Assessing Climate Change Impacts on Water Availability in Upper Awash Sub-Basin, Ethiopia.

By

Kiya Kefene Benti

A Thesis Submitted to

Water Resources Engineering Program
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the award of Degree of Masters in Water Resources Engineering (Irrigation Engineering).

Office of Graduate Studies
Adama Science and Technology University

June, 2018
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Approval sheet of the board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Kiya Kefeni Benti have read and evaluated his thesis entitled "Assessing Climate Change Impacts on Water Availability in upper Awash Sub-basin, Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters in Water Resources Engineering (Irrigation Engineering).

____________________	____________________	____________________
Advisor	Signature	Date
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Declaration

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree in Water Resources Engineering (Irrigation Engineering) at Adama science and Technology University and deposited at the University Library to be made available to borrowers under rules of the Library.

Name: Kiya Kefeni Benti

Signature: _____________

This MSc has been submitted for examination with my approval as thesis advisor.

Advisor: Abel Tadesse (PhD)

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Date of submission: _____________

Advisor's approval sheet

To: Water Resources Engineering Program

Subject: Thesis Submission

This is to certify that the thesis entitled "Assessing Climate Change Impacts on Water Availability in Upper Awash Sub-basin, Ethiopia submitted in partial fulfillment of the requirements for the degree of Master's in Water Resources Engineering (Irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by Kiya Kefeni Benti Id. No GSR/0007/09, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

______________________ ____________ ____________

Name (student) Signature Date

Abel Tadesse (PhD) [signature] 13/6/2018

Major Advisor Signature Date

______________________ _________________ ___________

Co- Advisor Signature Date

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

CORDEX	Coordinated Regional Climate Downscaling Experiment
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GCM	Global Climate Model
GFDL	Geophysical and Physical Dynamics Laboratory
GIS	Geographical Information System
HRU	Hydrological Response Units
ITCZ	The inter tropical convergence zone
LULC	Land use Land Cover
NMA	National Meteorological Agency
MoWIE	Ministry of Water, Irrigation and Electricity
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SWAT	Soil and Water Assessment Tool
SUFI-2	Sequential Uncertainty Fitting 2
UARB	Upper Awash River Basin
UNESCO	United Nations Education, Scientific and Cultural organizations
USDA-SCS	United States Department of Agriculture Soil Conservation Service
WMO	World Meteorological Organization

Abstract

Variations and change in climate in the past has influenced and will continue influencing the availability of water. This study assessed the likely impacts of climate change on water availability in the Upper Awash sub-basin using the Soil and Water Assessment Tool (SWAT).

The study specifically analyzed the historical trends in precipitation and temperature, downscaled the projected climate variables (temperature and precipitation) for the 2030s (2021-2040) and 2050s (2041-2060) for the Upper Awash sub-basin and estimated the impacts of the projected variables on stream flow. Dynamical downscaling method was used to downscale the future climate data from CORDEX Africa using Regional climate models and bias correction was done using delta change approach method for hydrological impact analysis. The period 1985-2014 was considered as the baseline period against which comparison was made. In assessing historical precipitation and temperature trends, Mann-Kendall trend test were used.

Results for the Mann-Kendall tests showed a declining trend in Precipitation and a statistically significant rising trend in maximum and minimum temperature. The results of downscaled maximum and minimum annual and monthly temperature reveal that there is increase in temperature for both RCP4.5 and RCP8.5 scenarios at 2030's and 2050's. However, the result of downscaled rainfall shows decrease in annual and both increase and decrease mean monthly rainfall for RCP4.5 scenario and decrease for RCP8.5 scenario. Dynamically downscaled climate outputs were used as an input to the SWAT model for the future impact assessment. Performance of the SWAT model was evaluated using R^2, NSE, and P_{BIAS}*. During calibration (1999-2003) of the model, values 0.82, 0.78 and 11.23% were obtained for* R^2, NSE, and P_{BIAS}*. Whereas during validation period (2004-2006) values 0.78, 0.75 and 8.9% were obtained for* R^2, NSE, and $P_{BIAS.}$ *Besides, the uniformly scattered points along the 1:1 line during calibration and validation justify that the model is good in simulating stream flow of upper Awash sub-basin*.

The total annual surface water resource potential of upper Awash sub-basin at the base period according to this study is estimated to be about 3.302BCM/year. However, in 2030's increasing water availability is shown by 3.83% and decreased by 2.32% in 2050s under RCP 4.5 scenarios. Similarly, water availability reduces by 34.04% and 37.57 % in 2030s and 2050s respectively under RCP 8.5 scenarios.

Key Words: Climate change, CORDEX Africa, RCM, Mann Kendall test, SWAT, Upper Awash Sub basin, Delta change.

1. INTRODUCTION

The global climate is changing and is becoming one of the most important issues around the world (Kassie *et al*.,2013). One of the most significant potential consequences of climate change in the long-term would be changes in regional hydrological cycle. The main contributors in the significant changes in global climatic patterns are the increasing concentrations of atmospheric greenhouse gases (GHGs), which subsequently leads to global warming. Changes in the climate patterns affect the access and availability of various crucial natural resources with water resources among the top.

According to (IPCC, 2014) the precipitation pattern and the temperature will significantly change by the end of 21st century, which will affect the hydrologic system. The observational evidence around the world shows that many natural systems are being affected by regional climate changes (IPCC, 2007). The environmental crisis on natural ecosystems, agriculture and food supplies, human health, forestry, water resources and availability, energy use, and transportation directly or indirectly in many areas of the world are partly caused by global climate change (Chen *et al*., 2012). For instance, it has significant effects on the hydrological cycle because the distribution of water resources is very sensitive to climate change (Kassie *et al*., 2013). Global climate change has also the potential to impose additional pressures on water availability and water demand (Bates *et* al., 2008). Azman (2007) projects approximately 65% of the African population will be at risk of water stress by the year 2025. Projected climate changes are expected to cause significant consequences in the alterations of the availability of water resources (Dile, 2013; Gutu *et al*., 2012; IPCC, 2014). Variability in the hydrological cycle will have effects in the timing and magnitude of runoff, ecosystem dynamics, social and economic systems. The magnitude and spatial distribution of the changes in climatic variables and the characteristics of the area, clearly defines severity of the impacts on water resources at local level.

Ethiopia is vulnerable to climate change since the economy of the country mainly depends on agriculture, which is very sensitive to climate change and variations (Abadi and Kassa, 2014). Based on different climate change scenarios the temperature is expected to rise with two or more degree centigrade, rainfall predicted to increase in some places and to decrease in other parts (IPCC, 2014). Changes in precipitation patterns affect water availability and runoff directly; while changes in temperature, radiation and humidity have an effect on evapotranspiration. Population distribution, irrigated agriculture, urban and industrial water use are major factors deriving water availability issues. Therefore, Assessing and evaluating the significance of climatic change impacts on water availability of the basin at catchment and sub-basin scale is crucial for water resource development. For disaster preparedness, structural development and irrigation planning it is crucial to evaluate the probable impacts of climate change on water resources.

Global climate models (GCMs) are suitable tools for the assessment of climate variability and change. Current GCMs have spatial resolution on the order of 100– 250 km and have the potential to simulate the main characteristics of general circulation at the range of this scale (Almseged and Rientjis, 2015; Claudia and Jan, 2010). However, GCMs are not capable of capturing the detailed processes associated with regional climate variability and changes. In order to formulate adaptation policies in response to climate change impacts, reliable climate change information is usually required at finer spatial scales than that of a typical GCM. Regional climate models (RCMs) are useful for understanding local climate in regions that have complex topography.

Awash Basin is an intensively utilized river basin in Ethiopia due to its strategic location, access roads, available good land and water resources. The basin has an estimated irrigation potential of 206,000 ha and this potential was estimated based on gravity surface irrigation systems on lands up to maximum slope of 5% (Hassen, 2004). The current survey showed that about 159,530 ha of land including medium and large scheme irrigation schemes has been irrigated in 2012. However, the basin suffers from severe environmental degradation, annual flooding due to mismanagement of land and water resources, socio-economic constraints, poor agricultural practices resulting in low yielding and community health problems (Belete and Semu,2013).

Upper Awash River Basin is normally endowed with land features that are characterized by; downstream irrigation, several towns, including the capital city, Fifinne, and industrial enterprises in the study area has been expanding from time to time. This area contributes a significant proportion of stream flow volume of the large Awash River since it forms the upper reaches of the river. However, the hydrological processes within the catchment are likely to be influenced by change in climate perhaps increasing the vulnerability of communities to extreme events.

In Upper Awash River basin, due to fast growing population rates and industrial development, the fundamental components of climate, rainfall and temperature is changed. Due to this water is becoming a very scarce and valuable resource. Also there are uncertainties over the exact nature of impacts of future climate change on water availability in the basin.

Therefore, assessing the impacts of climate change on the water availability is very important mainly because it enables proper planning and forecasting as well as design of adaptation and mitigation measures in response to climate change. Besides, this research increases awareness on the possible future risks of climate change in order to mitigate the impacts of climate change on water resources system. Therefore, this study was conduct to assess the impacts of climate change on water availability in upper Awash sub basin using hydrological model, Soil and Water Assessment Tool (SWAT), Regional climate model and GIS.

1.1 Problem Statement

Water availability is an essential component of welfare and productivity. However, currently over billions of people do not have access to adequate supply of safe water. Climate change is one of the greatest pressures on the hydrological cycle along with population growth, pollution, land use changes and others (Yinhong *et* al., 2009).

According to (IPCC, 2014) future projections, precipitation and temperature will increase over eastern Africa in the coming century. Water evaporated from surface and transpired from plants rises with air temperature. These make large reductions in runoff and increase water shortages as a result of a combination of increased evaporation and decreased precipitation.

Due to climate change and increasing population pressure, water availability will be the main pressures for societies and the environment in Africa. By 2025, it is assumed that 22 countries will experience a water-stress situation due to rapid population growth, expanding urbanization, increased economic development and climate change (Azman, 2007). Developing countries, such as Ethiopia, will be more vulnerable to climate change mainly because of the larger dependency of their economy on agriculture which is very sensitive to climatic variations. Precipitation and temperature are one of the most determinant climate patterns for the country, because more than 80% of the country’s agriculture is reliant on rain fed.

Ethiopia has ample water resources, which can be appropriately utilized to enhance socioeconomic development of its people. However, due to underdevelopment of this resource among others, the people of Ethiopia have been exposed to major problems such as impacts of drought and flood; shortage of clean water supply and inadequate energy supply. El Nino and the associated climate change are the main reasons for unpredictable rainfall conditions and drought in Ethiopia. Over the past years, some parts of the country has experienced frequent droughts, increase in the intensity and occurrence of heavy rains which have led to floods and these have in turn had an effect on surface water quantity.

The El Nino, which causes for water shortage is apparent in basins like Awash River basin and this happened due to both climatic and anthropogenic factors. The basin is experiencing water scarcity for the last few years as the need of water for development is not parallel with the available water resource. As a result of enormous industrial and agricultural activities in the basin water allocation and scarcities are critical issues.

In Upper Awash sub basin, due to the rapid economic and population growth; the demand of water is increasing time to time. As climate variability and change have impact on water resources availability, there should be clear study to combat the demand problem. In order to do so, analyzing climate change impact on water resources availability is very keen in upper Awash sub-basin. In upper Awash sub-basin no significant attempt has done regarding impact of climate change on water resources availability using the recent climate change study scenarios to enable water resources planning study appropriately.

1.2 Objective of the study

The general objective of this study is to assess the impacts of climate change on water availability in Upper Awash sub- basin, Ethiopia.

In order to achieve the general objective of the study, the following specific objectives were adopted:

1. Determination of historical trends of precipitation and temperature in upper Awash sub-basin.
2. Selection of appropriate climate models that fits (characterize) the study area.
3. Simulation of the stream flow patterns of the study area under different climate Scenarios (RCP4.5 and RCP8.5).
4. Estimation of the change of monthly and annual water availability of the study area under different RCP scenarios for future time.

1.3 Research Questions

In this study, the following research questions are addressed:

1) What type of trend exists in the temperature and precipitation of the study area?
2) Which Climate model characterizes the study area?
3) To what extent the stream flow is sensitive to climate change in the study area?
4) What is the impact of climate change on quantity of water in the study area? Will it increase or decrease in the future climate condition?

1.4 Scope of the study

The study focuses on the analysis of potential impacts of climate change on water availability under current and future climate condition of upper Awash sub-basin. Observed hydro-meteorological data of the study area were tested for quality and homogeneity. Future climate data output from CORDEX Africa were used for projections of future climate elements. Bias correction of RCM's output was undertaken before employing output to the model. Finally, application of SWAT model for determination of water availability was conducted. However, the study didn't take in to account the effect of climate change on the groundwater availability and water quality. Moreover, the study didn't identify the problem of flooding and drought if it happen under future climate condition.

2. LITERATURE REVIEW

2.1 Climate Change and Variability

Climate change is any systematic and statistically significant change in the long term statistics of climate elements, such as precipitation and temperature sustained over several decades or longer. Thus, climate change can be an expression of changes in long-term average precipitation or temperature, and/or changes in the frequency of extreme climate events (IPCC, 2014; Dumenu and Obeng, 2016).

Climate varies on time scales ranging from months to millennia. For water availability studies, climate variations from months to centuries are most relevant. The seasonal cycle is the most regular of all climate variations. Seasonal changes in precipitation and temperature greatly influence variations in stream flow, lake, reservoir, and groundwater levels, and groundwater recharge. Potential climate change resulting from anthropogenic emissions of carbon dioxide and other greenhouse gases does and will increasingly have impressive environmental, social and economic impacts and costs if we don't change our habits (Jianxin, 2009).

According to IPCC (2007) continued increases of greenhouse gases will cause the global mean temperature to rise from 1.8 to 4.0°C and the sea level to rise from 18 to 59 cm by the end of this century compared to 1980-1999 levels. Climate change actually accounts for about 20% of the global increase in water scarcity, and countries that already suffer from water shortages will be hardest hit (IPCC, 2014). There will also be a general reduction in potential crop yield in most tropical and subtropical regions due to a significant increase in global temperature, and some extreme events like droughts and floods will become more intense as a result of the even more uneven spatial and temporal distribution of precipitation (Gutu *et al*., 2012).

2.2 Climate Change Impacts on Water Resources

Climate change leading to increased surface temperatures, melting of snow and glaciers, rise in sea level and an increase in extreme weather events such as droughts and floods, can significantly affect water resources(IPCC, 2007; Pantuliano and Wekesa, 2008 and Kinfe,2009). Global warming increases the evaporation of water into the atmosphere and changes the patterns of major airstreams and ocean currents such as El Niño and La Niña (Pantuliano and Wekesa, 2008). This in turn alters the distribution of precipitation, so some regions experience greater rainfall and flooding while others become more prone to droughts. The top down approach on global warming that is through emission of greenhouse gases is not the only source of climate variability. Many researches are out there suggesting that the bottom up climate forcing such as human influence on the environment and the land use/land cover change play a very important role in affecting regional climate. Land use is actually the first order human climate forcing.

More frequent and longer periods of drought reduce the amount of run-off into rivers, streams and lakes; also the water table drops, so there is less groundwater to supply springs and shallow wells. Changes in climate due to an increasing concentration of greenhouse gases have obvious effect on the hydrological cycle. The hydrologic cycles and regimes within watersheds are altered by the climate change at global scale and also local scale which undesirably impacts forests, water resources, sustainable agriculture, environment and ecosystems (Dile *et al*., 2013). The amount of water that is available for recharge will also be affected by reduced precipitation or increased evaporation and runoff which are as result of changes in the water cycle. It could further decrease the stream flow and groundwater recharge in many water-scarce areas in the world particularly in arid and semi-arid countries (Azman, 2007). Stream flow during seasonal low flow periods would decrease in many areas due to greater evaporation. Decreased river flows and higher temperatures, then, would degrade water quality of the rivers. Flood magnitude and frequency could increase in many regions as a consequence of increased precipitation events. Changing climate (more specifically, global average temperature rise is the crucial component for sea level rise as it contributes to melting of polar ice) will cause sea level rise, resulting saline water intrusion into ground water aquifers near the coasts and will decrease the available groundwater resources (Dile *et al*., 2013). All the above are proofs that, impacts on water availability are among the most direct results of climate change.

2.3 Climate Change in Ethiopia

Climate change will have a profound impact on the availability and variability of fresh water as the frequency of climatic extremes increases in response to global warming. The uncertainty of the availability of water resources will affect agricultural production, challenge socio-economic systems, and threaten environmental sustainability (Anwar *et al*., 2015). The effect of climate change will be significant particularly in developing countries where their economy is heavily dependent on agricultural production. The IPCC (2007) suggested that Africa as one of the most vulnerable continents to climate change. Ethiopia is one of the African countries whose economy is largely dependent on agriculture. Therefore, the country's economy is subjected to a direct impact of climate change.

According to the Ethiopian National Meteorological Agency (NMA, 2001) study for 42 meteorological stations, the country has experienced both dry and wet years over the last 50 years. Trend analysis of the annual rainfall showed there was a declining trend in the northern half of the country and southern Ethiopia while there is an increasing trend in the central part of the country. Associated with rainfall and temperature change and variability, there was a recurrent draught and flood events in the country. There was also observation of water level rise and dry up of lakes in some parts of the region depending on the general trend of the temperature and rainfall pattern of the regions (Yehun, 2009). The study of NMA at the same year for 40 stations showed that there have been very warm and very cold years. However the general trend showed there was an increase in temperature over the last 50 years and the average annual minimum temperature over the country has been increasing by about 0.25^0c every ten years while average annual maximum temperature has been increasing by about 0.1^0c. The study also noted that the minimum temperature is increasing at a higher rate than the maximum temperature.

A large portion of lands in Ethiopia is arid or semi-arid and these poorly managed lands can easily degrade with increasing climatic extremes and desertification (Anwar *et al*., 2015). It is therefore important to understand the impact of climate change on water resources to implement appropriate climate change adaptation and mitigation strategies. Expansion of small scale irrigation is one of the mitigation strategies under consideration where dry season stream flow is reliable. However, implementation of such strategies requires a thorough assessment of the impact of climate change on stream flow that is highly sensitive to climate, especially to changes in precipitation, snow regime and evapotranspiration.

2.4 Climate Change Emission Scenarios and Models

A climate scenario is reasonable description of future climate based on a range of climatological relationships and assumptions of radiative forcing. It can be visualized by global climate models (GCMs) and regional climate models (RCMs), which are complicated three dimensional mathematical representations to show the processes of interactions between the atmosphere, land surface, oceans, sea and ice which resulted from climate change (Yinhong *et al*.,2009). IPCC (2007) develop four climate scenarios to project emission gases and temperatures for the future. These scenarios are used by researchers and policy makers to assess potential future conditions and compare them to baseline conditions in lack of climate change. A set of scenarios known as Representative Concentration Pathways (RCPs) have been adopted by climate researchers to provide a range of possible futures for the evolution of atmospheric composition (Moss *et al*., 2008).

According IPCC fifth assessment report (AR5, 2014) four representative concentration pathways are developed for impact assessment studies. RCP2.6, RCP4.5, RCP6.0, and RCP8.5 are termed after probable variety values of radiative forcing +2.6, +4.5, +6.0, and +8.5 W/m^2 correspondingly, relation to pre-industrial values in the year 2100. The four pathways are summarized as follow:

RCP 2.6 – Low emissions: This RCP is developed by PBL Netherlands Environmental Assessment Agency. Here Radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time. (Comparable SRES scenario: None). This future would require declining use of oil, low energy intensity, a world population of 9 billion by year 2100, use of croplands increase due to bio-energy production, more intensive animal husbandry, methane emissions reduced by 40% and CO2 emissions stay at today's level until 2020, then decline and become negative in 2100.

RCP 4.5 – Intermediate emissions: This RCP is developed by the Pacific Northwest National Laboratory in the US. Here radiative forcing is stabilized shortly after year 2100 and it can be comparable with SRES scenario B1. This future is consistent with lower energy intensity, strong reforestation programmes, decreasing use of croplands and grasslands due to yield increases and dietary changes, stringent climate policies, stable methane emissions and CO_2 emissions increase only slightly before decline commences around 2040 .

RCP 6 – Intermediate emissions: This RCP is developed by the National Institute for Environmental Studies in Japan. Radiative forcing is stabilized shortly after year 2100, which is consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions. It is comparable with the previous SRES scenario, B2. The feature of this high emission scenario is consistent with heavy reliance on fossil fuels, intermediate energy intensity, increasing use of croplands and declining use of grasslands, stable methane emissions and CO_2 emissions peak in 2060 at 75 per cent above today's levels, then decline to 25 per cent above today.

RCP 8.5 – High emissions : This RCP is consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas feature of this high emission scenario is consistent with rapid increase in methane emissions, three times today's CO_2 emissions by 2100, heavy reliance on fossil fuels, lower rate of technology development, high population growth, increased use of croplands and grassland which is driven by an increase in population and no implementation of climate policies.

2.5 Downscaling Techniques

To drive a hydrological model, reliable information on climatological variables (e.g. temperature, precipitation, evapotranspiration, etc.) and their distribution in space and time are required.
The most commonly used tools for climate predictions are global climate models (GCMs). Because their insufficient spatial scale (grid-cell resolutions of approximately 100–250 km) is lacking detailed regional information (IPCC, 2007), downscaling procedures are required in order to provide fine-resolution climate parameters for hydrological modeling. Downscaling GCM data is normally achieved by using one of two techniques; dynamical or statistical approaches.

