HYDROLOGICAL RESPONSE OF CLIMATE CHANGE ON WEYB RIVER WATERSHEDS: THE CASE OF BALE MOUNTAINOUS AREA, ETHIOPIA

MSc. Thesis

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DEDICATION

I dedicate this thesis manuscript to my father Bahmud Ushi, and my mother Bulo Jilo for nursing me with affection, love and for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an advanced M.Sc. degree at Hawassa University and is deposited at the University Library to be made available under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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ABBREVIATIONS AND ACRONYMS

AOGCM	Atmosphere/Ocean General Circulation Model
ArcSWAT	SWAT Integrated with ArcGIS
ARS	Agricultural Research Service
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BMNP	Bale Mountains National Park
CMhyd	Climate Model data for hydrologic modeling tool
CMIP5	Coupled Model Inter comparison Project version 5
CN	Curve Number
CORDEX	Coordinated Regional climate Downscaling Experiment
DEM	Digital Elevation Model
ERSDAC	Earth Remote Sensing Data Analysis Center
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FAST	Fourier Amplitude Sensitivity Test
GCM/s	Global circulation Model/s
GDEM	Global Digital Elevation Model
GHGs	Greenhouse gases
GDMP	Genale Dawa Master Plan
GIS	Geographic Information System
HRU	Hydrologic Response Unit
IWMI	International Water management Institute
IPCC	Inter-Governmental Panel on Climate Change
ISRIC	International Soil Reference and Information Center
ITCZ	Inter tropical Convergence Zone
IVF	Index of volumetric fit
LH	Latine Hypercube
LULC	Land Use / Land Cover
m.a.s.l	mean above sea level
MoWE	Ministry of Water and Energy
MoWIE	Ministry of Water, Irrigation and Electricity
NAPA	National Adaptation Programme of Action for Ethiopia
NARCCAP	North American Regional Climate Change Assessment program

NASA	National Aeronautics and Space Administration
NMSA	National Meteorological Service Agency
ENS	Nash Sutcliffe Efficiency
OAT	One factor At a Time
ParaSol	Parameter Solutions
PET	Potential Evapotranspiration
PRUDENCE	Prediction of Regional Scenarios and Uncertainties for Defining European Climate change Risks and Effects
R^2	Coefficient of determination
RCA4	Rossby Centre regional atmospheric model version 4
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
RVE	Relative volume error
SCS	Soil Conservation Service
SHMI	Swedish Metrological and Hydrological Institute
Rs	Solar shortwave radiation [MJ m-2 day-1]
SWAT	Soil and Water Assessment Tool
SWAT-CUP	Soil and Water Assessment Tool - Calibration and Uncertainty Programs
SUFI-2	Sequential Uncertainty Fittings version 2
UNESCO	United Nation Educational Scientific and Cultural Organization
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WCRP	World Climate Research Program
WXGEN	Statistical weather generators file for SWAT

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ABSTRACT

The hydrological regimes and cycles within a certain watershed can be changed by the global climate variability and change. This change adversely impacts on environmental sustainability,water resources, agriculture and ecosystems. The current study investigates the hydrological impacts of climate change in essence, changes in precipitation and temperature over the Weyb river watershed. It is based on a sample of Coupled Model Inter comparison Project version 5 (CMIP5) downscaled over the Africa-Coordinated Regional climate Downscaling Experiment (CORDEX) domain by a Rossby Centre regional atmospheric model version 4 (RCA4) output, under RCP 4.5 and RCP 8.5 scenarios. Variance scaling and linear transformation bias correction methods was used to develop the simulation output of RCA4 regional climate model with high correlation to the observed data. ArcSWATmodel was used to generate future water availability in the basin. The bias corrected data were then used as input to the SWAT model to simulate the corresponding future flow regime in Weyb river watershed which is calibrated daily at R^2= 0.6,E_{NS} = 0.5, and validated daily at R^2=0.58,ENS 0.57. The future projections are made for three time periods; 2020 (2010-2039),2050 (2040-2069) and 2080 (2070-2099). Results revealed that future predicted both temperatures, and precipitation revealed a statistically significant (at 5% significant level) increasing trend in the forthcoming periods as perceived by MannKendall test.Trend analysis with test using Mann-Kendall (MK) and Sen's slope non-parametric test was applied to detect significant trends on the climate parameters and stream flow for future periods using XLStat software. The level of statistically significant trend was selected at $\alpha = 0.01, \alpha = 0.05 and \alpha = 0.1$ level of significance. The annual mean daily stream flow revealed an increase, possibly, in the ranges 9.16-23.39% (RCP8.5), and 3.97-20.30% (RCP4.5). The result revealed that the maximum and minimum temperatures increase for all the two scenarios in all future time horizons. Rainfall change for all the two RCPs scenarios were variable. Results also revealed that a decrease of stream flow in all months on the dry season this might cause water shortage in the lowland region, and greater increase of stream flow in an intermediate and rainy seasons this might cause flooding to some flood prone region of the basin. A significant conclusion from the study is that changes in rainfall have larger effects on stream flow.The use of integrated hydrological modeling in impact assessment and the inclusion of other factors that cause imbalance in the stream flow should be enhanced in the Weyb watershed.

Key words: CMIP5 , CORDEX, SWAT, Weyb river watershed, Genale-Dawa River Basin, GCM RCM,Bias correction, RCP scenario.

1. INTRODUCTION

1.1. Background

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an comprehensive period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014). Climate change is projected to be a powerful stressor on terrestrial and freshwater ecosystems in the second half of the 21st century, especially under high-warming scenarios such as RCP6.0 and RCP8.5. Through to 2040 globally, direct human impacts such as land-use change, pollution, and water resource development will continue to dominate threats to most freshwater ecosystems and most terrestrial ecosystems. Many species will be unable to move fast enough during the 21st century to track suitable climates under mid- and high-range rates of climate change (IPCC, 2014).

According to National Adaptation Programme of Action for Ethiopia (2007), "developing countries in general and Ethiopia in particular are more vulnerable to the adverse impacts of climate variability and change''. This is due to their low adaptive capacity and high sensitivity of their socio-economic systems to climate variability and change. Sensitivity and adaptive capacity also vary between sectors and geographic locations, time and social, economic and environmental considerations within a country.

Climate model projections under the A2 and B1 scenarios over Ethiopia show warming in all four seasons across the country, which may cause a higher frequency of heat waves as well as higher rates of evaporation (Conway *et al.*, 2011). Projected maximum and minimum temperatures over equatorial eastern Africa show a significant increase in the number of days warmer than 2°C above the 1981–2000 average by the middle and end of the 21st century under the A1B and A2 scenarios (Anyah *et al.*, 2012). With respect to hydrology, climate change can cause significant impacts on water resources by resulting changes in the hydrological cycle. For instance, the changes on temperature and precipitation can have a direct consequence on the quantity of evapotranspiration and on both quality and quantity of the runoff component. Consequently, the spatial and temporal availability of water resource, or in general the water balance, can be significantly affected which in turn affects agriculture, industry and urban development. Extreme hydrological variability and seasonality have constrained Ethiopia's past economic development by negatively affecting crop production chiefly through droughts and by destroying roads and other infrastructure due to flooding. As climate change unfolds, average climatic variables will shift, and weather variability will intensify, exposing Ethiopian agriculture to higher levels of risk and jeopardizing economic growth, food security, and poverty reduction (You *et al.*, 2009).

Agriculture is the backbone of Ethiopia's economy and 85 percent of the population lives in the highlands depending on agriculture and favorable climatic conditions. However, in the present time climate change and unseasonal rainfall is often observable that limits water availability and the productiveness of the area (Conway *et al.*, 2010). The limited water resources that Ethiopia has for about 80 million people is dependent on seasonal rainfall and there is high rainfall variability that causes extreme climate events, which can further affect the society (CIA, 2008). The Genale Dawa River Basin stream flow is completely dependent on the seasonal rainfall that comes from two rainy seasons in the region. A systematic study, analyzing the impact of climate-induced scenarios on water resources availability and adaptation strategies on the sub-basin as the basic unit of assessment, is still missing (Faramarzi et al. 2013). Developing countries in general and least developed countries like Ethiopia in particular are more vulnerable to the adverse impacts of climate variability and change. This is due to their low adaptive capacity, its economic and geographic settings, and high sensitivity of socioeco- nomic systems to climate variability and change (NMSA 2007). The recent flooding occurrences and the frequent drought in Ethiopia can be sited as concrete evidences for these impacts.

Mountainous watersheds are the origin for many of the largest rivers in the world and represent major sources of water availability for many countries (Sanjay et al. 2010). They represent not only the local water resources but also considerably influence the runoff regime of the downstream rivers. Farm Africa-SOS Sahel Ethiopia (2007) described that among the prior ecological services of the Bale Mountain National Park (BMNP), afro-alpine ecosystem is one of its hydrological systems. Moreover, BMNP is a source of over 40 streams on which more than 10 million people are dependent. The importance of the hydrological services that the area provides to southeastern Ethiopia and parts of Somalia and Kenya has gradually been recognized and its conservation is now a primary purpose of the park.

Climate change has already become a global issue and a concern for all caring for the future. There are some studies on climate change impact on water resources of river basins in Ethiopia (Lijalem 2006; Abdo et al. 2009; Melesse et al. 2009; Setegn et al. 2011; Yirefu 2012). Despite the fact that the impact of different climate change scenarios is projected at a global scale, the exact type and magnitude of the impact at a small watershed scale remain untouched in most parts of the world. Therefore, identifying localized impact of climate change at a watershed level and quantitative estimates of hydrological effects of climate change is crucial. This also gives an opportunity to define the degree of vulnerability of local water resources to climate change and plan appropriate adaptation measures that must be taken ahead of time.

This study aims to assess climate change scenarios for precipitation and temperature over Weyib River catchment to assess their impacts on the flows of this catchment. The rainfall and temperature scenarios have been downscaled to the fine resolution required by the hydrological model from CORDEX using RCA4 Regional climate Model (RCM).

1.2. Statement of the problem

The variation of climate due to global warming is becoming the cause for the change in the frequency of severe floods and droughts; and land degradation for resource competition as a result of rapid population growth. This in turn is leading to higher peak discharges, stream sediment loads and unstable rivers channels. Weyib River is highly affected river by sedimentation, in which the amount of discharge from the river is reduced due to sediment accumulation. The study of (Hailemariam, 1999) which illustrates the Awash River Basin would be significantly affected by the climate change; that is, a considerable water deficit is projected. Genale Dawa River Basin would also the basin which is affected by the same of Awash River Basin with climate change and increases in climate variability, the need for managing water resources requires immediate action or attention. Due to climate change and variability there is an increase in severity of extreme events which results in fluctuation of storages. This may lead to an increase in floods and droughts. Ethiopia has ample water resources, which can be appropriately utilized to enhance socioeconomic development of its people. 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 (Hailemariam,1999). There have been few studies performed utilizing GCM under SRES scenarios for climate change impact studies in Weyb river watershed. However, Studies performed at regional scale to investigate the future changes of hydrologic regimes, and water resources availability under climate change in in Weyb river watershed with respect to RCMs are very limited. Therefore, studies that fill this gap and provide information are very important. Just like other, studies done on Weyb river watershed showed that the watershed's water resource is very sensitive to incremental climate variability. However, these studies were only based on hypothetical precipitation and temperature change, which of course didn‘t take into consideration the Regional Climate Model (RCMs). Hence, studies that can narrow this gap are very important (Eman S.A. Soliman, 2009). Even if, climate and hydrological models was applicable before in the study area there is the gap. Therefore, in this study high resolution CORDEX (RCA4) with two RCP scenarios RCP4.5 and RCP8.5, and hydrological models

SWAT has been utilized to evaluate climate change impacts on the hydrology of Weyib river watershed, because knowledge of climate change is important for planning and management.

1.3. Objectives of the study

1.3.1. General objective

To evaluate Hydrological Response of Climate Change on Weyb River Watersheds**.**

1.3.2. Specific objectives:

- To detect trend on future temperature and precipitation using regional climate models in Weyb river watershed
- To estimate the future river flow under RCP 4.5 and RCP 8.5 climate change scenarios on Weyb river watershed.

1.4. Scope of the study

The study was focus on the capabilities to fulfill water demand of the Agriculture (irrigation the main focus of the Sub Basin) in the upstream catchments and supply of environmental flow downstream of Weyb river under climate change. To know the level of impact of climate change on the river water availability and flow generation potential, climate change scenarios of precipitation, and temperature was developed for future periods using bias corrected and dynamically downscaled by regional climate model (RCM) for a newly climate change scenario analysis RCPs. In this study the land use change initially included in the new climate scenario analysis (RCPs) and assumed as was remain the same which is somewhat better than previous emission scenarios. The study also doesn't consider the sediment inflow to the river at future time horizons and also assess only the specified climate adaptation options among many water resource management listed in the objectives.

1.5. Research questions

The research questions addressed in this study are:

1.What are the general trends of the future climate compared to the present condition and how can this affect the Weyb river watersheds ?

2. What are the general patterns of maximum temperature, minimum temperature and precipitation scenario in the future compared to the present condition and how this is reflected on the hydrology of the Weyb catchment?

1.6. Significance of the study

The major significant of this study is, it allows the planners, decision makers and any concerned persons to understand the consequences of climate change on hydrological variables and the impacts these have on potential water resource planning management and accordingly device decision and management support tools.The other significance of the study is to produce good understanding for water resource planner, decision makers, stakeholders and any concerned person to the consequences of climate change on hydrological variables (such as precipitation, temperature, stream flow etc) and the impact of those have on water resource system performance and provide possible mitigation measures to cope up with the problems. It was try to quantify the actual climate change mitigation that was an input for the provision of new sustainable catchments. Thus, the result of this study was expected to add new insight in adopting. It will also serve as a benchmark data for further investigation of the existed problems of drought and flood under different climate change scenarios.

1.7. Limitation of the study

Several limitations introduced during the course of this study. One of the major limitations will the spatial variability associated with precipitation. There is only few number of rain gauge station used in the Weyb river watershed. This can cause considerable errors in runoff estimation if one gauge is used to represent an entire watershed as SWAT requires spatially distributed data. The daily stream flow record also available only for short period which caused calibration process extremely difficult. In this study also the impact of climate change was assessed by using one GCM model and by assuming the land cover will remain the same. The study also doesn’t consider the sediment inflow to the river at future time horizons. However, in real world the land cover change and sediment inflow will occur due to natural and human influences.

2. Literature review

2.1. Climate change

Climate change means a change of climate which is accredited directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. Climate change is the most grave problem that the whole world is facing today. It is now widely accepted that climate change is already happening and further change is inevitable; Over the last century (between 1906 and 2005), the average global temperature rose by about 0.74°C. This has occurred in two phases, from 1910s to 1940s and more strongly from the 1970s to the present (IPCC-TGICA, 2007).

Many studies into the detection and attribution of climate change have found that most of the increase in average global surface temperature over the last 50 years is attributable to human activities (IPCC, 2001a). Study of climate change is important to water planners and managers because it may change underlying water management conditions [(Barnett *et al.*, 2008; IPCC, 2007)] and increase the need for new water management programs and capital investments (CUW, 2007).

2.2. Climate change aspects

The cognizance of the level to which the society, environment and economy can be affected by the change of climate has increased. Increasing greenhouse gases concentration mainly carbon dioxide has led to the observed long-term climate change globally, regionally and also at local scales. These encompass changes in timings and amounts of precipitation, temperatures, extreme weather like droughts and heavy precipitation, wind patterns and heat waves (IPCC, 2014). Precipitation patterns are influenced by moisture availability and circulation patterns of the atmosphere and are unevenly distributed across the globe. These patterns of precipitation are anticipated to change since the temperature is changing and it influences the moisture availability and the atmospheric circulation patterns.

The changes embrace of the amount, frequency intensity and nature of precipitation. In most parts of Northern Europe, North America and South America, precipitation has increased and decreased in most of Africa, the Mediterranean and southern Asia (Trenberth & Shea 2006; IPCC 2014). The world leading international organizations in climate change research associate climate change to human causes through activities that increases emissions of heat- absorbing GHGs (IPCC, 2014). These emissions change the composition of atmosphere and vary the natural climate witnessed over a relatively longer time periods. Climate change is the state variation of the climate that can be predictable by mean fluctuations or the inconsistency of its characteristics and that takes longer period, normally decades or longer (IPCC, 2014).

2.2.1. Source and emission of greenhouse gas

The anthropogenic activities that contribute to climate change mostly encompass the emissions of greenhouse gases (GHGs) which trap heat. These GHGs include methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (NO_2). GHGs such as CO_2 and CH_4 absorb energy emitted on earth's surface, and this prevents or reduces the loss of heat to space. Therefore, these gases form a blanket near earth's surface rising the average temperature of the earth's climate system. This process is called greenhouse effect (IPCC, 2014). The major cause of global warming is CO_2. Its main source is increased and continuous burning of fossil fuels for electricity generation (30% of 2014 greenhouse gas emissions), transportation (26% of 2014 greenhouse gas emissions), industrial (21% of 2014 greenhouse gas emissions) and household uses (12% of 2014 greenhouse gas emissions) (Pachauri *et al.*,2014). 57% of the global CO_2 is produced from fossil fuel use while 17% of CO_2 is from decay of biomass and 8% of CO_2 is from unknown sources. 8, 14, and 1% of the total GHG emitted is contributed by NO_2, CH_4 and fluorinated gases respectively (IPCC, 2014; Oluwatomiwa, 2014).

Recent research works reliably show that the CO_2 emissions primarily from the combustion of fossil fuel on a global scale have constantly increased (Karl *et al.,* 2009; Schnoor, 2010; IPCC, 2014). In the previous several decades, 20% of CO_2 brought about by human activities stemmed from deforestation and associated agricultural practices, while about 80 percent emissions were produced from fossil fuels burning, globally (Forster *et al.,* 2007; Mach & Mastrandrea, 2014).The CO_2 concentration in the atmosphere has increased by roughly 35 percent since the beginning of industrial revolution (IPCC, 2014). During the biological carbon cycle, plants take up the CO_2 from the atmosphere which helps in the process of CO_2 sequestration. CH_4 results from production and transport of natural gas, coal, oil. Another factor that contributes to the emission of methane to a greater extent is waste decay in municipal solid waste landfills and agricultural practices such as livestock farming (IPCC, 2014). Another GHG is NO_2 which is emitted during industrial activities, fossil fuels combustion and solid waste as well as in agricultural related activities such as raising livestock (IPCC, 2014).

Fluorinated gases (F-gases) which are emitted from a range of industrial processes that are applied in fire extinguishers, pesticides, coolants, foaming agents, aerosol propellants and solvents, include hydro fluorocarbons (HFCs),Chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFCs), sulfur hexafluoride(SF6),and per fluorocarbons (PFCs) also cause greenhouse effect (Pachauri et al., 2014; IPCC, 2014).

Ozone (O_3) is another considerable GHG with a short atmospheric lifetime produced when nitrogen oxides and explosive organic compounds reacts with sunlight (IPCC, 2014). Tropospheric ozone is a major pollutant which adversely affects respiratory health of living organisms and damages plants and ecosystems (Pinto *et al.,* 2010; IPCC, 2014). Nevertheless, water with its short lifetime in the atmosphere is another factor that is considered as the most ample GHG contributing to the natural greenhouse effect. Temperature generally controls the concentration of water vapor globally which in turn influences precipitation and evaporation rates. The emission of water vapour on a global scale is not fundamentally influenced generally by human induced emission (Rothausen & Conway, 2011; IPCC, 2014). Major greenhouse gas concentrations are shown Figure 2.1.

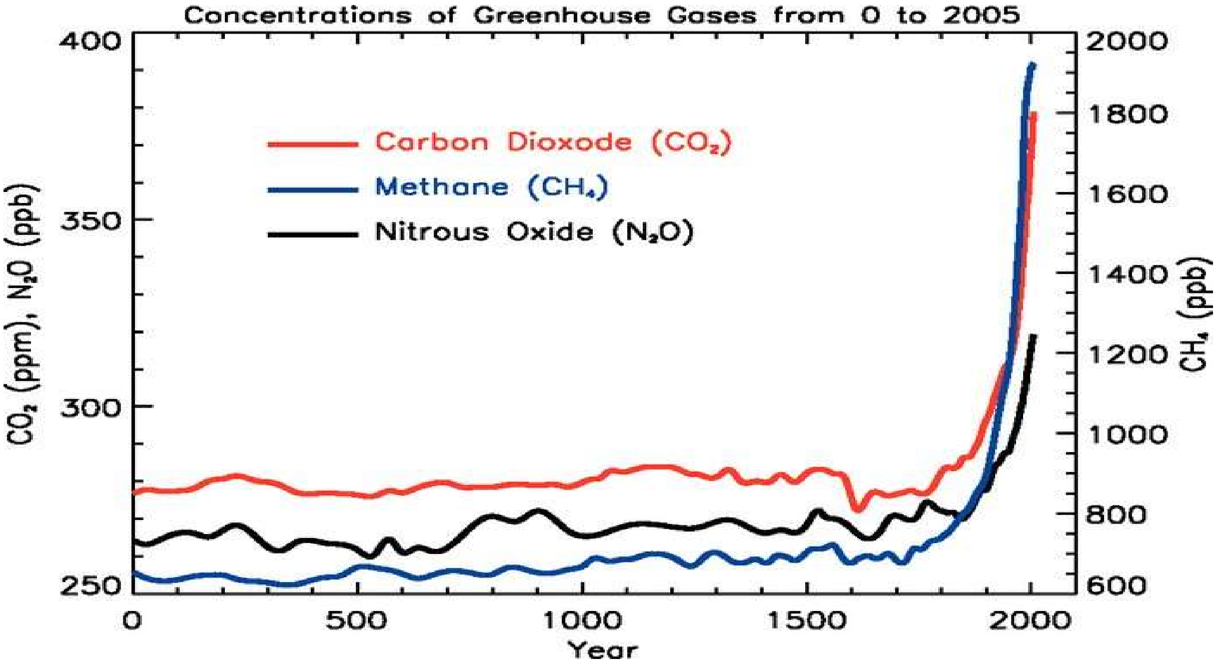


Figure2.1: Concentration of Green House Hases from 0 to 2005(Source: IPCC , 2014).

