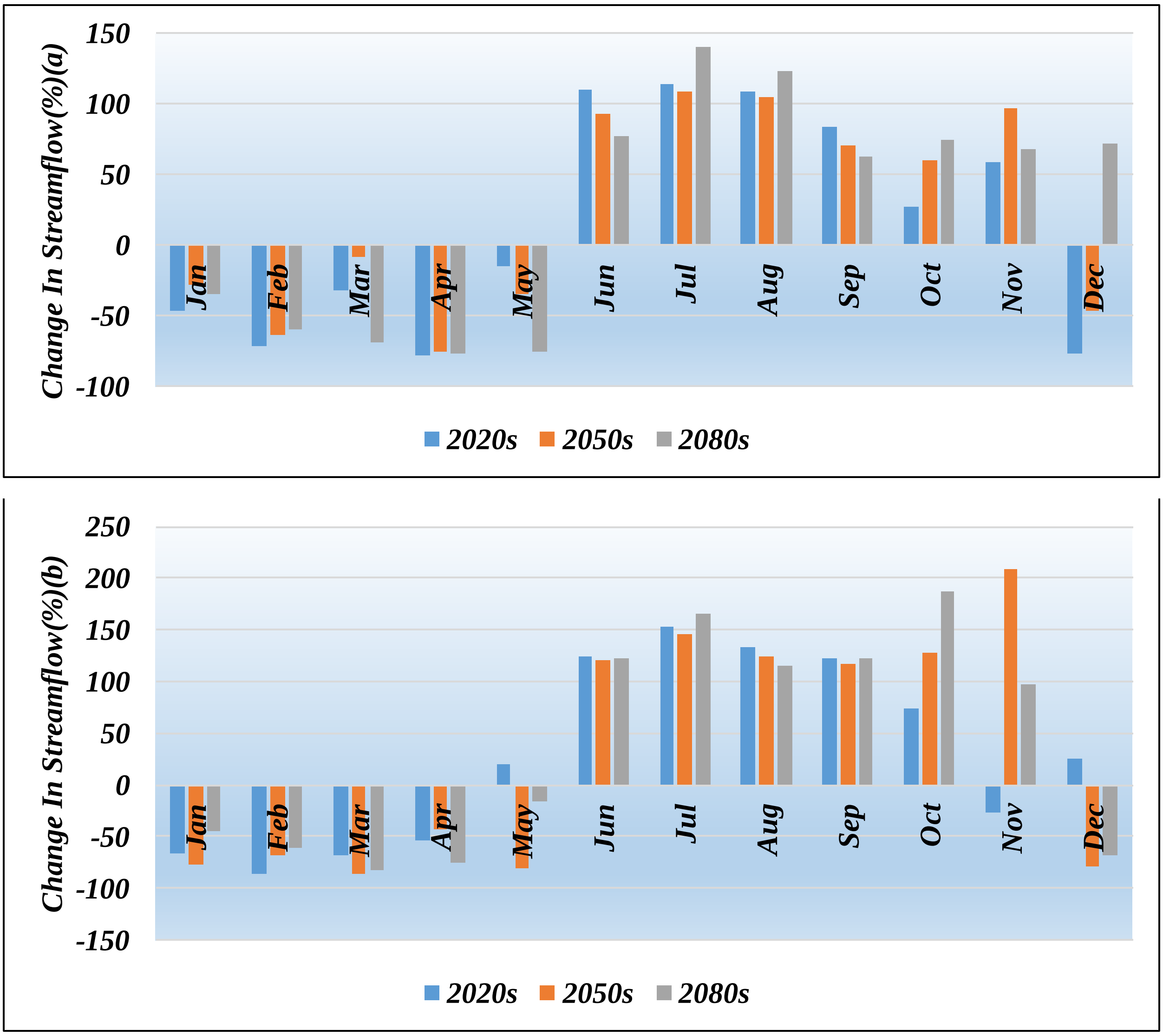


Figure 4. 11 Monthly percentage change in streamflow for both (a) RCP 4.5 and (b) RCP 8.5 scenario

4.4.2. Climate Change Impact on Seasonal and Annual Streamflow

The impacts of climate change on the seasonal and annual streamflow are discussed so as to foresee its consequence on the socio-economic condition on Tikur wuha sub-watershed. As mentioned in the previous section, there are three seasons in the study area: Bega (October to February). Belg (March to May), Kiremt (June to September).