2.5.1 Statistical Downscaling Techniques

The statistical (empirical) downscaling approach entails the use of any of several statistical techniques that map large-scale climate GCM 'predictors' and circulation characteristics to local or regional-scale meteorological 'predictants' (Wilby *et al.*, 2004). It involves establishment of empirical relationships between historical and current large scale atmospheric and local variables. The future global climatic variables projected by GCMs are used to predict future local climate variables.

Advantages of statistical downscaling are that it is computationally inexpensive and efficient. This allows many different emissions scenarios and GCM pairings. The statistical downscaling methods are also simple and flexible enough to be applied for specific purposes. Also the disadvantages of statistical downscaling are that high quality observed data may be unavailable for many areas and it assumes that relationships between large and local-scale processes will remain the same in the future (Wilby *et al.*, 2004). Stationary assumption is also the main drawback of statistical downscaling in addition to the large amount of recorded data required.

2.5.2 Dynamical Downscaling

Until recently, most hydrological impact studies were based on GCM simulations. However, as the resolution of these models was, and still is, much coarser than the typical catchment size, downscaling is necessary. Instead of the traditionally used statistical downscaling, the ‘nested’ RCM approach allows a dynamic downscaling to capture climate processes at local scale (Claudia and Jan, 2010). These are capable of achieving spatial resolutions of about 0.5 (longitude, latitude) and can simulate regional climatic features including orographic precipitation and extreme climate events (Mohobane, 2015).

The basic steps to use the GCMs to simulate the response of the global circulation to large-scale forcing and the nested RCM to account for sub-GCM grid scale forcing such as complex topographical features and land cover heterogeneity in a physically-based way, and thus enhance the simulation of atmospheric circulations and climate variables at fine spatial scales.

Advantages of dynamic downscaling are that it is based on consistent physical mechanisms and the fact that it resolves atmospheric and surface processes occurring at sub-GCM grid scale. Dynamic downscaling is also not constrained by historical records so that scenarios can be simulated and the experiments involving an ensemble of RCMs are becoming available for uncertainty analysis (Wilby *et al*., 2004). However, it has its own setbacks such as being computationally intensive which cause it to be typically driven by only one or two GMC/emission scenario simulations. The other disadvantages are that a limited number of RCMs are available and there are no model results for many parts of the globe.

2.6 Bias Correction Methods

Regional Climate Models (RCMs) are an important source of climate input for climate impact studies. However, Outputs from RCMs are subject to systematic biases. Nowadays, modelers are aware of the uncertainty involved in modeling, and the necessity to quantify the model output reliability (Terink, 2010). Christensen *et al*. (2007) state that one inherent source of uncertainty comes from the RCM’s inability to simulate present day climate conditions accurately. Therefore it is of major importance that RCM output is validated with historical observations. Biases in climate model simulations are commonly detected by validation (i.e., comparison) with observations where the observations were considered to be “true” and unbiased (Ménard, 2010). Applying a bias correction to the RCM data often seems necessary to match the RCM data with the observations (Shabalova *et al*., 2003). Sahilu and Nigussie, (2015) confirmed that bias correction satisfactorily compensate any tendency to overestimate or underestimate the mean of downscaled variables.

In various researches different bias correction methods have been applied to nudge the projected climate variable to make a better comparison with the observed data. The delta change approach and the linear transformation are the two most common transfer methods and have been widely used (Graham *et al*., 2007; Sahilu and Nigussie, 2015), since they are straightforward and easy to implement due to their simplicity. 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.

Several techniques are available to create an interface for translating RCM output variables to hydrological models. For instance, precipitation and temperature can be bias-corrected by applying one of the following methods (Claudia and Jan, 2010):

a) The simpler techniques such as; Precipitation threshold, Scaling approach, linear transformation and Power transformation.

The simpler techniques are less computationally demanding, but aim only at preserving monthly mean values.

b) The advanced procedures such as; Distribution transfer, Precipitation model and Empirical correction. The advanced procedures are more computational demanding, but are also able to conserve standard deviation or day-to-day and seasonal variability.

The general climate change signal (i.e. differences between control and scenario runs) simulated by the RCMs is usually preserved. Most bias-correction procedures are limited to regions with existing weather stations and rely on the fact that the correction procedure and its parameters are valid for larger areas.

The delta-change approach is an alternative to the direct use of RCM simulations. RCM-simulated changes between control and scenario runs are superimposed upon observational precipitation and temperature time series.

2.7 Trend Analysis of climatic data

Trend is a unidirectional gradual increasing or decreasing in the average value of a variable (Karamouz *et al*., 2003). This is observable in hydrologic system because natural and human factors cause variation in systems causing non stationary time series. In water resources planning and management it is necessary to quantify these trends.

Climate change is likely to accelerate the global hydrological cycles, and a greater increase is expected in extreme rainfall as compared to the mean (Kundzewi and Robson, 2004). In fact, temperature, evapo-transpiration and rainfall changes mainly influence the distribution of river flows and groundwater recharge. According to Kinfe (1999) report for Awash River basin; the projection of GFD3 showed a 5% increment in precipitation, while CCCM indicate a 2% decrease with the doubling of CO_2.

With respect to climate variability and change impact on water resources, recent detected decreasing trend in water resources will continue in the future due to warming and rainfall declines (Alenender and Genev, 2003) and a decrease in runoff is expected for 2050. Temperature and rainfall are fundamental components of climate, and so, the analysis of changes in these climatic variables characterizes key task in detecting climatic changes.

There are many approaches that can be used to detect trends in hydrological data. The choice of approach should however be based on the validity of the test procedure .Wilcoxon signed rank test and Mann-Kendall trend test are common method to detect trends in climatic data (Jain and Kumar, 2012).

The Wilcoxon signed rank test is a statistical test for assessing the significance of a difference in two data sets. The paired data sets are naturally linked. The test sums up the ranks of the positive differences and also the ranks of the negative differences. If the mean rank for the positive differences is greater than that for the negative differences it means that period 2 has more higher values compared to those of period 1 and vice versa (Jaagus, 2006).

The Mann–Kendall trend test is a commonly used non-parametric test to detect trends in hydro meteorological time series. The test compares the relative magnitudes of sample data rather than the data values themselves. The advantages of this test are that the data does not need to conform to any particular distribution and it is less sensitive to sudden breaks due to inhomogeneous time series (Jaagus, 2006).

2.8 Hydrological Models

Nowadays, it seems hard to deal with problems of environment and water resources without applying some kind of watershed models (Milad *et al*., 2012). In fact, watershed models are the main tools in environmental and water resource problems such as water resource development, planning and management watersheds (Milad *et al*., 2012). Hydrological models represent part of the hydrological cycle. The features of a basin like geography, geology and land use have a significant role in specifying the quantity, quality and timing of stream flow. Topography, land use/land cover and soil are the main physical parameters which determine the amount of precipitation that translates to runoff or stream flow. These parameters are mostly used for understanding the hydrologic processes in a certain catchment. Temperature and precipitation are the most crucial climatological inputs that are essential for the calibration and validation of hydrological models.

2.8.1 Classification of hydrological modeling

There are many hydrological models with unique and common characteristics that are being developed day by day (Milad *et al*., 2012). Proper classification can be helpful for engineers, experts and researchers to understand the characteristics of models before deciding to employ them for their works.

Hydrologic models are classified based on different criteria however the most convenient classification distinguishes between empirical, conceptual and physically-based models. Empirical models use statistical relationship to relate climate inputs to hydrological properties such as a regression analysis. The physical-based or water balance model uses equations to simulate the movement of water throughout the system until it leaves. On the other hand, the conceptual model attempts to give an idealistic representation of the catchment determining the water balance at different time scale through the use of parameters. They are further classified as either lumped or distributed. Different views make the diversity of hydrological models classifications to come under four basic terms, namely simulation basis, spatial presentation (Lumped and Distributed), temporal presentation and method of solution (Abdella, 2013). These categories show the comprehensive and explicit perspective of classifications for hydrological models.

2.8.2 Selection criteria for hydrological models

Currently, there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. Although there are no clear rules for making a choice between models, some simple guidelines can be stated (Abdella, 2013). However, one of the most important things that should be considered during hydrological model selection is availability of input data to model the watershed. Subsequently the simplest method that can provide the answer to the questions has to be chosen. In particular it's necessary to identify the simplest model that will yield adequate accuracy. There are numerous criteria which can be used for choosing the right hydrologic model. These criteria are always project-dependent, since every project has its own specific requirements and needs. Among the various project-depended selection criteria, there are four main common, fundamental ones that must always be considered (Haileyesus, 2011):

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?
2. Hydrologic processes that need to be modeled to estimate the desired outputs adequately – is the model capable of simulating regulated reservoir operation, single event or continuous processes?
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?

A watershed model can be used to better understand the relationship between climate change and water quantity process occurring within a watershed. There are numerous models that can continuously simulate stream flow, sediment, and nutrients loading from watersheds. Some of the most important and widely used models are AGNPS (Agricultural Nonpoint Source; Young *et al.*, 1989), GWLF (Generalized Watershed Loading Function Model; Haith and Shoemaker, 1987), HSPF (Hydrologic Simulation Program-Fortran; Bicknell *et al*., 1996) and SWAT (Soil and Water Assessment Tool; Arnold et al., 1994). All models have different strengths and limitations.

SWAT is one of the most frequently used conceptual model for climate change impact study assessment. It is a physically based, semi-distributed and continuous time-step hydrologic model that is used for rainfall-runoff modeling as well as for predicting the impacts of land use and land management practices and climate change on the hydrology, water quality and quantity of watersheds or river basins. SWAT has been successfully applied to many parts of the world and proved to adequately reproduce hydrological processes of watersheds across a range of geographical regions and climates (Fengping *et al.*, 2016). The application of SWAT in predicting stream flow and sediment as well as evaluation of the impact of land use and climate change on the hydrology of watersheds has been documented by various studies (Anwar *et al*., 2015; Zelalam, 2016; Yitea, 2015; Yehun *et al*., 2009). The simulated water balance are compared with the observed discharge to evaluate the change. This assessment was accomplished through the use of hydrological model SWAT.

2.9 Related Studies in Ethiopia

Despite the increasing trend of both climatic variables in the future, the increase in monthly average precipitation seems to be obscured by increases in monthly average temperature. The impact of temperature on the hydrological process by increasing Evapotranspiration and thereby reducing the inflow volume. As a result, the total average annual inflow volume into Lake Ziway might decline significantly up to 19.47% for A2a- and 27.43% for B2ascenarios. The decreasing trend of the average annual inflow volume is mainly associated with the decrease in the *Kiremt* inflow volume by between 11.8 and 28.4% for the A2a scenario and between 16.5 and 27.8% for the B2a scenario (Zeray, 2006).

Meresa and Gatachew, (2016) assesses the expected climate change impact on hydrology extremes of selected catchments from the upper Blue Nile river basin and its implication on the water resource management and planning. They used seven CORDEX Regional Climate Model future projection runs for this purpose based on the CMIP 5 RCP 2.6, RCP 4.5, and RCP 8.5 scenarios. The run results for daily rainfall, and minimum and maximum temperatures were bias corrected against observed data using the distribution based quantile mapping. They conclude that in most areas of northern, western, and northeastern part of the river basin; climate change may have favorable impacts on the distribution of hydrological extremes in the study area.

Also Tarekegn & Tadege, (2006), assessed the impact of climate change on water resources of Lake Tana-sub basin. The result shows that if the temperature is increased by 2^0 C and there is no change in rainfall the mean annual flow will be decreased by 11.3%. But if the rainfall is decreased by 10% and 20% the decrease in runoff will be 29.3% and 44.6% respectively. On the other hand, if the rain fall is increased by10%and 20%, the mean annual runoff will increase by 6.6% and 32.5%respectivly. And it was concluded as the basin is more sensitive to change in rainfall than temperature

3. MATERIALS AND METHODOLOGY

3.1 Description of the Study Area

The study area, upper Awash sub-basin is one of sub-basin of Awash River basin. It is located in the Oromia Regional State and Upper part of Awash River Basin. The sub-basin is located in the western highland part of the basin and covers part of the basin above Hombole, including the capital city Finfinne (Figure 3.1). Awash River rises on the high plateau near Ginchi town west of Finfinne and flows along the rift valley into the Afar triangle, and terminates in salty Lake Abbe on the border with Djibouti. The total length of the main course is 1,200 km (Tamirat and Adane, 2016).

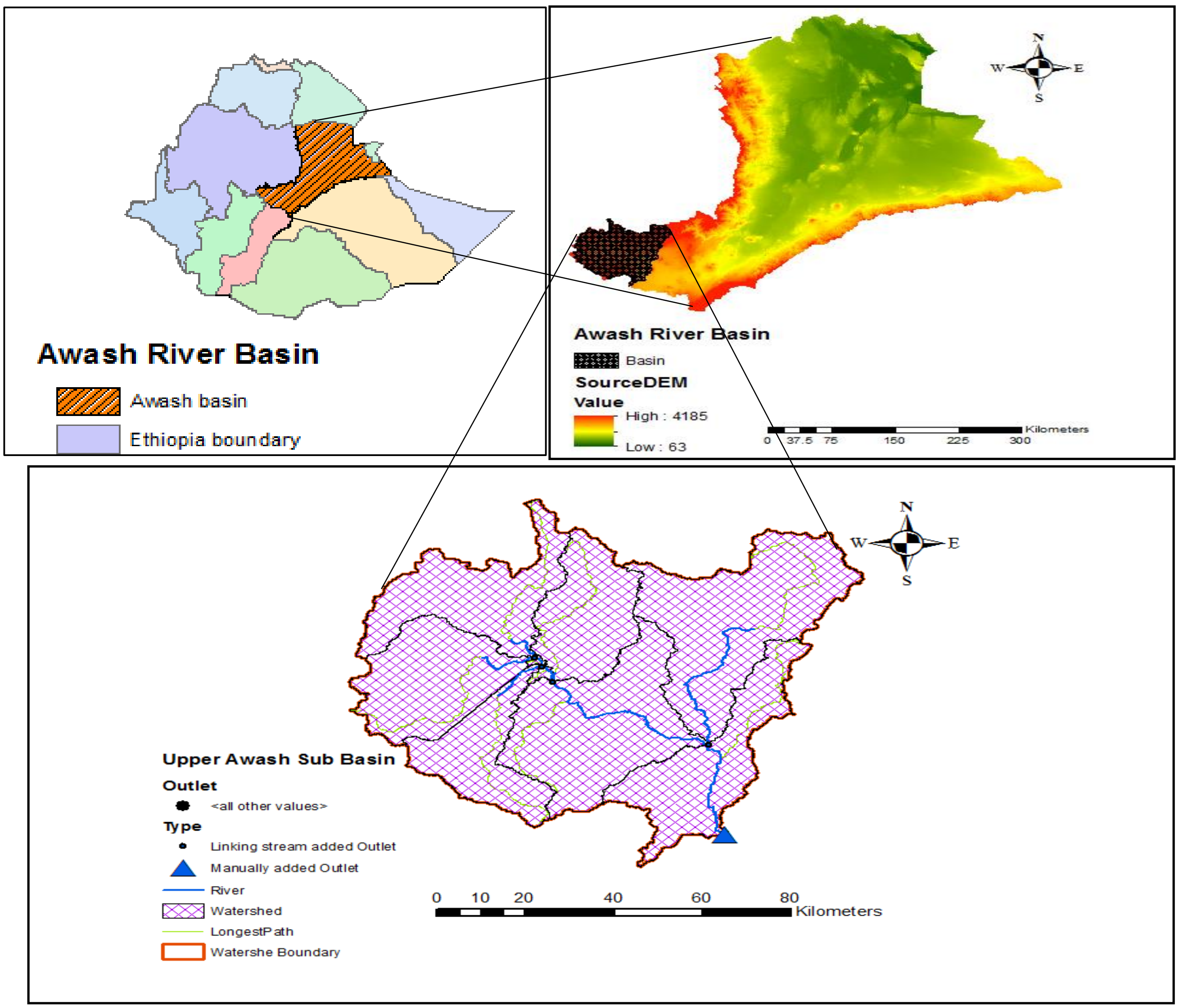


Figure 3.1 Location of upper Awash sub-basin

Based on physical and socio-economic factors, Awash basin is divided into four distinct zones. These are; Upper Basin (Headwaters to Koka Dam), Upper Valley (Koka Dam to Awash station), Middle Valley (Awash station to Gewane) and Lower Valley (Gewane to lake Abe). The Upper Awash sub basin covers 7285 km^2 area stretching from the headwaters to the Hombole gauging station.

3.1.1 Topography

The physical settings of the study area are characterized by the heterogeneity of the large natural systems such as orographic groups, the high plains, mountains and plateaus. Based on physical and Socio-economic factors the Upper Awash Basin is topographic level of all lands above 1500 m (Yitea, 2015). The area lies next to the northeast of Rift Valley Lakes Basin and the topographical elevation decreases toward the northeast in general. Relatively, the most utilized river basin and the only river entirely in the country, Awash River covers parts of the Amhara, Oromia, Afar, Somali regional states, Dire Dawa, and Finfinne City administrative states of the country.

3.1.2 Climate

The climate of the Awash basin is humid to sub-humid in the highlands and semi-arid to arid in the rift valley. The climate of the Awash Basin comes under the influence of the Inter-Tropical Convergence Zone (ITCZ). This zone of low pressure marks the convergence of dry tropical easterlies and the moist equatorial westerlies. The seasonal rainfall distribution within the basin results from the annual migration of the ITCZ. The ITCZ starts its advance across the basin from south in March, bringing the small- or spring – rains. In June and July reaches its most northerly location beyond the basin, which then experiences the heavy or summer rains throughout. The ITCZ returns southwards during August, September and October, restoring a drier, easterly air stream that prevails until the ITCZ resumes its northward migration in March. The distribution of rainfall over the highland areas tends to be modified by orographic effects.

Annual rainfall ranges from 850mm to 1000mm in the plain area and amounts in the mountains of Upper Awash River basin respectively. Mean annual temperature is about 15°C in the highlands and around 21°C in the lowlands. The rainfall shows strong altitudinal variations. The Sub-basin receives approximately 70% -75% of its annual rainfall during the wet season (Figure 3.2) which covers the months June–September (Dilnesaw *et al*., 2007).

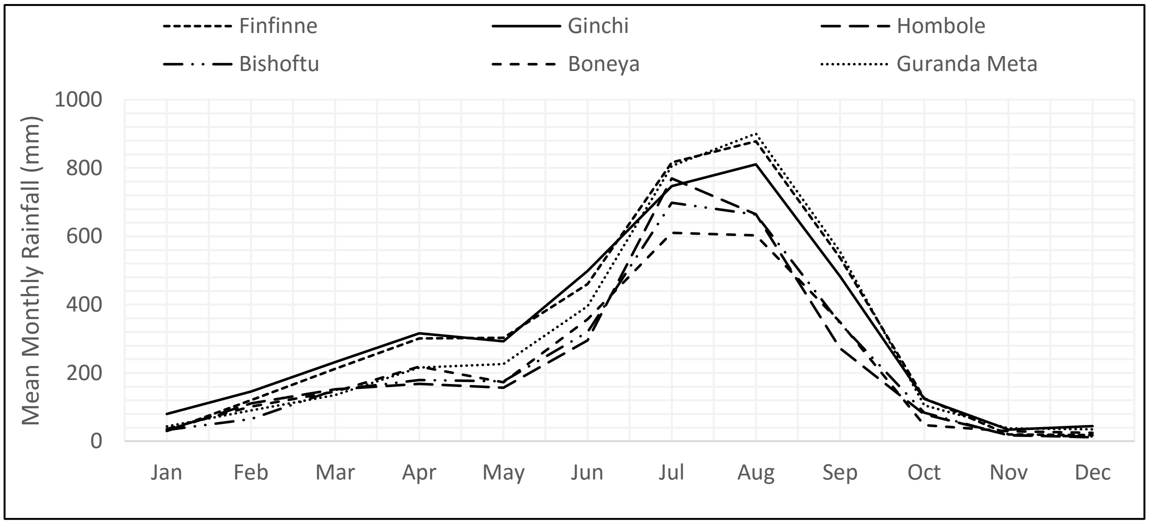


Figure 3.2 Mean monthly rainfall pattern in upper Awash sub basin

3.1.3 Hydrology

The total annual surface water resource potential of the Awash river basin according to previous studied by Kinfe, (1999) is estimated to be about 4640 MCM. Awash is fed by several major tributaries at the upper, middle and lower parts of the basin. Ginchi, Berga, Holleta, Bantu, Leman, Akaki, Mojo and Hombole are the major tributaries of the upper Awash and contribute an annual flow of about 1600 MCM. Arba I, Arba II, Keleta,Kesem, Najeso and various other small perennial tributaries contribute an annual flow of about 2960 MCM to the middle Awash. Logia is another tributary of Awash which adds an annual flow of about 80 MCM to the lower Awash (Kinfe, 1999).

3.1.4 Land use Land cover

Land use is one of the main factors affecting surface erosion and evapotranspiration in a watershed**.** The Upper Awash River Basin comprises a combination of open grasslands, rain-fed and irrigated croplands (Agricultural land), water bodies, forest, shrub lands, wetland and Urban (Figure 3.3).