2.2.2.Naturally driven climate change aspect

The volcanic eruptions and the sun are among the major natural factors contributing to global climate change (IPCC, 2014). The energy output of the sun has followed its historical cycle of 11- years of small ups and downs without any significant increment. This is as was measured by satellites since 1979 several decades ago. Though the above stated natural influences cannot substantially give details on the global warming in latest decades, there has existed a minor cooling influence over this period as a result of their net effect on climate (Hansen *et al.,* 2006; IPCC, 2014). On thousands of year"s timescales, the unhurried variations in the earth"s orbit around the Sun and its tilt in the direction of or away from the Sun are also a natural influence on climate, (Kaufmann *et al*., 2011; Burck *et al.,* 2014; Mach & Mastrandrea 2014).

2.2.3. Climate change indicators

Climate, generally defined by the temperature and precipitation characterizes an enduring average condition of the weather in a given place. Weather can change within a few minutes or hours, but development of changes in climate is over longer time periods, i.e., decades to centuries). The warming of the climate system is undisputable, a statement from the Fifth Assessment Report of IPCC (2014). This is a claim deduced from observations of rising average sea level, prevalent melting of snow and ice and rise in overall average air and ocean temperatures.

The emission GHGs which trap heat into the atmosphere continuously and increasingly is basic but not the sole source of increase in temperature and global warming (Karl *et al.,* 2009; IPCC, 2014; Mach & Mastrandrea, 2014). Since the 1970"s there has been noticeable increase in average surface temperature extending from 0.31- 0.51°F per decade. (Haeberli *et al*., 2007; Rothausen & Conway, 2011).The accessibility of water for use in the industries and households, agricultural purposes and drinking water is generally affected by the rainfall and snowmelt timing (Mimikou *et al*.,2000; Philippart *et al*., 2011). Plant types and animals that can survive in a particular region heavily depend on the rate of precipitation (IPCC, 2014). The effect of climate change varies globally with the unstable wind patterns and shifting ocean currents that drive climate system of the world (IPCC, 2014). This causes some areas to experience increased precipitation while others decreased precipitation (Funk & Brown, 2009; EPA, 2011). Moreover, higher temperature causes more evaporation reducing the amount of water available regardless of an increased precipitation (Melillo *et al*., 2014; Martens, 2014; Schewe *et al*., 2014; IPCC, 2014).

2.3. Climate change impacts

2.3.1. Impacts on water quantity

For human survival and sustenance, water as a natural resource is very crucial. Water is also important for energy production, agricultural science, manufacturing, recreation and navigation (Karl *et al*., 2009; Melillo *et al*., 2014). These natural water resources include ocean, seas, lakes, underground aquifers and rivers (Furniss, 2010).

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 (Poff *et al.,* 2002; Karl *et al.,* 2009; Chien *et al.,*2013; Rwigi, 2014). Runoff is one of the significant components of water resources and will be affected by changes in the climate in terms altering of precipitation and temperature. Quite several researches are steered towards evaluation of climate change effects on runoff due to the importance of runoff for water supply (Githui *et al*., 2009; Faramarzi *et al.,* 2010; Mango *et al.,* 2011). Demand for water could likely be increased by change in climate while the supply is being reduced (IPCC 2014; Melillo *et al*., 2014).

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 (Mach & Mastrandrea, 2014). Temperature changes, fire or pest outbreaks that lead to changes in soils and vegetation which in turn leads to changes in the rates evaporation and infiltration are also likely to affect recharge (Bates *et al.,* 2008). More frequent and larger floods in semi-arid and arid areas may likely increase the groundwater recharge (Bates *et al.,* 2008). Lastly, extreme weather conditions for instance drought caused by the stretched imbalance between precipitation and evaporation, is another resulting impact of climate change (Melillo *et al*., 2014). Increasing demand for drinking water which accompanies the more rates of urbanization will put stress on the existing water sources (Bates *et al.,* 2008).

2.3.2. Impacts on water quality

When considering the human health, ecosystems and their survival, the quality of water becomes a very important issue (Quansah *et al.,* 2008; Melillo *et al*., 2014). Regions expected experience increased rainfall intensity due to climate change, the water quality could depreciate. The increased runoff in rivers could lead to washing human and animal waste, sediment, trash, nutrients, pollutants and other materials into water supplies, making them insecure or requiring water treatment process before use (Parry *et al*., 2007; Ebi *et al.,* 2008). The same could cause problems in water treatment plants and sewer systems as these infrastructures can be overwhelmed by the increased volumes of water and materials (Mimikou *et al.,* 2000; Karl *et al.,* 2009; EPA, 2011).

Sea level upsurge caused by climate change may also affect freshwater resources along the coasts (Karl *et al.,* 2009; Mach & Mastrandrea 2014). Availability of dissolved oxygen in water is an indispensable resource for various living things, and also for self-purification abilities of rivers. However, increased temperatures in the water could compromise its availability (Mimikou *et al.,* 2000; Karl *et al.,* 2009). Nation"s largest water quality deprivation is the non-point source pollution and is linked to why the apportioned water quality principles for various activities like recreational activities or fishing are not met by a greater percentage of rivers, lakes etc. (Maingi & Marsh,2002; Kauffman *et al.,* 2014). The principal source of non-point source pollution is agriculture (Hunink, *et al.,* 2012; Melillo *et al*., 2014).

2.3.3. Impacts on agriculture

Climate change has adverse impacts on the agricultural sector. Warmer temperatures may decrease crop yields and also could favor a quick growth of some crops (Mach & Mastrandrea, 2014). Like in the case of crops like grains, there is decline in the quantity of crop produced in a farm because of reductions in the extent of time the seed have to develop and mature, (EPA, 2011; Mach & Mastrandrea, 2014).

Water availability, soil nutrients and optimal temperature of the crop for reproduction and growth, controls the effects as a result of increased temperature (Mogaka, 2006; Kauffman *et al.,* 2014). Agricultural activities largely depend on water resources. Farming in the upper Weyib will become altered due to climate change and this will affect economic growth of the country. Crop yield is also affected by higher atmospheric concentrations and extreme weather conditions e.g. flood and drought (Funk & Brown, 2009). Human health and livestock can also be negatively impacted by increased temperatures in the form of heat waves (Githeko & Woodward, 2003; Nardone *et al*., 2010; Ouma, 2015).

2.4. Climate change in Ethiopia

Climate change affects various dimensions of Ethiopia’s economy including power generation; the country’s health, education and industry sectors; and public spending on productive investments. However, estimating the impact of climate variability on agriculture is more straightforward and easy to quantify (Emerta, 2013).

As explained in NAPA (2007), baseline climate that was developed using historical data of temperature and precipitation from 1971- 2000 for selected stations in Ethiopia showed a very high year-to-year variation in rainfall for the period 1951 to 2005 over the country expressed in terms of normalized rainfall (Figure 2.2).

Over those periods (1951-2000), some of the years have been dry resulting in droughts and famine while others were characterized by wet conditions. The observed trend in annual rainfall, however, remained more or less constant when averaged over the whole country (NAPA, 2007).

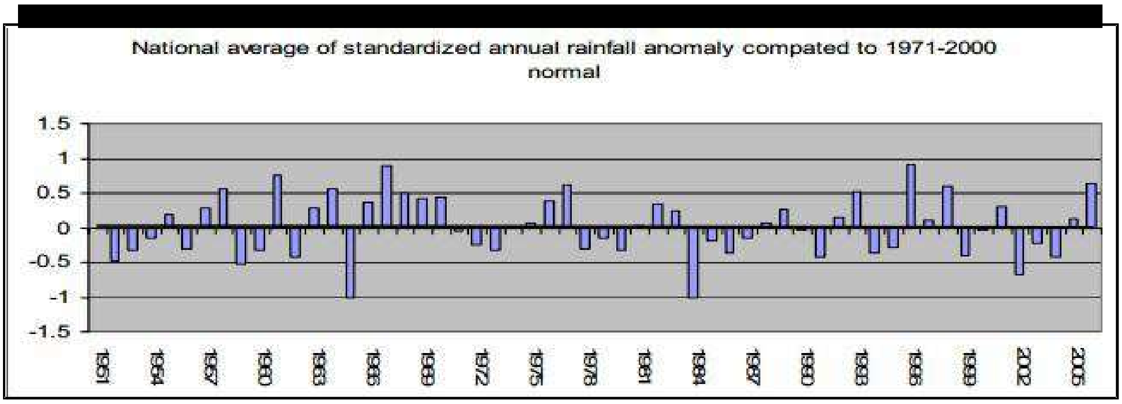


Figure 2.2: Year to year variability of annual rainfall and trend over Ethiopia expressed in normalized deviation (compared to 1971-2000 normal) Sourc: NAPA (2007).

Studies also indicate that there has been a very high temperature variation and change in its trend over time. Annual minimum temperatures for the period 1951 to 2005 expressed in terms of temperature differences from the mean and averaged over 40 stations showed a very high variability (NAPA, 2007).

The country experienced both warm and cool years over those 55 years even though the recent years are generally warmest compared to the early periods (Figure 2.3). Moreover, there has been a warming trend in the annual minimum temperature from 1951 to 2005. It has been increasing by about 0.37^{0}C every 10 years (NAPA, 2007).

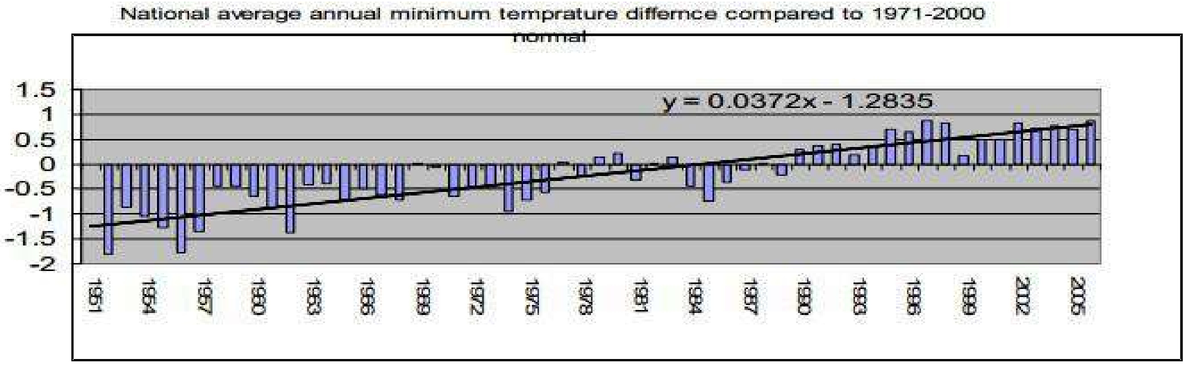


Figure2 . 3: Year to year variability of annual minimum temperature over Ethiopia expressed in temperature difference. Source: NAPA (2007).

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 country depending on the general trend of the temperature and rainfall pattern of the regions.

2.5. Modeling climate change

Climate models are important tools for improving our understanding and predictability of climate behavior on seasonal, annual, decadal, and centennial time scales. Models investigate the degree to which observed climate changes may be due to natural variability, human activity, or a combination of both. Their results and projections provide essential information to better inform decisions of national, regional, and local importance, such as water resource management, agriculture, transportation, and urban planning. Climate modeling is an attempt to represent the wide ranges of processes that produce climate. Climate models are mathematical representations of the climate system, based on established physical laws, such as conservation of mass, energy and momentum, along with a wealth of observations (Randall *et al.*, 2007). The most important components to be considered in constructing or understanding a model of a climate system are radiation, dynamics, surface processes, chemistry and resolution in time and space (McGuffie & Henderson-Sellers, 2005).

2.6. Climate change scenarios

The development of climate change scenarios is an important step in the hydrological impact of climate change study. A climate change scenario is a plausible representation of a future climate that is constructed from consistent assumptions about future emission of greenhouse gases (GHGs) and other pollutants, for explicit use in investigating the potential impacts of anthropogenic climate change (IPCC 2001a). Scenarios are not forecasts of future climate but rather are intended to provide adequate quantitative measures of uncertainty that are represented with a range of plausible future paths (IPCC 2001a). Future greenhouse gas concentrations are an unknown because we cannot predict what activities humans will engage in that will reduce or increase them.

The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (Smith & Hulme, 1998). It follows that the selection of scenarios can also be controversial, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis.

2.6.1. Future climate scenarios

Representative Concentration Pathways (RCPs) are the four new greenhouse gas concentration trajectories embraced by the IPCC, 2014 in its fifth Assessment Report (AR5). These define four likely climate futures in the coming years which are considered potential depending on the amount of emitted greenhouse gases. These pathways are applied in climate modeling and research and replace the projections on Special Report on Emission Scenarios (SRES) published in 2000 (Moss *et al.,* 2008). 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 (Van Vuuren *et al.,* 2011; IPCC, 2014).

The RCPs are comprised of extensive variety of possible changes of anthropogenic (i.e.,human) Greenhouse Gases (GHG) emissions in the future (Ebi *et al.,* 2014). The global annual emissions of GHGs from 2010-2020 (as per CO_2-equivalents) will peak with a substantial decline of emissions thereafter is assumed in the RCP2.6 (Meinshausen *et al.,* 2011; IPCC,2014). Emissions peak around 2040 in the RCP 4.5 and then decline (Meinshausen *et al.,* 2011; IPCC, 2014). Around 2080 there is a peak in the emissions in RCP6.0 and then decline and in RCP8.5, continuous rise of emissions throughout the 21st century (IPCC, 2014). 2046-2065 and 2081-2100 are the mid and late 21st century averages respectively and projections established on the RCPs 21st century. Table 2.1 below shows the global mean sea level rise and global warming projections from the IPCC AR5 relative to sea levels and temperatures in late 20th to early 21st centuries. Projected Atmospheric Greenhouse Gas Concentrations are shown in Figure 2.4.

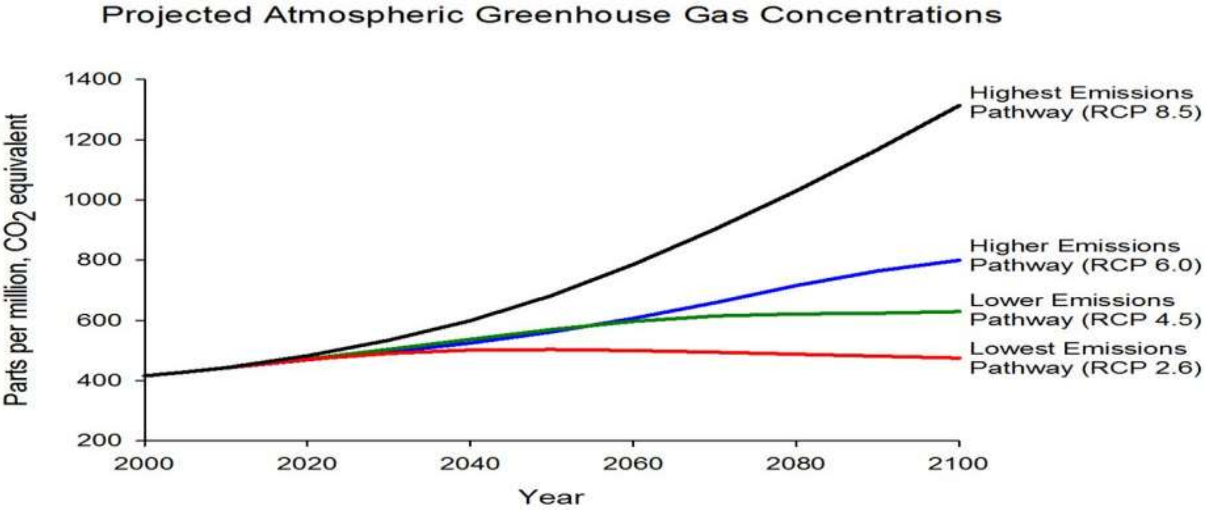


Figure2.4: Projected atmospheric Greenhouse gas concentrations(Source: IPCC,2014)

TABLE 2.1: AR5 Global warming projections (Source:IPCC,2014)

AR5 global worming rise (ºC)Projections		
	2046 to 2065	2081 to 2100
Scenario	Possible range and average	Possible range and average
RCP2.6	1.0(0.4-1.6)ºC	(0.4-1.7)1.0ºC
RCP4.5	(0.9-2.0)1.4ºC	(1.1-2.6)1.8ºC
RCP6.0	(0.8-1.8)1.3ºC	(1.4-3.1)2.2ºC
RCP8.5	(1.4-2.6)2.0ºC	(2.4-4.8)3.7ºC

A rise of 0.3 to 4.8 °C in the global mean temperature is expected across all RCPs by the late-21st century. A change in climate beyond the 21st century is also projected by the AR5.Continual net negative anthropogenic GHG emissions are assumed by the prolonged RCP2.6 pathway after the year 2070 (Ebi *et al.,* 2014, Pachauri *et al.,* 2014). "Negative emissions" occur when in overall, more GHG is absorbed from the atmosphere than it is release by humans. According to Pachauri *et al.,* 2014 a persistent anthropogenic GHG emission is assumed by the stretched RCP8.5 pathway after 2100.

2.6.2. Low carbon pathway for development in Ethiopia

A development path pointed at creation of a prosperous country with a high quality of life is set out by the Ethiopia Vision 2030. Climate Change Action Plan of Ethiopia encourages people-centered development and supports determinations towards the accomplishment of Vision 2030. This ensures movement of the country towards long-term development goals guided by the climate change actions (GOK, 2010; GOK, 2013). The country has preferred an incorporated low carbon climate resilient pathway which emphasizes on sustainable development, adaptation and mitigation (Parry *et al.,* 2012; Ngaira & Omwayi, 2012).

Ethiopia considers that climate change and action on development are interlinked. The country recognizes that increasing the ability of the country to adapt to climate change, in as low carbon as possible will help achieving the Vision 2030 goals and sustainable development (GOK, 2010). Ethiopia considers a low carbon development pathway crucial which climate resilient for addressing the risks and threats posed by climate change on development visions and livelihoods. Investments made to meet Vision 2030 goals are destabilized by the changes in climate. Increased strength and occurrences of extreme weather occasions such as droughts and floods, the rising of average temperatures, varying rainfall patterns are some of climate change indicators.

Droughts and floods have interference with on the economy, water resources, infrastructure, food security and environment.

In the water sector, a low carbon climate resistant pathway can have significant viable benefits and contribute to enhanced management of water resources in Ethiopia. Proposed interventions in this sector are mainly environmental including growing tree covers to 10% of the entire land as a goal indicated in Ethiopia's constitution. Actions intended towards increase in the forest cover have indispensible low carbon and climate resilience benefits. Landslides, flooding, erosion and increased sediment discharge into rivers can be barred by forests.

Loss of rainwater from the ecosystem can be decelerated by forests hence contributing to water availability. Recently, the country has taken measures towards restoration and afforesting of the key water towers and water catchments. Additionally, conservation of the forests has biodiversity benefits and may contribute to enhancement of livelihoods. According to Ngaira & Omwayi (2012), restoration of forests on bankrupt lands is an imperative low carbon climate resilient action which has a mitigation potential of over 30 MtCO2e a year in 2030.

2.6.3. Criteria for selecting climate scenarios

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

Criterion 1: Consistency with global projections: They should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases. This range is variously cited as 1.4°C to 5.8°C by 2100 (IPCC, 2001a), or 1.5°C to 4.5°C for a doubling of atmospheric CO_2concentration (IPCC, 2001a).

Criterion 2: Physical plausibility and realism: They should be physically plausible; that is, they should not violate the basic laws of physics. Hence, changes in one region should be physically consistent with those in another region and globally. In addition, the combination of changes in different variables (which are often correlated with each other) should be physically consistent.

Criterion 3: Applicability in impact assessments: They should describe changes in a sufficient number of variables on a spatial and temporal scale that allows for impact assessment. For example, impact models may require input data on variables such as precipitation, solar radiation, temperature, humidity and wind speed at spatial scales ranging from global to site and at temporal scales ranging from annual means to daily or hourly values.

Criterion 4: Representative: They should be representative of the potential range of future regional climate change. Only in this way can a realistic range of possible impacts be estimated.

Criterion 5: Accessibility: They should be straightforward to obtain, interpret and apply for impact assessment. Many impact assessment projects include a separate scenario development component which specifically aims to address this last point. Various types of climate scenarios are used in impact assessment.

2.7. Representative concentration pathways (RCPs)

In climate research, different types of emission scenarios are used to assess the long-term impact of atmospheric greenhouse gases and pollutants based on assumptions of population growth, economic development level, etc. Scenarios previously approved by the IPCC include SA90 (IPCC, 1990), IS92 (Leggett *et al.*, 1992) and SRES (Nakic′enovic′ *et al.*, 2000). The latest scenarios developed by the research community are denoted by Representative Concentration Pathways (RCPs); (Van Vuuren *et al.*, 2011). There are four RCPs defined by their level of the total radiative forcing pathway in the year 2100, and are representative for the existing literature about emission scenarios. Each RCP was developed by a different modeling group. Since the RCPs had been developed with different, independent models, they are not directly comparable. The definition of the RCPs allows for a parallel development of new socioeconomic, technical and policy scenarios that provide insights into the impact of policy decisions on the future climate (Van Vuuren *et al.*, 2011).

RCP 2.6 – Low emissions(lowest emission path way) a low mitigation scenario

This RCP is developed by PBL Netherlands Environmental Assessment Agency. Here radiative forcing reaches 3.1 W/m^2 before it returns to 2.6 W/m^2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time. Cropping area increases faster than current trends, while grassland area remains constant. Forest vegetation continues to decline at current trends.

RCP 4.5 – Intermediate emissions(Lower emissions path way)

This RCP is developed by the Pacific Northwest National Laboratory in the US. Here radiative forcing is stabilized shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. The RCP4.5 stabilization scenario is a cost-minimizing pathway. It assumes that all nations of the world undertake emissions mitigation simultaneously and effectively, and share a common global price that all emissions to the atmosphere must pay with emissions of different gases priced according to their hundred-year global warming potentials (Forster *et al.*, 2007).