During Kiremt season there will be an increment in streamflow in both scenarios, the increment may reach up to 104.68% for the RCP 4.5 scenario and 133.23% for the RCP8.5 Scenario whereas during Belg season the streamflow may decrease for both scenarios up to 73.73% and 69.77% in RCP4.5 and RCP8.5, respectively. During Bega except for the decrement in the 2020s which may reach up to 21.67% and 15.52% for both RCP 4.5 and RCP 8.5scenarios respectively, there might be an increment in streamflow up to 24.28% and 22.27% for RCP 4.5 and RCP8.5 scenarios (Fig. 4.14).

Overall, the increment in annual precipitation by 15.51%,16.91% & 18.27% leads to an increment in annual streamflow by 15.43%,23.48% & 25.42 for RCP 4.5scenario whereas the increment in annual precipitation by 23.87%,29.51% & 33.01% leads to an increment in annual streamflow by 29.58%,34.20% & 38.72% for RCP 8.5 scenario (Fig. 4.14). The detailed annual and seasonal percentage change of streamflow under both scenarios are available on Table 4.8.

The study was in line with the previous study conducted by Diriba, 2015, had used CMIP3, estimated that there will be annual streamflow increment at the end of the century. Even though there is the difference in magnitude of change between this study and the current study, both confirmed that the streamflow of the Tikur Wuha sub-watershed will be increased for the coming 90 years. Also, the current result was consistent with study done on Gidabo by Shanka, 2017, which shows in the 2020s, 2050s, and 2080s, the total average annual runoff in Gidabo river basin is increasing of up to 3.4%, 2.9 and 6.8% for HadCM3A2a and 5.1 %, 5.6% and 5.8% for HadCM3B2a scenarios, respectively.

The result also consistent with study done by Getahun ,2017 on Blate watershed in Rift Valley using ensemble of 20 GCMs, shows that based on the different climatic scenarios (RCP 4.5 and RCP 8.5), the simulation results indicated a range of possible hydrologic futures; mostly an increase in annual streamflow compared with the baseline is projected under all scenarios. The magnitude of increase for annual river discharge ranges from 10.34% to 42.42 %.

Sarfaraz, 2015 study also show that in the 2050s, mean annual streamflow is found to increase in all the scenarios. The maximum projected increase in the annual discharge of 32.46% was found for GISSE2-H (RCP 4.5), whereas MIROC-ESMCHEM (RCP 8.5) and BCC-CSM1.1(RCP 8.5) showed an almost same increase in projected annual discharges which are 26.89% and 26.27% consecutively. In the 2080s, the maximum projected increase in the discharge of 47.44% was found for BCC-CSM1.1 (RCP 8.5). Other scenarios give a variable increase in discharge, 29.50%, 18.96%, 38.82%, and 13.60% increase in mean annual streamflow were found for MIROC-ESMCHEM (RCP 8.5), HADGEM2- ES (RCP 8.5), GISS-E2-H (RCP 4.5)

Generally, the obtained result for the Tikur Wuha Sub-Watershed depicts a positive change of annual streamflow throughout the century by the ensemble of 20 GCMs which is driven by the projected increase in precipitation. As Tikur Wuha River is the only River feeding in to Lake Hawassa, any change in River flow is likely to affect the Lake. The increased runoff improves water supply reliability and contributes significant inflows into the Lake Hawassa. Thus, the increased streamflow in Kiremit season may devastate flood damages and due consideration should be taken to prevent future flood hazards.