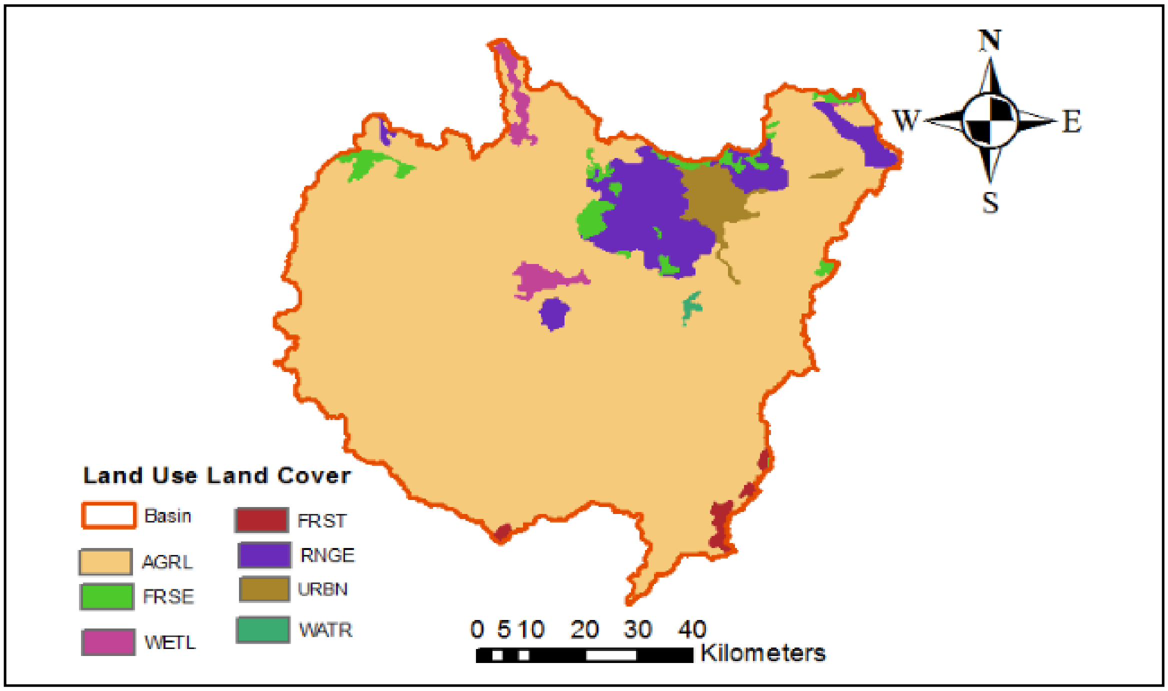


Figure 3.3 Land use land cover types of upper Awash sub basin

According to SWAT land use classification, Agricultural (Cultivation) is the dominant Land use within the area of study. About 59.45 % of the total land within the watershed is Agricultural (cultivation) land. Land use of the study area has changed over time (Yitea, 2015) due to over increasing population density, changing agricultural practices, urbanization and water related infrastructure such as irrigation and hydropower production.

3.1.5 Soil Type

According to the FAO/UNESCO soil classification system the study area comprises of Seven major soil types such as Euric Nitosol, Pellic Vertisols, Orthic Luvisols, Vertic Camibsol, Leptosoils , Eutric fluvisols and Eutric Cambisols (Figure 3. 4).

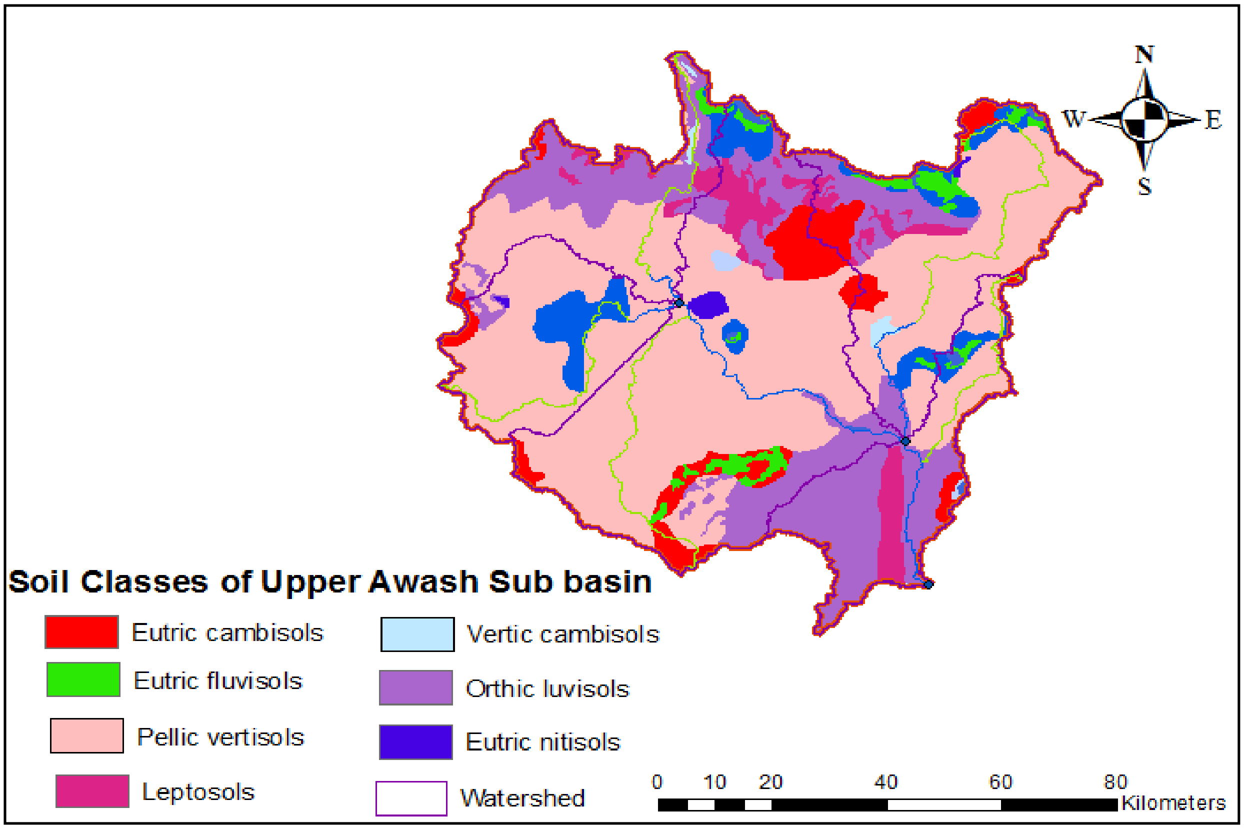


Figure 3.4 Soil classes of upper Awash sub basin

The Nitosols are found in the upland areas, whereas the Cambisol and Luvisol are found in the escarpment and Vertisols are found in most part of areas. Vertisols are the dominant soil class and cover about 57.2 % of the total land within the watershed.

3.2 Methodology

3.2.1 Data Collection and Processing

3.2.1.1 Meteorological, Hydrological, and Spatial datasets

A daily continuous observed meteorological datasets for a period of 30 years (1985-2014) for rainfall, maximum and minimum temperature, relative humidity, wind speed and solar radiation of six representative station found in watersheds (Finfinne, Bishoftu, ,Boneya ,Hombole ,Guranda Meta and Ginchi were collected from Ethiopia national meteorological agency (NMA). The future climate datasets for the period 2006 to 2100 were obtained from CORDEX Africa data repository. Simulated monthly rainfall, minimum and maximum temperature from the CORDEX models were used in this study.

For hydrological modelling of the watershed, stream flow datasets of Hombole gauging station from (1997-2010) and GIS datasets were collected from Hydrology and GIS department of ministry of Water, Irrigation and Electricity (MoWIE) respectively.

3.2.2 Estimating the missing data

While working with hydrological models, it is common to encounter missing weather data values from observed records for so many reasons. It is very essential to fill in the missing data when a hydrological basin analysis needs a continuous data. Also in climate studies it is common to check the gaps in the time series of precipitation and temperature before filling the missed data. Simple mathematical equation was applied to quantify the total percentage of missed values from the total data series as follows.

$$\%\text{ of missed data} = \left[\frac{X_1}{X_2}\right] * 100 \qquad (1)$$

Where, X_1 is count of missed data

X_2 is whole data set

To perform meteorological analysis and simulation using data of long time series, filling in missing data is very essential. In this study two methods was applied to fill the missing values; Arithmetic mean method (for the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation of station with missed data) and the normal – ratio (for the surrounding gauges have the normal annual precipitation exceeding 10% of the gauge with missed data) for rainfall.

3.2.3 Data Consistency and Homogeneity test

After filling missed rainfall data, consistence and homogeneity of recorded rainfall data was checked. In this study, double mass curve method was used to check the consistency of the data (Figure 3.5) by comparing data for a single station with that of a pattern composed of the data from other stations. The data of the annual rainfall of the doubtful station and the average rainfall of the group of base stations covering a long period was arranged in the reverse chronological order. The cumulative values of the doubtful stations were plotted against the cumulative average group.

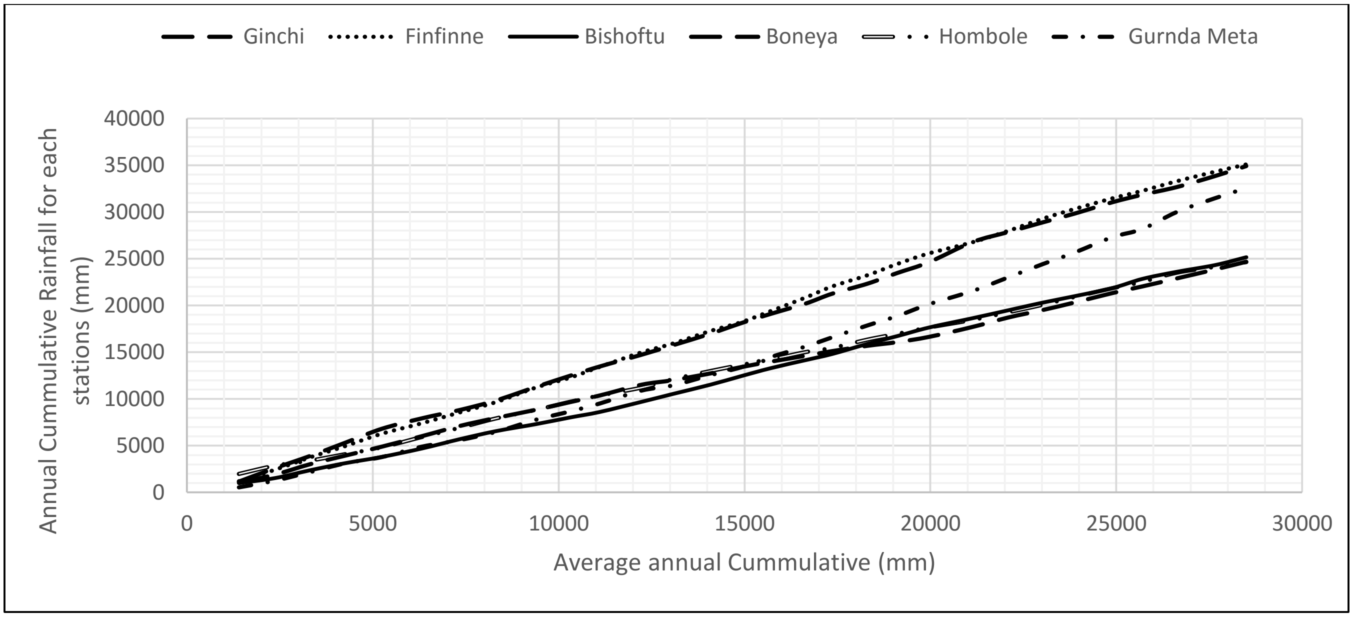


Figure 3.5 Double mass curve for six representative meteorological station of upper Awash sub basin

Rainbow software package, which was produced by K.U.Leuven University for analyzing climatological/hydrological data frequency analysis, was used for checking homogeneity test. In RAINBOW the test for homogeneity is based on the adjusted partial sums or cumulative deviations from the mean (Buishand, 1982). The rainfall and stream flow data has been tested for homogeneity at different significance levels and it is found to be generally homogeneous.

3.2.4 Estimation of average Areal Rainfall over Upper Awash Sub Basin

The area weighted average method was used to calculate the average rainfall from the CORDEX RCMs received by the entire catchment. Average rainfall and temperature were also considered for the stream flow projection. The weighing area of recorded rainfall station was done by Thiessen polygon method using Arc GIS to investigate areal contribution of each station (Figure 3.6). In this method, the data at each station is weighted based on the corresponding polygon area fraction and this weighted values gives the rainfall *Pi* in that area *Ai* represented by the polygon. The areal average rainfall *P* of the entire area A derived from *n* stations is then calculated as:

$$P_{ave} = \frac{P_1A_1+P_2A_2+ P_3A_3+\cdots+P_nA_n}{A_1+A_2+A_3+\cdots+ A_n} \quad (2)$$

Where, P1, P2 and Pn are rainfall recorded by the stations 1, 2 and 3 respectively and A1, A2 and A3 are respective areas of the Thiessen polygon and n is the number of stations.

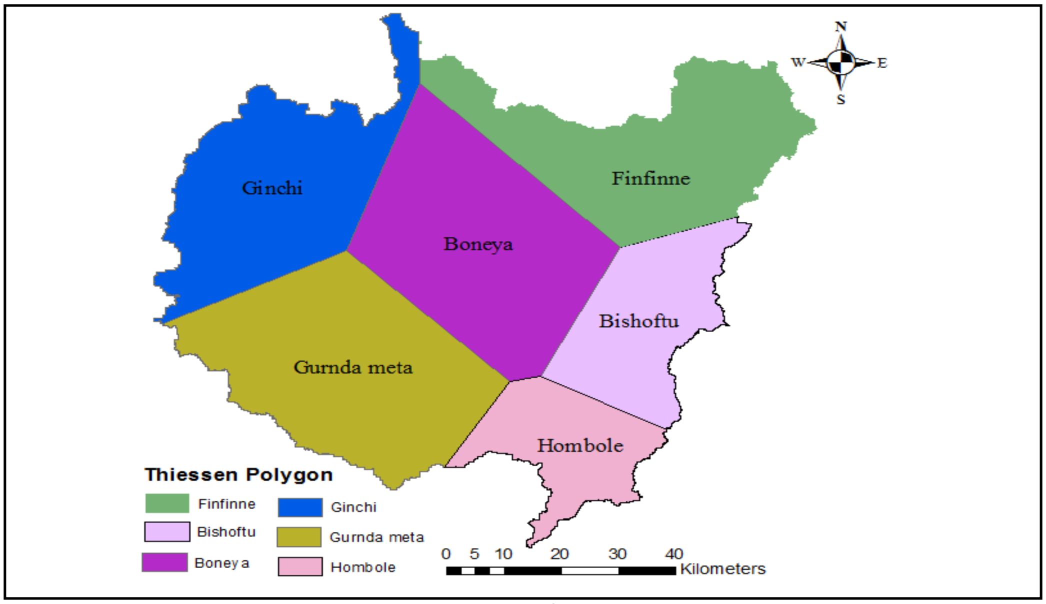


Figure 3.6 Thiessen polygon for upper Awash sub basin

3.3.2 Trend Analysis of Rainfall and Temperature

The precipitation and temperature time series were subjected to normality tests to determine whether the data was normally distributed or not. This is very important because it helps to choose whether to use parametric tests or non–parametric tests for the trend analysis.

3.3.2.1 Mann-Kendall test (M-K)

The Mann-Kendall trend test was used to test for the presence of trends in the precipitation and temperature data. The null hypothesis being that there is no trend in the time series whilst the alternative hypothesis was that there is a trend in the time series. The Mann-Kendall trend tests were performed in XLSTAT. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Yue and Wang, 2004). The MK test was commonly applied to detect significant trends in hydro-meteorological time series and is highly recommended by the World Meteorological Organization (WMO) (Jain and Kumar, 2012). The tests were carried out at 5 % level of significance. The major variables for test interpretation were the p-value and the Sen's slope. The Mann-Kendall test statistics was given as follows (Jain and Kumar, 2012).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(Xj - Xk) \qquad (3)$$

Where S is the Mann-Kendal's test statistics which is any integer between $-n\left(\frac{n-2}{2}\right)$ and $n\left(\frac{n-1}{2}\right)$ **,** X_j and X_k are the sequential data values of the time series in the year's *j* and *k*

(k > *j)* and *N* is the length of the time series. A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The sign function was given as:

$$\text{Sgn } (X_j\text{-}X_k) = \begin{cases} 1 \text{ if } (\text{Xj} - \text{Xk}) > 0 \\ 0 \text{ if } (\text{Xj} - \text{Xk}) = 0 \\ -1 \text{ if } (\text{Xj} - \text{Xk}) < 0 \end{cases}$$

For n > = 10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0 \tag{4}$$

$$\sigma^2 = \text{n}\left(\frac{\text{n}(\text{n}-1)(2\text{n}+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18}\right) \tag{5}$$

Where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and ti is the number of data points in the i^{th} group.

Under this situation the standardized Z test was given as;

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \tag{6}$$

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

Trend analysis of representative stations in Upper Awash sub-basin has been done for six rainfall station at annual and monthly time series for period of 1985-2014 and four station temperatures (maximum and minimum) (1985-2010 for three station and 1985-2014 for one station) at annual time series. Mann Kendall and Sen's slope estimator has been used for the determination of the trend.

3.2.3 Evaluation of the future climate change scenarios over the Upper Awash sub basin

Different models have their own strengths and weaknesses (Endris *et al.*, 2013). To achieve this specific objective, the performance of each model used in the study was evaluated against observation. An ensemble of the models was also computed and its performance evaluated together with the models against the observation. The climate data of high resolution regional climate models obtained from CORDEX-Africa database was used in this study. The driving model or GCMs are selected depending on the previous literatures or analysis that takes place over the Awash River Basin (Kinfe, 1999) and Upper Awash River Basin (Yitea, 2015; Daba ,2014). Accordingly, CNRM-CM5, EC-EARTH and MPI-ES-LR driving model was selected and the downscaling was accomplished by the latest version of regional climate model CCLM4. Outputs from models were evaluated against observations using some of the statistical measures recommended by the World Meteorological Organization (WMO). These statistics include bias, root mean square error and coefficient of variation.

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(Fi - Oi) \qquad (7)$$

$$\text{RMSE}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Fi - Oi)^2} \qquad (8)$$

$$\text{Correl} = \frac{\sum_{i=1}^{N}(Fi-Fmean)(Oi-Omean)}{\sqrt{\sum_{i=1}^{N} Oi-Omean)^2}\sqrt{\sum_{i=0}^{N}(Fi-Fmean)^2}} \qquad (9)$$

Where, F and O are the simulated and observed values respectively, while *i* refers to the simulated and observed pairs and N is the total number of such pairs.

3.2.3.1 Bias Correction for climate Data obtained from Climate Models

Bias correction is usually needed as climate models often provide biased representations of observed times series due to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. The reliability of the spatially distributed model output is strongly dependent on the quality of the climate forcing data. Christensen et al. (2007) state that one inherent source of uncertainty comes from the RCM's inability to simulate present day climate conditions accurately. Therefore, it is of major importance that RCM output is validated with historical observations, before calibrating the hydrological model with the RCM data. Bias correction was applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables. For this study Delta change method was used for post processing and bias correction of RCMs output for further impact analysis.

The delta-change approach is an alternative to the direct use of RCM simulations and it is one of the most widely and commonly used correction methods for RCMs scenarios of future conditions for climate change impact studies (Shabalova *et al.*, 2003, Sahilu and Nigussie, 2016). The average monthly precipitation/temperature is corrected to match the average monthly precipitation/temperature for 20 years. The formulas used for rainfall and temperature bias correction are indicated in Equations 10 and 11, respectively.

$$p_{bc} = P_p \frac{P_o}{P_r} \qquad (10)$$

$$T_{bc} = T_P + T_o - T_r \qquad (11)$$

Where, P_{bc} is Bias corrected future rainfall amount in mm:

P_P is predicted future rainfall amount in mm;

P_o is mean of observed rainfall amount in mm:

Pr is mean of computed historical rainfall during the observation period in mm.

T_{bc} is Bias corrected future temperature in ^{0}C;

T_p is predicted future temperature in ^{0}C;

T_o is mean of observed temperature in ^{0}C;

T_r is mean of computed historical temperature during the observed period in ^{0}C.

3.2.4 SWAT Model Description and Setup

3.2.4.1 Description of SWAT model

SWAT is a physically based, computationally efficient, semi distributed watershed model and is designed to simulate and predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Ling et al., 2016). In addition, SWAT is capable of assessing the impacts of climate change on hydrologic response and agricultural activities by adjusting climatic variables based on future projections. Moreover, the model has been widely used in different catchments across the world and proved to be an effective tool to examine hydrological responses to land-use and climate changes (Shi *et al*., 2013).

In SWAT, the target watershed is divided into sub basins linked by the channel network, which are further subdivided into a number of hydrological response units (HRUs) of homogeneous land use, slope, management and soil characteristics. The HRUs represent percentages of the sub watershed area and are not identified spatially within a SWAT simulation.

The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile, shallow aquifer, and deep aquifer. The soil profile is subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. Flow, sediment, nutrient, and pesticide loadings from each HRU in a sub watershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet.