RCP 6 – Intermediate emissions(higher emission path way) a high stabilization scenario

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. Oil consumption remains high, while bio fuel and nuclear play a smaller role than in the other three scenarios. Cropping area continues to change on current trend, while grassland area is rapidly reduced. Natural vegetation is similar to RCP4.5.

RCP 8.5 – High emissions (highest emission path way) very high emission scenario

This RCP is consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time. This scenario is highly energy intensive with total consumption continuing to grow throughout the century reaching well over three times current levels. Oil use grows rapidly until 2070 after which it drops even quickly. Land use continues current trends with crop and grass areas increasing and forest area decreasing.

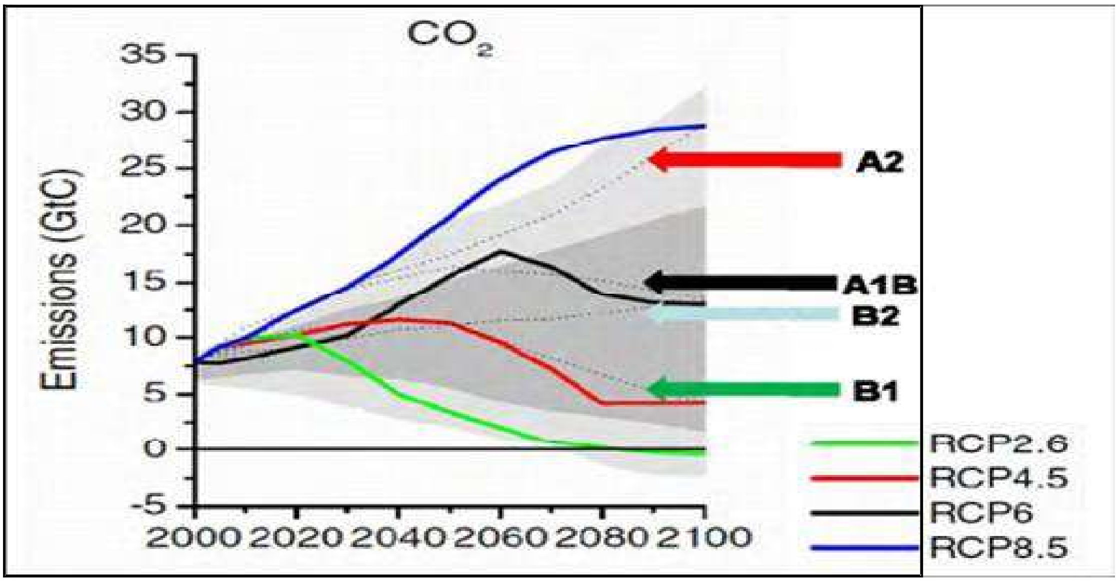


Figure2. 5: Comparison of emission in the SRES and RCP emission scenarios (Van Vuuren et al., 2011).

A key difference between the new RCPs and the previous scenarios is that there are no fixed sets of assumptions related to population growth, economic development, or technology associated with any RCP.

Another key difference is that the RCPs are spatially explicit and provide information a global grid at a resolution of approximately 60 kilometers. This gives the spatial and temporal information about the location of various emissions and land use changes. This is an important improvement as the location of some emissions affects their warming potential.

2.8. Downscaling methods and tools

Downscaling is the term used to describe the various methods used to translate the climate projections from coarse resolution GCMs to finer resolutions deemed more useful for assessing impacts. Projections of future climate are produced using complex, coupled atmosphere-ocean models (AOGCMs). The GCMs are most reliable at the continental scale. Due to the inherent uncertainty of the climate system and the inevitable existence of model errors, multi-model ensembling is the recommended approach for characterizing expected climate changes. As downscaling is dependent on the ability of GCMs to successfully project the climate change signal, it is limited to where that signal is clear.

Selection of GCMs that “do better” over Africa, or any region, is difficult and probably not warranted, given the general parity in model skill and the difficulty in identifying which models are more skillful. Ensemble means or medians offer the highest level of projection accuracy. The complete modeling chain for future hydrological projections includes the employment of three kinds of models: GCMs, downscaling models (Stastical downscaling or Dynamic downscaling) and hydrological models. Downscaling approaches are generally categorized as dynamical, using regional climate models, and statistical, using empirical relationships. However, dynamical downscaling often includes statistical modeling in the form of bias correction.

2.8.1. Dynamical downscaling

Dynamical downscaling is usually based on the use of regional climate models (RCMs), which generate finer resolution output based on atmospheric physics over a region using GCM fields as boundary conditions (Giorgi & Mearns, 1991). Thus, this method is also called ‘nested’ RCM approach, which was first applied in climate change studies in the late 1980s by (Dickinson *et al.*, 1989). RCMs, also referred to as Limited-Area Models (LAMs), produce highly resolved spatial and temporal climate information (Mearns *et a*l., 2003).

Dynamical downscaling seeks to couple large scale climate dynamics and local climate and hydrological features. It does so by utilizing higher resolution regional climate models (RCMs) that respond to the output of GCMs. The GCM output is provided as boundary conditions, which are the values at the edges of the spatial domain of the RCM. RCMs are used for downscaling seasonal climate forecasts and for diagnostic studies of regional climate in addition to their use with climate change projections. The main drawbacks are the requirement of powerful computing capacities and the dependency on initial and boundary conditions. There is also still a lack of readily available climate scenario ensembles for most regions in the world, although the number of publically available ensemble archives from European projects on similar grid size is increasing, e.g., CORDEX (Evans, 2011).

2.8.2. Statistical downscaling

Based on particular statistical relationships between the coarse GCMs and fine observed data, statistical downscaling is a straightforward means of obtaining high resolution climate projections. Statistical downscaling may be used whenever impacts models require small-scale data, provide suitable observed data are available to derive the statistical relationships and covers all kind of locations. The output obtained is generally small scale information on future climate or climate change (maps, data, etc.), the key input being appropriate observed data to calibrate and validate the statistical model(s) and GCM data for future climate to drive the model(s) (Wilby *et al.*, 1998).

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

Table.2.2:Advantages, disadvantages, outputs, requirements, and applications of dynamical downscaling and statistical downscaling. source (Sylwia & Emilie, 2014

	Dynamical downscaling	Statistical downscaling
Provides	20–50 km grid cell information • Information at sites with no observational data • Daily time-series • Monthly time-series • Scenarios for extreme events	Any scale, down to station level information • Daily time-series (only some methods) • Monthly time-series • Scenarios for extreme events (only some methods) • Scenarios for any consistently observed variable
Requires	High computational resources and expertise • High volume of data inputs	Medium/low computational resources • Medium/low volume of data

	• Reliable GCM simulation	inputs • Sufficient amount of good quality observational data • Reliable GCM simulations
Advantages	Based on consistent, physical mechanism • Resolves atmospheric and surface processes occurring at sub-GCM grid scale • Not constrained by historical record so that novel scenarios can be simulated • Experiments involving an ensemble of RCMs are becoming available for uncertainty analysis.	Computationally inexpensive and efficient, which allows for many different emissions scenarios and GCM pairings • Methods range from simple to elaborate and are flexible enough to tailor for specific purposes • The same method can be applied across regions or the entire globe, which facilitates comparisons across different case studies • Relies on the observed climate as a basis for • driving future projections • Can provide point-scale climatic variables for GCM scale output • Tools are freely available and easy to implement and interpret; some methods can capture extreme events
Disadvantages	Computationally intensive • Due to computational demands, RCMs are typically driven by only one or two GMC/emission scenario simulations	High quality observed data may be unavailable for many areas or variables • Assumes that relationships between large and local-scale processes will remain the same in the future

	• Limited number of RCMs available and no model results for many parts of the globe • May require further downscaling and bias correction of RCM outputs • Results depend on RCM assumptions; different RCMs will give different results • Affected by bias of driving GCM	• The simplest methods may only provide projections at a monthly resolution

2.9. Coordinated regional climate downscaling experiment (cordex)

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

The goal of the initiative is to provide regionally downscaled climate projections for most land regions of the globe, as a compliment to the global climate model projections performed within the fifth Coupled Model Inter comparison Project (CMIP5). CORDEX includes data from both dynamical and statistical downscaling. It is anticipated that the CORDEX dataset will provide a link to the impacts and adaptation community through its better resolution and regional focus. Participation in CORDEX is open and any researchers performing climate downscaling are encourage to engage with the initiative (Evans, 2011). The first part of this framework is a set of common regional domains. These domains are shown in Figure 2.6. The Rossby Centre, with extensive experience in climate model development and application, is producing future climate projections for a number of the regional CORDEX domains, e.g. Africa, Europe, South Asia, the Middle East and the Arctic. CORDEX results will serve as input for climate change impact and adaptation studies within the timeline of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and beyond. To develop an inter-comparable downscaling protocol with newly developed future scenarios, the Coordinated Regional

Climate Downscaling Experiment (CORDEX) project has launched to provide unified framework for the downscaling researches (Giorgi *et al.*, 2009)

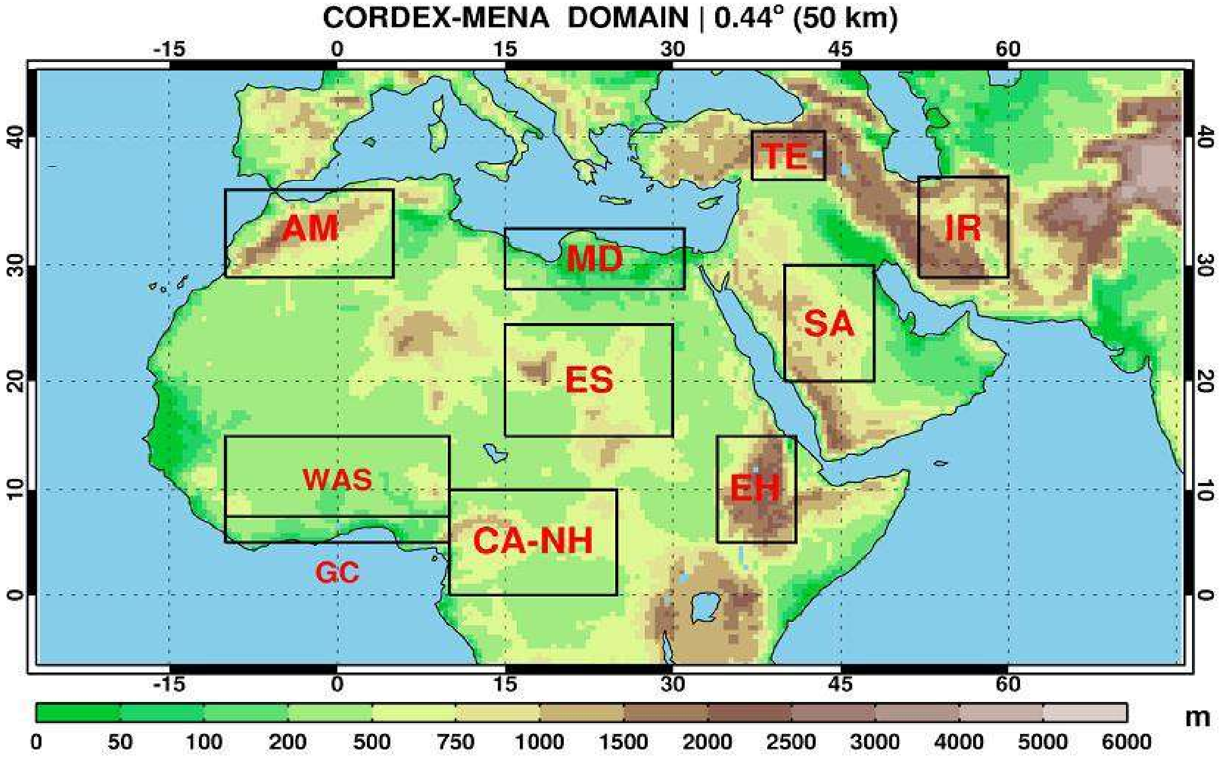


Figure.2.6: Cordex-Mena domain and sub-regions at 50 km resolution (Grigory, 2013)

2.10. Hydrologic modeling

Hydrologic modeling is an approach where mathematical equations or programming approach, are applied to simulate the behavior of watershed, hydrologic processes, physical responses of a watershed for a given input like the rainfall (Miller et al., 2007; Pechlivanidis et al., 2011). Hydrological models are required in the environmental applications like the prediction of flood, water resources planning, climate modeling and water quality modeling (Pechlivanidis et al., 2011). Hydrological models represent part of the hydrological cycle. These models can be used to simulate the physical courses of a certain catchment that control the transformation of precipitation to runoff or water yields (Droogers et al., 2006).

The 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 (Arnold et al., 2012). Temperature and precipitation are the most crucial climatological inputs that are essential for the calibration and validation of hydrological models (Akhtar et al., 2009; Rwigi, 2014).

In evaluation of impacts on water yields on the upper Weyib River catchment due to changing climate the study applied two diverse future climate scenarios. The simulated water yields are compared with the observed discharge to evaluate the change. This assessment was accomplished through the use of SWAT. This model has been demonstrated to be an operational tool to be applied in assessing water resource issues at small and wide scales in various environmental conditions across the world (Arnold et al., 2012; Oluwatomiwa, 2014). A brief explanation of the SWAT model is given under section 3.6.

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

2.10.1. Classification of hydrological models

Hydrological models can reduce highly complex processes in the watershed to simple outputs. Since these hydrological models are developed for multi purposes, they require a large quantity of data. This fact forces to classify the hydrology models based on the data requirement and the purpose of the model. Singh (1995) classified hydrologic models based on the process description, the time and space scale, needed technique to get solution and model use. Two broad classes are to be categorized first:(1) a physical model which represents the system as on a reduced scale and (2) a mathematical model in which the system operation links input and output variables with asset of equations.

The next classification is deterministic and stochastic hydrological models we forget discussions of the latter and focus on the former, the deterministic hydrological model as it is the most commonly model approach in hydrology. A deterministic hydrologic models can be classified into three main categories (Cunderlik, 2003) classify models as lumped, distributed and semi distributed models.

Lumped Models: Parameters of lumped models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly counting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes.

Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins.

There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL).

Distributed Models: Parameters of distributed models are allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms. Distributed models generally require large amounts of data for parameterization.

2.10.2. Hydrological model selection criteria

There are a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. (Beven & Freer, 2001) suggested four criterions for selecting model structures as below.

1. Consider models which are readily available and whose investment of time and money appeared worthwhile.
2. Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.
3. Prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes.
4. Make a list of the inputs required by the model and decide whether all the information required by the model can be provided within the time and cost constraints of the project.

In addition to the above listed criteria, adaptability of the hydrologic model, the type of the problem what I am addressing are also considered. The choices of a model for a particular case study depend on many factors, the purpose of the study and model availability being the dominant ones. For detailed assessment of surface flow, conceptual models were applied in many parts of the world. Booij(2005) discusses the advantages of conceptual models for climate change study as a nice compromise between the need for simplicity on one hand and the need for a firm physical basis on the other hand. One of the various and mostly used conceptual models for climate change impact study is the SWAT model. SWAT model is the widely used model in all over the world and in over all parts of Ethiopia.

2.11. Related studies in Ethiopia

2.11.1. Study on lake Ziway watershed

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 seems to excel. 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 B2a scenarios. 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).

2.11.2. Blue Nile basin

A) Study on Gilgel Abbay Catchment

Studies in the Gilgel Abbay river watershed reveals that the result of down scaled precipitation does not manifest a systematic increase or decrease in all future time horizons for both A2 and B2 scenarios unlike that of minimum and maximum temperature. And the result from synthetic (hypothetical) scenario indicates that the catchment is sensitive to climate change especially in rainfall. An increase of 2^{o}C without change in rainfall decreases the seasonal an annual runoff by 1.7 and 2%. However; if the change in temperature is changed by 20% rainfall reduction, seasonal and annual runoff will reduce by 33%. If the change in temperature is 4^{o}C, the seasonal and annual runoff decreased by 3.3 % and 4% respectively. If the 2^{o}C increase of temperature is occur simultaneously with rainfall reduction in 10% the seasonal and annual runoff will decreased by 17.7%. And it is concluded the Gilgel Abbay Catchments is more sensitive to change in rainfall than change in temperature (Kedir, 2008).

B) Study on Tana Sub-Basin

The impact of climate change on water resource of lake Tana sub-basin was assessed on the basis of CCCM and GFCD3 UK89 climate change prediction. The CCCM and GFCD3 GCMs predict a reduction of annual runoff by 18.2% and 12.6% respectively , while UKMo GCM predicts wetter condition and as result of an increase in 2.5% in annual runoff (Tarekegn and Tadege, 2006).

C) Study on the water availability of the Blue Nile Basin catchment under climate change

In this study the assessment was done on selected 10 catchments of the basin. The water availability of the selected catchment were evaluated by developing a hypothetical scenario within the range of (-30 to +30 percent change) for both precipitation and potential evapotranspiration have been investigated and shows that most of the stations exhibit more than 18% increase in runoff for PET decrease of 30% but Chacha catchment has shown extreme increase of runoff above 48.32 %. On contrary, 30% increase in PET showed slightly reduced percentage of reduction in runoff than the Decreased in PET produced. Meanwhile most of the stations exhibit more than 50% increase in runoff for rainfall increase of 30% but Chacha catchment has shown extreme increase of runoff above 100%. On contrary, 30% reduction in rainfall showed slightly reduced percentage reduction in runoff than the increased rainfall produced.

And a general climate change sensitivity map for the basin is developed. For both scenarios impact assessment has shown that Chacha is the most sensitive catchment followed by catchments Sechi, Birr, Guder, G/Belese,Teme, Muger;Koga, Neshi, and Little Anger. And from the sensitivity map developed for the whole Basin Jemma, Dabus, Part of Belese, Woleka, Wonbera and Beshilo are a Special and overstress sensitive Sub basins, however; Fincha, Anger and Tana Sub Basins have relaxed water resource change sensitivity (Muluneh, 2008).

2.12.Trend detection in hydro climatic time series

2.12.1 Hydrological trend

Trend is 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 cause variation in system resulting in non-stationary time series. In water resource planning and management it is important to quantify these trends. The use of empirical approach to quantify and explain changes in hydrologic time series is called hydrologic trends analysis (Scott and Chandler, 2011). Analysis of hydrological trend from different causative factors like climate change and land use /land cover have been the major deal of many researchers for the case of Ethiopia (Sileshi and Zanke,2004,Tewdros, 2008, Woldeamlak,2009,Zelalem, 2009, Ayalew et al,2012, Hadgu et al, 2013 and Wondimagegn, 2013).

There two advance of trend detection: The parametric and non-parametric (Tewdros, 2008). Parametric test depends on the distribution of data set. Statistical t-test is one methods of parametric test to detect linear trends. Such test requires data set to have normal distribution; otherwise transformation of the data is necessary prior to the test. Assumption of normality, linearity and independence of the data is the feature of parametric test. Hydrological data usually fails to such quality and hence fails to fit to parametric test. Non-parametric test does not consider the distribution of the data and therefore, it is more powerful than the parametric test in that it is suitable for skewed data with outlier and missing values, which is common case in hydro-meteorological time series. Un like in parametric test, non-parametric does not need any data transformation because of the absence of any assumption about the data distribution.

2.12.2. Mann-Kendall test

Mann-Kendall (MK) is one of the broadly used none-parametric test statistics in detection of monotonic trend in hydro-climatic time series (Singh et al., 2007). It is very appropriate in cases where the data with skewed variables, non-normally distributed, data with outliers and data showing non-linear trend (Mann 1945; Kendall 1975). MK test compares the relative magnitude of a data value with all subsequent data values in ordered time series. The initial values of the MK test statistics S is assumed to be zero implying no trend. If a data value from a later time period is found to be greater than the data value from an earlier time period, then S is incremented by one. On the other hand, if the data value from a later time period is lower than that of the earlier period, the MK test statistics S is reduced by one. The overall result of all increments and decrements provides the final S value which lies between -1 and +1. Mann-Kendall test has been used by many researchers for detecting trends in hydro-climatic variables (Karpouzos et al., 2010, Babar and Ramesh, 2013, Sigh et al., 2007, Hadgu et al ., 2013, Getahun, 2012 and Longobardi and Villani, 2009).