Table 4. 8 Annual and Seasonal streamflow changes (%) under both scenarios

Scenario	**Period**	**Season**			**Annual**
		Bega(ONDJF)	***Belg(MAM)***	***Kiremt(JJAS)***	
RCP 4.5	***2020s***	*-21.67*	*-41.72*	*104.68*	*15.43*
	2050s	*4.24*	*-39.17*	*94.53*	*23.48*
	2080s	*24.28*	*-73.73*	*101.24*	*25.42*
RCP 8.5	***2020s***	*-15.52*	*-33.47*	*133.23*	*29.58*
	2050s	*22.27*	*-69.77*	*127.58*	*34.20*
	2080s	*22.13*	*-57.46*	*131.58*	*38.72*

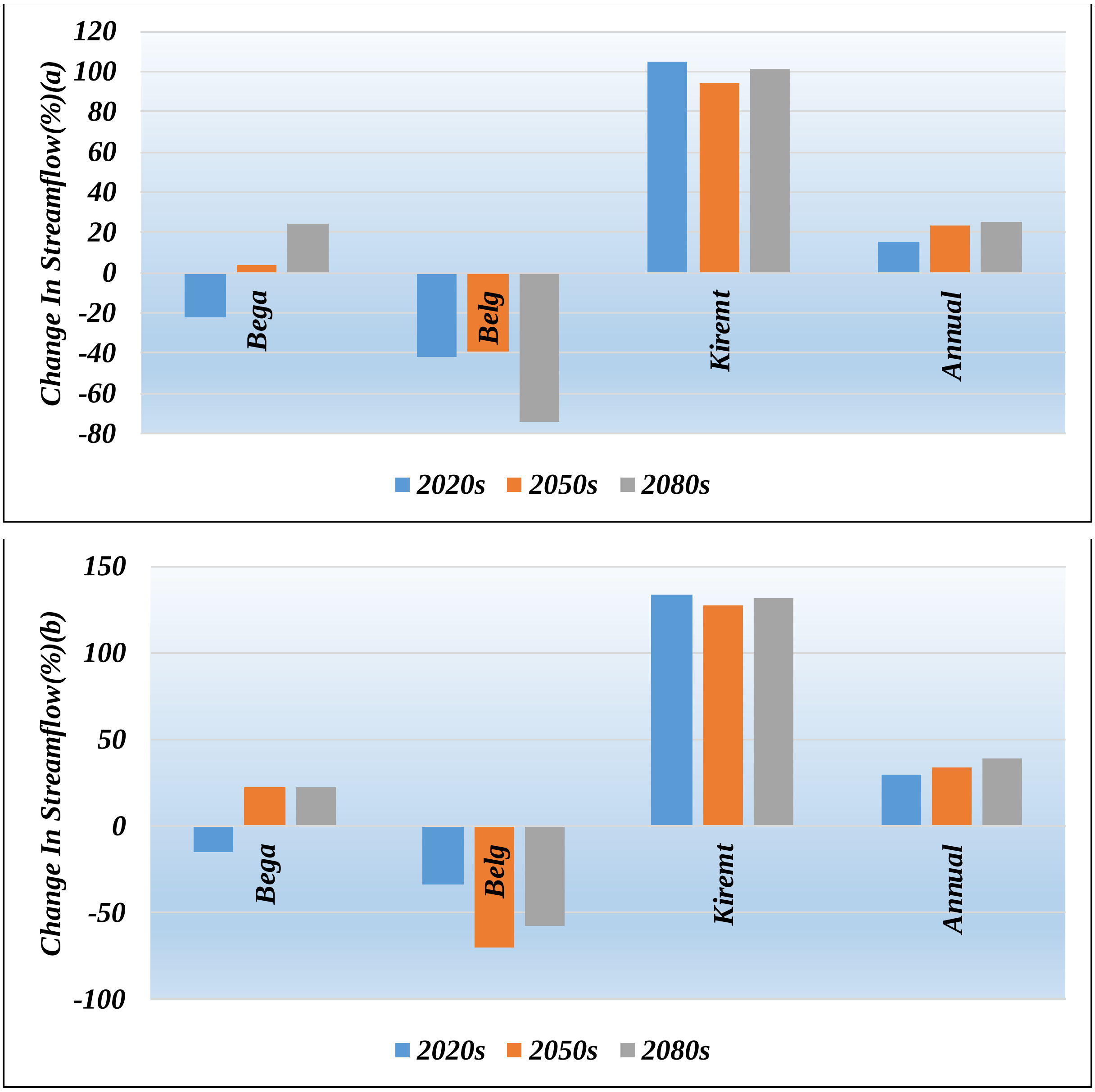


Figure 4. 12 Percentage change in seasonal and annual streamflow for ; (a) RCP 4.5 and (b) RCP 8.5 scenario