3.2.4.2 Simulation of stream flow for Upper Awash Sub Basin

During simulation of stream flow ArcSWAT breaks preprocessing into four main steps: Watershed Delineation, Hydrologic Response Unit (HRU) Analysis, Weather Data Definition and SWAT simulation including sensitivity analysis and calibration. The conceptual framework of each step as shown (Figure 3.7), as well as what data are used and how they are integrated into Arc SWAT.

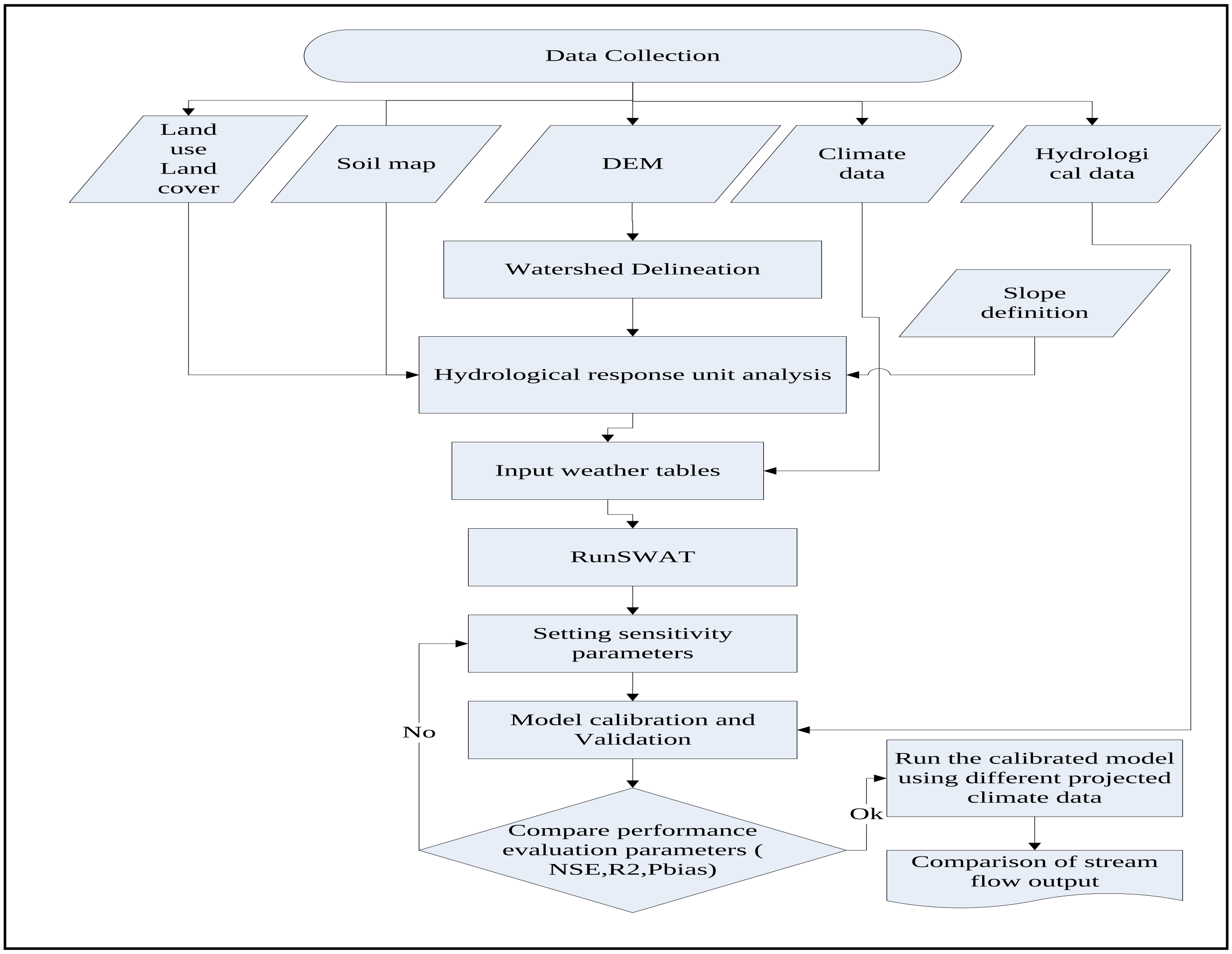


Figure 3.7 Conceptual frame work of ArcSWAT for stream flow simulation

3.2.4.3 SWAT Model Inputs

The SWAT model works with spatial and temporal data. Spatial data include elevation, soil type, and land use/land cover. For this study the digital elevation model (DEM) data with a resolution of 30mx30m was collected from Ethiopian Ministry of Water, Irrigation and Energy (MOWIE). To delineate the watershed Digital Elevation Map (DEM) grid, mask grid and digitized stream network files were loaded using the watershed delineation tool.

Land use and land cover was also one of the most important spatial input data in SWAT model that affect water runoff, evapotranspiration, surface erosion and other hydrological process in a given watershed. The land use/land cover map of the study area was collected from GIS department, Ethiopian Ministry of Water, Irrigation and Energy (MOWIE) which was obtained in shape file format. The land use/cover data was reclassified according to the SWAT land use/cover type.

Soil data are another spatial input required by SWAT model. SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. Basic physical and chemical properties of major soil types in watershed were collected from the Ministry of Water and Energy (MoWIE).

The temporal input data for the model are meteorological datasets and stream flow data. For this study, the meteorological data elements such as daily precipitation, minimum and maximum air temperature, Relative humidity, wind speed and sunshine hours for thirty years (1985-2014) of six representative weather stations (Finfinne, Bishoftu, Hombole, Ginchi, Boneya and Guranda Meta) were obtained from the National Meteorology Agency (NMA). Station those have missing meteorological data values were filled using weather generator model (WXGEN). Finfinne stations was used as weather generator station. Other parameters required in user weather generator were calculated using pcpSTAT.exe and dew02.exe computer program. PcpSTAT.exe is a computer program used to calculate statistical parameters of daily precipitation data used by weather generator of the SWAT model and the other weather parameters such as average daily dew-point temperature and humidity was calculated using dew02.exe computer program.

Stream flow are another temporal input data required by SWAT model. Stream flow data of the Hombole gauging station from (1995-2013) was collected from Ministry of Water, Irrigation and Electricity (MoWIE) and were used for performing calibration and validation of the model.

3.2.4.4 Hydrological Components of SWAT Model

SWAT uses two steps for the simulation of hydrology; land phase and routing phase. The land phase is the phase in which the amount of water, sediment, nutrient and pesticides loadings in the main channel from each sub basin are calculated.

In SWAT, the hydrologic cycle simulation is described by the water balance equation which is given as (Neitsch et *al*., 2011);

$$SWt = SW_o + \sum_{i=1}^{n}(Rday, i - Qsurf, i - Eact, i - Wseep, i - Qlat, i) \quad (12)$$

Where;

SWt is the final soil water content (mm water); *SWo* is the initial soil water content on day *i* (mm water); *Rday* is the amount of precipitation on day *i* (mm water); *Qsurf* is the amount of surface runoff on day *i* (mm water); *Eact* is the actual evapotranspiration on day *i* (mm water); *Wseep* is the amount of water entering the vadose zone from the soil profile on day *i* (mm water); Q_{lat} is amount of return flow on day *i* (mm water) and *t* is the time (days).

SWAT uses the concept that surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. Based on this assumption, SWAT uses two methods for estimating surface runoff: the Soil Conservation Service Curve Number technique (USDA Soil Conservation Service, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911). In the Soil Conservation Service (SCS) curve number method often called the Curve-Number (CN) method, land use and soil characteristics are lumped into a single parameter.

Since sub-daily rainfall data was not available in study area that can be used for Green and Ampt infiltration method, modified Soil Conservation Service curve number equation (USDA, 1972) has been used to estimate the surface runoff of the catchment. The SCS curve number method is simple, widely used and efficient for determining the approximate amount of runoff from a rainfall event under a varying land use and soil types.

The SCS curve number equation is (SCS, 1972):

$$Q=\frac{(R-0.2S)}{R+0.8S} \qquad R > 0.2S \qquad (13)$$

$$Q=0 \qquad R<0.2S \qquad (14)$$

Where *Q* is the daily surface runoff (mm), *R* is the daily rainfall (mm), and *S* is a retention Parameter. The retention parameter, *S*, varies (a) among watersheds because soils, land use management, and slope all differ from each other and (b) with time because of changes in soil water content. The parameter *S* is related to curve number (*CN*) by the SCS equation

$$S=25.4\left(\frac{100}{CN}-10\right) \qquad (15)$$

SWAT calculates the peak runoff rate with a modified rational method. The rational formula is given by:

$$q=\frac{CIA}{3.6} \qquad (16)$$

Where: q: is the peak runoff rate (m3/s), C- is the runoff coefficient, i- is the rainfall intensity (mm/hr), A- is the sub basin area (km^2) and 3.6 is a unit conversion factor.

The second division is the water or routing phase of the hydrological cycle which is the movement of water, nutrients, sediment and pesticides through the channel network of the watershed into the outlet.

Most of the water in the earth's surface is removed by evapotranspiration. Roughly 62% of the precipitation that falls on the continents is evapotranspired (Neitsch et al., 2005). Hence accurate estimation of Evapotranspiration is vital in the assessment of water resources and the impact of climate and land use on these resources. SWAT uses the Penman-Monteith method, the Priestley-Taylor method, and the Hargreaves method for the estimation of potential evapotranspiration .The Penman-Monteith method requires solar radiation, air temperature, wind speed and relative humidity. Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only. In this study Penman Monteith method (Monteith 1965) was applied to estimate the PET.

3.2.4 SWAT Model Setup

3.2.4.1. Watershed Delineation

The first step in creating SWAT model input was delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. The SWAT model provides three spatial levels: the watershed, the sub basins, and the hydrologic response units (HRUs). Each level was characterized by a parameter set and input data. The largest spatial level, the watershed, refers to the entire area being represented by the model. The watershed and sub watershed delineation was done using DEM data. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub basin. The ArcSWAT interface allows the user to fix the number of sub basins by deciding the initial threshold area. The threshold area defines the minimum drainage area required to form the origin of a stream.

3.2.4.2 Hydrologic Response Units

The land area in a sub basin was divided into Hydrologic Response Units (HRU). Hydrologic response units (HRUs) are lumped land areas within the sub-basin that are comprised of unique land cover, soil and management combinations. The Hydrologic Response Units (HRUs) Analysis tool in Arc SWAT helps to load land use and soil layers to the project. The delineated watershed by Arc SWAT and the prepared land use overlapped analysis in Arc SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this study a 10% threshold value for land use, 15% for soil and 20 % for slope were used.

3.2.4.3 Sensitivity analysis

The determination of the most sensitive parameters is the key, and first step, for model calibration and validation at the watershed scale. Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Sensitivity analysis determines the sensitivity of the input parameters by comparing the output variance due to the input variability and carried out to identify the sensitive parameters of the SWAT model. The sensitivity analysis is done by varying parameters value and checking how the model reacts.

Generally, twenty hydrological parameters related to stream flow (Table3.1) were considered for sensitivity analysis. These parameters were selected from previous studies done in Upper Awash River basin (Zelalem, 2016; Daba, 2014; Kinfe, 1999).

Table 3.1 Selected parameters for sensitivity analysis

No.	Parameter	Description	Min	Max	Category
1	r__CN2	runoff Curve Number	35	98	.mgt
2	v__ALPHA_BF	Base flow alpha factor (days)	0	1	.gw
3	v__GW_DELAY	Ground water delay (day)	30	450	.gw
4	a__GWQMN.gw	Deep percolation(mm)	0	25	.gw
5	r__SOL_K	Soil depth (mm)	-0.8	0.8	.sol
6	v__RCHRG_Dp	Deep aquifer percolation fraction	0	1	.gw
7	a__ESCO.hru	Soil evaporation compensation factor	0	0.2	.hru
8	r__SLSUBBSN	Average slope length	0	0.2	.hru
9	r__HRU_SLP	Average slope steepness	0	0.2	hru
10	v__CH_N2	Manning coefficient of tributary channel	0	0.5	.rte
11	v__CH_K2	Hydraulic Conductivity (mm/hr)	5	130	.rte
12	v__ALPHA_BNK	Base flow alpha factor for bank storage.	0	1	.rte
13	v__SURLAG	Surface runoff lag coefficient	0	10	.bsn
14	r__OV_N	Manning's "n" value for overland flow	-0.2	0	.hru
15	v__REVAPMN	Threshold depth of water (mm)	0	500	.gw
16	a__SOL_ALB	Soil albedo	-0.01	0.3	.sol
17	a__EPCO.hru	Plant uptake factor	0	0.2	.hru
18	r__SOL_K	Soil hydraulic conductivity (mm/hr)	-0.5	0.5	.sol
19	r__SOL_AWC	Available water capacity of a soil	-0.5	0.5	.sol
20	r__GW_REVAP	Ground water evaporation coefficient	0	0.2	.gw

3.2.4.4 Calibration and Validation of SWAT model

In SWAT model calibration, the parameters are adjusted within their physical acceptable range in such a way that practical agreement between simulated and observed stream flows is accomplished. To perform parameter calibration and uncertainty analysis different programs are introduced. SWAT-CUP is one of the program which is currently used by different researchers. It is a public domain and used for calibration, uncertainty or sensitivity analysis procedures linked with SWAT. It enables sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models. Automatic calibration and uncertainty analysis incorporated in SWAT 10.4 through SWAT-CUP software developed and tested by Abbaspour (2012), with the semi-automated program SUFI2 was used for this study.

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation. After the model is calibrated, its performance is validated where by the calibrated model is run with a different data set without adjusting the parameters that were set during calibration process (Dile *et al.,* 2013).

3.2.4.5 Performance Evaluation of SWAT Model

During calibration and validation of a hydrological model it is necessary to assess the performance of the model. This is done by statistically comparing the model output and observed values using various statistical measures. Model evaluation is normally based on its ability to simulate major hydrological processes in a watershed. Model performance assessment is normally carried out by comparing the model predictions at the basin outlet with the corresponding observed records (Moriasi et al., 2007). Evaluation of model performance involves assessing the 'goodness-of-fit' of the simulated and the observed hydrological variables such as stream flow. There are a large number of model performance measures available to a hydrologist. For this study, three model performance evaluation techniques such as; coefficient of determination, Nash-Sutcliffe coefficient and P_{BIAS} recommended by Moriasi et al. (2007) were used.

The coefficient of determination R^2 shows the degree of collinearity between the observed and simulated values. It has ranges from 0 to 1, with a value of 0 indicating no correlation and the closer the value to 1 representing higher agreement between measured and simulated stream.
The coefficient of determination was given as following (Moriasi *et al*, 2007)

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(Q_{obs} - Q_{obs,m}\right)\left(Q_{sim} - Q_{sim,m}\right)\right]^2}{\left[\sum_{i=1}^{n}\left(Q_{obs} - Q_{obs,m}\right)^2 \sum_{i=1}^{n}\left(Q_{sim} - Q_{sim,m}\right)\right]^2} \qquad (17)$$

Where,

Q_{obs} is observed flow, Q_{sim} is the simulated flow, $Q_{obs,\ m}$ is the observed mean flow and $Q_{sim,}$ is average simulated flow.

Nash-Sutcliffe model efficiency (NSE) coefficient (Nash and Sutcliffe, 1970), indicates how well the plot of observed versus simulated data fits the 1:1 line. The value of the coefficients varies from minus infinity to one (1) with the value indicating perfect agreement between the simulated and observed data. A smaller NS value indicates poorer fit between the simulated and observed data. If the ENS is between 0 and 1, it indicates deviations between measured and simulated values. The Nash-Sutcliffe model efficiency (NSE) coefficient was given as following (Moriasi *et al*, 2007).

$$E_{NS} = \frac{\left[\sum_{i=1}^{n}\left(Q_{sim} - Q_{obs}\right)\right]^2}{\left[\sum_{i=1}^{n}\left(Q_{obs} - Q_{obs,m}\right)\right]^2} \qquad (18)$$

Where, Q_{obs} is observed flow, Qsim is the simulated flow, $Q_{obs, m}$ is the average observed flow and $Q_{sim, m}$ is average simulated flow.

P_{BIAS} indicates the sum of differences between measured and simulated values over the sum of measured value. It has the ability to indicate poor model performance and measures the average tendency of the simulated data to be larger or smaller than observed data. Low values of P_{BIAS} indicate accurate model simulation, positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Ajai *et al*., 2014). The values of P_{BIAS} are determined by the following equations.

$$PBias = \frac{\left[\sum_{i=1}^{n}\left(Qobs - Qsim\right)\right]}{\left[\sum_{i=1}^{n} Qobs\right]} *100 \qquad (19)$$

Where, Q_{obs} is observed stream flow and Qsim is the simulated stream flow and n is the total number of observations.

Generally, Moriasi *et al*., (2007) defined values of E_{NS}, P_{BIAS} and R^2 as following tables for the evaluation of models.

Table 3.2 Classification of statistical indices (Moriasi et al., 2007)

E_{NS}	P_{BIAS}	R^2	Classification
$0.75 < E_{NS} \leq 1$	$P_{BIAS} \leq \pm 10$	$0.75 < R^2 \leq 1$	Very good
$0.6 < E_{NS} \leq 0.75$	$\pm 10 \leq P_{BIAS} \leq \pm 15$	$0.6 < R^2 \leq 0.75$	good
$0.36 < E_{NS} \leq 0.6$	$\pm 15 \leq P_{BIAS} \leq \pm 25$	$0.5 < R^2 \leq 0.6$	satisfactory
$0.00 < E_{NS} \leq 0.36$	$\pm 25 \leq P_{BIAS} \leq \pm 50$	$0.25 < R^2 \leq 0.5$	Bad
$E_{NS} \leq 0.00$	$\pm 50 \leq P_{BIAS}$	$R^2 \leq 0.25$	Inappropriate

3.2.4 Assessing change of future climate Scenarios and projected stream flow

The change in projected climate data was determined by using the observed (1985-2014) as base period for both rainfall and temperature. For analysis of projected Stream flow; the calibrated SWAT model was used to simulate the stream flow in the sub-basin for 2030 and 2050 periods for both the RCP4.5 and RCP8.5 climate change scenarios. Coordinated Regional Downscaling Experiments (CORDEX) provides new climate change model outputs which have been applied in evaluating the impacts of climate change on water availability in Upper Awash sub basin. This study uses the CORDEX products to drive SWAT hydrological model. The SWAT outputs were used to analyze how changes in climate will impact on the Upper Awash sub basin water yields.

4. RESULTS AND DISCUSSION

4.1 Trend Analysis of Historical climate Parameters

For investigating hydro climatic trends for both baseline analysis and projected period, the non-parametric Mann-Kendall method was used to test the existence of a trend in the annual and monthly time series. Sen's slope estimator was also applied to estimate the magnitude of the trend. This was attained by the application of trend analysis software and statistical template, Makessens 1.0 developed by the Finnish Meteorological Institute (FMI).

4.1.1 Historical annual Rainfall Trend Analysis

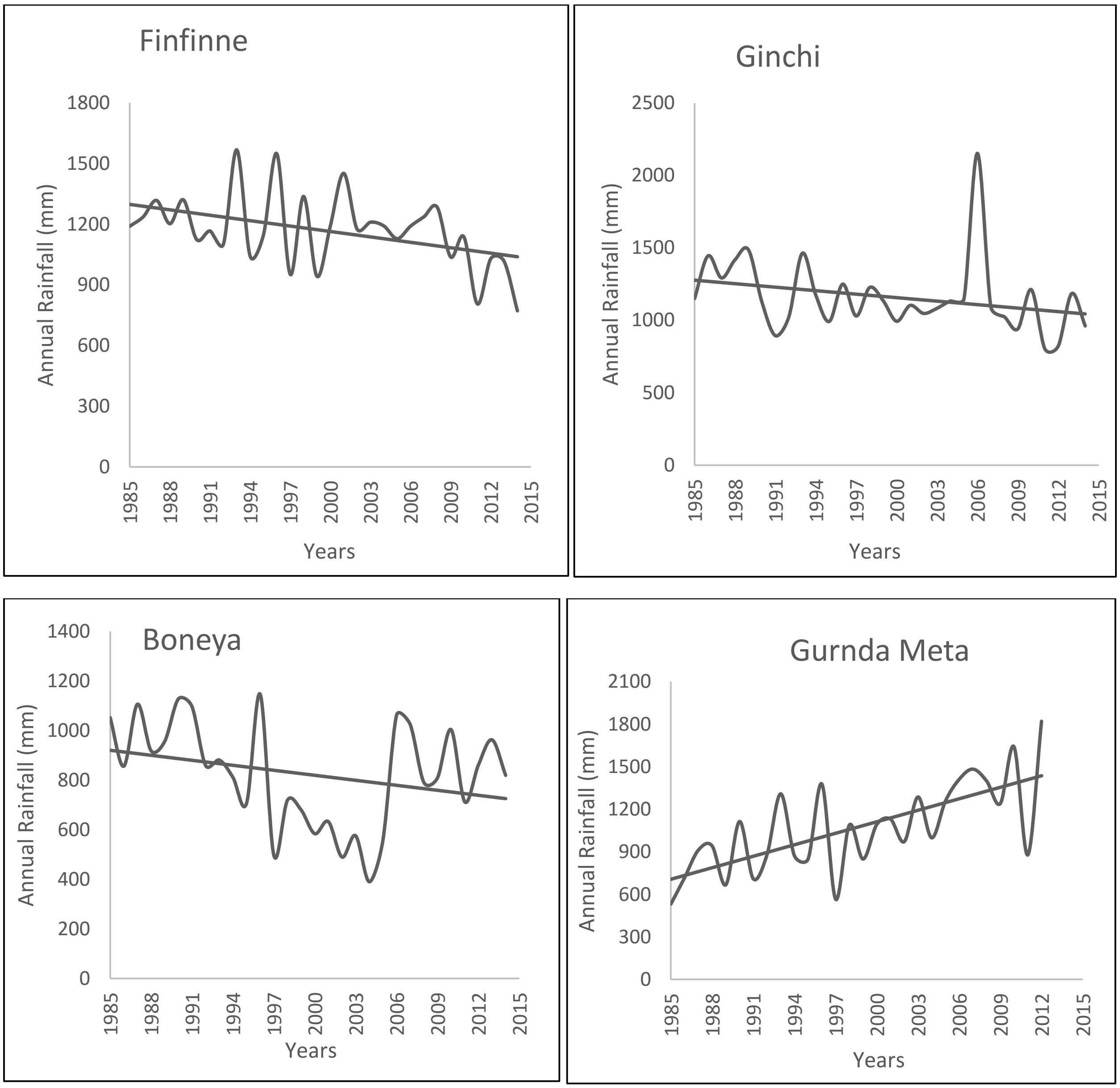
Annual rainfall data for six representative stations; Finfinne, Gurnda Meta, Hombole, Bishoftu, Boneya and Ginchi (1985-2014) was tested for trend to investigate the existence of a long term trend in the basin and the magnitude through Mann-Kendall and Sen's slope estimator respectively. The tests were done at 90%, 95% and 99% level of significance and the results are presented in Table 4.1.