3. MATERIALS AND METHODS

3.1 Description of study area

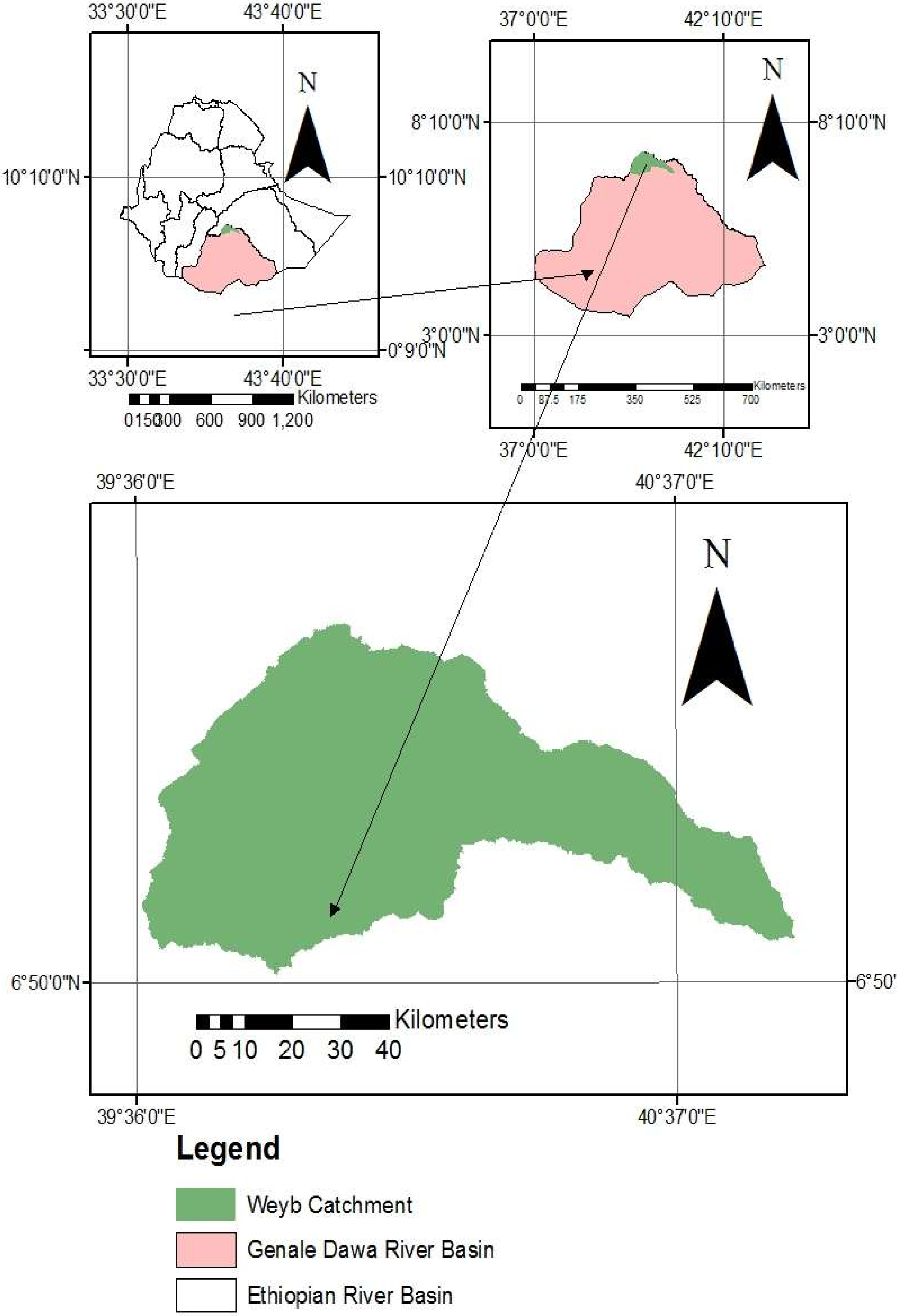
3.1.1. Location

Ethiopia is located in the eastern part of Africa between 3^0 30‘and 18^0 12‘N latitude and 32^0 42‘and 48^0 12‘east longitude. The country has great geographical, topographical and climatological diversity: From high rugged mountains to deep gorges; from lowest altitude at about 120m below sea level to highest altitude of 4600m above sea level; from 2000mm high annual rainfall to 200mm of low annual rainfall. Besides, the Great Rift Valley divides the country in two parts forming the eastern and western high lands (Belay, 2011).

Genale Dawa river basin in which the study area found were also lies in the southern part of Ethiopia, covering parts of Oromia, SNNP, and Somali regions. Geographically located between 3^0 30' and 7^0 20' North latitude and 37^0 05' and 43^0 20' East longitude. The basin covers an area of 168,000 km^2. It is the third largest river basin, after Wabi Shebelle and Abbay river basins. Neighboring river basins are the Wabi-Shebelle to the north and east, Rift Valley basin to the west (Awulachew *et al*., 2007).

Weyb River watershed is found in southeastern part of Ethiopia in Genale-Dawa basin, and it is located between 6°30'-7°30' N latitudes and 39°30'-41°02' E longitudes as shown in Fig.3.1.below.It has a total basin area of 4414.445 km2. The Weyb River originates from the northerly sides of the Bale Mountains and first flows generally north-eastwards then flows to east and south eastwards for the remainder of its course. Finally, it joins with Genale and Dawa Rivers near Ethiopia-Somalia border to strengthen its journey to Somali lowlands.

Its major tributaries are Shaya, Tegona and Tebel. The Tebel River originates close to the northern Wabi-Shebelle divide near Ginir and joins Weyb main River at elevations of 1000m a.m.s.l. (GDMP – Main Report, 2005). The Weyb river watershed is a region of rich environmental diversity, but with increasing levels of environmental stress in recent years from a rapidly expanding human population (MoWE, 2007). The upper stream part of the watershed is situated in the BMNP the place where the second highest summit in Ethiopia known as mount Tullu Dimtu (4377 m.a.s.l.) and larger areas of afro alpine dominated by grasses including the Sanetti plateau and Mount Batu (4307 m.a.s.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Legend
Weyb Catchment
Genale Dawa River Basin
Ethiopian River Basin

Figure.3.1. Location map of the study area.

3.1.2. Topography

There is high elevation change between the upstream and downstream of the watershed which is 4343 and 1530 m.a.s.l. at the upstream and downstream edge of the watershed, respectively.The upper most parts of the watershed topographically are the steepest parts up to 77% maximum slope range while the middle and the downstream parts have flat to gentle slope which is very suitable for agriculture. The altitude decreases from south to north in the watershed. (Alemayehu, 2015)

3.1.3. Climate

The climate of Weyb watershed is in the range of frost (Wurch) at the upper most part near Sanetti Mountains to humid highlands of Bale Mountains. Rainfall during the year occurs in distinctly different seasons .The rainfall pattern is bimodal type, which divide the year into two main seasons: a main rainy season Kiremt (June to October) and short rainy season Belg (March to May). The bimodal type of rainfall pattern is generally characterized by a double peak rainfall pattern with a small peak in April and maximum peak in October (MoWE, 2007).

Based on meteorological data from Robe, Sinana, Ginnir stations the average annual rainfall distribution is 903.8mm and generally, the temperature and rainfall pattern in all stations follows similar trend as shown in Figure 3.2 for temperature distribution and Figure 3.3 for rain fall distribution(1986-2005) source NMSA. The annual maximum and minimum temperature of the watershed area is about 22.6 ºC and 9.6 ºC, respectively.

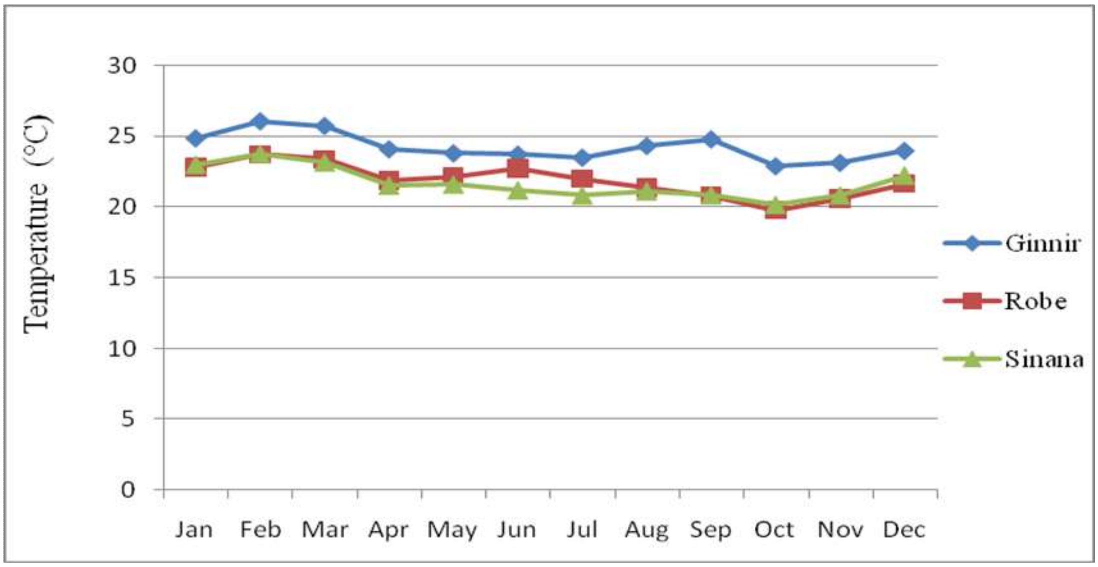

Figure. 3.2: Average monthly temperature of Ginnir,Robe and Sinana stations (1986-2005) source NMSA.

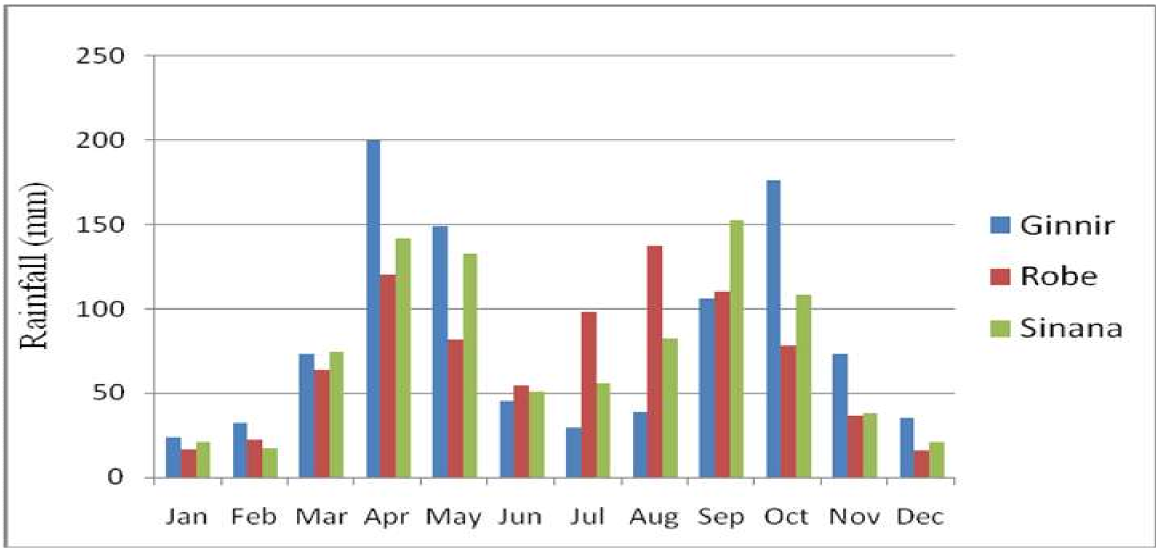

Figure.3.3 : Mean monthly rainfall of Ginnir,Robe and Sinana stations at Weyb river watershed (1986-2005) source NMSA.

3.1.4. Soil

There are three major Soil groups in the Weyib watershed, the Cambisol, Luvisol and Regosol of which again classified into six soil units, the Dystric Cambisols, Eutric Cambisols, Chromic Cambisols, Haplic Luvisols, Vertic Luvisols and Eutric Regosols. The Eutric Regosols and Dystric Cambisols are found in the upper most edge, Chromic Cambisols is found down from the earlier two, Eutric cambisols and Vertic Luvisol are found in the middle part and Haplic Luvisols is found at the downstream part of the watershed. But the greater portion of the basin is occupied by two soil types Eutric Vertisol and Dystric Cambisol, 19.93% and 17.85% respectively. Unlikely, Calcaric Cambisol and Calcic Vertisol covers comparatively minor percentage of the basin 1.91% and 1.77% respectively.

3.1.5. Land use and/or land cover

The land cover in the Weyb river watershed is represented by cultivated lands, natural vegetation and built-up areas. Each of these cover types are tremendously influenced by properties of land form, soils and climate as elsewhere in Ethiopia. The natural vegetation cover especially the forest land is encroached by cultivated fields as a result of high population growth followed by peoples and the government preferences for food and export crops in order to alleviate the prevailing food and employment insecurity (MoWE, 2007). The major land using activities in the watershed are rainfed crop production; livestock raising that involves beekeeping, nature conservation and wood cutting while the minor land uses are planting trees mostly in the upstream areas of the watershed and fishery in some selected parts of the river.

The land use/land cover (LULC) of the study area includes the Afro-alpine and Sub-afro-alpine vegetation; pasture land, woodland, range land and agricultural land. Afro-alpine is the LULC types that occur in the upper most parts of the watershed and includes short shrubs, heath and giant Lobelia, sedentary grazing with barley, onions and honey as main crop/product (MoWE, 2007). The pasture type of LULC is distributed in different parts of the watershed. Agricultural land is also the LULC type which is distributed from the middle to downstream parts of the watershed. It is the land cover under the intensive and moderate crop cultivation for the production of annual crop (wheat and barley crops are grown widely).

3.2. Material used

The materials used for this research are:Arc GIS 10.1 to attain hydrological and physical structure and information, Microsoft office excel spread sheet ,SWAT 2012 software ,SWAT processing software:- PcpStat, Dew 02, XLStat, CMhyd to extract and correct precipitation (PCP) and temperature (TMP) data.

3.3. Data quality checking

3.3.1. Estimating missing data

Gaps that are found in most of the climatological records must be filled before such data is used for any scientific research. Such gaps may occurs due to instrument failure or failure due to the observer to make the necessary visit to the gauge, inaccessibility of the gauge location especially after heavy flood, break out of war or simply negligence of the gauge attendant which make a cause of rainfall and hydrological data missing. Standards for the world meteorological organization (WMO) for estimating missing data is that, the missing data of a station should be less than 10% of the total records (WMO, 1966).

Several methods are available for estimating the missing hydro- meteorological data, such as arithmetic mean, normal ratio method, inverse distance method, correlation, and regression. Some of the meteorological and hydrological stations selected for this study had missing data for few days or months. Analyzing the data could not be further carried out with missed values, so that one of the methods should fill in periods of missed data. For the filling in of the missed data, linear regressions, and inverse distance weighting methods were tested and used depending on the correlation coefficient or estimation error between predicted and predictor nearby stations. There was a higher estimation error problem in linear regression method in some of the stations, which might have connection to its assumption such as co linearity, and normality of data distribution. In that case, inverse distance weighting was used and there was lower estimation error in some of the stations. Linear regression techniques and inverse distance weighting were applied for estimating the missing data .Inverse distance weighting prediction at a point is more influenced by nearby measurements than that by distant measurements.

$$P_x = \frac{\sum_{i=1}^{n} WiPi}{\sum_{i=1}^{n} Wi} \text{ ---------------------------------- } 3.1$$

Where; $W_i = \frac{1}{di^b}$: di is distance from gage with missing data to the neighboring gages; P_X is the is the missing precipitation value for station X for a certain time period; Pi is the precipitation values at adjacent stations for the same period; n is the number of neighboring stations; Wi is the Weight of distances where b is a proportionality factor (b = 1, 2)

Among different methods available to estimate flow observation data, regression analysis method was used to fill missing flow data since good correlation was obtained by this method.

3.3.2. Consistency test

Sometimes a significant change may occur in and around a particular rain gauge station due to some of the following factors like; change in location of rain gauge station, which may go unreported; the neighboring station may undergo significant changes such as new heavy built up coming in and around the station; surrounding ecosystem may undergo significant changes due to calamites like slide, forest fire etc; damage and replacement of rain gauge; change in measurement procedure or human, mechanical or electrical error in taking reading.

Such change will start affecting the rain gauge data being reported from particular station. After number of years, it may be felt that the data of the station is not give consistent rainfall value. Due to these significant factors, when analyzing rainfall data; it is essential to check the consistency of the records of the rainfall stations.

For Weyb river watershed, the missing data were first estimated, and then consistency analysis was applied. Double mass curve technique was used to check the consistency of the stations of the Weyb river watershed. The cumulative rainfall data for each individual station is plotted against the cummulative average rainfall of the all stations. The results of the consistency analysis are plotted in Figure 3.4. From the figure, it is clear that all the stations are internally consistent, and the data can be further analyzed. The data plotted in Figure 3.4 are for the periods (1986-2005) for all the stations. If all stations are consistent, this should result in a straight line (Mandefro,2015).

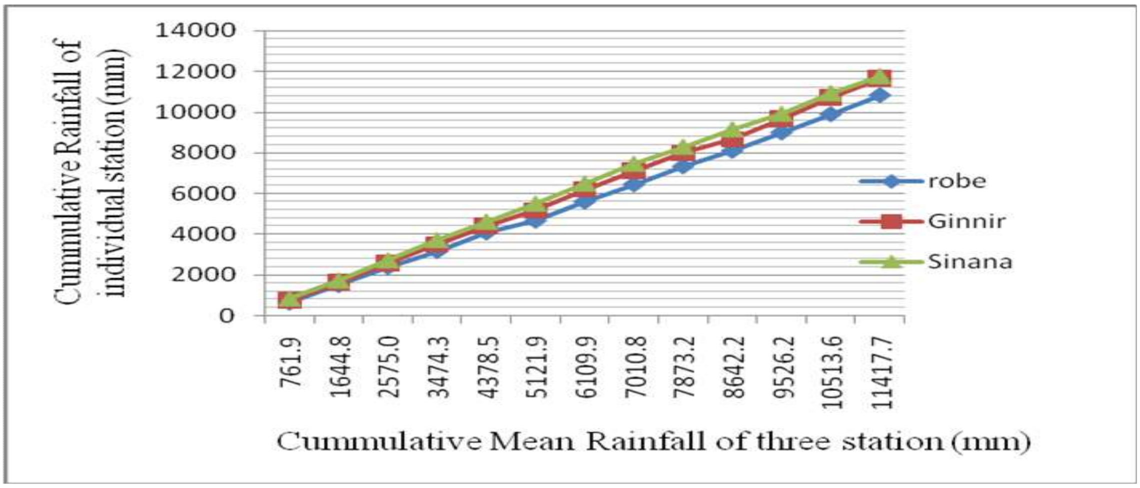

Figure. 3. 4: Double mass curve for the stations of Weyb river watershed

3.3.3. Homogeneity test

Homogeneity of rainfall data from individual stations was evaluated.

Rainfall records at gauging stations are exaggerated by the location of the station, the tool and method of data recording and collection and the observation quality and the time series might have in homogeneity. It is difficult to correct for such errors, but by homogenizing the precipitation series (i.e. testing and correcting for eventual in homogeneities) avoid systematic variation of the errors throughout the series. The methods for testing the homogeneity of the series classified into two groups as absolute method and relative method (Karabork et al, 2007). In the relative method, the neighboring (reference) stations are used for the testing process. For this study the graphical relative homogeneity (Non-dimensional plot) analysis applied. The non-dimensional monthly value was obtained as:

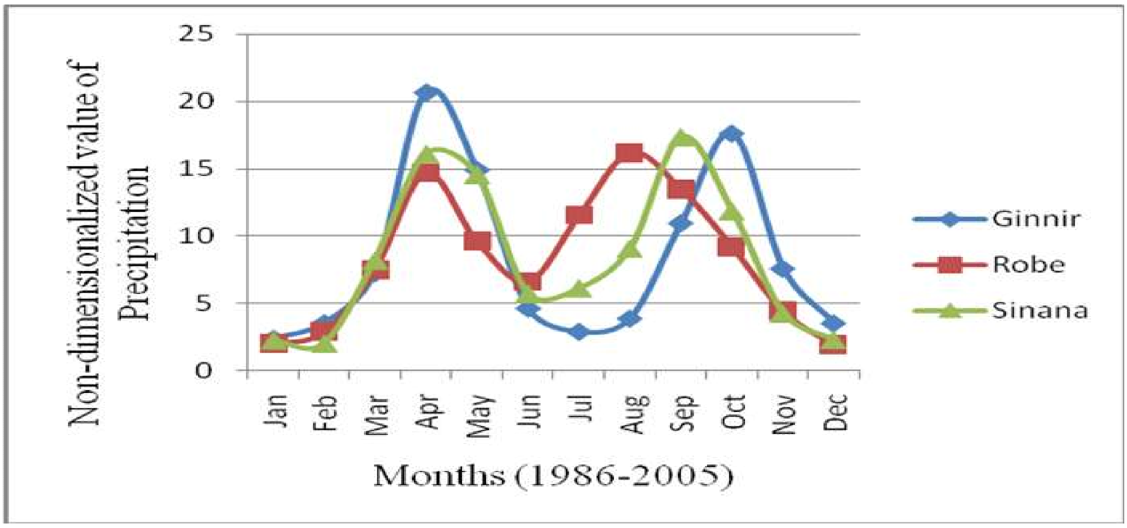

Figure.3. 5: Non-dimensional plot of Ginnir, Robe and Sinana stations

The Weyb river watershed has two distinct rainy seasons, the main rain fall season in which heavy rain fall from June to October and short rainy season from March to May. The non-dimensional plot of the data recorded in the stations that used for this study shows a bi-modal rain fall pattern, i.e. two peaks for both rainy seasons. The graphical sketch of the non-dimensional plot was conducted with truly shows that all the stations have followed the same pattern.

3.4. Regional climate model

Regional Climate Models (RCMs) are currently one of the basic tools used to downscale large-scale climate information to regional/local scales. Therefore, RCMs are very useful for understanding local climate and assessing the impact of climate change on different sectors. Over the past decade, several international projects have applied Regional Climate Models (RCMs) to generate high-resolution, multi-model ensembles of future climate projections by downscaling output from AOGCMs. These include: PRUDENCE (Christensen *et al.* 2007) and ENSEMBLES (van der Linden & Mitchell, 2009) for Europe; NARCCAP (Mearns *et al.*, 2009) for North America; CLARIS-LPB (Menéndez *et al.*, 2010) over South America and ENSEMBLES-AMMA (van der Linden & Mitchell, 2009) for West Africa. Each of these projects has made significant contributions to downscaling efforts over their specific region, but there has been very limited international coordination of such projects and therefore limited transfer of knowledge between projects and regions. A new initiative - the Coordinated Regional climate Downscaling Experiment - CORDEX (Giorgi *et a*l., 2009; Jones *et al.* 2011), sponsored by the World Climate Research Programme, aims to fill this gap by coordinating international efforts in regional climate downscaling.

An initial focus in CORDEX will be on Africa, which is particularly vulnerable to climate change and has a low adaptive capacity. For example, water supply and food security are of critical importance in Africa. CORDEX Regional Climate Models ensemble mean has better agreement with observation than individual models and can therefore be used for the assessment of future climate projections for the Eastern African region (Endris *et al.*, 2013).

In this study, outputs from the fifth phase of the Coupled Model Inter comparison Project (CMIP5) downscaled over the Africa-CORDEX domain at the Rossby Centre (SMHI) by a regional climate model, RCA4 at 0.44° resolution were used. RCA4 is abbreviation for Rossby Centre regional atmospheric model developed at Rossby Centre (SMHI) for Climate Prediction. For this study the model output of RCA4 was employed for the RCP4.5 (Intermidiate Emissions) and RCP8.5 (High emissions) Scenarios.