5. Conclusions and Recommendations

5.1. Conclusions

Climate change has potential impacts on future hydrological and meteorological variables due to increased greenhouse gas emissions which are associated with increasing temperature of the globe. The future impact of climate change on hydrometeorological characteristics of the basin has been studied such as precipitation and Temperature (Maximum and Minimum) for the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) using CMIP5 projection output. SWAT 2012 hydrological model was used to study impacts of climate change on Tikur Wuha Streamflow.

The bias of dynamically downscaled raw RCPs data was corrected using CMhyd tool successfully as the bias-corrected climate variables produced consistent results with the historical records. The residuals between corrected and historical monthly values were smaller than the residuals between raw RCP and historical monthly values of precipitation and temperature. The bias correction methods performance evaluation for precipitation, maximum temperature, and minimum temperature was also performed and better improvement was gained after bias correction. So it can be concluding that the bias correction method used was the most accurate for downscaled climate variables to reproducing the main features of the observed data.

The mean monthly precipitation projection result was inconsistent throughout three window periods and with both scenarios. The seasonal projection result showed that there will be increments during Kiremt and Bega(except the decrement for 2020s window period for both scenarios) seasons whereas there will be a decrement in precipitation during Belg season. This shows as there will be a shift in season. So due attention should be given for Belg season. The mean annual rainfall projection expected to experience an increment by 15.51, 16.91, and 18.27% for RCP4.5 scenarios at the 2020s, 2050s, and 2080s, respectively. The mean annual increment was repeated by RCP8.5 scenarios with 23.87, 29.51, and 33.01% at the 2020s, 2050s, and 2080s, respectively. Likewise, under both RCP scenarios and for all considered future time period the maximum and minimum temperature projection expected to increase.

The difference in precipitation and Temperature projection between the Diriba's study and current study probably due to the difference in GCM and scenarios used as Diribas study considered only one GCM(HadCM3) under SRES scenarios whereas the current study used an ensemble of 20 GCMs and RCP scenarios. Moreover, IPCC(2008a) indicate that there is a considerable variation in various model projection.

The Curve number(CN2), groundwater delay (GW_DELAY), and Soil bulk density (SOL-BD) showed a relatively very higher sensitivity. Soil water assessment tool (SWAT) models were well calibrated and validated using observed flow data as the coefficient of determination was above 0.6, Nash Sutcliffe efficiency index was above 0.5 and PBIAS was within <±25 for Tikur Wuha Sub-watershed. The uncertainty analysis also showed a better result in both P-factor and R-factor, as the result close to one, which is recommendable.

Bias-corrected daily precipitation and temperature data of both RCP 4.5 and RCP 8.5 scenarios were used to simulate future stream flow. The streamflow projection was highly correlated with precipitation, hence the increment and decrement in streamflow were in line with the availability of precipitation for a given period of time. Streamflow projections for future time periods showed that mean annual streamflow may increase by 15.43, 23.48, and 25.42% in 2020s, 2050s, and 2080s, respectively, from the baseline period for RCP 4.5 scenario, whereas for RCP8.5 Scenario, it will be expected to increase by 29.58, 34.20, and 38.72 % for the 2020s, 2050s, and 2080s, respectively.

The result of this study confirmed that in the future mean annual streamflow will increase due to climate change at the outlet of Tikur Wuha sub-watershed that feeding the lake Hawassa. The increases in water availability will play significant benefits for small and large scale farmers for agricultural activities, moreover, for water resources development projects. If farmers are adopted themselves to cropping schedule, the climate change may contribute in a positive direction for crop water availability.