Table 4.1 Historical trend analysis of rainfall over Upper Awash sub basin

Stations	Mann-Kendall trend First year	Last year	N	Z	Sen's slope estimate Significance	Q(mm/year)
Gurnda Meta	1985	2014	30	3.74	***	27.68
Ginchi	1985	2014	30	-2.24		-10.5
Boneya	1985	2014	30	-1.68		-8.03
Finfinne	1985	2014	30	-2.28		-7.82
Bishoftu	1985	2014	30	0		0
Hombole	1985	2014	30	-1.78		-7.38

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

From representative stations, Gurnda Meta stations were shows increasing trends at 90% level of significance. The trends were also statistically significant. For other four station, the Mann-Kendall trend analysis results for annual rainfall shows there was statistically decreasing trends for Ginchi, Boneya, Finfinne, and Hombole. This shows that the amount of precipitation was decreasing with time. But, Bishoftu station shows the historical trends of rainfall has no change and Sen's slope also shows no change. Also linear trend line plotting indicates increasing trend in annual rainfall for Gurnda Meta stations and decreasing trend for Finfinne, Ginchi, Hombole and Boneya. The above results are illustrated in Figures 4.1, fitted with trend lines.



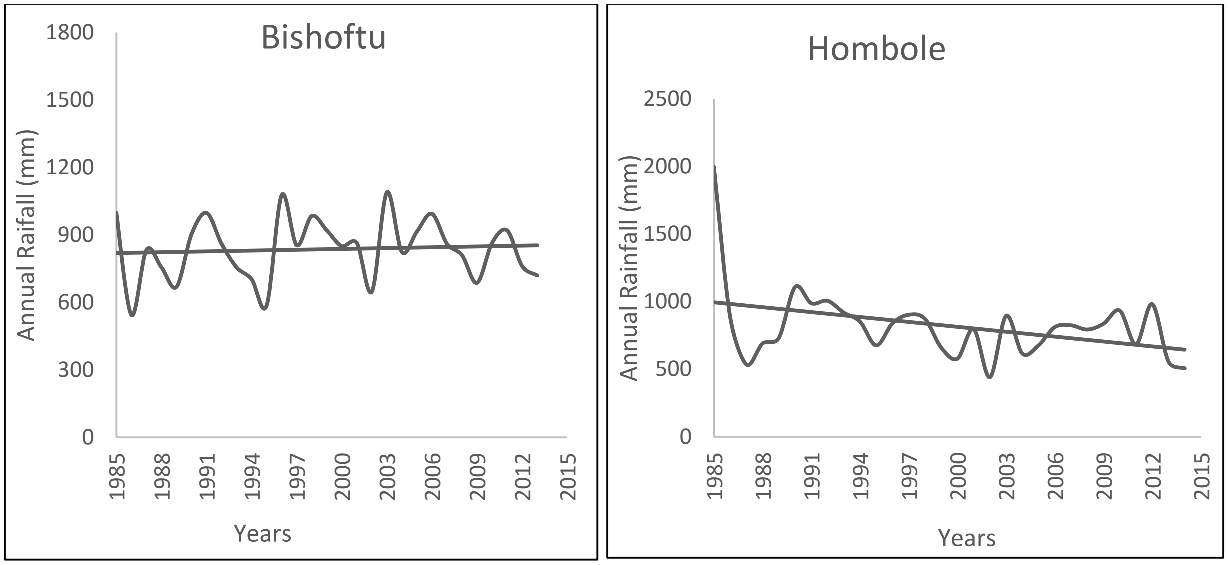


Figure 4.1 Trends of mean annual rainfall for representative station over period of (1985-2014) in upper Awash sub basin

4.1.2 Monthly rainfall Trend analysis for Representative stations

The Mann-Kendall test was applied on monthly scale to detect trend in the rainfall at six representative stations. Table 4.2 to 4.7 shows monthly trend of rainfall and their magnitude (in mm/year) obtained by the Mann–Kendall test.

Table 4.2 Mann-Kendall trend and sen's slope for monthly rainfall of Finfinne station

Station: Finfinne	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	-0.97		0.000
Feb	1985	2014	30	-1.62		-0.041
Mar	1985	2014	30	-0.25		-0.010
Apr	1985	2014	30	-1.36		-0.056
May	1985	2014	30	1.04		0.051
Jun	1985	2014	30	-0.04		-0.003
Jul	1985	2014	30	-0.79		-0.023
Aug	1985	2014	30	-2.00	*	-0.068
Sep	1985	2014	30	-1.57		-0.068
Oct	1985	2014	30	-0.21		-0.001
Nov	1985	2014	30	0.84		0.000
Dec	1985	2014	30	-0.87		0.000

Note: * indicate that the trends are significant at 99% level of confidence.

Table 4.3 Mann-Kendall trend and Sens's Slope for Monthly rainfall of Ginchi station

Station: Ginchi	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	0.09		0.000
Feb	1985	2014	30	-1.92		-0.063
Mar	1985	2014	30	-1.52		-0.049
Apr	1985	2014	30	-0.79		-0.040
May	1985	2014	30	0.18		0.008
Jun	1985	2014	30	0.86		0.030
Jul	1985	2014	30	-0.75		-0.026
Aug	1985	2014	30	-1.25	*	-0.056
Sep	1985	2014	30	-1.03		-0.043
Oct	1985	2014	30	-1.28		-0.020
Nov	1985	2014	30	-0.62		0.000
Dec	1985	2014	30	-1.05		0.000

Note: * indicate that the trends are significant at 99% level of confidence.

Table 4.4 Mann-Kendall trend and Sen's slope for monthly rainfall of Boneya station.

Station: Boneya	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	0.74		0.000
Feb	1985	2014	30	-1.45		-0.018
Mar	1985	2014	30	0.12		0.001
Apr	1985	2014	30	-0.46		-0.015
May	1985	2014	30	0.30		0.013
Jun	1985	2014	30	-1.00		-0.022
Jul	1985	2014	30	-1.28		-0.082
Aug	1985	2014	30	-1.93		-0.114
Sep	1985	2014	30	-2.07	*	-0.074
Oct	1985	2014	30	0.38		0.000
Nov	1985	2014	30	3.17	**	0.000
Dec	1985	2014	30	0.56		0.000

Note: ** and * indicate that the trends are significant at 95% and 99% level of confidence, respectively.

Table 4.5 Mann-Kendall trend and Sen's slope for monthly rainfall for Bishoftu station

Station: Bishoftu	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	-0.29		0.000
Feb	1985	2014	30	-0.99		0.000
Mar	1985	2014	30	1.00		0.026
Apr	1985	2014	30	-0.55		-0.014
May	1985	2014	30	-0.11		-0.003
Jun	1985	2014	30	-0.05		-0.001
Jul	1985	2014	30	-0.18		-0.011
Aug	1985	2014	30	-0.77		-0.038
Sep	1985	2014	30	-1.59		-0.032
Oct	1985	2014	30	0.95		0.009
Nov	1985	2014	30	2.64	**	0.002
Dec	1985	2014	30	2.97	**	0.000

Note: ** indicate that the trends are significant at 95% level of confidence.

Table 4.6 Mann-Kendall trend and sen's slope for monthly rainfall for Gurnda Meta station.

Station: Gurnda Meta	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	1.75		0.002
Feb	1985	2014	30	-1.33		-0.023
Mar	1985	2014	30	-0.25		-0.005
Apr	1985	2014	30	-0.96		-0.038
May	1985	2014	30	2.52	*	0.093
Jun	1985	2014	30	3.00	**	0.110
Jul	1985	2014	30	2.71	**	0.166
Aug	1985	2014	30	2.37	*	0.159
Sep	1985	2014	30	4.17	***	0.206
Oct	1985	2014	30	2.15	*	0.037
Nov	1985	2014	30	3.12	**	0.001
Dec	1985	2014	30	2.16	*	0.000

Note: ***, ** and * indicate that the trends are significant at 90%, 95% and 99% level of confidence, respectively.

Table 4.7 Mann-Kendall trend and sen's slope for monthly rainfall for Hombole station.

Station: Hombole	Mann-Kendall trend				Sen's slope estimate	
Month	First year	Last year	N	Z	Significance	Q(mm/year)
Jan	1985	2014	30	-0.3		0.000
Feb	1985	2014	30	-0.49		0.000
Mar	1985	2014	30	-1.2	*	0.026
Apr	1985	2014	30	-0.35		-0.014
May	1985	2014	30	-0.21		-0.003
Jun	1985	2014	30	-0.15		-0.001
Jul	1985	2014	30	-0.18		-0.011
Aug	1985	2014	30	0.17		0.038
Sep	1985	2014	30	-1.19		-0.032
Oct	1985	2014	30	0.25	**	0.009
Nov	1985	2014	30	-1.64	**	-0.002
Dec	1985	2014	30	-0.97	**	-0.01

Note: ** and * indicate that the trends are significant at 95% and 99% level of confidence, respectively.

In the non-parametric Mann-Kendall test, trend of rainfall for 30 years from January to December has been calculated for each month individually together with the Sen's magnitude of slope (Q) for all representative stations. Monthly trend tests showed a mix of positive (increasing) and negative (decreasing) trends at different stations. Except Gurnda Meta, all station shows that negative trend. Gurnda Meta station's monthly rainfall trend shows increasing trend from May to January at 90%, 95% and 99% significance level, but three months February, March and April shows decreasing trend. However, the monthly rainfall trends at Hombole station shows statistically significant decreasing trend for November and December and statistically significant decreasing trends for October at 95% significance level, but only August shows increasing trend.

4.1.3 Historical Maximum and Minimum Temperatures Trend Analysis

4.1.2.1 Annual maximum temperature trend analysis for representative stations

Temperature is also an important variable with regard to climate change. Table 4.8 and 4.9 shows statistical results for annual maximum temperature trends. Mann-Kendall trend analysis for all stations shows an increasing trend in the annual maximum temperature.

Table 4.8 Trends of annual Maximum Temperature for representative station over the period of (1985-2010) in Upper Awash sub basin

	Mann-Kendall trend				Sen's slope estimate	
Stations	First year	Last year	N	Z	Significance	Q(mm/year)
Gurnda Meta	1985	2010	26	0.86		0.009
Bishoftu	1985	2010	26	2.47	*	0.023
Hombole	1985	2010	26	0.71		0.012

Note: * indicate that the trends are significant at 99% level of confidence.

Statistically significant increasing trend is noticed in Bishoftu station which is represented with approximately 0.023 ^{0}c/year in the study area. Annual maximum temperature trend in Finfinne station shows increasing but not statistically significant (Table 4.9).

Table 4.9 Annual maximum temperature trend for Finfinne station over the period of (1985-2014) in Upper Awash sub basin.

	Mann-Kendall trend				Sen's slope estimate	
Stations	First year	Last year	N	Z	Significance	Q(mm/year)
Finfine	1985	2014	30	1.21		0.007

The increasing slopes showed the rate at 0.007 ^{0}c/year for annual maximum temperature.

Figure 4.2 shows annual maximum temperature trends.

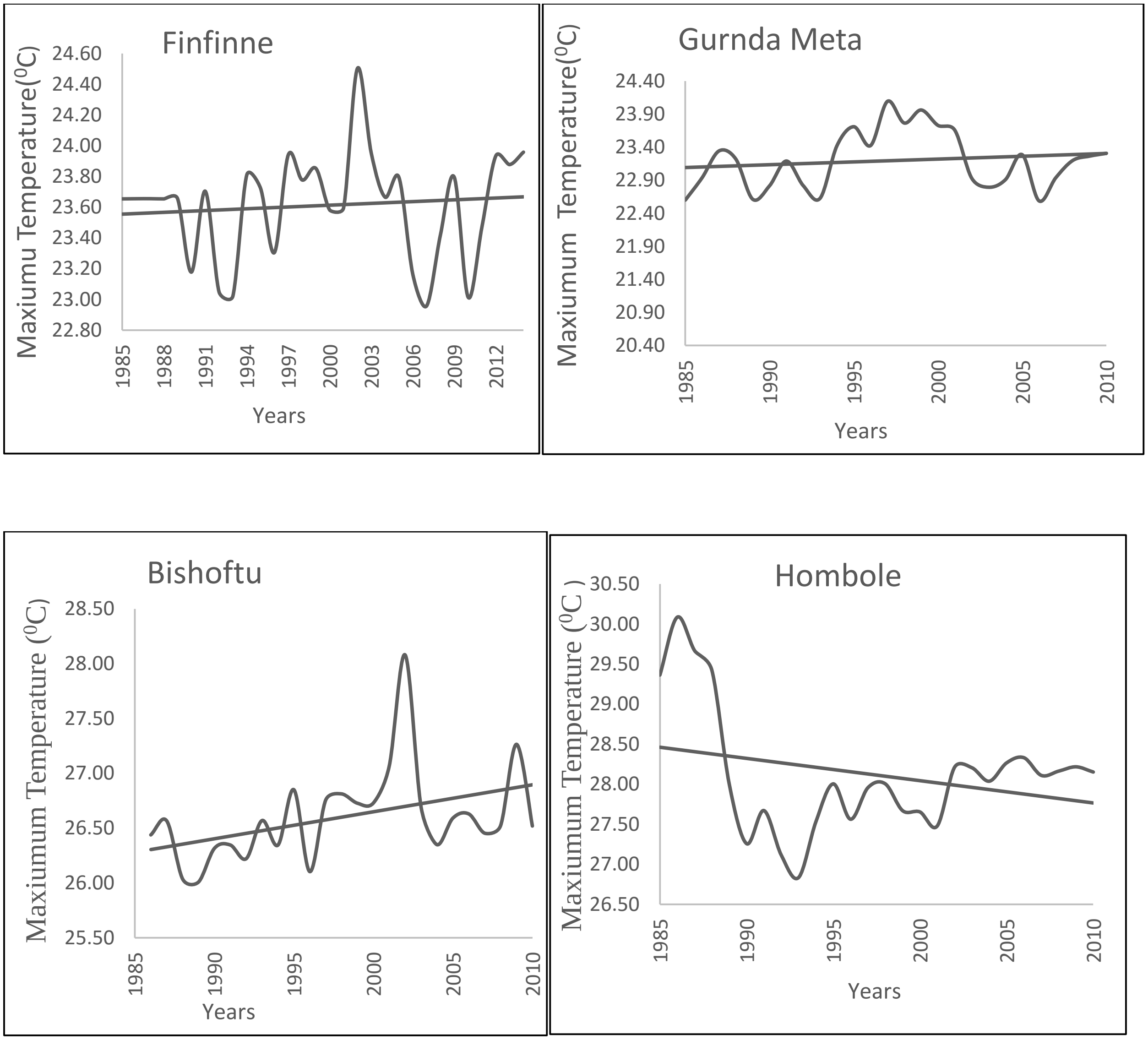


Figure 4.2 Mean annual maximum temperature trends of representative stations in Upper Awash sub basin

4.1.2.2 Annual minimum temperature trend for representative stations

Apart from maximum temperature trend analysis, the trend analysis was also done for minimum temperatures. Table 4.10 and Table 4.11 shows statistical results for annual minimum temperature trend analysis.

Table 4.10 Mann Kendall trend and Sens slope of representative station for annual minimum temperature (1985-2010)

	Mann-Kendall trend				Sen's slope estimate	
Stations	First year	Last year	N	Z	Significance	Q(mm/year)
Gurnda Meta	1985	2010	26	-0.57		-0.004
Bishoftu	1985	2010	26	-0.26	*	-0.006
Hombole	1985	2010	26	1.50	*	0.014

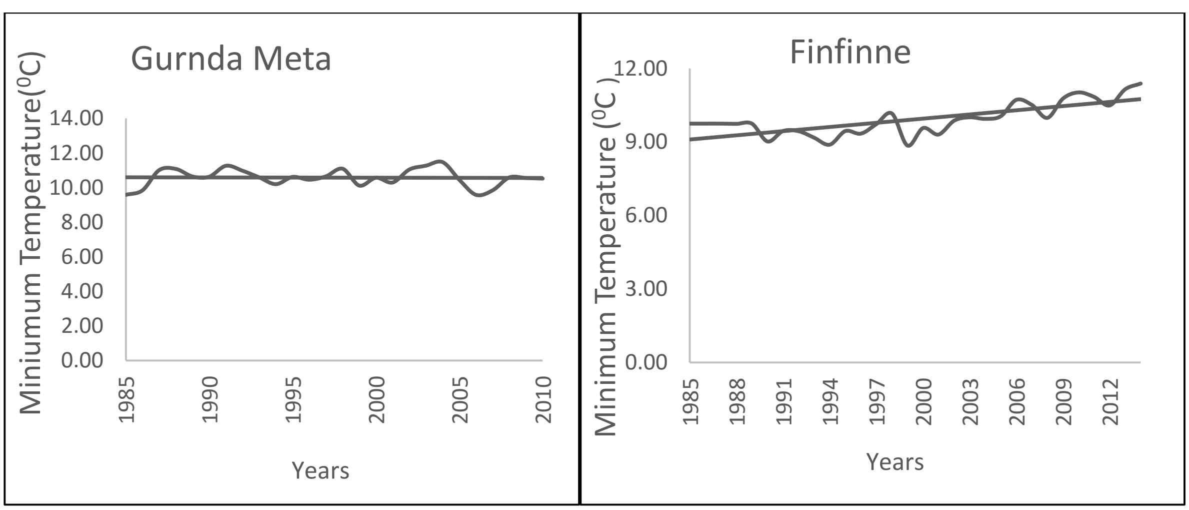
Note: * indicate that the trends are significant at 90% level of confidence.

Table 4.11 Mann Kendall and sens slope of Fifinne station for annual minimum temperature (1985-2014)

	Mann-Kendall trend				Sen's slope estimate	
Station	First year	Last year	N	Z	Significance	Q(mm/year)
Finfine	1985	2014	30	3.89	***	0.055

Note: *** indicate that the trends are significant at 99% level of confidence.

Mann-Kendall trend analysis results for Finfinne and Hombole stations shows that there was a rising/increasing trend in the annual minimum temperature. Statically significant increasing trend is noticed in Hombole station which is represented with approximately 0.014 ^{0}c/year and statically significant decreasing trend is noticed at Bishoftu. Also minimum annual temperature trend were decreasing for Gurnda Meta station but not statistically significant. Figure 4.3 shows the annual minimum temperature trend.



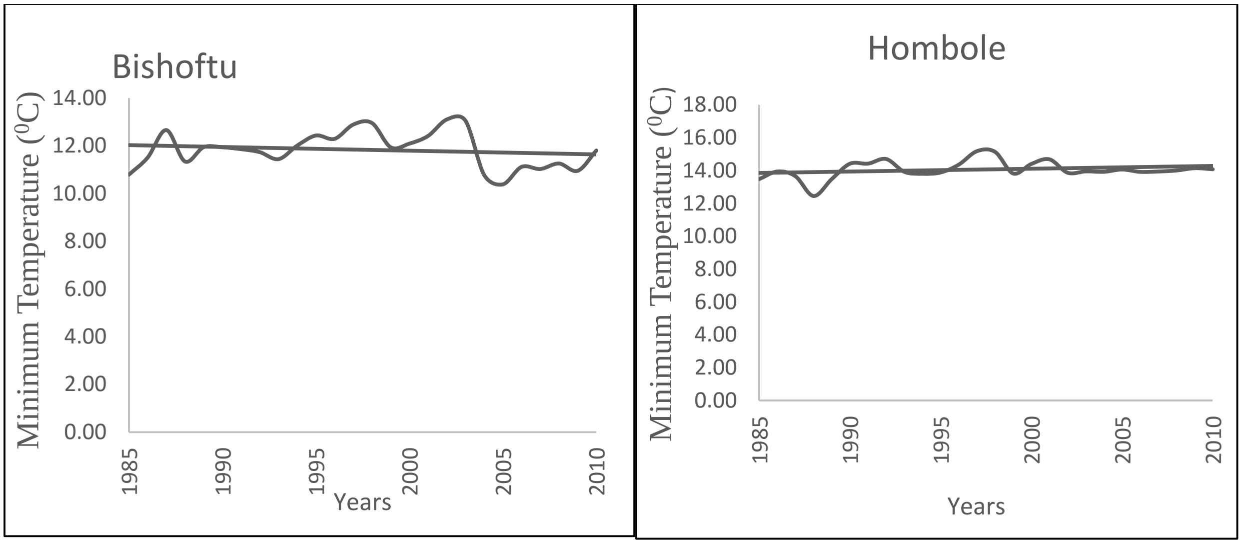


Figure 4.3 Mean annual minimum temperature trends of representative stations in Upper Awash sub basin (1985-2010) and (1985-2014 for Finfinne station)

4.2 Performance evaluation of climate model against observed data

Coefficient of variation, root mean square error, correlation coefficient and bias were used in the evaluation of the performance of the three models and their average in relation to the observed data. The performance measures are statistically based and the results of individual performance measures method for annual total rainfall over the upper Awash sub-basin are shown in Table 4.12 below.