This model is selected for two reasons. First, the model is widely applied in many climate change impact studies, and second, it provides large-scale daily variables which can be used for dynamical downscaling model . The relative performance of GCMs depends on the size of the region as small regions at sub-grid scale are less likely to be well described than large regions at continental scale. It also depends on location as the level of agreement between GCM outputs varies a lot from region to region, and on variables such as regional precipitation which has high spatially variation and is more difficult to model than regional temperature (Carter et al. 2001).

3.5. Bias correction

The term 'bias correction' describes the process of re-scaling climate model output to reduce the effects of systematic errors in the climate models (Teutschbein & Seibert, 2010). The main idea of bias correction is the identification of possible biases between observed and simulated climate variables, which is the basis for correcting both control and scenario RCM runs with a transformation algorithm. In fact, most bias correction methods are by their nature a form of statistical downscaling which was originally designed to downscale GCM runs. In this study in addition, to the original (i.e., uncorrected) RCM output data, applied and analyzed the following two bias correction methods to adjust RCM simulations:

(1) Linear transformation: - The Linear-scaling approach (Teutschbein & Seibert, 2010) is adopted for this study due to its suitability for bias correction at daily basis. The linear correction applies a scaling factor to transform raw precipitation to corrected precipitation magnitude (Negash *et al*, 2013). From observed climate time series RCM simulation is adapted with estimated daily mean for each future time horizons. Observational data from1986 to 2005 is calculated at daily mean basis. The future daily bias corrected temperature $\left(T^*_{RCM,daily}\right)$ and daily precipitation $\left(P^*_{RCM,daily}\right)$ time series will be built by using equations 3.2 and 3.3 respectively.

$$T^*_{RCM,daily} = T_{RCM,daily} + \left(\overline{T_{obs,daily}} - \overline{T_{RCM.daily}}\right) \text{--} 3.2$$

$$P^*_{RCM,daily} = P_{RCM,daily}\left(\frac{\overline{P_{obs,daily}}}{\overline{P_{RCM,daily}}}\right) \text{---} 3.3$$

Where , $T_{RCM,daily}$ is the daily RCM simulated temperature data; $\overline{T_{RCM,daily}}$ is the mean daily RCM simulated temperature for respective time horizons; $\overline{T_{obs,daily}}$ is the mean daily observed temperature for the period of 1986-2005; $P_{RCM,daily}$ is the daily RCM simulated precipitation; $\overline{P_{obs,daily}}$ is the mean daily observed precipitation for the period of 1986-2005 and $\overline{P_{RCM,daily}}$ is the mean daily RCM simulated precipitation for respective time horizons (i.e. 2020 (2010-2039),2050 (2040-2069) and 2070-2099).

(2)Variance Scaling for Temperature

Temperature cannot be corrected using a related power law as was used for correcting precipitation, because temperature is known to be approximately normally distributed. Correcting normally distributed data set with a power law function results in a data set which is not normally distributed.

The power transformation method is an effective method to correct both the mean and variance of precipitation, but it cannot be used to correct temperature time series, as temperature is known to be approximately normally distributed (Yang et al, 2015). The variance scaling method was developed to correct both the mean and variance of normally distributed variables such as temperature (Teutschbein and Seibert, 2012).

For this study, the corrected daily temperature *Tcorr* was obtained as:

$$T_{corr} = \overline{T_{obs}} + \frac{\sigma(T_{obs})}{\sigma(T_{rcm})}\left(T_{rcm} - \overline{T_{rcm}}\right) \text{ ------------------------ } 3.4$$

Where Tcorr : the corrected daily temperature.Trcm is the uncorrected daily temperature from RCM model and TObs is the observed daily temperature. In this equation an over bar denotes the mean observed temprature and mean simulated temprature over the considered period and σ is the standard deviation. This method was not appropriate for precipitation because it may cause negative values.

3.6. SWAT-2012

3.6.1. General description of SWAT model

SWAT is the acronym for **S**oil and **W**ater **A**ssessment **T**ool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). It is a physically-based continuous-event hydrologic model developed to predict the impact 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 (Arnold et al., 1998, 2000; Neitsch et al. 2001).

It is computationally efficient and physical based hydrological model that can be applied at watershed scale or an extended river basin (Arnold & Fohrer, 2005; Arnold, 2012). It is applied in projection of management practices of land on water, changes in climate and the effects on water, agricultural chemical yields and sediment over certain period (Neitsch *et al.,* 2011; Arnold, 2012). A platform whereby GIS and the Hydrologic model are integrated is provided by SWAT. Various studies have proven SWAT model to be a flexible tool that can be used in the simulation of numerous watershed issues (Githui, 2008; Faramarzi *et al.,* 2010; Kilonzo *et al.,* 2012). Water yields, ground water flows, weather, evapotranspiration, surface runoffs, reservoir storage are among the products of the SWAT model.

While the model is not new, it was developed from earlier models: SWRRB (Simulator for Water Resources in Rural Basins) model (Williams et al. 1985; Arnold et al., 1990) which is a continuous time step model that was developed to simulate non-point source loading from watershed, CREAMS (Chemical Runoff, and Erosion from Agricultural Management System) (Knisel, 1980), GLEAMS (Ground Water Loading Effects on Agricultural Management Systems) (Leonard et al. 1987), EPIC (Erosion-Productivity Impact Calculator) (Williams, 1975).

SWAT simulates "sub basins" within a watershed. This helps spatial referencing and is useful when considering spatiality for watersheds dominated by one land use and soil type. Input information for each sub basin is organized as: Climate, HRUs (Hydrologic Response Units), water storage structures, Ground water (a shallow unconfined and deep confined aquifer), main channel and tributary channels. Thus, HRUs, ponds, groundwater and channel routing are the components of the hydrological process (Neitsh et al. 2005). 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.

$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$--------------------------------------3.5

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

In recent years, SWAT model developed by Arnold *et al.* (1998), has gained international acceptance as a robust interdisciplinary watershed modeling. SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman *et al.*, 2005). The review of SWAT model applicability to Ethiopian situations (Dilnesaw, 2006; Setegn, 2010) at relatively larger watersheds and (Ashenafi, 2009; Biniam, 2009; Eyob, 2010) indicated that the model is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged watershed. SWAT model can be a potential monitoring tool for watersheds in mountainous catchments of the tropical regions (Birhanu *et al*., 2007).

Major model components include weather, hydrology, soil, temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. The HRUs represent percentages of the sub-basin area and are not identified spatially within a SWAT simulation. Alternatively, a watershed will be subdivided into only sub-basins that are characterized by dominant land use, soil type, and management (Gassman *et al*., 2007).

Reasons which led to the use of SWAT model in the study includes; its capability to use data that is readily available. Once operating in areas with insufficient or undependable data it is an advantage essentially. Secondly, SWAT model is capable of running simulations of vast management practices or basins economically hence it is computationally efficient. SWAT requires precise data about land management practices, vegetation, topography, soil properties and weather to simulate the physical processes related to movements of sediments, crop growth, nutrient transportation and water movement.

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

To perform calibration and uncertainty analysis, in recent years many procedures have become available. For this study the hydrologic simulator SWAT under the same platform, SWAT-CUP (SWAT Calibration Uncertainty Procedures) will be used.

SWAT-CUP is a public domain program and it is an interface that was developed for SWAT. Using this generic interface, any calibration, uncertainty or sensitivity program can easily be linked to SWAT. The program links Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Sequential Uncertainty Fitting (SUFI2) and Markov Chain Monte Carlo (MCMC) procedures to SWAT (Abbaspour, et al., 2007). It enables sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models. For this particular study SUFI-2 can be used.

3.6.2. Model input and data source

The availability of consistent hydro-meteorological data is the key for the success of any climate impact study. One of the main problems in hydrological analysis especially in developing countries is the scarcity of hydrological data both in quantity (length of record) and quality (standard of scientific approach). The output of any research depends highly on the quality of data input. Hydrological model (SWAT) used in this research are data-intensive on the daily time scale.

The model input data used in this study consist of meteorological data (daily rainfall, temperature (maximum and minimum), relative humidity, solar radiation, and wind speed at monthly time series), hydrological data (daily stream flow data), and climate projection data of (RCP4.5 and RCP8.5). Below are comprehensive description of the data sets and their sources.

3.6.2.1. Digital elevation model (DEM)

To delineate the watershed and sub-basins and to determine stream networks SWAT was used the digital representation of the topographic surface *i.e.* Digital elevation model (DEM). The DEM forms the base to delineate the watershed boundary, stream network and create sub-basins. This was performed by the pre-processing module of the SWAT but requires a so-called minimum threshold area. Topography was defined by a DEM which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. It was also be used to analyze the drainage patterns of the land surface terrain. And sub-basin parameters such as slope, slope length, and defining of the stream network with its characteristics such as channel slope, length, and width was derived from the DEM. For this specific study a DEM with a resolution of 30 m*30m was used and sourced from MOWIE. In the original data there is a missing data which creates a hole in the DEM. But, the hole was edited and filled in the ArcMap using the raster editor. The edited DEM was projected to WGS1984 UTM Zone37N using the raster projection in ArcMap toolbox before it was imported to ArcSWAT. The projected map was used in the watershed delineation in ArcSWAT which is the interface in the ArcMap to use it in SWAT model.

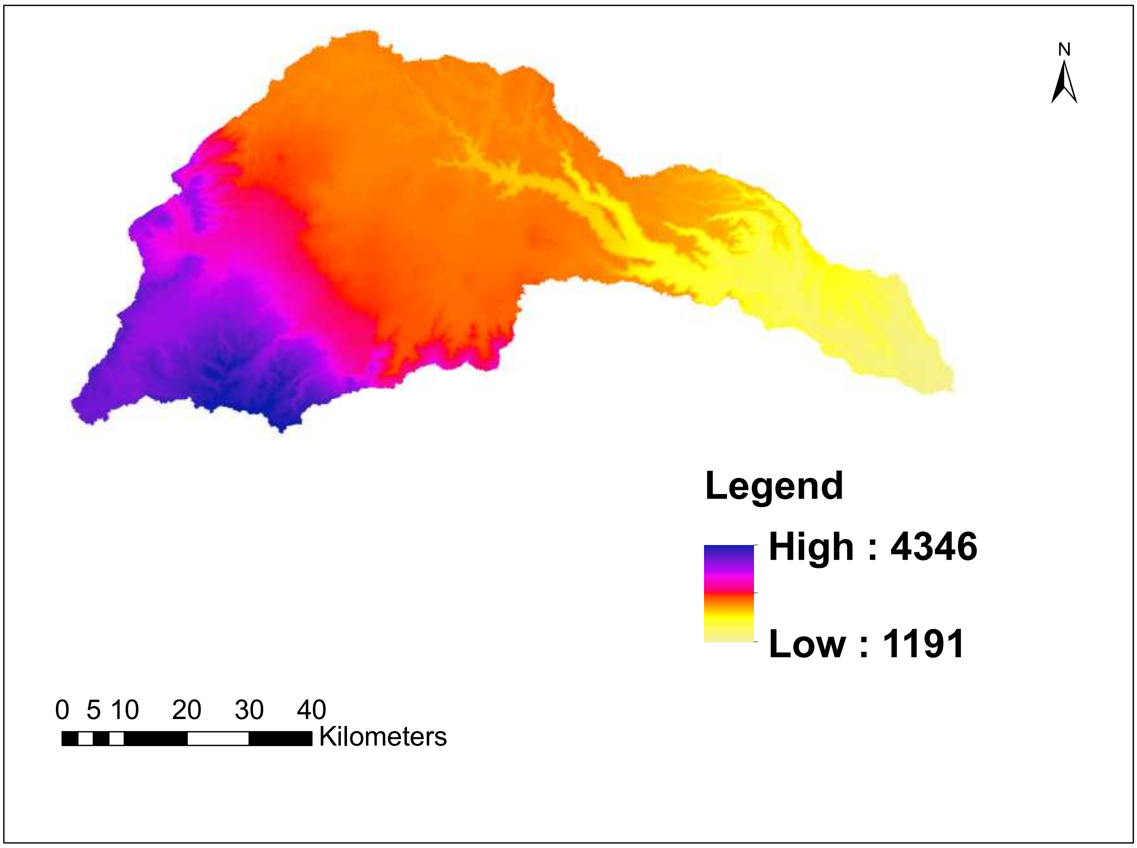

Figure.3.4. Digital elevation model of the Weyb watershed

3.6.2.2. Land use / land cover map

LULC is one of the most important spatial input data by SWAT model that affect runoff, evapotranspiration, surface erosion and other hydrological process in a given watershed. The LULC map and datasets was obtained from MoWIE, Genale-Dawa Integrated resources development master plan. This spatial database was derived from satellite imagery and field data collected between year 2004 to 2007 (MoWE, 2007) and is the most current and detailed LULC data known to be available for the study watershed. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database. A lookup table that identifies the SWAT land use code for the different categories of LULC was prepared so as to relate the grid values to SWAT LULC classes. The reclassifications of the LULC in SWAT database in Weyb watershed were made according to the description shown below in Table 3.1.The land use for Weyib River watershed was projected to WGS1984 UTM Zone37N using the raster projection in ArcMap before it was imported to ArcSWAT.

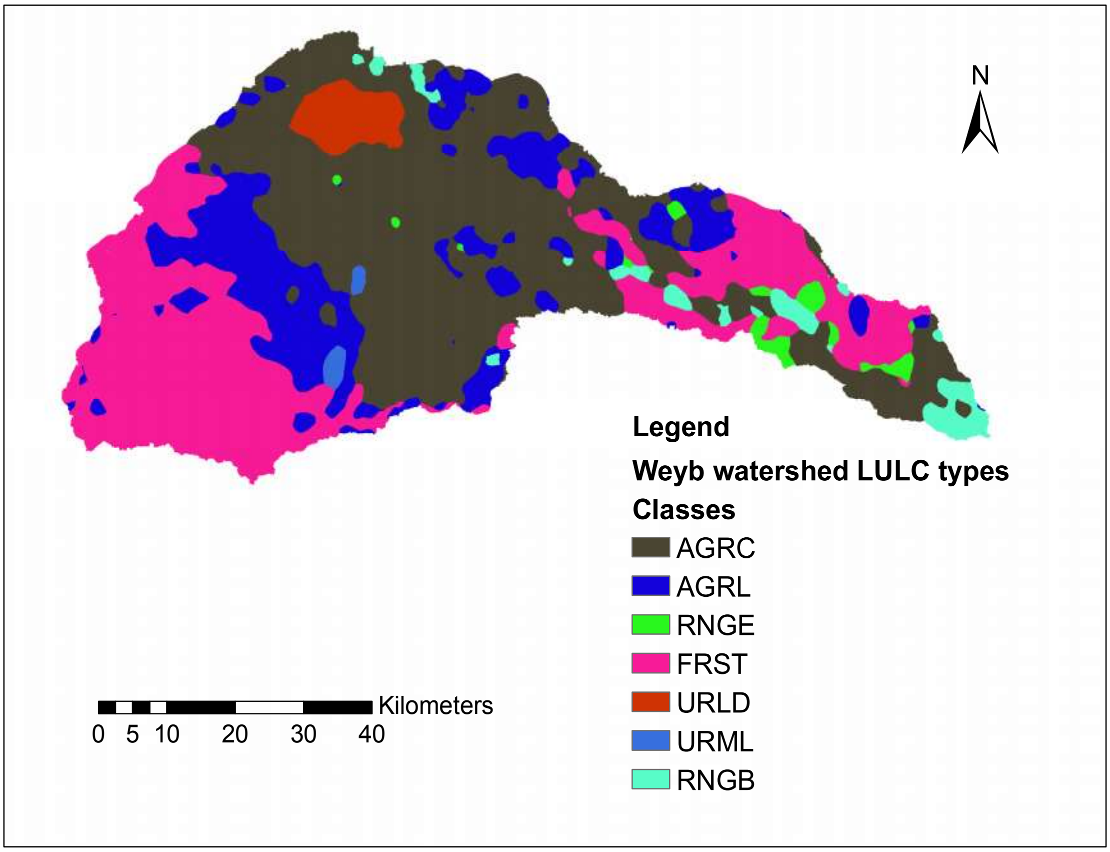

Figure. 3.7.Land use/land cover map of the study area.

3.6.2.3. Soil data

Nature and conditions soils affect how river basin responds to a certain rainfall event greatly (Shrestha *et al*., 2013). Soil properties such as the hydraulic conductivity, moisture content availability, physical properties, bulk density, chemical composition, organic carbon content and texture, for the different layers of each specific soil type are required by SWAT model (Setegn, 2008). A soil in the study watershed was classified on the basis of the revised FAO/UNESCO-ISWC (1998) classification system. The soil data was extracted from the 1:250,000 scale of soil map developed by MoWE (2007). Basic physico-chemical properties of major soil types in the watershed was mainly obtained from the following sources: Genale-Dawa River Basin integrated resources master plan Soil database and digital soil map from the Ministry of Water, Irrigation and Electric city (MoWIE) produced between the year 2004 and 2007;

Soil and Terrain Database for north-eastern Africa CD-ROM (Food and Agriculture Organization of the United Nations FAO, 1998). In addition to these sources, some soil properties was estimated based on available soil parameters. Table.3.2. below presents an important soil properties required by SWAT soil database. The soil map obtained from FAO was projected to WGS1984 UTM Zone37N using the raster projection in Arc Map before it was imported to ArcSWAT.

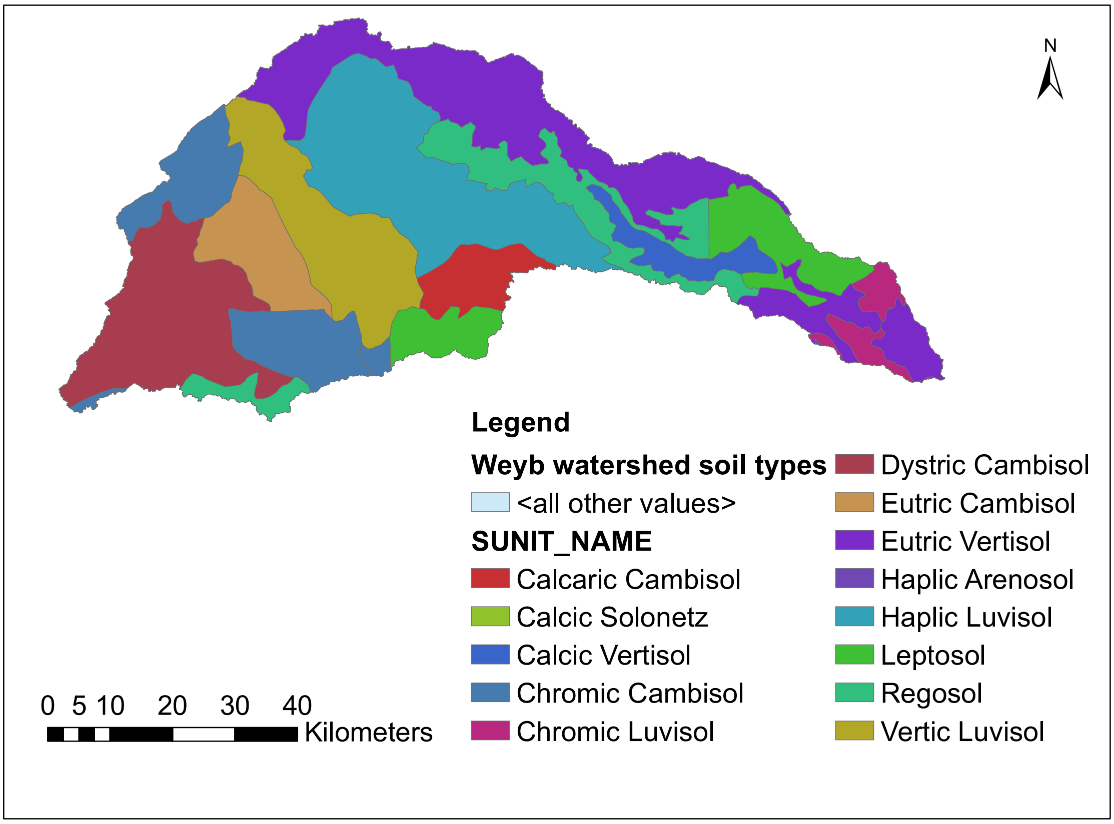

Figure. 3.8. Soil map of the study area

Table 3.2. Soil of Weyb river watershed required by the SWAT model

No.	Soil unit name	Soil unit code	Area [ha]	Percentage catchment area (%)
1	Chromic Cambisol	CMx	52855.24	12.54
2	Dystric Cambisol	CMd	75257.57	17.85
3	Eutric Cambisol	CMe	20564.47	4.88
4	Haplic Luvisol	LVh	72401.70	17.17
5	Vertic Luvisol	LVv	40063.73	9.50
6	Calcaric Cambisol	CMc	8063.79	1.91
7	Leptosol	LP	26628.50	6.32
8	Eutric Vertisol	VRe	84026.42	19.93
9	Regosol	RG	34281.81	8.13
10	Calcic Vertisol	VRk	7449.74	1.77
11	Calcic Solonetz	SNk	18578	1.55
12	Haplic Arenosol	ARh	27200	7.3
13	Chromic Luvisol	LVx	23224	6.4

3.6.2.4. Meteorological data

The SWAT model requires daily meteorological data that could either be read from a measured data set or be generated by a weather generator model which include precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity for the simulation of hydrological processes.

The metrological data required for this study was collected from the Ethiopia National Metrological Service Agency (NMSA) Addis Ababa. There are three meteorological stations which have relatively long period of record inside and outside the catchment. In this study, daily rainfall records of three stations for the year between1993-2005 is used to analyze the current flow condition in the catchment. The number of meteorological variables collected varies from station to station depending on the class of the stations. Some stations contain only rainfall data. The other group includes maximum and minimum temperature in addition to rainfall data. There are also stations that cover variables like humidity, sunshine hours, and wind speed in addition to rainfall, maximum temperature and minimum temperature. Meteorological data from these three station and their location are listed below in the Table 3.3.

Table 3.3. Meteorological data records

SN	Station Name	LAT(ºN)	LON(ºE)	Elevation (m)	Rainfall	Max temp	Min temp	RHM	Wind	Solar rad
1	Robe	7.13	40.05	2480						
2	Sinana	7.07	40.22	2364		-		-	-	-
3	Ginnir	7.13	40.7	1750				-	-	-

All stations listed above contain daily rainfall and maximum, minimum temperature data for at least 20 years from (1986-2005). Therefore all stations were used for hydrological model development.