To sum up, the hydrology of Tikur Wuha River, which is the only perennial river feeds Lake Hawassa, is highly vulnerable to climate change which causes high temporal variation of streamflow. This may need serious concerns for conserving ecosystem in the Lake, and food security and water resource sustainability. Therefore, adaptation strategies in and around the Tikur Wuha sub-watershed have to be developed so as to maintain the sustainability of available water resources and to prevent extreme events. Furthermore, the Results presented in this study can provide valuable insight to decision makers on the degree of vulnerability of Lake Hawassa to climate change, which is important to design appropriate adaptation and mitigation strategies.

5.2. Recommendations

Based on the obtained results the following recommendation was drawn;

Data quality and availability should be stressed much while using distributed hydrological models. Because the applications of SWAT model were very challenging and a lack of appropriate data was one of the biggest concerns throughout the study. Hence, without proper data, model implementation is very difficult if not impossible.

The decrement in precipitation during Belg season as it's crop growing season,may hamper crop growth hence water harvesting practice should be adapted.

The increment of precipitation during the kiremt may exacerbate soil erosion and subsequent sedimentation to the lake that needs special attention.

The increment of streamflow during the Kiremt season may devastate flood damages and due consideration should be taken to prevent future flood hazards, through early warning.

The current study indicates that there exists a difference in the result found between SRES scenarios of previous research work and the RCP scenarios in the current study. Hence, further analysis can be undertaken with more RCPs and more bias correction method so as to give a clear picture of the result.

To link the study results to the sustainable development of the community, it is recommended to use the hydrological models' outputs in water resource management models to take the socio-economic aspects of the hydrological system.

Finally, in the study the model simulations considered only future climate change scenarios assuming all spatial data constant. But the change in land use scenarios and other climate variables will also have an effect on future streamflow. Therefore, a further study considering the land use/cover change would increase the confidence of projected result.

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APPENDICES

Appendix 1 Meteorological data

Table 7. 1 Climatic Data_Summary of average monthly climatic data values of all the stations in the study area (1981-2005)

HAWASSA								HAISAWITA						
Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-Shin (Hrs)	Wind Speed (m/s)		Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-Shin (Hrs)	Wind Speed (m/s)
Jan	30.84	11.04	28.40	53.06	8.72	0.93		*Jan*	27.48					
Feb	41.35	11.63	29.41	50.97	8.52	0.94		*Feb*	43.29					
Mar	83.50	12.85	29.43	56.95	7.93	0.98		*Mar*	120.99					
Apr	117.61	13.86	27.90	66.54	6.79	0.87		*Apr*	151.80					
May	118.75	14.06	26.85	69.51	7.27	0.93		*May*	134.97					
Jun	104.80	14.10	25.47	69.23	6.63	1.16		*Jun*	88.08					
Jul	120.76	14.04	24.03	73.02	5.02	1.06		*Jul*	105.25					
Aug	119.10	13.95	24.55	72.34	5.33	0.97		*Aug*	115.34					
Sep	120.04	13.20	25.38	72.92	5.95	0.77		*Sep*	166.44					
Oct	77.71	12.01	26.66	65.64	7.21	0.68		*Oct*	94.32					
Nov	28.42	9.63	27.68	53.95	8.44	0.75		*Nov*	37.74					
Dec	19.88	9.86	28.02	51.76	9.03	0.91		*Dec*	27.60					
Yearly	**81.90**	**12.52**	**26.97**	**63.06**	**7.23**	**0.91**		***Yearly***	**92.77**					
SHASHEMANE								WENDO GENET						
Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-Shin (Hrs)	Wind Speed (m/s)		Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-Shin (Hrs)	Wind Speed (m/s)
Jan	25.24							*Jan*	29.99					
Feb	36.00							*Feb*	48.83					
Mar	85.81							*Mar*	106.68					
Apr	130.21							*Apr*	148.50					
May	107.85							*May*	132.45					
Jun	72.97							*Jun*	102.39					
Jul	103.36							*Jul*	126.60					
Aug	101.89							*Aug*	124.89					
Sep	124.41							*Sep*	140.46					
Oct	71.04							*Oct*	98.41					
Nov	20.40							*Nov*	29.58					
Dec	17.47							*Dec*	22.25					
Yearly	**74.72**							***Yearly***	**92.59**					