Table 4.12 Performance of dynamically downscaled models representing mean annual rainfall over Upper Awash sub basin (1985-2005)

	Annual rainfall(mm)	Bias (%)	CV (%)	RMSE (mm/year)	Correlation
Observed	987.17	-	11.5	-	-
MPI-ESM-LR	984	-12.52	13.1	225.04	0.96
CNRM-CM5	1091.13	47.05	11.2	228.36	0.92
EC-EARTH	950.71	-38.62	9.24	236.28	0.91
Ensemble	1008.61	-7.88	11.18	129.57	0.994

When the correlation value is +ve, it denotes a positive linear relationship and if it is -ve, it denotes a negative linear relationship. In the results, all models showed a positive relation whileCNRM-CM5 and EC-EARTH indicated low correlation than MPI-ESM-LR and Ensemble. Using the correlation analysis method MPI and ENSEMBLE had the best data set which performed well against the observed.

Bias shows large differences with the largest bias of 47.05% for CNRM-CM5 and -38.32 for EC-EARTH which suggests the presence of a systematic error as large as half of the annual rainfall amount. The smallest bias of -7.88% is shown for ENSEMBLE which suggests that basin wide rainfall is well captured and represented. Almsegad and Rientjes (2015) also concluded that biases of the models can be considered relatively large with values larger than ±10%.

When comparing the gauged mean annual rainfall to model based there exists differences showing overestimation 1091.13 mm for CNRM-CM5 and underestimation at 950.71 mm for EC-EARTH. For RMSE performance measure, ENSEMBLE has the smallest value 129.57mm per year whereas EC-EARTH resulted in the largest value 236.28 mm per year. Generally, all models were found best in capturing the observed (gauged) rainfall (Figure4.4).

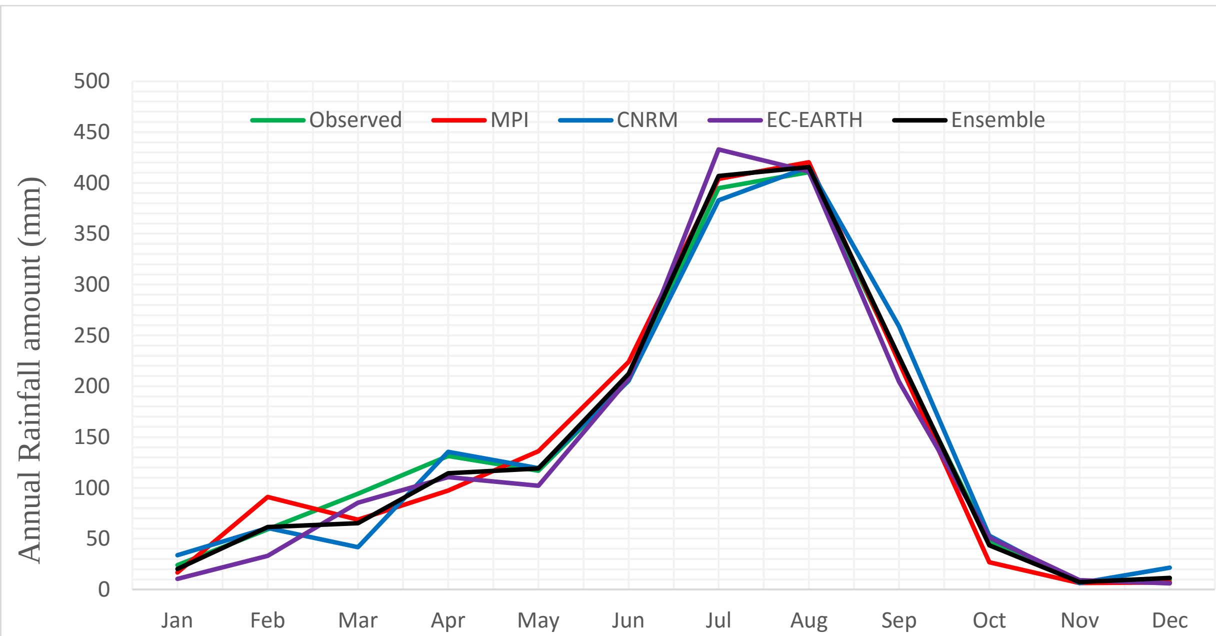


Figure 4.4 Dynamically downscaled climate model simulations and gauged rainfall data at monthly based for Upper Awash sub basin

MPI-ES-LR performed best when evaluated in terms of rainfall correlation coefficient between observed and simulated and also CNRM-CM5 best in terms of coefficient of variations. However, no individual model is best in all performance measures and the Ensemble of models is better to simulate the rainfall rather than individual models. Therefore, in this study the Ensemble of the models is used for further analysis in Upper Awash sub basin. The performance of CORDEX

RMCs in East Africa was also done by Endris *et al.,* (2013) it was found that multi-model ensemble models the rainfall over Eastern Africa well.

4.3 Evaluation of projected rainfall and temperature for the period 2030s and 2050s relative to base period (1985-2014)

4.3.1. Bias Correction for Data obtained from Climate Model

The outputs of the raw RCMs underestimate and overestimate the mean monthly rainfall and temperatures as compared to areal precipitation and temperatures. These outputs are adequately corrected by delta change method for rainfall and temperature (delta change multiplicative for rainfall and delta change additive for temperature). Bias correction improves the efficiency coefficients for the RCMs with rainfall correlation being about 0.99 and R^2 is greater than or equal to 0.98. Similar improvements are found in temperature where performance measures are ranges from 0.99 to perfect fit between simulated and observed temperatures at base period. The results of the long term mean monthly temperature and precipitation of the observed and the outputs of the RCM within the base period show good agreement. This implies that the bias corrected output of the model is well capturing and representative of the study area.

4.3.2 Scenario Generation

4.3.2.1 Projected Rainfall

The percentage change in mean monthly and annual rainfall over upper Awash sub-basin is presented in Figure 4.5. For RCP 4.5 scenario decreasing annual rainfall are observed in the future during both time slices. Accordingly, the mean areal annual rainfall over upper Awash sub-basin decrease by 1.11 % and 8.15 % in 2030's and 2050's respectively under RCP 4.5 scenarios (Figure 4.5a). Also decreasing future annual rainfall is observed in 2030's and 2050's in RCP 8.5 scenarios by 16.93 % and 22.59 % respectively (Figure 4.5b).

The average mean monthly rainfall result shows that in the future monthly rainfall decreases in all months during 2050's, except July, November and December in which increasing mean monthly rainfall is observed under RCP 4.5 scenario. Similarly, decrease in monthly mean rainfall is observed in months January, March, April, October and November under RCP4.5 during 2030's and increasing mean monthly rainfall is observed in months February, May, June July, August, September and December during 2030 (Figure 4.5a).

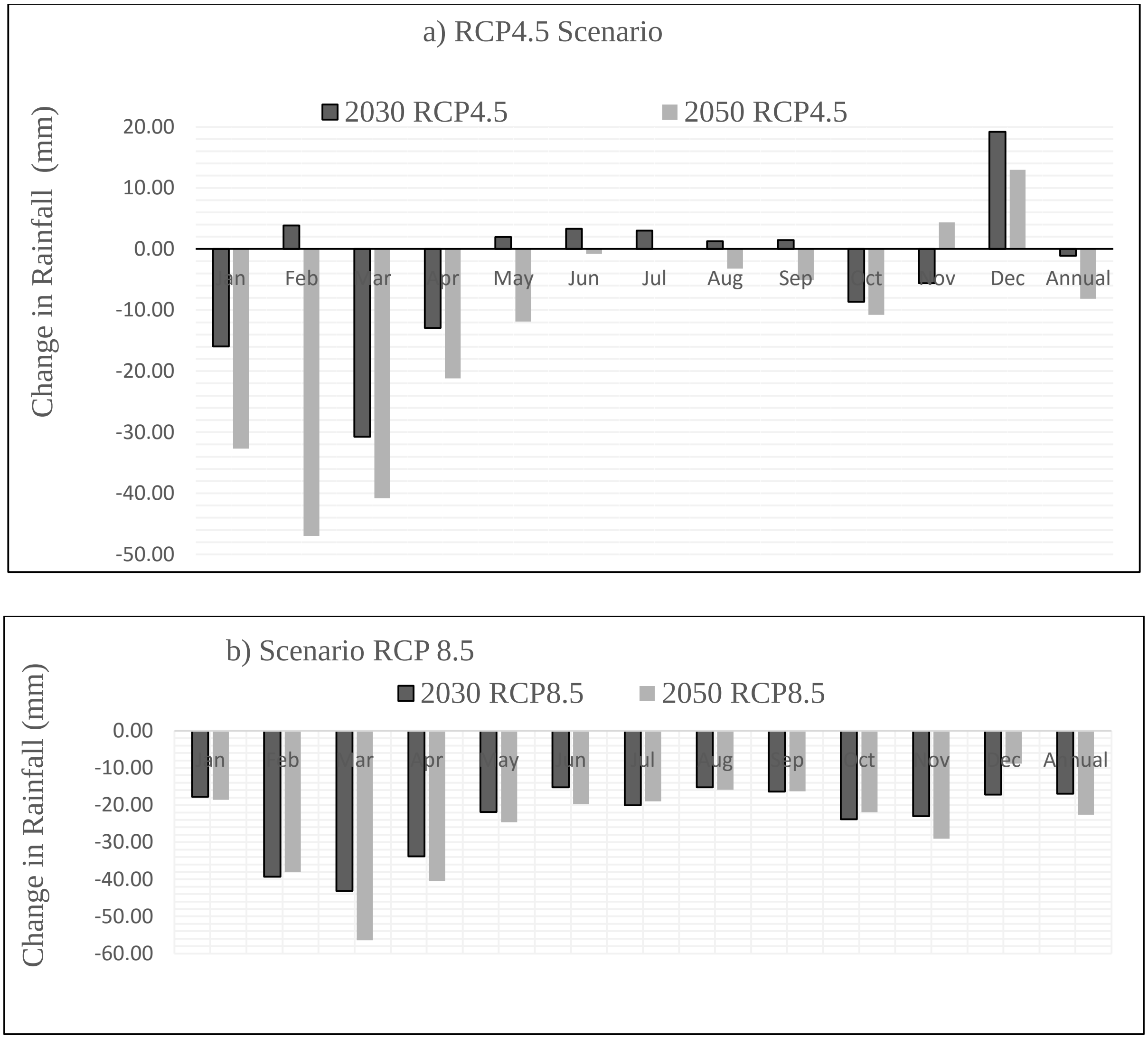


Figure 4.5 Percentage change in mean monthly and Annual Rainfall for 2030`s and 2050`s as compared to the base line period (1985-2014) of Upper Awash sub basin

Under RCP8.5 scenarios, the average monthly and annual rainfall result shows decrease in all months and annual during 2030’s and 2050’s.

The projected rainfall shows there would be an increment of seasonal rainfall in the first time horizon (2030’s) in winter and summer seasons by 2.37% and 2.53% respectively under RCP4.5 scenario. Also the projected rainfall shows a reduction of -4.27% and -13.9% during spring and autumn seasons respectively under RCP4.5 from the base time rainfall in 2030s. By 2050’s time horizon the projection shows a decrement of rainfall in all seasons under RCP4.5 scenarios. In this scenario, the maximum decrement would be seen in autumn season by -24.61% and winter by -

22.21 % at 2050s and also the maximum increment would be seen in summer and winter by 2.53 and 2. 37 respectively at 2030s.

For RCP8.5 scenario unlike RCP4.5 scenario at both time horizon (2030s and 2050s) the projected rainfall showed a reduction rainfall in all seasons. During autumn season there would be more decrement in rainfall in the sub-basin as compared to other season in both RCP4.5 and RCP8.5 scenarios (Table 4.13).

Table 4.13 Percentage change of projected seasonal Rainfall for 2030`s and 2050`s as compared to the base line period (1985-2014) of Upper Awash sub basin

		Time horizon	
Scenario	Season	2030s	2050s
RCP4.5	Winter (DJF)	2.37	-22.21
	Spring (SON)	-4.27	-3.85
	Summer (JJA)	2.53	-1.29
	Autumn (MAM)	-13.9	-24.61
RCP8.5	Winter (DJF)	-24.78	-21.79
	Spring (SON)	-21.09	-22.46
	Summer (JJA)	-16.84	-18.21
	Autumn (MAM)	-32.94	-40.53

4.3.2.2 Projected Maximum Temperature

The maximum temperature scenario generation showed an increase in mean maximum temperature in all the months in the 2030s and 2050s under both RCP4.5 and RCP8.5 scenario. The change in monthly mean maximum temperature ranges between 0.4^0C in November and 1.17^0C in February for RCP4.5 scenario's in 2030's (Figure 4.6a). Also the change in mean monthly maximum temperature ranges between 1.28^0c in August and 1.84^0C in April for RCP4.5 scenario in 2050's.

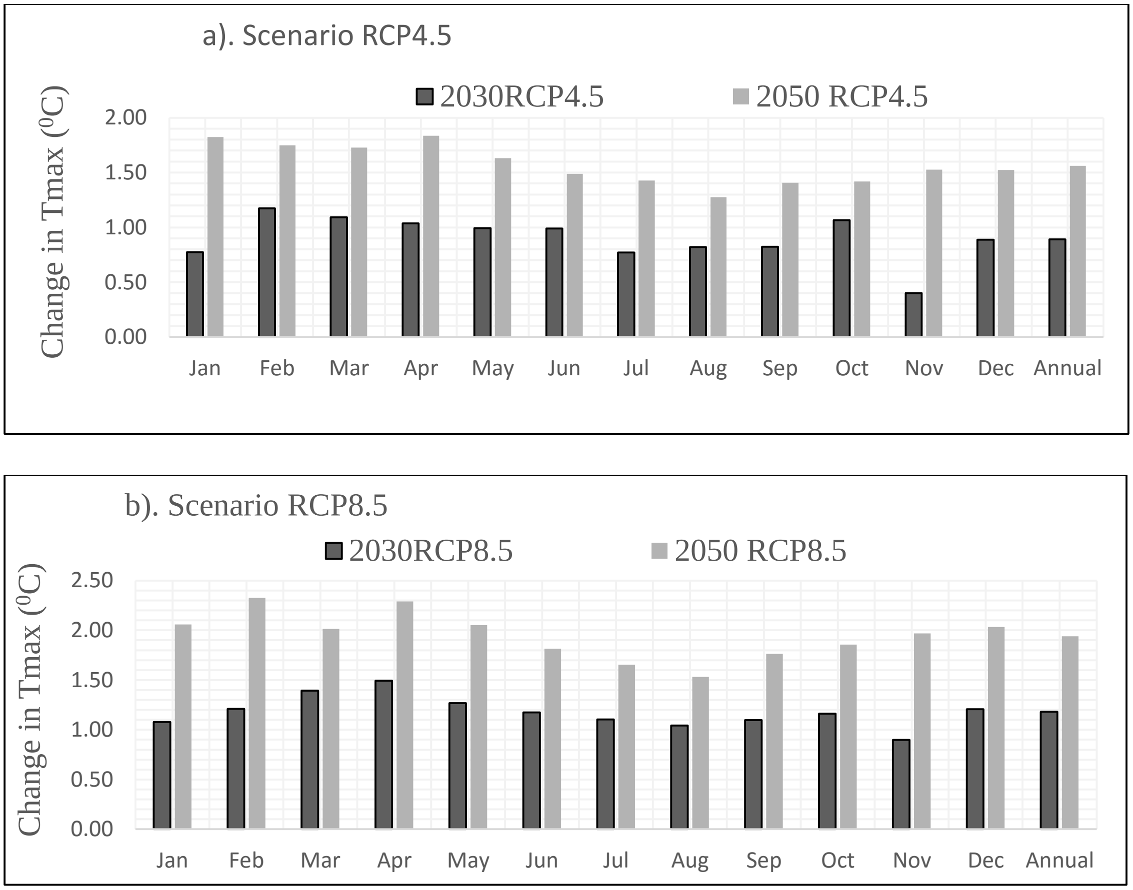


Figure 4.6 Projected change in mean monthly maximum temperature during the scenario periods compared to the baseline period for RCP 4.5 and RCP 8.5 scenarios respectively

For RCP8.5 scenario, the change in mean monthly maximum temperature ranges between 0.9^0c in November and 1.49^0C in April for RCP8.5 scenario in 2030's. Also the change in monthly mean maximum temperature ranges between 1.53^0C in August and 2.33^0C in February for RCP4.5 scenario's in 2050's (Figure 4.6b). The projected minimum and maximum temperature in both future time horizons is within the range projected by IPCC (2013), average temperature increases ranging from 1.4°C to 5.8°C towards the end of century.

Annually, the maximum temperature increases in the range from 0.89^oC to 1.56^oC and from 1.18^oC to 1.94^oC under RCP 4.5 and RCP 8.5 in 2030's and 2050's respectively. The overall analysis of the mean maximum temperature showed that there is an increasing trend in both scenarios (RCP4.5 and RCP8.5).

4.3.2.3 Projected Minimum Temperature

The downscaled minimum temperature scenario also showed that an increase in mean monthly minimum temperature in all the months in the 2030s and 2050s under both RCP4.5 and RCP8.5 scenario. The future projection shows that the change in mean monthly minimum temperature ranges between 0.85^{0}C in July and 1.39^{0}C in April for RCP4.5 scenario in 2030's. As shown in Figure 4.7a the change in mean monthly minimum temperature increases in range between 1.03^{0}C in August and 1.78^{0}C in April for RCP4.5 scenario in 2050's.

The scenario RCP 8.5 also projects the minimum of 0.9^{o}C (August and September) and maximum of 1.68^{o}C (February) in 2030's. Also the mean monthly minimum temperature increases in range between 1.44^{0}C in August and 2.74^{0}C in December for RCP8.5 scenario in 2050's (Figure4.7b). The annual mean minimum temperature trend also increased as compared to the baseline period for both scenarios. The annual mean minimum temperature increased by 1.43^{0}C and 1.82^{0}C for RCP4.5 in 2030's and 2050's respectively. Also the annual mean minimum temperature increased by 1.45^{0}C and 2.36^{0}C for RCP8.5 in 2030's and 2050's respectively. The result of this analysis

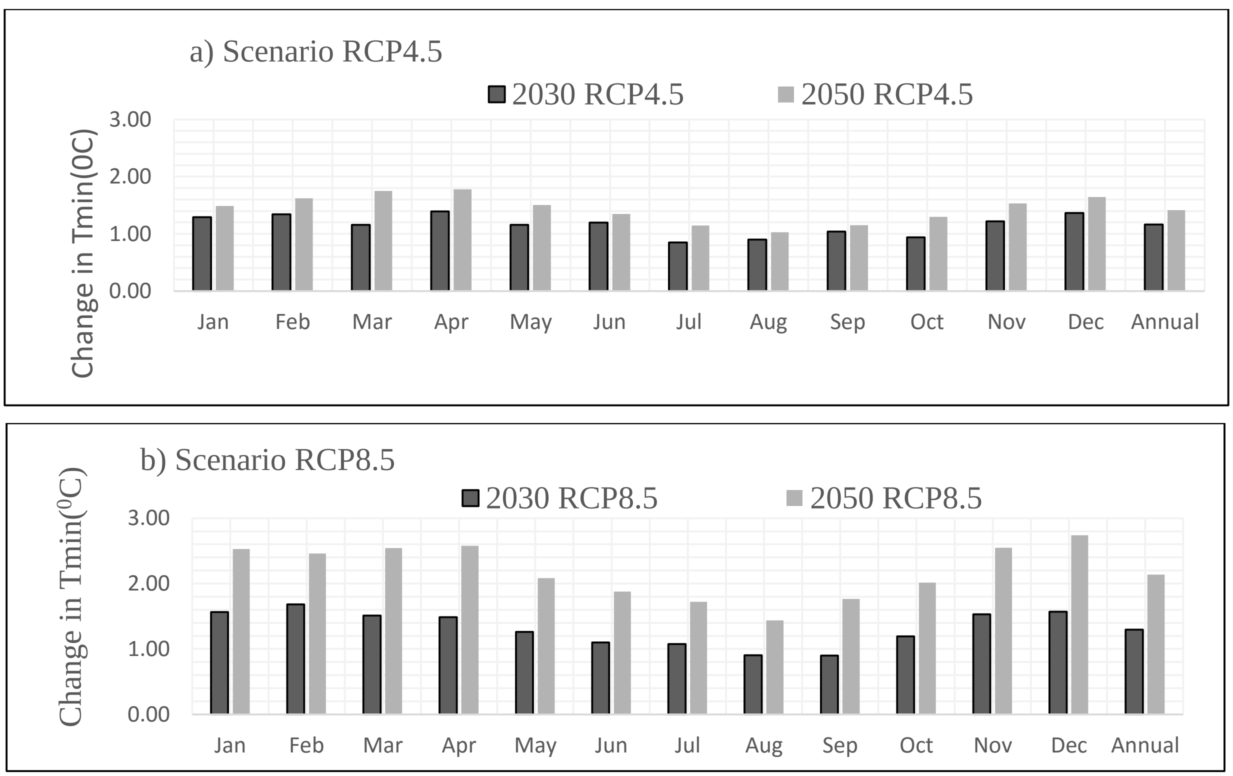


Figure 4.7 Projected change in mean monthly minimum temperature during the scenario period (2030's and 2050's) compared to the baseline period for RCP 4.5 and RCP 8.5 scenarios

also agree with World Bank, 2008 report, which says at annual basis as it reports the mean annual temperature increases 1.1 to 3.1ºC and 1.5 to 5.1ºC during 2060's and 2090's respectively.