3.6.2.5. Hydrological data

The hydrological data was required for performing sensitivity analysis, calibration and validation of the model. Daily stream flow data within Weyb river was collected from the Ethiopian Ministry of Water, Irrigation and Electricity (MoWIE) hydrology department. The hydrological data collected was daily flow which used for modeling and climate change impact analysis. Even though, long record of time series data are available, concurrent data set for all the stations from a period of 1993-2000 has been used for model calibration and from 2001-2005 used for model validation from thirtheen year available data records(1993-2005). Hence, the hydrological data of the river was used for sensitivity analysis, calibration and validation. The observed average monthly discharge hydrograph is presented in Figure 3.8.There is only three stream flow gauging station in the study area. The other gauged rivers near or inside the catchment have been used to fill the missed flow using linear regression techniques. Their details are presented in Table 3.4 as below. An automated base flow separation and recession analysis technique (Arnold and Allen 1999) was employed to separate the base flow and surface runoff using the total daily stream flow records.

Table 3.4: Hydrological gauging stations of Weyb river

SN	Station Name	Location		Elevation	Periods
		LAT	LONG		
1	Weyb@Alemkerem	6.59ºN	40.58ºE	2712.0m	1993-2005
2	Weyb@Agarfa	7.22ºN	39.48ºE	3315.0m	1993-2005
3	Weyb@SofUmer	6.54ºN	40.50ºE	-	1993-2005

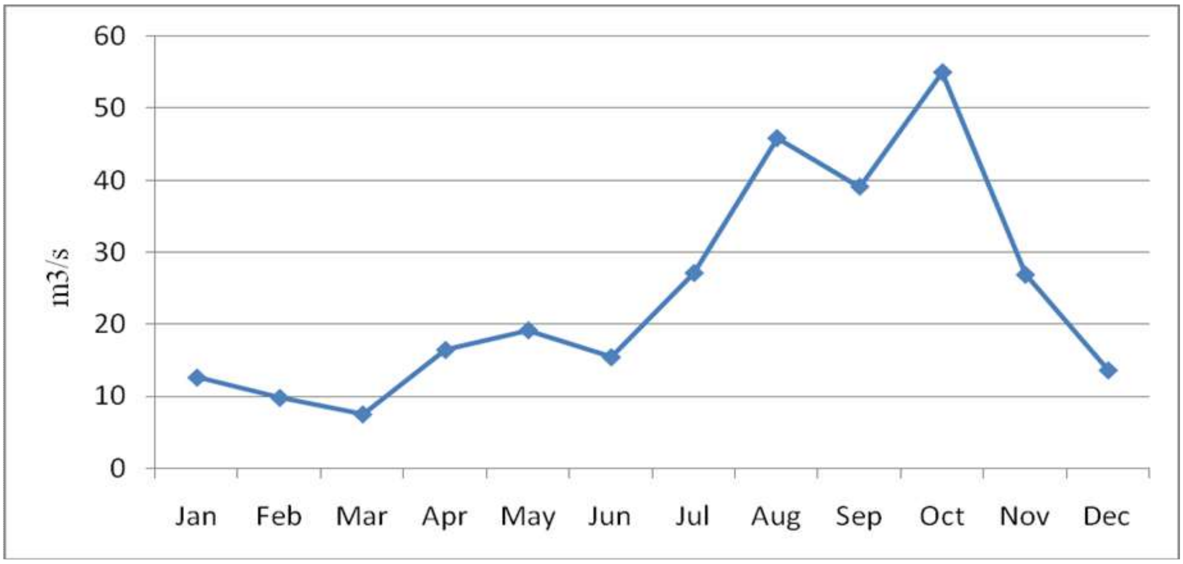

Figure.3.9. Observed average monthly discharge of Weyb river watershed at Sof-Umer gauging station (Source MOWIE).

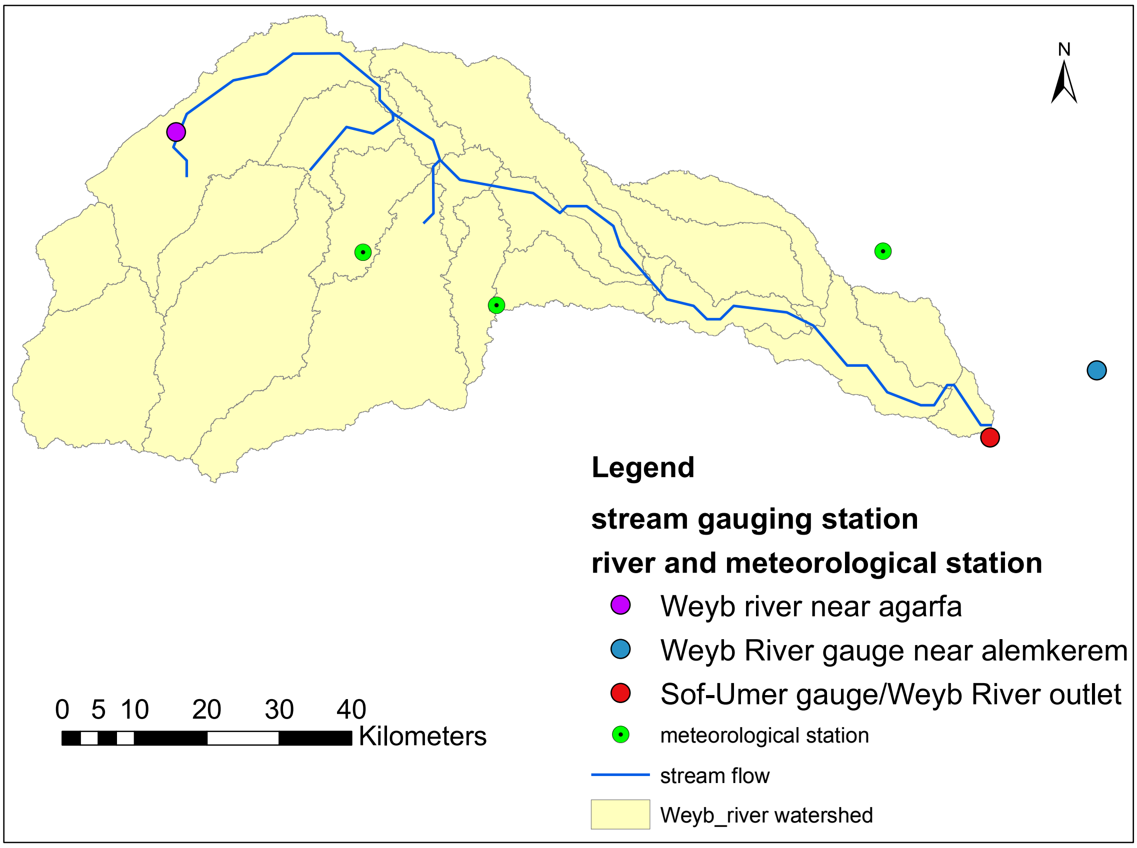

Figure.3.10: Selected hydro-meteorological stations in Weyb river watershed.

3.6.2.6. Climate projection data sets (Climate scenario data)

Climate scenario data is required to measure the relative change of climatic variables between the current and future time horizon which in turn is used as input to hydrological model for assessment of hydrological impacts. The World Climate Research Program (WCRP) initiated the CORDEX RCPs climate scenario runs which were forced by lateral and surface boundary condition from the European Centre for Medium Range Weather Forecasting (ECMWF) Interim Re-Analysis using the region of Africa (Endris *et al.,* 2013). A 50 km resolution was used to perform CORDEX-African domain simulation and the experimental data are available for the period 1993-2005 (Endris *et al.,* 2013).

These pathways have been provided by the CORDEX (near-term and long-term modeling experiment) datasets for the regional climate modeling and research (Moss *et al.,* 2010; Van Vuuren *et al.,* 2011). Simulated daily and monthly rainfall, minimum and maximum temperature from the CORDEX models (RCP4.5 and RCP8.5) were used in this study. Downscaled rainfall, and average, minimum and maximum temperatures for the period 1951-2100 will be obtained from IWMI. In order to best conduct a future climate change study, RCP 4.5 and RCP 8.5 forced scenarios will be selected from 2010 to 2100 for available climate stations in the study area, and downscaled to the same climate stations which will be used for SWAT model for impact assessment.Arc GIS was used to extract grid with latitudes and longitudes that fall within and nearby the watershed as shown in Figure 3.9. The downscaled daily climate variable (precipitation, maximum temperature and minimum temperature) regional climate model for RCP4.5 and RCP 8.5 scenarios have been bias corrected using the linear transformation and variance scaling methods, these bias corrected data taken directly as an input of the hydrological model (SWAT) to assess the future climate change impact on hydrology of the watershed.

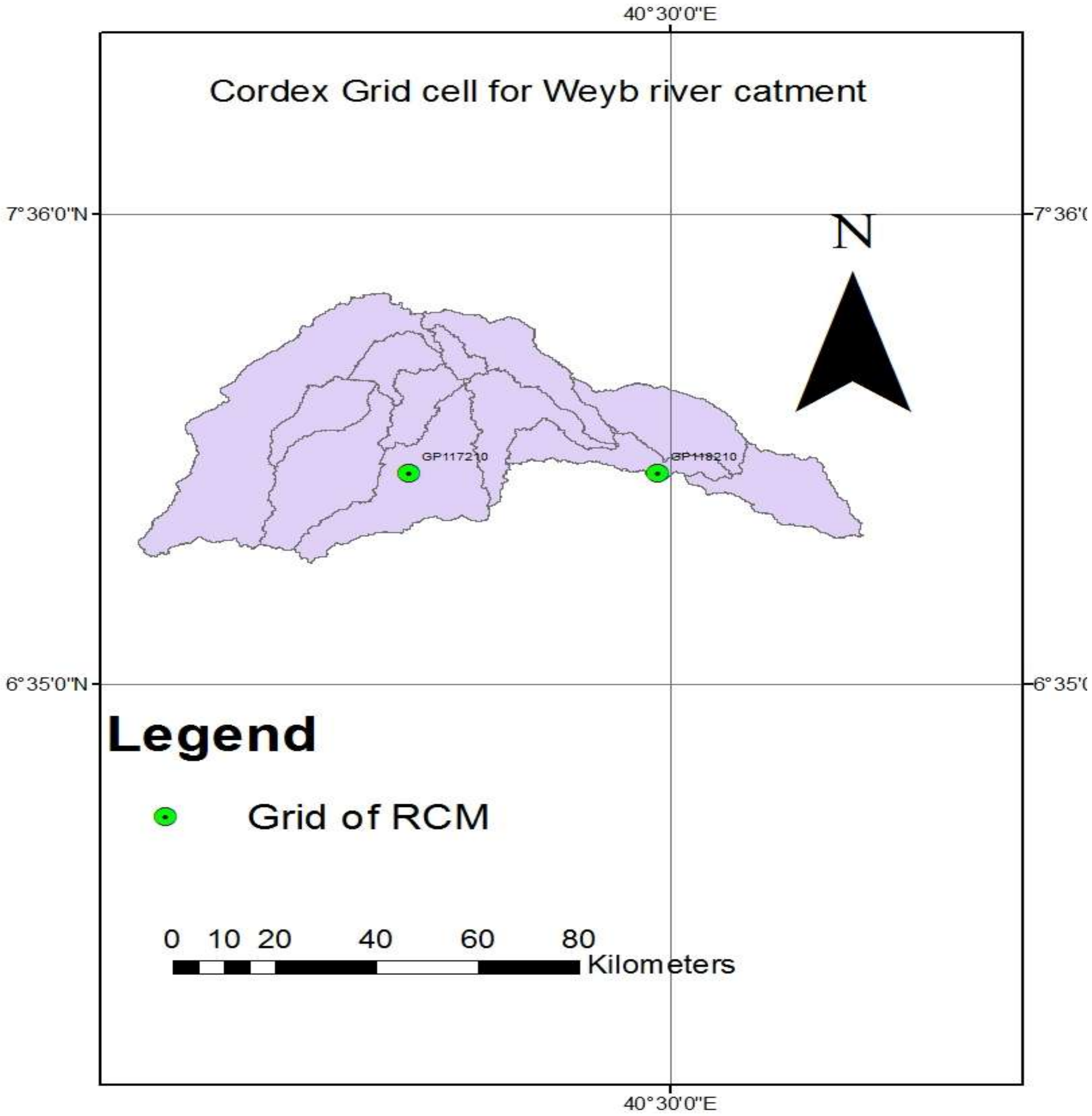

Figure.3. 11: Map of the CORDEX gridded cells of the Weyb watershed(Source: IWMI).

3.6.3. Model set up

3.6.3.1 Watershed delineation

It is essential to develop physical properties of the basin. This is so because the direction and the rate of flow over the surface of land are influenced by basin‟s topography (Arnold *et al.,*2012; Shrestha *et al.,* 2013). To delineate the area of interest, the SWAT uses Digital Elevation Model which gives the height at certain spatial resolution of precise points and this is done under the ArcGIS environment. Exploration of the land surface features and drainage patterns are provided

(Arnold *et al.,* 2012). The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data *i.e.* the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameters for Ethiopia. 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. A watershed was partitioned into a number of sub-basins, for modeling purposes. The number of sub-basins partitioned are 13. The watershed and sub-basin delineation was done using DEM data. A mask was first created over the DEM around the study watershed, to reduce the processing time of the GIS functions. 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. Outlet of the watershed was manually added to fix it at the river gauging station. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub-basin. About three fourth (3/4) of suggested threshold area by the ArcSWAT interface was used for the delineation of sub-basins to increase the number of sub-basins for a more detailed analysis of the hydrologic processes. The DEM was also used to analyze the drainage patterns of the land surface and also it was used to determine slope, slope length, channel slope and length**.**

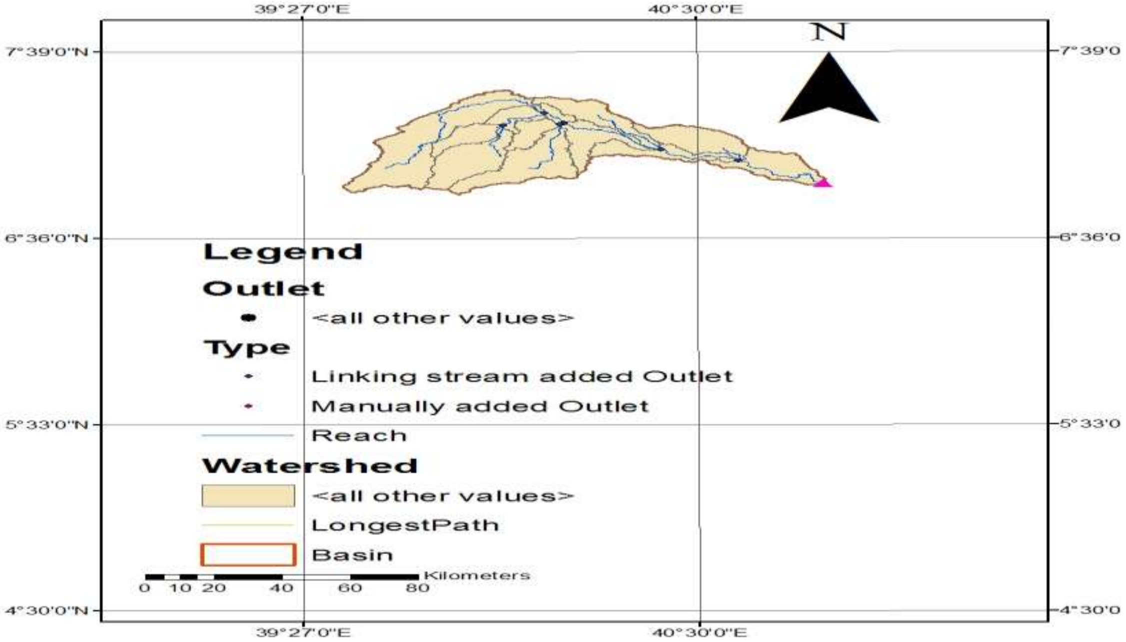

Figure .3.12. Watershed of the study area.

3.6.3.2. Hydrological response units

HRUs are areas within a sub-basin possessing distinctive land use management, soil attributes and slope characteristics. HRUs are used by SWAT tool for description of land complexity within sub-basins (Neitsch *et al.,* 2011; Arnold *et al.,* 2012).The land area in a sub-basin was divided into HRUs. The HRU Analysis tool in ArcSWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by ArcSWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. 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.The threshold level set for multiple HRU is a function of the project goal and the detail desired by the modeler (Neitsch *et al*., 2005). In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 10 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to consideration, 10%, 20%, and 20% threshold levels for the land use, soil and slope classes were applied, respectively so as to encompass most of spatial details. The land use threshold level used was to eliminate minor land uses in each sub-basin. Land uses that cover a percentage (or area) of the sub-basin area less than the threshold level were eliminated. After the elimination process, the area of the remaining land uses was reapportioned so that 100% of the land area in the sub-basin is modeled. The same was true for soil classes and slope ranges distribution in all sub-basins. The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin.

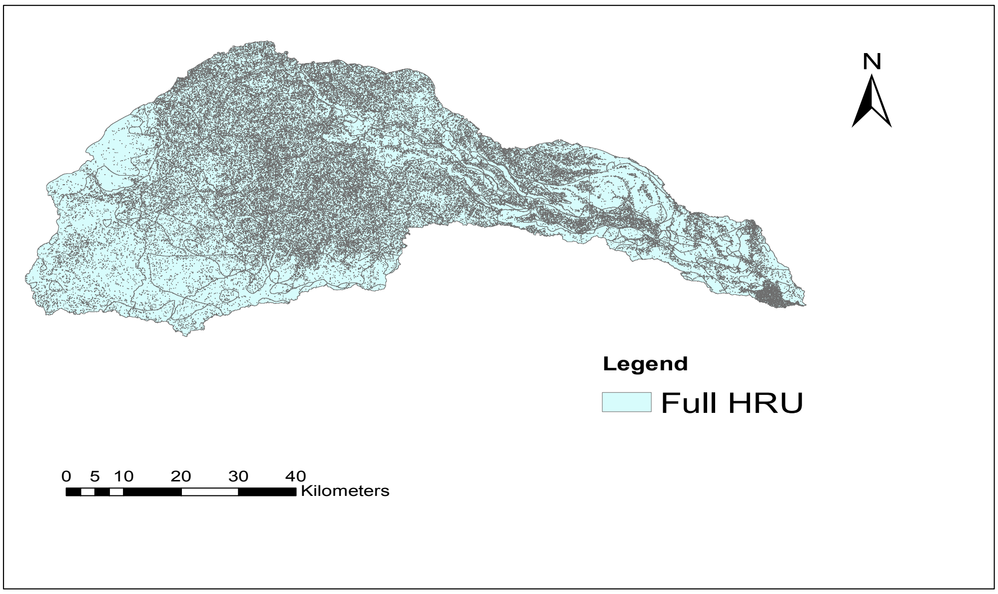

Figure.3.13. HRU map of the study area.

3.6.3.3. Weather generator.

SWAT includes the WXGEN weather generator model (Sharpley and Williams, 1990) to generate climatic data or to fill in gaps in measured records. The occurrence of rain on a given day has a major impact on relative humidity, temperature and solar radiation for the day. The weather generator first independently generates precipitation for the day. Once the total amount of rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green & Ampt method is used for infiltration, maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently.

In order to prepare the weather generator the monthly average value of minimum and maximum temperature, wind speed, humidity and sunshine hours were determined using PCPSTAT program and the rest solar radiation value were determined.

Finally, a statistical weather generator file WXGEN for Ginnir, Robe and Sinana stations was prepared for 20 years to generate climatic data and fill in gaps in the measured records of climatic data. The daily precipitation generator is a Markov chain-skewed (Nicks, 1974) or Markov chain exponential model (Williams, 1995). A first-order Markov chain is used to define the day as wet or dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount. In this research work a skewed distribution has been used.

3.6.3.4. Sensitivity analysis

SWAT is a complex model with many parameters that makes manual calibration difficult. Hence, sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. Sensitivity analysis helps to determine the relative ranking of which parameters most affect the output variance due to input variability (van Griensven et al., 2002) which reduces uncertainty and provides parameter estimation guidance for the calibration step of the model.

In SWAT model a sensitivity analysis has to be performed to choose sensitive parameters for calibration purposes. This is done until goodness of fit to observation is acceptable (Neitsch *et al*., 2011; Rwigi, 2014).After a thorough preprocessing of the required input (temporal and spatial) for SWAT model, flow simulation was performed for an 13 years of recording periods starting from 1993through 2005. The first two years was used as a model initialization/warm up so that, it was discarded and the simulation was then used for sensitivity analysis of water flow parameters and for calibration of the model.

The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven, 2005). The inputs were the observed daily flow data, the simulated flow data and the sensitive parameter in relation to flow with the absolute lower and upper bound and default type of change to be applied (method of application) was used. LH-OAT combines the OAT design and LH sampling by taking the Latin Hypercube samples as initial points for OAT design (Van Griensven 2005). Therefore sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Hamby, 1994 cited in Lenhart *et al.*2002). Using the built in tool in SWAT model auto sensitivity analysis has been performed for stream flow in the basin and the result is found in modeling section of this report.

3.6.3.5. Model calibration and validation

3.6.3.5.1. Model calibration

After parameter sensitivity analysis was undertaken to identify flow parameters which significantly affect the flow hydrograph a trial and error, manual method of parameter adjustments were made several times until the simulated annual water yield fit closer to the actual value. Before going for the determination of the hydrologic components, thorough attempts were made to fine tune the parameters of the model so that the predicted values were in a very close agreement with available measured data.

Calibration encompasses adjusting parameters in a model to best capture the local conditions hence minimizing the model output uncertainties before putting it in to use. For the model to be in a position to be used for a certain assessment it has to be calibrated and validated for the existing conditions (Arnold *et al.,* 2012).

Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. The parameters were calibrated by SUFI-2for the period of 1993 through 2000 until the model simulation results were acceptable as per the model performance measures.