Appendix 2 meteorological stations location

Table 7. 2 Location of the Meteorological stations used in the study

No.	*Station Name*	*Latitude*	*Longitude*	*Elevation(m.a.s.l.)*
1	*Hawassa*	7.06	38.48	1694
2	*Haisawita*	6.90	38.56	2267
3	*Shashemane*	7.20	38.48	1694
4	*Wendo Genet*	7.08	38.61	1742

Appendix 3 Weather Generator Parameters

Table 7. 3 Weather generator (WGEN) parameters used by the SWAT model

Legend of the parameter used in the weather generation		
	Symbol	**Description**
A	TMPMX	Average or mean daily maximum air temperature for the month(°C)
B	TMPMN	Average or mean daily minimum air temperature for the month(°C)
C	TMPSTDMX	The standard deviation for daily maximum air temperature in a month(°C)
D	TMPSTDMN	The standard deviation for daily minimum air temperature in a month(°C)
E	PCPMM	Average or mean total monthly precipitation(mm H_2O)
F	PCPSTD	Standard deviation daily precipitation in a month(mm H2O/day)
G	PCPSKW	The skew coefficient for daily precipitation in the month
H	PR_W1	The probability of a wet following a dry day in the month
I	PR_W2	The probability of a wet day following a wet day in the month
J	PCPD	Average numbers of days of precipitation in the month
K	RAINHHMX	Maximum half hour daily precipitation in the month
L	SOLARAV	Average daily solar radiation for a month($MJ/m^2/day$)
M	DEWPT	Average daily dew point temperature in a month(°C)
N	WNDAV	Average daily wind speed in a month(m/s)

The number 1 to 12 next to letters in the following table represents the month from January to December

STATION	WLATITUDE		WLONGITUDE		WELEV	RAIN_YRS	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Hawassa	7.06		38.48		1679	25	28.7	29.6	29.5	27.9	26.9	25.4	24.0	24.6	25.4	26.8
A11	A12	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	C1	C2	C3
28.1	28.2	10.8	11.7	12.8	13.9	13.9	14.0	14.1	14.1	13.3	12.0	9.8	9.8	1.6	2.0	2.2
C4	C5	C6	C7	C8	C9	C10	C11	C12	D1	D2	D3	D4	D5	D6	D7	D8
2.4	1.9	1.5	1.7	1.6	1.6	1.9	1.6	1.4	3.1	2.9	2.5	1.9	1.7	1.6	1.6	1.6
D9	D10	D11	D12	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	F1
1.7	2.8	2.7	2.9	31.5	42.2	83.0	117.2	119.1	105.9	121.2	118.9	119.0	78.7	28.6	20.0	4.3
F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	G1	G2	G3	G4	G5	G6
4.7	5.4	7.4	7.9	7.3	7.9	8.0	6.5	5.5	3.8	2.4	7.7	5.7	3.7	3.1	3.8	3.3
G7	G8	G9	G10	G11	G12	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11
3.6	5.7	3.4	4.2	9.5	6.2	0.1	0.2	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.2	0.1
H12	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	J1	J2	J3	J4
0.1	0.4	0.5	0.6	0.7	0.7	0.6	0.7	0.7	0.8	0.7	0.6	0.5	5.6	8.0	16.3	18.5
J5	J6	J7	J8	J9	J10	J11	J12	K1	K2	K3	K4	K5	K6	K7	K8	K9
18.0	16.8	19.3	20.4	22.8	14.6	5.9	5.1	19.6	16.6	16.1	18.9	22.7	14.9	21.5	36.8	19.0
K10	K11	K12	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	M1	M2
16.9	22.4	10.1	20.9	21.7	21.7	19.9	20.1	18.7	16.6	17.5	18.5	19.8	20.6	20.8	11.7	11.8
M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	N1	N2	N3	N4	N5	N6	NN7 7
13.7	15.4	15.6	14.6	14.6	14.8	15.2	14.0	11.3	10.8	0.8	0.9	0.9	0.8	0.9	1.1	1.0
N8	N9	N10	N11	N12												
1.0	0.7	0.6	0.7	0.8												