Generally, the results have shown that there is significant change of rainfall and temperature in the coming years of the 21st century in consistence with prediction for the east Africa region by IPCC (2013). Annual mean maximum and minimum temperature shows increasing trend under both scenario's (RCP4.5 and RCP8.5) and minimum annual temperature is increased higher than maximum annual temperature (Table 4.14).

Table 4.14 Annual maximum and minimum temperature under the climate change scenarios

Scenario		Average max. temperature	^{0}C change in maximum temperature	Average min. temperature	^{0}C change in minimum temperature
	Historical	24.64	-	11.03	-
Scenario RCP4.5	2030 RCP4.5	25.54	0.89	12.46	1.43
	2050 RCP4.5	26.21	1.56	12.85	1.82
Scenario RCP8.5	2030 RCP8.5	25.83	1.18	12.48	1.45
	2050 RCP8.5	26.59	1.94	13.39	2.36

Also the estimated range is same with results of Daba (2014) and IPCC‟s average annual temperature across Ethiopia will increase by between 0.9 and 1.1°C by the year 2030 and from 1.7 to 2.1°C by the year 2050.

When comparing the two scenarios, in RCP8.5 due to high emission which is consistent with rapid increase in methane emissions, three times today's CO_2 emissions, heavy reliance on fossil fuels, lower rate of technology development, high population growth, increased use of croplands and grassland which is driven by an increase in population and no implementation of climate policies. Due to above mentioned assumptions the result of this study show that there is a higher changes of rainfall and temperatures observed in RCP8.5 scenario than RCP4.5 scenarios.

4.4 Hydrological Modeling Result

4.4.1 Sensitivity Analysis

Sensitivity analysis is useful to identify input parameters which significantly affect the model outputs. Automatic sensitivity analysis was conducted using input monthly flow. Sequential Uncertainty Fitting (SUFI2), a semi-automated procedure that is linked to SWATCUP is used and sensitivity analysis of parameters were done before calibration for identification of most sensitive parameters. After conducting series of simulations, SWAT provides sensitivity of parameters in rank order. The most sensitive parameters during the calibration step is presented at the top of the rankings, that is, the highest value of the t-stat index module which represents the ratio of the parameter coefficient by the standard error; and the lower value of the "p-value" which is related to the rejection of the hypothesis that an addition in the value of the parameter provides a significant increase in the variable response (Abbaspour, 2007). The 10 most sensitive parameters in the sub basin during automatic calibration and validation are given below. Table 4.15 shows the most sensitive parameters and their fitted values.

Table 4.15 Final calibrated sensitivity parameters

No.	Parameter	Lower	Upper	Calibrated /fitted
1	CN2	-25	25	-15
2.	GW-DELAY	30	450	423.8
3	Sol-AWC	-14	14	12
4	ESCO	0	1	0.6
5	Slope	-13	13	11
6	Sol-Z	-25	25	20
7	CANMX	0.2	10	6
8	Blai	0.25	0.73	0.5
9	OV-N	-0.2	0	-0.087
10	Sol-K	-0.5	0.5	0.389

As shown in table 4.15 Cn2 and Gw_Delay were the most sensitive parameters which has effect on surface runoff and base-flow contribution respectively. While, Sol-AWC, ESCO, and slope were among the most sensitive parameters which has effect on the surface runoff.

4.4.2 Calibration and Validation of Hydrological Model (SWAT)

4.4.2.1 Calibration

Once the sensitive parameters for the model are identified, the next step is to calibrate and validate the model. Both manual and automatic calibration (using SUFI-2) calibration procedures were used in this study. Initially, the curve number at moisture condition II (CN2), delay time for aquifer (GW-DELAY), available water capacity of the soil (SOL_AWC) and soil evaporation compensation coefficient (ESCO) values were adjusted manually for calibration. For model calibration five years Awash River data (1999-2003) at Hombole gauging station and two year data's (1997-1998) was used for model warm up. The performance of the model was evaluated using R^2, E_{NS} and P_{BIAS} statistical measures for both manual and auto-calibration. Evaluations were performed at monthly time scales and the result of statistical parameters during calibration obtained were 0.82 for R^2, 0.78for E_{NS} and 11.23% for P_{BIAS}. The values indicate that there is good agreement between observed and simulated stream flow. Figure 4.8 below shows hydrography comparison during model calibration.

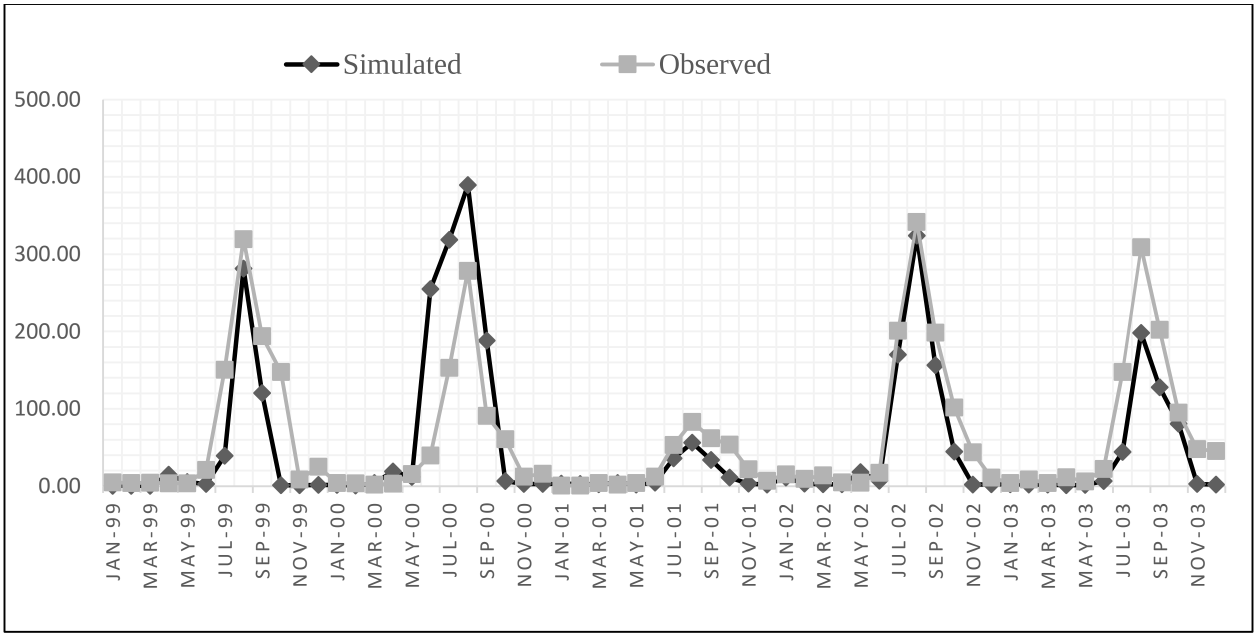


Figure 4.8 Hydrograph comparison during model calibration

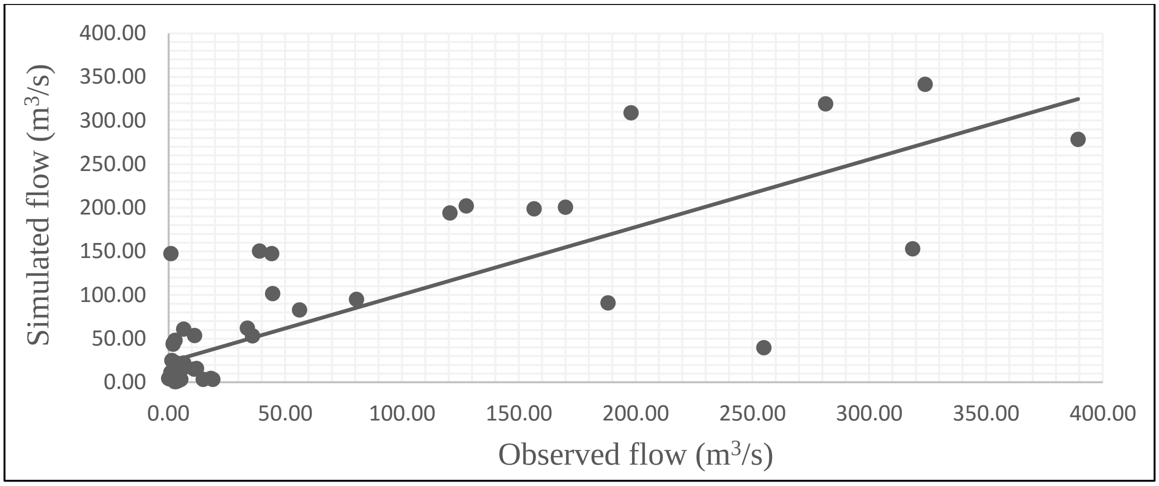


Figure 4.9 Scatter plot of observed and simulated monthly flow for the calibration period

4.4.2.2 Validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Three year monthly basis data (2004-2006) were used for model validation without any adjustment of fitted value during calibration and values of 0.78 for $R^{2,}$ 0.75 for E_{NS} and 8.9% for PBias were obtained. Values obtained for performance indices shows good agreement as they are within recommended values by Moriasi *et al*., (2007. Figure 4.10 illustrates hydrography during validation.

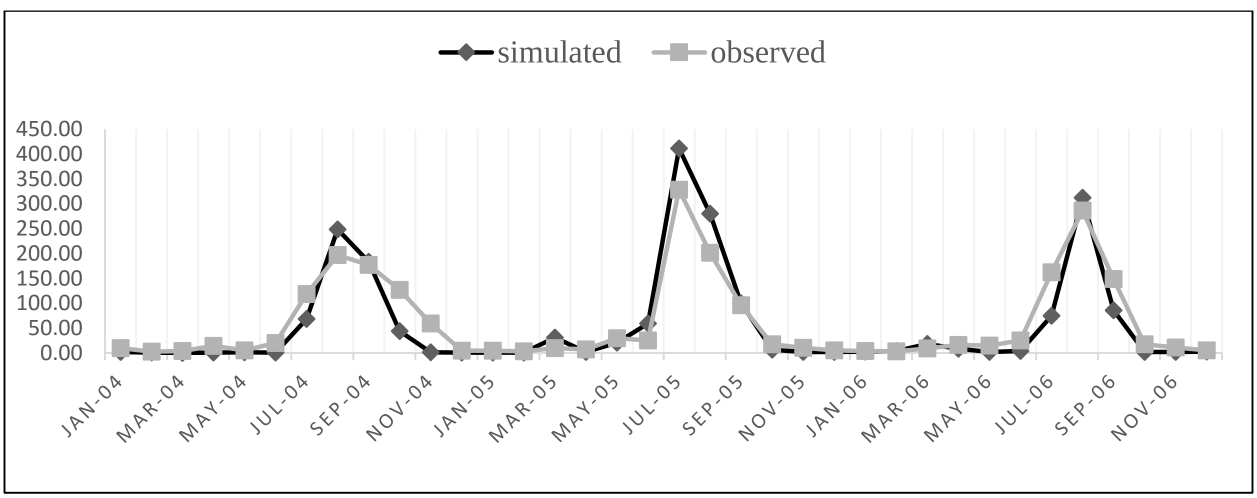


Figure 4.10 Hydrograph comparison during model validation

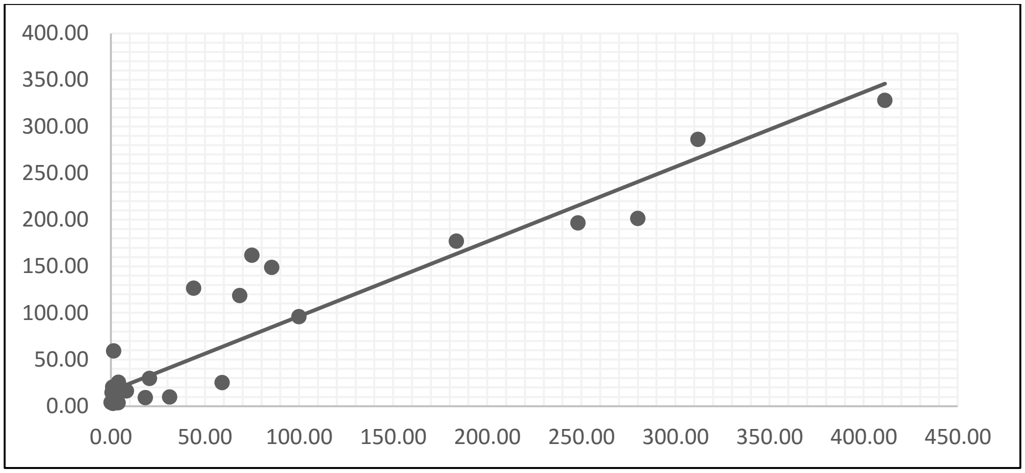


Figure 4.11 Scatter plot of observed and simulated monthly flow during validation period

Generally, according to Moriasi *et al.*, (2007) model performance in terms of replicating the observed hydrography is acceptable during calibration and validation. Values of performance indices used during calibration and validation is presented in Table 4.16. With this performance the model under estimated the observed stream flow compared to the simulated mean monthly stream flow in 2000 during calibration and 2003and 2004 during validation period. One of the factors that have contributed to uncertainty of the model might be the effect of the SWAT parameters that are considered to have negligible influence on the stream flow but cumulative of which would have affected the model performance. Unconsidered factors in modeling processes that resulted in the model error is also another factors.

Table 4.16 Values of performance indices during Calibration and Validation

Model efficiency measures			
Period	R^2	ENS	P_{BIAS}
Calibration	0.82	0.78	11.23
Validation	0.78	0.75	8.9

Another source of uncertainty may be stream flow record at the gauging station and uncertainties that arise from filling the missing flow data. Also, water abstraction activities practiced around the river operated by government and individual owners like water supply and irrigation from tributaries influence the stream flow causing uncertainty during model processing.

4.4.3 Average annual water balance components of the watershed

The SWAT model estimated other relevant water balance components in addition to the daily and monthly discharge of the watershed. Average annual basin values for different water balance components during a base simulation periods shows average annual watershed gain and losses with change in soil water storage as shown in Table 4.17.

Table 4.17 Average annual water balances simulated for a base periods of 1997-2006

Water balance components	Amount(mm)
Precipitation; Precip	1040.3
Surface runoff; Sur_Q	216.41
Lateral soil flow contribution; Lat_Q	77.28
Ground water contribution to stream flow	185.57
Revap or shallow aquifer recharges	152.35
Deep aquifers recharges	23.93
Total water yield; Twyld	455.15
Percolation out of the soil; Perc	198.41
Actual evapotranspiration; ET	547.2
Transmission losses	0.01

From average annual water balance during calibration period shown, the largest portion of the average annual precipitation (52.6%) falling in the watershed is lost through evaporation.

4.4.4 Projection of stream flow for Upper Awash sub basin

4.4.4.1 Projected changes in mean monthly and annual stream flow

Future stream flow was simulated for two scenario periods 2030's (2021-2040) and 2050's (2041-2060) considering river flow (1997-2006) as baseline flow. The stream flow projection takes place by assuming the projected precipitation and temperature inputs to SWAT and also considering land use/land cover, soil and other parameters similar to present in the future. The mean monthly and annual percentage change in flow for both (RCP4.5 and RCP8.5) scenarios for the period 2030s and 2050s are presented in Figure 4.12a and b respectively. The percentage change of mean monthly flow increases for months January ,February, March, April, July, August, November and December and also decreases in months May, June, September and October is observed for both 2030s and 2050s under RCP 4.5 scenario.

The mean monthly stream flow result shows that future monthly stream flow decreases in all months and annual during 2030's and 2050's, under RCP 8.5 scenario. Dile *et al*., 2013 conclude that decrease in flow volume observed in months which showed a decrease in monthly rainfall. Generally results showed that the impact of climate change cause a decrease in mean monthly flow volume between -0.89% to –18.01% during 2030s and between -0.44 to -32.98% during 2050s under RCP4.5 scenario.

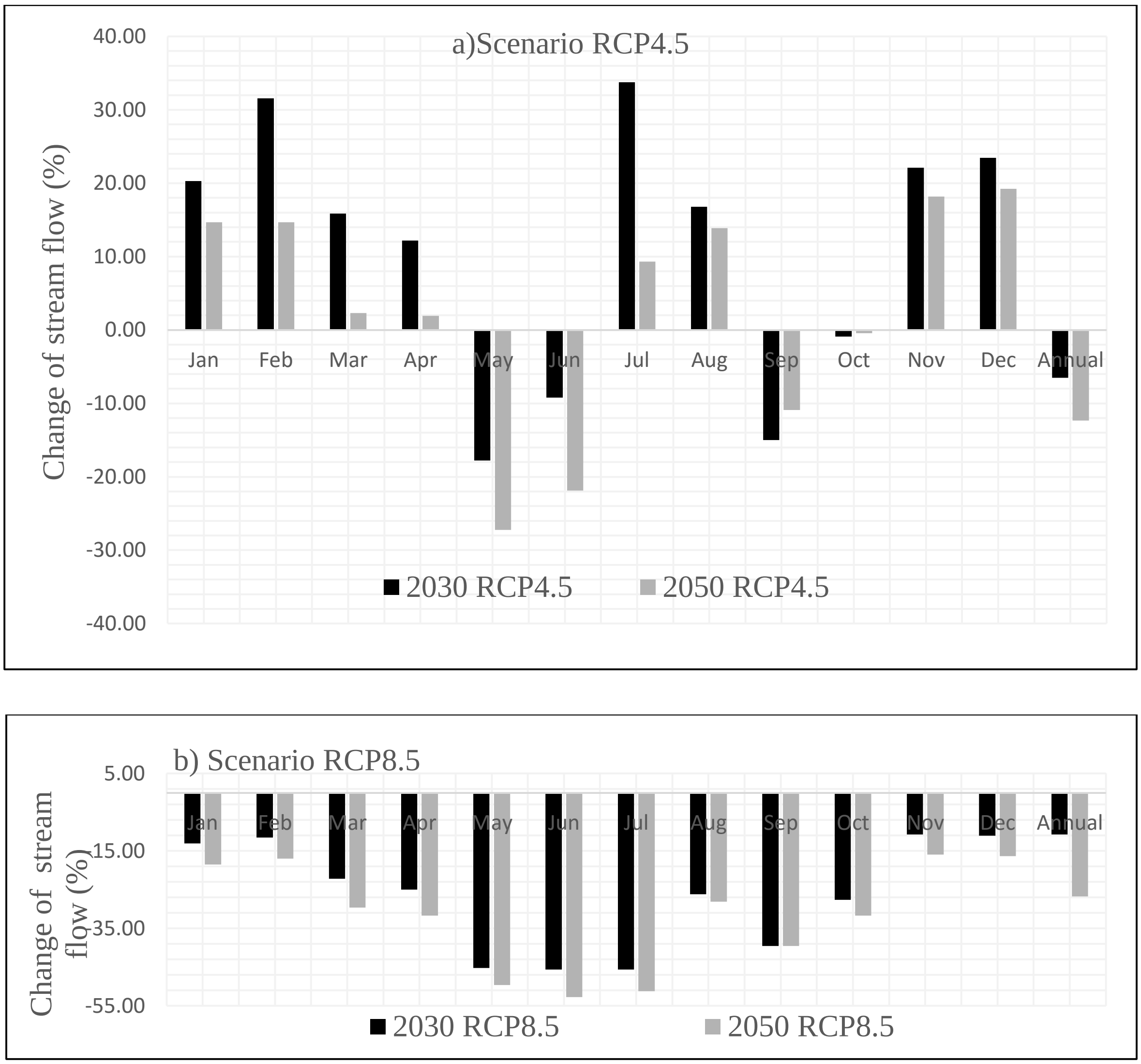


Figure 4.12 Mean monthly and annual percentage change of total flow pattern of Upper Awash sub-basin

Similarly, the projected mean monthly stream flow decreases between –10.75 % to -45.61% and decreases between -15.95% to -52.78% under RCP 4.5 scenarios in 2030s and 2050s respectively.

At annual basis generally, decreasing trend of stream flow was observed in the study area at 2030s and 2050s under RCP 4.5 and RCP 8.5 scenarios. As can be noticed from figure (19a and b) the projected annual stream flow decreased by –6.51% and -12.33 under RCP 4.5 scenarios in 2030s and 2050s respectively. Similarly for RCP8.5 the projected annul stream flow decreased by -10.76% and -26.74 in 2030s and 2050s respectively.