The graphical and statistical approaches E_{NS}, and r^2 were used to evaluate the SWAT model performance a number of times until the acceptable values were obtained for surface runoff and base flow independently. The flow calibration procedure made by SWAT developers in Santhi *et al*. (2001) and Neitsch *et al*. (2004) were carefully followed. For each calibration run and parameter change, the corresponding model performance statistics r^2, and E_{NS} were calculated. This procedure was continued until the acceptable calibration statics recommended by SWAT developer for hydrology was achieved. SWAT developers assumed an acceptable calibration for hydrology at $r^2 > 0.6$ and $E_{NS} > 0.5$ (Santhi *et al.,* 2001; Moriasi *et al.*, 2007)

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. In order to evaluate the performance of SWAT model to determine the quality and reliability of prediction compared to the observed values, the following methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods.

The regression coefficient (r^2) describes the proportion of the total variance in the observed data that can be explained by the model. R-squared (R^2) is a value that is generally computed as a measure of how well the observed values are replicated by simulated values as explained by the proportion of total variations by the model (Moriasi *et al.,* 2007; Rwigi 2014).Values reflected by the trend line help in the estimation of the coefficient of determination which is a number between 0 and 1 that reveals how closely the simulated values agree to the actual observed (Muthama *et al.,* 2008; Jain *et al.,* 2010).The closer the value of r^2 to 1, the higher is the agreement between the simulated and the measured flow and is calculated as follow:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i - X_{av})(Y_i - Y_{av})\right]^2}{\sum_{i=1}^{n}(X_i - X_{av})^2 (Y_i - Y_{av})^2} \text{--} 3.6$$

where: X_i is measured value of the quantity in each model time step, X_{av} is average measured value of the quantity in each model time step, Y_i is simulated value of the quantity in each model time step and Y_{av} is average simulated value of the quantity in each model time step.

Nash and Sutcliffe simulation efficiency (E_{NS}) indicates the degree of fitness of observed and simulated data and given by the following formula. The E_{NS} simulation efficiency for n time steps is calculated as:

$$E_{NS}=1-\frac{\sum_{i=1}^{n}(X_i-Y_i)^2}{\sum_{i=1}^{n}(X_i-X_{av})^2} \tag{3.7}$$

where: X_i is measured value of the quantity in each model time step, X_{av} is average measured value and Y_i is simulated value of the quantity in each model time step. The value of E_{NS} ranges from 1 (best) to negative infinity. The E_{NS} indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970).

3.6.3.5.2. Validation

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. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenarios. To be sure that the model can make satisfactorily accurate simulations a process known as validation is done (Arnold *et al.,* 2012).Stream flow data of five years from 2001 to 2005 were used for validation. The three statistical model performance measures used in calibration procedure were also used in validating daily and monthly stream flow.

3.6.4. Impacts of climate change on stream flow

The impacts of climate change on water resources variability, especially on river flows soil moisture , evapotranspiration, and ground flow, has been studied by analyzing projected and downscaled climatic data and using hydrological models (Mango et al.2011a,b;Behulu et al.2014;Setegn et al.2011,2014; Assefa et al.2014; Melesse et al.2009,2011; Dessu and Melesse 2012; Grey etal.2013). The downscaled climatic scenario (which consists of maximum and minimum temperature, and precipitation) was used as an input to the model. By adjusting the climatic inputs in the SWAT model, impact assessment of climate change on stream can be accomplished. Simulated water yields under the two future scenarios (RCP4.5 and RCP8.5) were evaluated relative to the observed monthly discharge for the gauge station.

This was done through graphical methods. Regression graphs of the annual totals of the observed flow for the period 1993- 2005 were compared with those of the simulated water yields. The analysis of stream flow was carried out for three time horizons in the future from the two climate change scenarios. ArcSWAT model first ran for historic or baseline period (1986-2005) was re-run again subject to future period (2010-2099) climate variables which were downscaled at station level. All other climatic and physiographic variables are supposed to be same in the upcoming periods. These periods were the 2020s, (2010–2039); the 2050s, (2040–2069); and the 2080s, (2070–2099).

3.7. Hydro-climatic trend analysis

3.7.1. Mann-Kendall trend test.

The trend in annual series was made so as to get an overall view of the possible change in climatic and stream flow processes. Mann-Kendall test was used to analyze the trends in rainfall and surface air temperature. Long term climatic changes could introduce trends in hydrologic data. Catchments response to effective rainfall could be changed due to the changes in land cover which introduces trends in the stream flow. In detecting trend in datasets there are many parametric and nonparametric methods available for use. Simple linear regression analysis which assumes constant variance, normality of errors and true linearity of relationships is one of the most useful parametric methods that are used to detect trend. However, in this study the trend in time series of different datasets was determined by Mann-Kendall trend test.

The Mann-Kendall test is based on the calculation of Kendall's tau(S) measure of association between two samples, which is itself based on the ranks of the samples. This method is a non-parametric rank-based procedure that has been commonly used to assess if there is a trend in a time series hydro-meteorological data (Hamed 2008; Karpouzos et al. 2010). The Mann-Kendall test was applied to test trends in future climatic variables which expressed by the equation given below. Let X1, X2, …, Xn represent n data points where X represents the data point at time j. The Mann-Kendall statistic (S) or tau is given by Eq. (3.12):

$$tau(S) = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_{j-}x_k) \text{--} 3.8$$

S = any integer between $-n\frac{(n-1)}{2}$ and $n\frac{(n-1)}{2}$, Xj and Xk are sequential time series values, n is the number of data in the set or the length of the data set, sign(Xj- Xk) is the sign function and is given as :

$$sign(X_j\_X_i) = \begin{cases} 1 \; if \; (X_j\_X_k) > 0 \\ 0 \; if (X_j - X_k) = 0 \\ -1 \; if \; (X_j - X_k) \; < 0 \end{cases} \quad \text{--3.9}$$

It is also assumed that for n ≥8, the S test statistics is normally distributed, its mean being zero and variance being:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad \text{--3.10}$$

Under these situation the standard test statistics Z wiil be:

$$Z = \begin{cases} \frac{S-1}{\sigma} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{s+1}{\sigma} \; if \; S \; < 0 \end{cases} \quad \text{---3.11}$$

The decision to either reject or accept the null hypothesis (that no trend is detected) was then made by comparing calculated Z with the critical value at a chosen level of significance.

This test was suggested by Mann in 1945 and it has been widely used (Yue *et al.,* 2002; Hamed, 2008; Mondal *et al.,* 2012; Ngaina & Mutai, 2013; Nasrollahi *et al.,* 2015; Ouma 2015). In this test, *tau* is the test statistic. When the value of *tau(S)* is positive, it indicates an increasing trend and when the value of *tau(S)* is negative, it indicates a decreasing trend on hydrologic time series. In this study, the level of significance of 0.05 (P-value=0.05) was used. If their P-value was equal to or less than 0.05 (P-value ≤ 0.05) the trend tests were considered significant.

3.7.2. Sen's slope estimator.

This also non-parametric test by which true slope (change per year) of a trend was estimated (Salmi et al.,2002). Sen's test Sen (1968) was used in case when the trend is assumed linear, i.e

$f(t) = Qt+B$---3.12

Where: f(t) = increasing or decreasing function of time, i.e, the trend; Q = the slope

B = intercept

The slope of each data pair Qi is calculated as: $Q_i = \frac{Xj - Xk}{j - k}$ -----------------------------3.13

Here, j>k and, if there is n number of Xj in the time series, we get as many as $N = \frac{n(n-1)}{2}$ slope estimates Qi.

Then the value of Qi will be ranked from small to large the median of which is the Sen's slope,i.e

$$\begin{cases} Q\left[\frac{N+1}{2}\right] if \; N \; is \; odd \\ \frac{1}{2}\left[\frac{N}{2}\right] + Q\left[\frac{N+2}{2}\right] \; if \; N \; is \; even \end{cases} \quad \text{---3.14}$$

3.7.3. Trend detection

For this study, climatic trend for maximum temperature, minimum temperature, precipitation and hydrlogic trend for Weyb river in the study area during 21st century was analyzed using non-parametric Mann-Kendall test, Sen's slope was estimated by using XLStat version 5.1. A significance level of 5% was used for the analysis which indicating 95% confidence interval was chosen arbitrarily. Data was entered to XLStat software in chronological order and calculates S statistics at the significance level of $\alpha = 0.01, \alpha = 0.05 and \alpha = 0.1$ and statement of test result. Once the yearly data entered , it calculates the test statistics Z and compares its absolute value to the standard normal cumulative distribution to define if there is a trend or not at the selected level α of significance. The trend of projected climate and stream flow for RCP 4.5 and RCP 8.5 scenarios for the 21st century was tested and the result is presented on section 4.2.

4. RESULTS AND DISCUSSION

4.1. RCM-derived climate simulations and bias correction for the baseline period

The potential impacts of climate change and climate variability on stream flow analyzed using the bias-corrected downscaled RCM output from the fifth phase of the Coupled Model Inter comparison Project (CMIP5) which downscaled over the Africa-CORDEX domain by a regional climate model, RCA4. The SWAT model was used to simulate the stream flow using observed meteorological data, and RCMs outputs by taking as other parameter as constant in the future. The RCMs data sets have been bias corrected using the linear correction methods. The reference (1986-2005), the near future (2010-2039) ,intermidiate future (2040-2069) far future (2070-2099) periods were used for further RCM analysis. As explained in the preceding section the downscaling experiment was conducted for minimum temperature, maximum temperature and precipitation for Weyb catchment which contains observed data for the specified period and the results are discussed in the coming section.

4.1.1. Precipitation

Figure 4.1 shows the mean daily precipitation of RCM bias corrected by the linear correction methods in comparison with observed data for the baseline period (1986-2005). The simulated mean daily precipitation in all of the months is representative of the observed magnitudes.

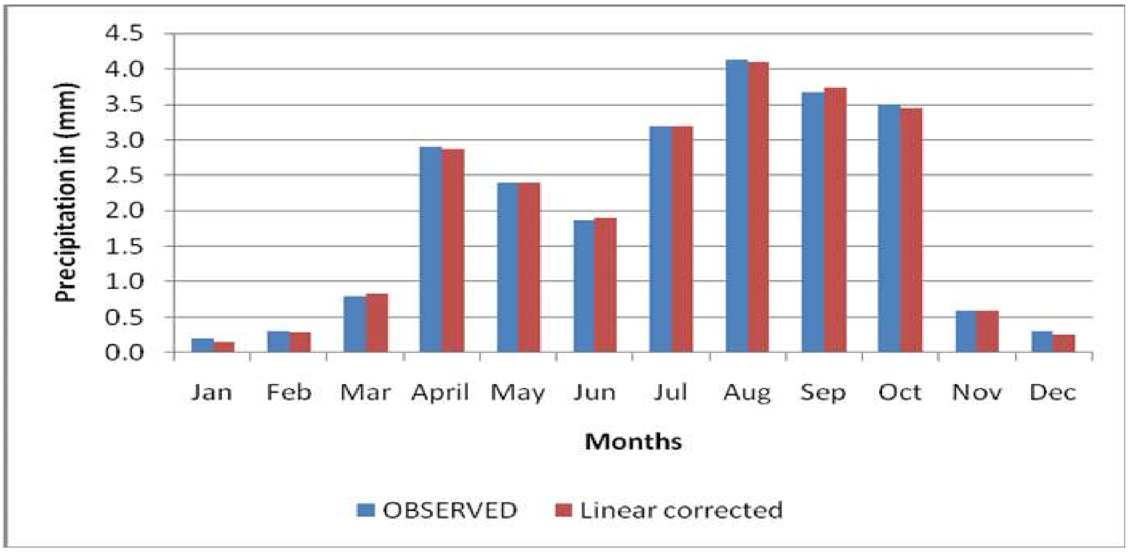

Figure.4.1: Linear bias correction and observed mean daily precipitation for the base line period (1986-2005)

4.1.2. Maximum temperature

Downscaled mean daily maximum temperature ranges from 17.0°C to 24.0°C in variance scaling RCM bias correction methods (Figure 4.2). The variance scaling RCM bias corrected output indicated reasonable agreement with observed daily maximum temperature.

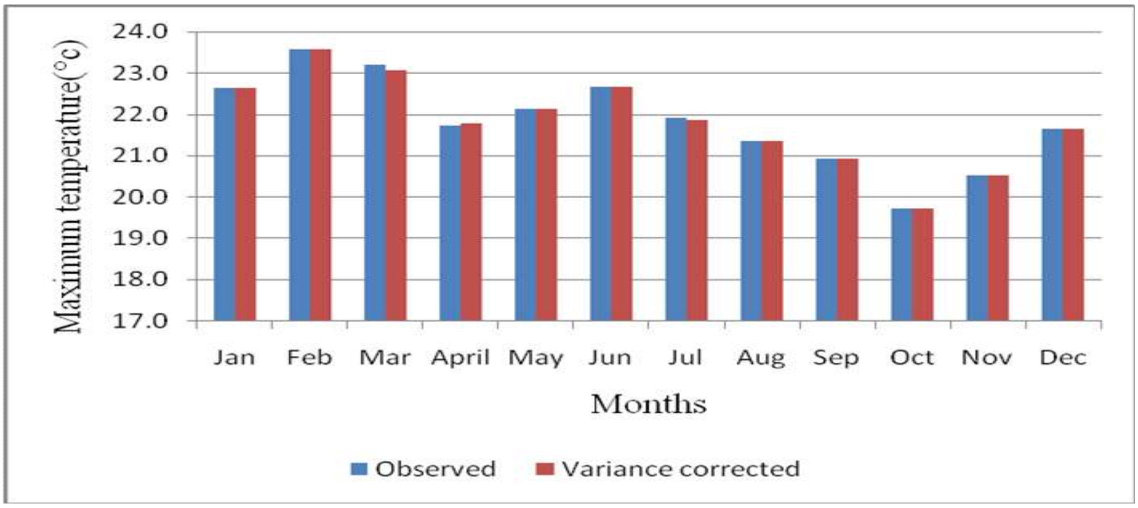

Figure.4.2:Variance scaling bias correction and observed mean daily maximum temperature for the base line period (1986-2005)

4.1.3. Minimum temperature

The Variance scaling bias correction mean daily minimum temperature indicated good agreement with observed mean daily data. The daily mean minimum temperature ranges from 8.6˚c and 12.3˚c. RCM simulation under linear scaling bias correction shown in significant difference from observed by over estimating approximately 0.2˚c and 0.5˚c at May and september respectively .However, in January and March shown under estimation by 0.32˚c.

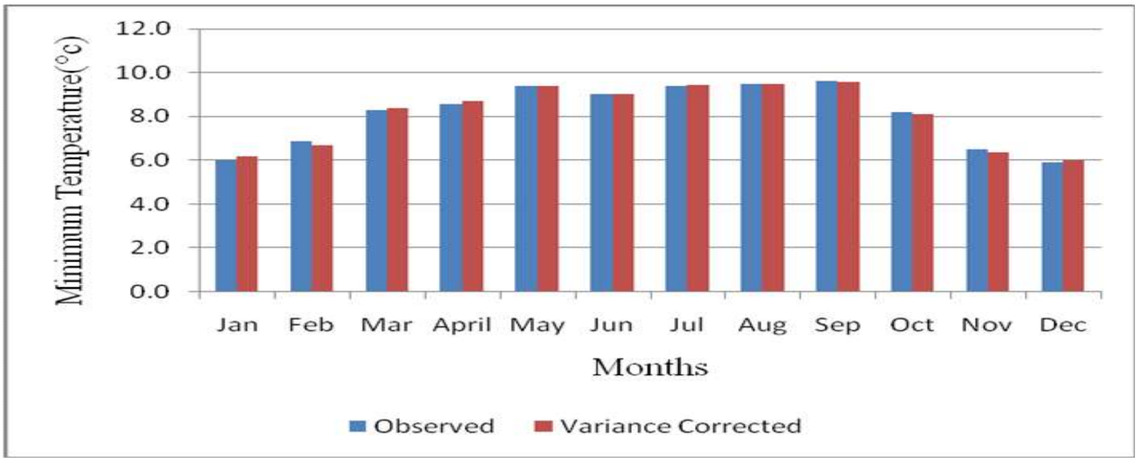

Figure.4. 3:V ariance scaling bias correction and observed mean daily minimum temperature for the base line period (1986-2005)

4.2. Projected future climate variables

The term climate variability is commonly used to denote deviations of climate data over a given period of time (1986-2005) from the long-term climate data relating to the equivalent calendar period. In this sense, climate variability is measured by those deviations, which are usually termed anomalies. In this study, baseline period climatic condition is analysed based on meteorological station records of the study area. Positive anomaly indicates an increase from the baseline period value, while a negative anomaly indicates decrease from the baseline period value. The anomaly of monthly precipitation is calculated as the difference from future monthly average precipitation to the baseline period (1986-2005) monthly average precipitation values. Similar approach is used to analyses temperature variability. Regional climate model RCA4 output temperature and precipitation was corrected by Variance scaling and linear correction method respectively for RCP 4.5 and RCP 8.5 scenarios to generate temperature and precipitation scenarios of the three future time windows, namely periods (2010-2039, 2040-2069, and 2070-2099) relative to the baseline period 1986-2005 in Weyb catchment were analysed.

Respective outputs of precipitation, maximum and minimum temperature of each scenario are discussed in the following sections.

4.2.1. Projected changes in monthly rainfall data

Projected changes in monthly rainfall data are vital means of evaluating the characteristics of rainfall at the study site. Anomalies were calculated as the difference from baseline period average areal precipitation to future periodic monthly average areal precipitation value. The projected areal precipitation experiences a mean annual increase of 0.9% and 0.87% for RCP 4.5 scenario at (2010-2039) and (2070-2099) respectively. Also, the areal precipitation exhibits a mean annual increase of 0.86% and 0.89% for RCP 8.5 scenario at (2010-2039) and (2070-2099) respectively. As can be shown from Figure 4.4 and 4.5 below, in all periods there may be an decrease in precipitation for months February, March, April , July and August for both RCP 4.5 and RCP 8.5 scenario and increase in all other months for RCP 8.5 scenario.

In 2010-2039 the February ,March, April, July and August areal rainfall is projected to increase by 19.8%,5%,5.8%,0.3% and 0.6% from the baseline period for RCP4.5 scenarios respectively, whereas in June and October 2010-2039 the areal rainfall is projected to decrease by 3% and 6.9% for RCP 4.5 scenarios respectively(Figure4.4). Generally, for the months (February –April) the rainfall exhibits a relative increase from the baseline period for both

RCP 4.5 and RCP 8.5 scenario in all future time horizons. Results also indicate that the variation in mean annual rainfall is smaller than the variation in the monthly rainfall.

The monthly precipitation change was highly variable in February for both RCP 4.5 and RCP 8.5 scenarios in all time horizons.

The unevenness of rainfall is greater in case of high emission scenario than an intermediate scenarios. Mann-Kendall test has shown a significantly (at 5% significant level) increasing trend of mean annual total precipitation upcoming period untill year 2099 for RCP8.5 and RCP4.5 scenarios.