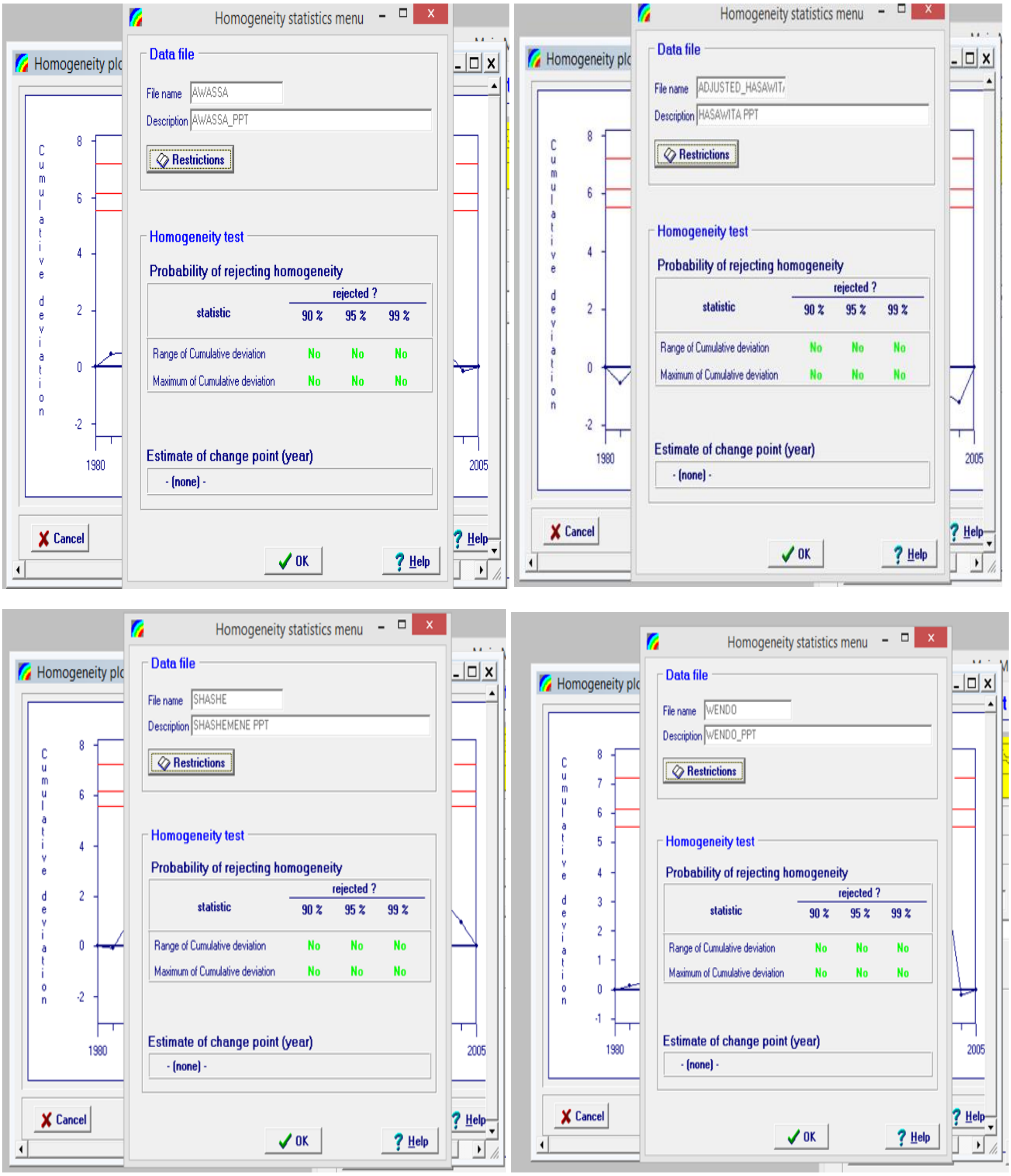

Figure 3. 13 Homogeneity test result using RAINBOW software for Hawassa, Haiswaita, Shashemene and Wendo Genet stations, respectively.