Overall, decreasing pattern of the average total annual flow in future is mainly because of a decrease in average monthly flow in all months for RCP 8.5 scenarios and for months May, June and September for RCP4.5. This is caused due to the fact that higher increment of projected maximum and minimum temperature as well as significant increase in evapotranspiration in the future over Upper Awash sub-basin. Also the decreasing pattern of the average total annual flow in future is higher in RCP8.5 than RCP4.5 due to high concentration of greenhouse gas, low technology development and no police implementation for climate in RCP8.5. This cause's high concentration of heat occurred in this scenario in future.

The seasonal variation of streamflow of the projected climate from the baseline period was comp uted for winter, spring, summer and autumn seasons (Table4.18). The seasonal projected stream flow shows increasing in all seasons for the first time horizon (2030s) under RCP4.5 scenario. Also for the second time horizon (2050s) the projected seasonal stream flow shows increasing except for autumn (MAM) season which shows decrease by -7.66% under RCP4.5 scenario. However, for RCP8.5 scenario the projected seasonal stream flow shows decreasing during both time horizon (2030s and 2050s).

Table 4.18 Percentage change of Projected Seasonal stream flow pattern of Upper Awash sub-basin

		Time horizon	
Scenario	Season	2030s	2050s
RCP4.5	Winter (DJF)	25.11	16.21
	Spring (SON)	2.07	2.27
	Summer (JJA)	13.79	0.45
	Autumn (MAM)	3.41	-7.66
RCP8.5	Winter (DJF)	-11.91	-17.29
	Spring (SON)	-25.98	-29.07
	Summer (JJA)	-39.15	-44.04
	Autumn (MAM)	-30.79	-36.98

When comparing the winter (dry) season with the summer (wet) season; the dry season average projected stream flow increase by 25.11% and 16.21% in 2030s and 2050s respectively under RCP4.5. Also the wet season average projected stream flow increase by 13.79% and 0.45% in 2030s and 2050s respectively. Similar findings were captured by Daba (2014) and Zelalem (2015) in Awash River basin.

4.4.5 Water Yield Simulation

The water yield was simulated for the base period on monthly time step at the outlet of Hombole gauging station. Moreover, the result was summarized in average monthly and annual bases. Mean monthly and annual water yield simulated for a base period found to be 37.92 mm and 445.15 mm respectively. Figure 4.13 shows the projected mean monthly water yields at 2030s and 2050s under the RCP4.5 and RCP8.5 scenarios together with the simulated base line mean monthly water yields.

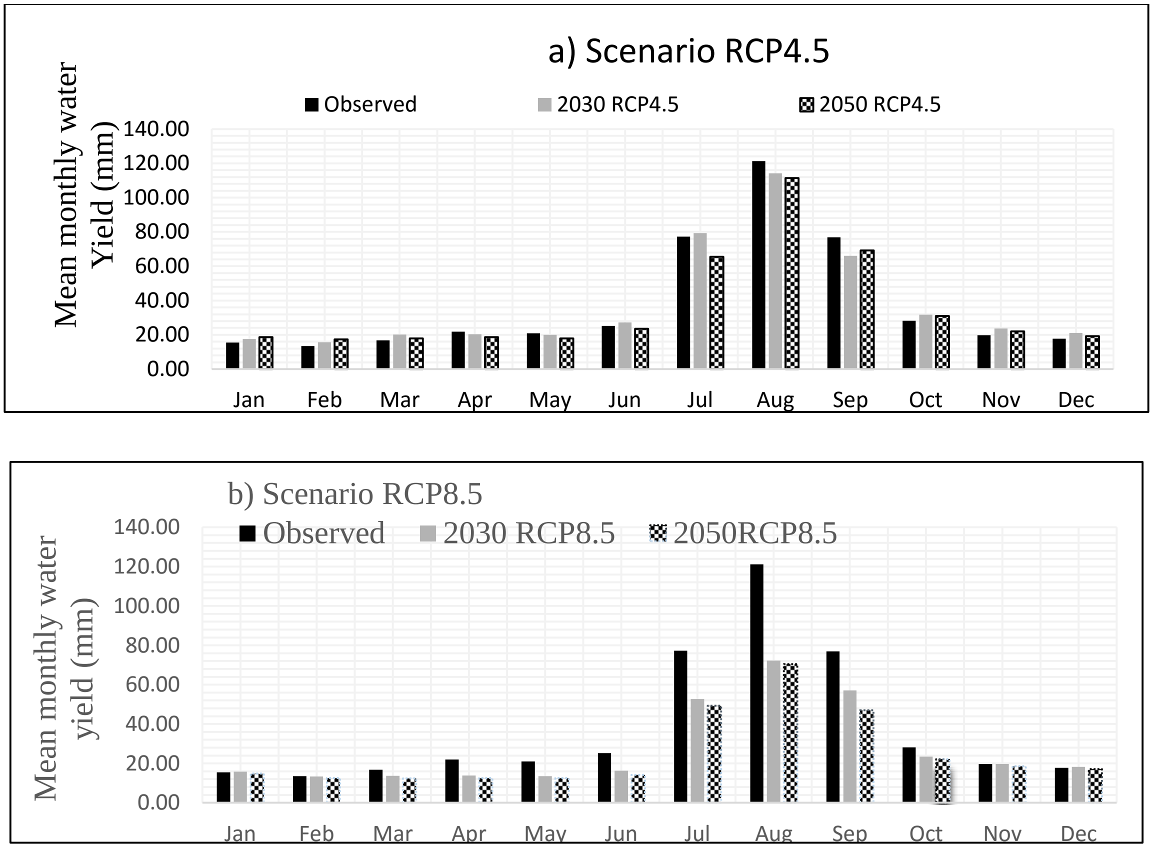


Figure 4.13 Comparisons of observed and projected mean monthly water yields at 2030s and 2050s under RCP 4.5 and RCP 8.5 with baseline period

Due to variability in precipitation and temperature the impacts of climate change will affect the water yields in the long term. The variations in the projected precipitation and temperature in both space and time different hydrological impacts are likely caused by the climate change. The impact of climate change on water yield was simulated based on the rainfall and temperature (minimum and maximum) changes on monthly basis. The impacts of climate change on water yield over the upper Awash sub basin was assessed using a baseline observed river flows for period of 1997-2006 at the Hombole gauging station. This was analyzed against the projected future river flows for the two time horizons 2030s (2021-2040) and 2050s (2041-2060) under two (RCP4.5 and RCP8.5) scenarios. As can be noticed from table4.19 shown below there is a decrease in annual water yield in 2050s under RCP4.5 and also in 2030s and 2050s under RCP8.5 scenarios. However, an increasing water yield is observed during 2030s under RCP4.5. The summer season months (June, July and August) show the larger share in decrease in water yields in the future. The mean monthly water availability decreased up to -14.1% and -15.36% at 2030s and 2050s for RCP 4.5

respectively. Similarly for RCP8.5 scenario the mean monthly water availability decreased up to -40.38% and -41.83% at 2030s and 2050s respectively. This may be caused due to the highest availability of projected evapotranspiration in future. Also the increase of water availability is observed in November months by 20.24% and 28.39% in February months at 2030s and 2050s under RCP4.5 respectively. Similarly the increase of water availability is observed in December months by 2.88% at 2030s under RCP4.5.

Table 4.19 Percentage change in mean monthly and annual total water availability in the two future time horizon from the base period simulation under RCP4.5 and RCP8.5 scenarios

	RCP 4.5 Scenario		RCP 8.5 Scenario	
Months	2030s (%)	2050s (%)	2030s (%)	2050s (%)
Jan	14.20	21.4	2.14	-4.02
Feb	16.31	28.39	-0.67	-6.67
Mar	19.66	6.77	-18.53	-26.13
Apr	-6.84	-14.6	-36.82	-42.34
May	-4.43	-14.68	-35.22	-40.18
Jun	7.87	-7.72	-35.51	-27.80
Jul	2.61	-15.36	-31.81	-36.26
Aug	-5.85	-8.16	-40.38	-41.83
Sep	-14.10	-9.94	-25.78	-38.8
Oct	12.6	9.63	-17.13	-17.81
Nov	20.24	11.29	-0.10	-5.82
Dec	19.31	9.03	2.88	-5.82
Annual	3.83	-2.32	-34.04	-37.57

The contribution of each sub-basin during the simulation period was summed up to arrive at the total yield of water by the sub-basin. The water yield is in depth unit and it is multiplied by the area of the basin to get the volume of the water yield. A total of 3.302 BCM of water is estimated for the sub-basin by the model at base period. The projected climate variables was used in to the model and re-run the model using fitted values of the parameters obtained during calibration period. In similar way to the base period, the contribution of each sub-basin were summed to achieve the total water availability for different time slices in the future at 2030s and 2050s.

Accordingly, the projected water availability over the Upper Awash sub-basin at 2030s shows significant increase for RCP 4.5 scenarios and decreasing of water availability is seen at 2050s for RCP 4.5 scenarios and also decreasing of water availability is seen for RCP8.5 scenario at 2030s and 2050s.

The water availability over Upper Awash sub-basin shows increase by 3.83% and decreases by -2.32% at 2030s and 2050s under RCP4.5 scenario. Similarly, the significant decrease of water availability is observed at 2030s and 2050s by -34.04% and -37.57% under RCP 8.5 scenario. As expected more decrease in water availability was observed under RCP 8.5 than RCP 4.5 scenarios in future due to higher temperature and evapotranspiration observed in future under RCP8.5 scenario. With the possibility of a change in climate from warm-wet to warm-dry decreases precipitation and a warmer climate decreases the amount of water available in the basin. The higher the temperature, the greater the amount of water that is lost from the Earth's surface and returned to the atmosphere through evaporation and transpiration, collectively known as evapotranspiration.

Seasonal water yield was simulated at four seasons (Winter, Spring, Summer and Autumn). The summer seasons show the larger share in decrease in flow volume in the future. The decrease may reach up to 7.85% and 29.92% at 2050s for RCP 4.5 and RCP 8.5 respectively.

Table 4.20 Seasonal changes of water yields at 2030s and 2050s under RCP 4.5 and RCP 8.5 with baseline period

		Time horizon	
Scenario	Season	2030s	2050s
RCP4.5	Winter (DJF)	2.60	2.91
	Spring (SON)	-1.09	-0.90
	Summer (JJA)	-1.03	-7.85
	Autumn (MAM)	0.29	-1.71
RCP8.5	Winter (DJF)	0.25	-0.69
	Spring (SON)	-8.23	-12.38
	Summer (JJA)	-27.49	-29.92
	Autumn (MAM)	-6.19	-7.37

Spring season also share decrease in flow volume up to 8.23% in 2030s and up to 12.38% in 2050s of RCP 8.5 in the future. This may be caused due to the highest availability of projected evapotranspiration and highest decrease of rainfall in future.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

This study analyzed the response of hydrological processes in the Upper Awash sub basin to possible future climate change predicted using an Ensemble of three GCMs driving models with dynamically downscaled approach and physically based distributed hydrological model (SWAT). Specifically the study assessed the historical trends in rainfall and temperature, downscaled the projected climate variables (rainfall and temperature) for the 2030s and 2050s under two RCP scenarios (RCP4.5 and RCP8.5) and also estimated the impacts of the projected variables on stream flow.

In assessing historical rainfall and temperature trends, the Mann-Kendall trend tests was used. Dynamically downscaling method was used to downscale the projected global rainfall and temperature for the 2030s and 2050s using data from three Ensemble GCMs driving models. Simulation of the changes in stream flow (runoff) was done using the soil and water assessment tool (SWAT) model.

Results from Mann-Kendall trend shows declining trend in rainfall and a rising trend in maximum and minimum temperature.

The projected rainfall and temperature were analyzed under two RCP scenarios (RCP4.5and RCP8.5). The results of projected annual rainfall showed that the rainfall will decrease by about 1.11% and 8.5% in 2030s and 2050s respectively under RCP4.5 scenario. Also decreasing of future annual rainfall is observed by 21.11% and 22.59% in 2030s and 2050s respectively under RCP8.5 scenario. The projected maximum and minimum temperature scenario showed an increase in mean monthly maximum and minimum temperature in all months in 2030s and 2050s under both RCP4.5 and RCP8.5s scenarios. The change in mean monthly maximum temperature increased in ranges between 0.4^{0}C in November and 1.17^{0}C in February in 2030s and ranges between 1.28^{0}C in August and 1.84^{0}C in April in 2050s under RCP4.5 scenario. For RCP8.5 scenarios, the change in mean monthly temperature ranges between 0.9^{0}C in November and 1.49^{0}C in April in2030s and ranges between 1.53^{0}C in August and 2.33^{0}C in February in2050s. The projected future mean minimum temperature increased by ranges between 0.85^{0}C in July and 1.39^{0}C in April for RCP4.5 and increased by ranges between 0.9^{0}C in August and September and 1.68^{0}C in February for

RCP8.5 scenarios respectively in 2030s. Also the change in mean monthly minimum temperature increases in ranges between 1.03^{0}C in August and 1.78^{0}C in April for RCP4.5 and ranges in between 1.44^{0}C in August and 2.74^{0}C in December for RCP8.5 scenarios in 2050s. The annual mean minimum temperature increased by 1.43^{0}C and 1.82^{0}C for RCP4.5 in 2030s and 2050s respectively. Also the annual mean minimum temperature increased by 1.45^{0}C and 2.36^{0}C for RCP8.5 scenarios in 2030s and 2050s respectively.

Using SWAT model on the Upper Awash sub basin, the probable impacts of climate change on the water yields in the catchment were evaluated. Prior to climate change study the model was calibrated and validated. The period 1999-2003 of the observed discharge was used for the calibration process of the model and 2004-2006 was used for the validation process. The study, the impacts of the projected climate variables on stream flow and water yields, show that the stream flow will decrease by -6.51% and -12.33% at 2030s and 2050s under RCP4.5 scenario respectively. Similarly for RCP8.5 scenario the stream flow will decrease by –10.76% and –26.74% at 2030s and 2050s respectively. The results also reveal that the water availability will decrease by -2.32% at 2050s under RCP4.5 and will decrease by -34.04% and -37.57% at 2030s and 2050s respectively under RCP8.5 scenario. However, the water availability will increase by 3.83% at 2030s under RCP4.5 scenarios. As expected more decrease in water availability was observed under RCP8.5 than RCP4.5 scenarios in future due to higher temperature and evapotranspiration observed in future under RCP8.5 scenario.

In summary, the results showed that there would be a decline in the amount of precipitation and rising in temperature under both RCP scenarios. This projected changes in precipitation and temperature dictates the projected changes in water yields.

5.2 Recommendations

This work was based on the regional climate model outputs to evaluate the likely impacts of climate change on water availability in Upper Awash sub basin. However, In addition to fluctuations in temperature and precipitation, deforestation, population growth and industrial expansion in the area are among current trends over the sub- basin. Therefore, future studies should focus on examine the impacts of land use changes along with climate change over the study area.

Future studies on Upper Awash sub basin modeling should also address the issues related to water quality including sedimentation, nutrients, and evaluate best management practices to address different water quality issues in the sub basin.

For this study only three GCMs (driving models) and one RCM was used for projections of climate variable. Future studies should consider as many GCM and RCM models as possible depending on their accessibility as that may enhance prediction efficiency. Also the GCMs were downscaled using the dynamic downscaling method therefore there is need to also test the Statistical down scaling method in further studies.

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7. APPENDICES

Appendix 1. Mean Monthly Flow of Awash River at Hombole station (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	4.9	0.2	7.1	9.2	14.7	124.5	321.6	535.9	428.7	212.6	102.8	28.1
1997	6.8	1.3	1.0	2.3	0.1	15.8	144.4	203.2	160.1	108.5	40.1	11.7
1998	19.9	8.2	10.1	2.6	6.8	73.5	219.3	383.9	286.9	220.6	89.3	30.6
1999	6.467	0.8278	2.11	1.53	0.5477	23.67	159.5	325.6	194.4	172.4	72.66	24.51
2000	4.634	0.5013	0.986	1.899	6.97	41.31	163.8	251.7	264.7	151.8	79.29	26.84
2001	5.075	1.55	29.05	3.479	9.784	48.25	274.8	294.5	221.6	113.2	43.77	8.182
2002	8.357	10.6	20.78	5.304	0.5519	12.52	105.7	248.5	202.4	105.7	47.32	13.56
2003	4.777	10.68	5.334	14.2	3.192	8.438	159	319.3	243.1	137.4	62.06	22.76
2004	11.28	1.215	0.5642	20.51	11.44	35.99	157.7	215.5	216	134.4	62.41	16.71
2005	4.358	0.2042	8.957	5.987	43.54	73.36	201.6	267.9	235.5	113.5	46.72	10.62
2006	2.062	7.869	20.32	15.75	13.75	37.97	234	355.9	335.4	177.1	83.46	26.22
2007	5.954	2.347	6.352	20.86	7.66	67.48	180.4	311.5	312.4	166.1	77.65	22.36
2008	4.059	2.091	0.754	0.08523	1.45	32.41	159.4	304.6	310.2	201.2	141.6	45.51
2009	13.16	3.27	0.3924	4.477	0.9874	21.97	164.6	384.4	290.8	173.5	75.87	23.4
2010	5.803	9.19	5.72	13.33	18.02	81.69	281.1	274.2	251.2	129.4	56.87	15.74

Appendix 2. Annual Rainfall Stations used in developing double mass curve (mm).

Year	Ginchi Cum.	Finfinne cum.	Hombole cum.	Bishoftu cum.	Gurnda Cum.	Boneya cum.	Average Cum.
1985	1149.80	1190.40	1997.86	998.10	531.70	1052.20	1153.34
1986	1444.90	1236.70	887.26	544.40	718.40	856.09	947.96
1987	1292.20	1317.90	534.50	833.40	911.90	1106.00	999.32
1988	1417.40	1202.60	690.30	756.10	941.50	918.34	987.71
1989	1486.40	1321.30	730.40	669.20	667.10	955.90	971.72
1990	1125.60	1124.60	1107.83	903.50	1113.40	1127.57	1083.75
1991	893.40	1167.00	987.50	998.10	709.70	1096.70	975.40
1992	1023.60	1101.40	1005.64	860.80	879.20	858.70	954.89
1993	1463.00	1567.90	918.23	756.10	1308.82	881.30	1149.22
1994	1173.50	1042.50	851.39	703.50	871.30	811.20	908.90
1995	991.80	1148.10	675.28	587.20	850.60	706.20	826.53
1996	1249.80	1548.50	839.65	1077.40	1377.50	1146.50	1206.56
1997	1029.20	952.40	902.51	854.40	565.60	497.30	800.23
1998	1226.50	1337.70	872.10	984.70	1088.70	718.90	1038.10
1999	1135.50	943.00	659.30	920.80	848.90	679.90	864.57
2000	993.20	1191.10	577.61	850.20	1093.40	583.90	881.57
2001	1102.60	1452.00	796.30	864.50	1130.50	632.40	996.38
2002	1047.40	1176.40	440.07	648.30	971.40	489.40	795.49
2003	1082.80	1210.30	894.60	1089.30	1286.50	575.60	1023.18
2004	1133.30	1192.00	614.70	824.10	998.60	389.80	858.75
2005	1148.30	1128.60	676.70	915.30	1258.00	557.31	947.37
2006	2152.60	1190.40	811.43	994.20	1411.00	1061.67	1270.22
2007	1090.70	1236.70	824.30	860.80	1483.10	1024.69	1086.72
2008	1024.10	1284.00	793.10	809.90	1399.10	790.80	1016.83
2009	940.40	1038.50	836.18	687.30	1240.52	808.82	925.29
2010	1211.40	1137.10	932.86	864.50	1639.60	1003.69	1131.53
2011	803.60	806.35	683.80	984.84	878.21	712.54	811.56
2012	822.40	1029.24	980.87	762.15	1820.44	860.60	1045.95
2013	1184.45	1017.42	626.60	721.11	1479.50	962.47	998.59
2014	1059.97	772.20	506.58	833.61	1071.40	819.39	843.86

Appendix 3. Parameters Used in Sensitivity Analysis

No.	Parameter	Description
1	r__CN2	runoff Curve Number
2	v__ALPHA_BF	Base flow alpha factor (days)
3	v__GW_DELAY	Ground water delay (day)
4	a__GWQMN.gw	Deep percolation(mm)
5	r__SOL_K	Soil depth (mm)
6	v__RCHRG_Dp	Deep aquifer percolation fraction
7	a__ESCO.hru	Soil evaporation compensation factor
8	r__SLSUBBSN	Average slope length
9	r__HRU_SLP	Average slope steepness
10	v__CH_N2	Manning coefficient of tributary channel
11	v__CH_K2	Hydraulic Conductivity (mm/hr)
12	v__ALPHA_BNK	Base flow alpha factor for bank storage.
13	v__SURLAG	Surface runoff lag coefficient
14	r__OV_N	Manning's "n" value for overland flow
15	v__REVAPMN	Threshold depth of water (mm)
16	a__SOL_ALB	Soil albedo
17	a__EPCO.hru	Plant uptake factor
18	r__SOL_K	Soil hydraulic conductivity (mm/hr)
19	r__SOL_AWC	Available water capacity of a soil
20	r__GW_REVAP	Ground water evaporation coefficient