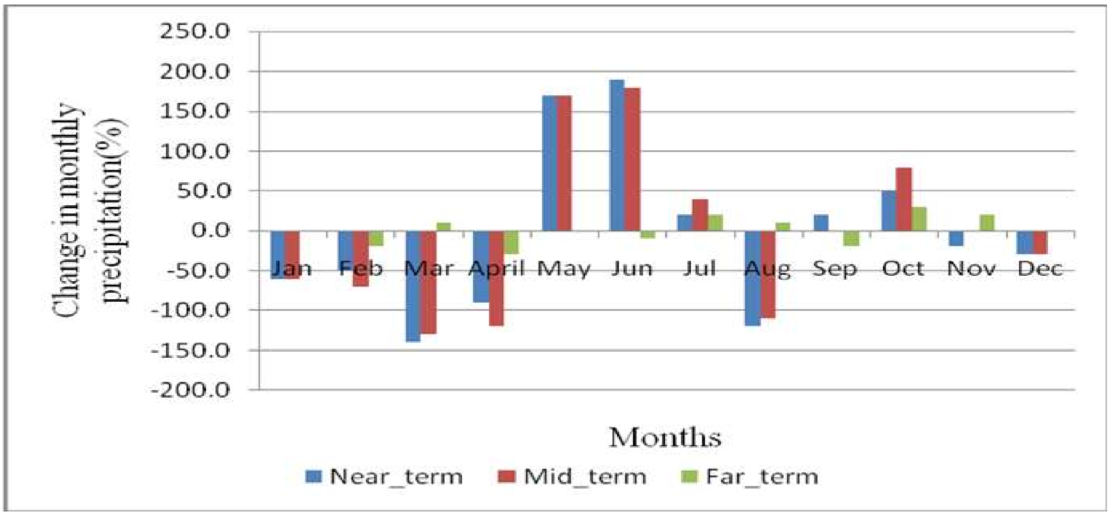

Figure.4. 4: Percentage change in monthly precipitation in the future from the baseline period for RCP 4.5 scenario

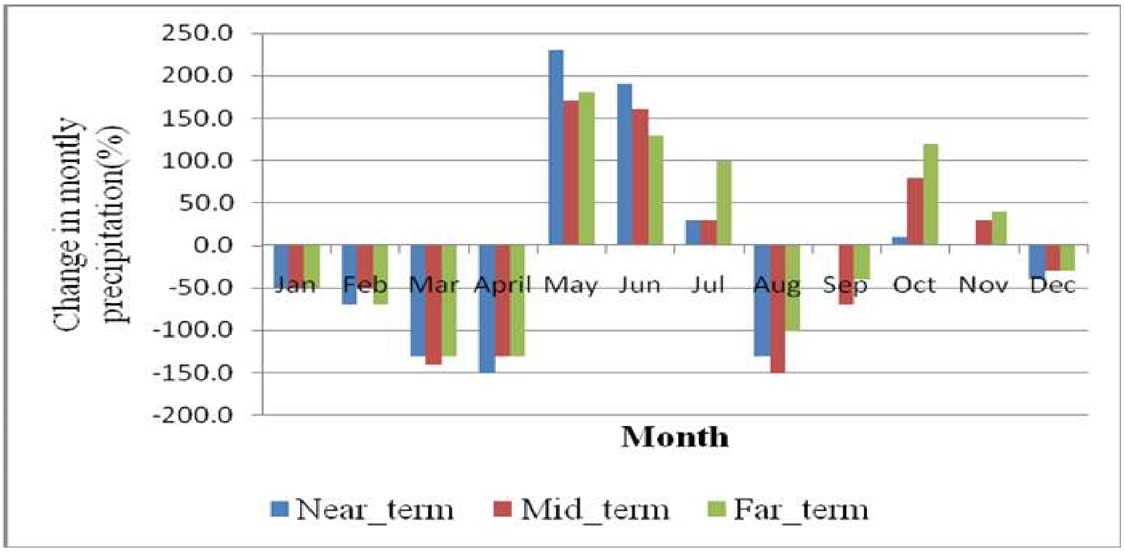

Figure.4. 5: Percentage change in monthly precipitation in the future from the baseline period for RCP 8.5 scenario

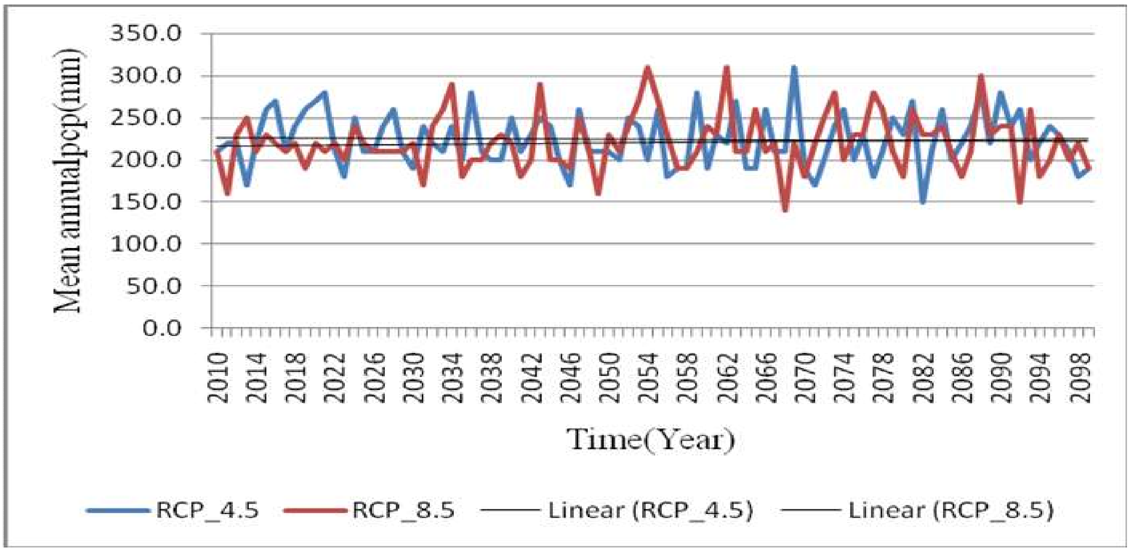

Figure.4.6: Future trend of mean annual precipitation

Table 4. 1: Mean annual precipitation changes (%) under RCP 4.5 and RCP 8.5 scenarios

Scenario	2010-2039	2040-2040	2070-2099
RCA4 RCP 4.5	0.9	0.89	0.87
RCA4 RCP 8.5	0.86	0.84	0.89

4.2.2. Projected changes in maximum temperature data

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

The average annual maximum temperature in (2010-2039) will be shown an increase by 1.2°C and 1.3°C for RCP 4.5 and RCP 8.5 scenario respectively. For the 2040-2069 periods the average annual maximum temperature will be increased by 1.1°C and 1.4°C for RCP 4.5 and RCP 8.5 scenario respectively.For the (2070-2099) periods the average annual maximum temperature will be increased by 1.4°C and 0.2°C for RCP 4.5 and RCP 8.5 scenario respectively. An increase for RCP 8.5 scenario is greater than RCP 4.5 scenario because RCP 8.5 scenario represents a high emission scenario which produces more CO_2 concentration than the RCP 4.5 scenario which represents an intermediate (lower) emission scenario. Increasing maximum temperature showed variation at the monthly time step with a range from 0.1°C to 2.8°C in all future period, (2010-2039), (2070-2099) and (2070-2099) 0.1°C to 2.4°C in all future period for RCP 4.5 and RCP 8.5 scenario respectively.

The projected mean monthly maximum temperature shows increasing trend for all time periods by 0.01, 0.02, and 0.11°C for RCP4.5 scenario for 2020s, 2050s, and 2080, respectively. RCP8.5 scenario also shows an increase of mean monthly maximum temperature with 0.01, 0.03, and 0.11°C for 2020s, 2050s and 2080s, respectively. As compared to RCP8.5 scenario, RCP4.5 scenario is almost the same (Figure4.7 and 4.8). Generally, the future scenarios have shown slightly increasing trend on maximum temperature and decreasing trend on minimum temperature.

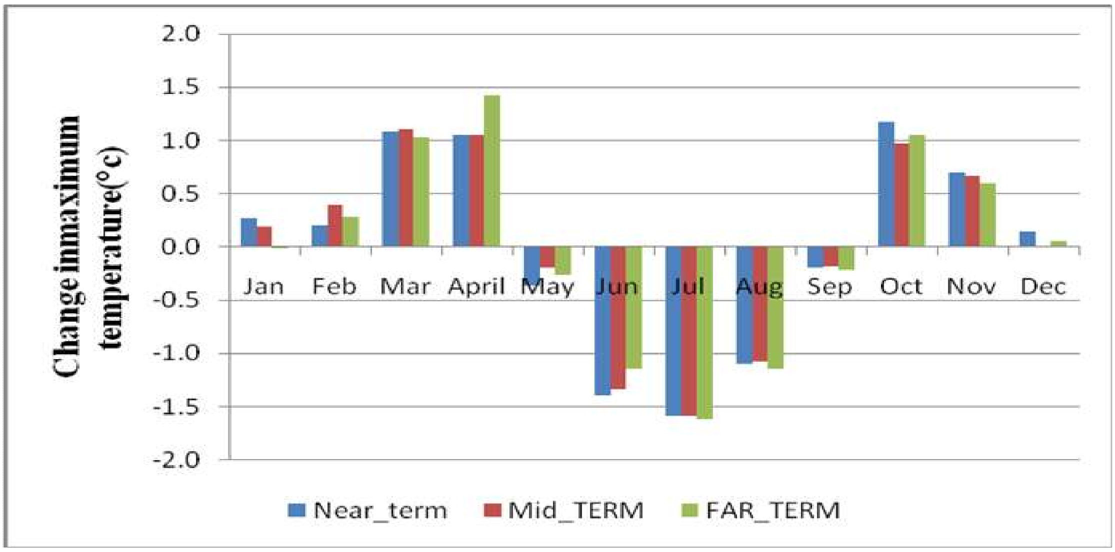

Figure.4. 7: Change in monthly maximum temperature between the baseline period and future period for RCP 4.5 scenario.

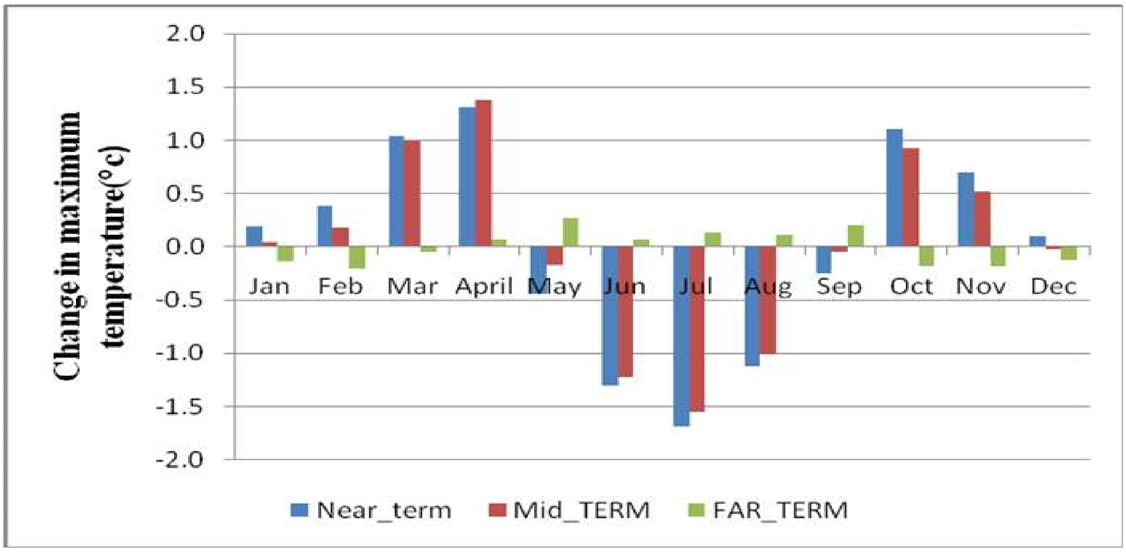

Figure.4. 8: Change in monthly maximum temperature between the baseline period and future period for RCP 8.5

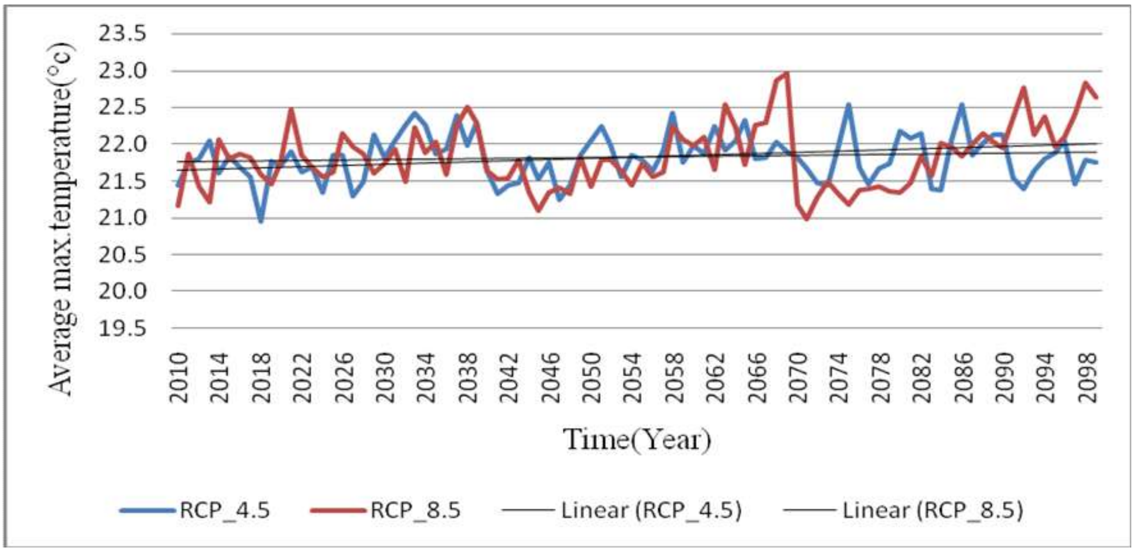

Figure.4. 9: Future trend of average annual maximum temperature (°c)

Table4.2: mean annual maximum temperature changes (˚c) under RCP 4.5 and RCP 8.5 scenarios

Scenario	2010-2039	2040-2069	2070-2099
RCA4 RCP 4.5	1.2	1.1	1.4
RCA4 RCP 8.5	1.3	1.4	0.2

4.2.3. Projected changes in minimum temperature data

The projected minimum temperature also shows a distinct increase for both RCP 4.5 and RCP 8.5 scenarios. The average annual minimum temperature in (2010-2039) will be increased by 1.5^{o}C and 0.7^{o}C for RCP 4.5 and RCP 8.5 emission scenario respectively. For the (2040-2069) periods the average annual minimum temperature will be increased by 0.1^{o}C and 0.6^{o}C for RCP 4.5 and RCP 8.5 emission scenario respectively.. For the (2070-2099) periods the average annual minimum temperature will be increased by 0.1^{o}C and 0.7^{o}C for RCP 4.5 and RCP 8.5 emission scenario respectively.

The relative change of monthly minimum temperature varies from month to month. The maximum relative change of minimum temperature is observed in February where the minimum temperature will be increased by about 1.9^{o}C for (2070-2099) for both RCP 4.5 and RCP 8.5 scenarios. Increasing minimum temperature showed more variation at the monthly time step with arange from 0.1^{o}C to 1.7^{o}C in 2010-2039 and 0.1^{o}C to 1.9^{o}C in 20070-2099 and for both RCP 4.5 and RCP 8.5 emission scenario. The minimum temperature change for RCP

4.5 and RCP 8.5 was low as compared to the maximum temperature change for all near, intermediate and far future periods.

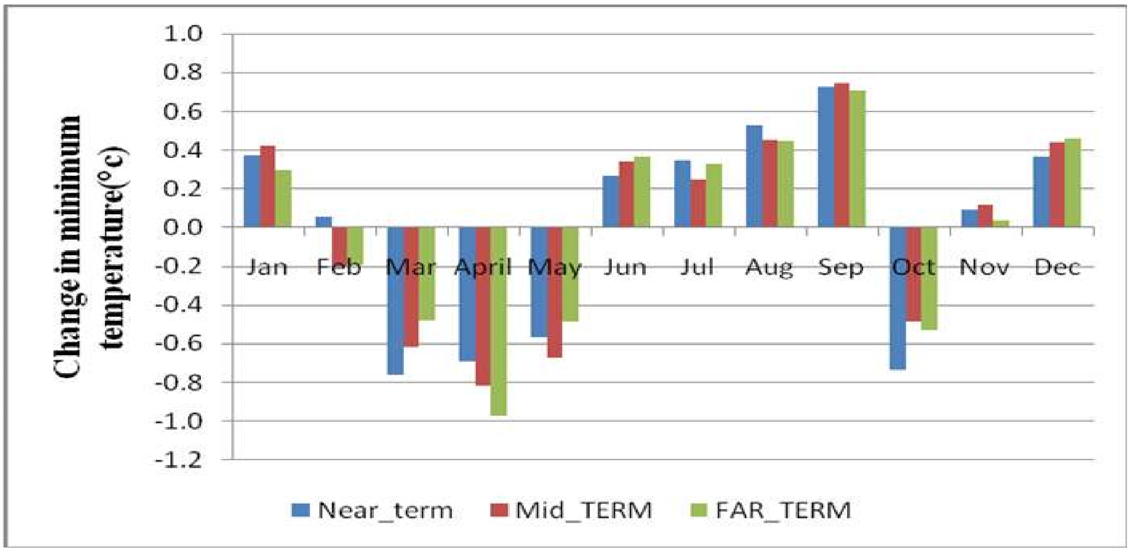

Figure.4. 10: Change in monthly minimum temperature between the baseline period and future period for RCP 4.5

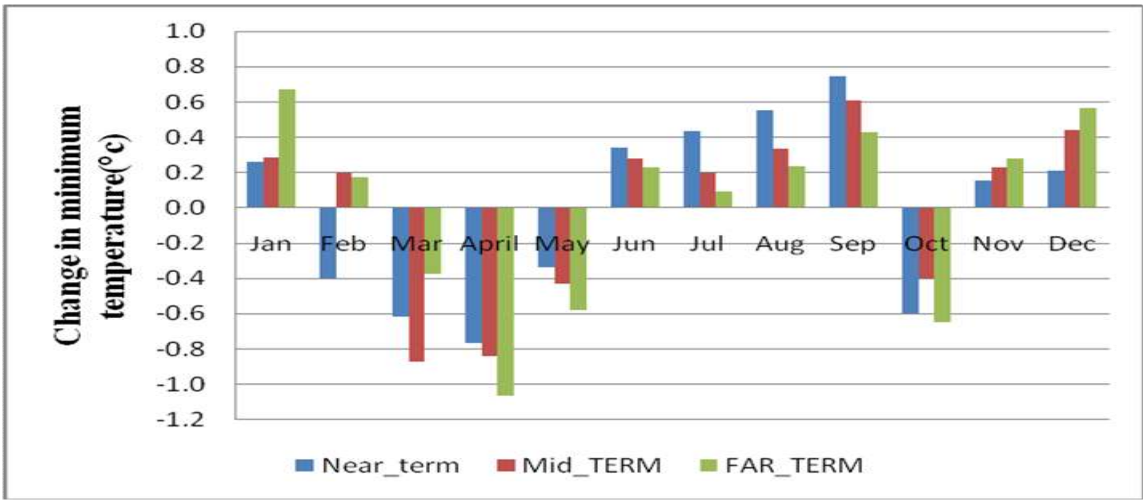

Figure.4. 11: Change in monthly minimum temperature between the baseline period and future period for RCP 8.5

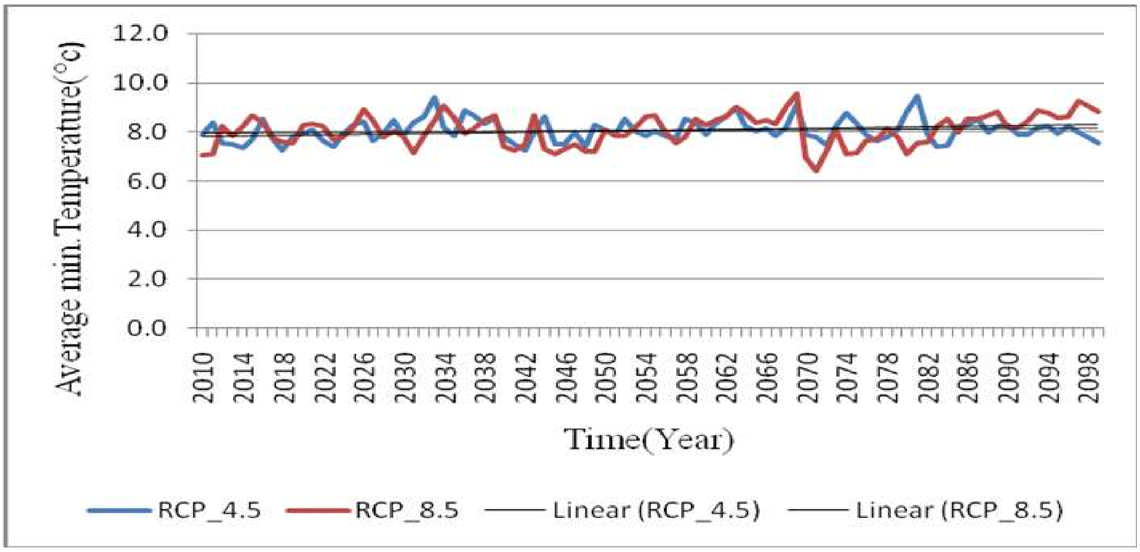

Figure.4. 12: Future trend of average annual minimum temperature (°c)

Table 4.3: Mean annual minimum temperature changes (˚c) under RCP 4.5 and RCP 8.5 scenarios

Scenario	2010-2039	2040-2069	2070-2099
RCA4 RCP 4.5	1.5	0.1	0.1
RCA4 RCP 8.5	0.7	0.6	0.7

As described in the IPCC Fifth Assessment Report(IPCC,2014) , the increase of global mean surface temperature by the end of the 21st century (2070-2099) relative to 1986-2005 is likely to be 0.3°C–1.7°C under RCP4.5and 2.6°C–4.8°C under RCP8.5. With reference to this study, our results also within the limits of the latest projection for most future time horizons.

4.3. Trend analysis of rainfall, and temperature

The results from the trend analysis are presented in this section. The long term trend in precipitation, maximum temperature, minimum temperature and stream flow was done by XLStat and presented in Table 4.4. The significance of the trend was tested at $\alpha = 0.01, 0.05 and 0.1$ level of significance. Minimum significance requirements was arbitrarily taken at $\alpha = 0.05$ to make conclusion in this study. To see the long term trend in precipitation, and maximum temperature, minimum temperature synthetic daily data of the 1986-2099 (113years) were fed in to XLStat software to see significance of the trend.

If the p-value is less than or equal to 0.05 the trend is regarded significant.

Table 4.4. Mann-Kendall trend test for future annual precipitation and temperatuere RCP 4.5 and RCP 8.5.

Scenario	Kendall's tau	Pvalue	Alpha	Sen's slope	Trenda
Precipitation at RCP4.5	−0.044	0.542	0.05	−0.111	Not significant
Precipitation at RCP8.5	0.196	0.007	0.05	0.604	Significantly increasing
Temp max RCP4.5	0.52	<0.0001	0.05	0.003	Significantly increasing
Temp max RCP8.5	0.479	<0.0001	0.05	0.003	Significantly increasing
Temp min RCP4.5	−0.349	<0.0001	0.05	−0.002	Significantly dicreasing
Temp min RCP8.5	−0.113	0.119	0.05	−4.36E−04	Not significant

4.4. Projected stream flow patterns under climate change scenarios for RCP4.5 and RCP8.5

4.4.1. Simulation of the hydrology of the watershed

4.4.1.1. Watershed and HRU delineations

From a minimum user-defined threshhold area,13 sub-basins were delinated in the Weyb watershed area of 4414.445 km2. Each sub-basin boundary marks the ends of a reach, the end of point accummulation for all flow upstream, which then is fed into a downstream sub-basin and reach (Fig 4.12). Once the main reach and the longest paths/tributaries are formed, the model uses other physical parameters (soils, land use and land slope) to define HRUs. From assumed threshold values for HRU delination of 10%, 20%, and 20%) for land use , soil, and slpoe respectively, 51 HRUs were identified in 13 sub-basins. As shown in Table 4.5, the larger part of the watershed is coverd by the two soil types Eutric Vertisol and Haplic Luvisol, 21.13% and 20.27%, respectively of the middle to lower end of the watershed. On the other hand , Calcic Vertisol and Calcaric Cambisol cover relatively smaller portion of the watershed 2.89 and 2.03% respectively.

The dominant land use type within the study watershed is Agricultural Land-Close-grown(intensively cultivated cereal crops such as wheat and barely) about 35.68% of the total watershed area. Rsidential-Med –Low Density (towns) and Residential –Low Density farm villages covers about 0.03 and 0.66% of the total watershed area(Table 4.6). Depending on the maximum and standardevation of land slope in the watershed, three slope classes were considered by dividing land slope classes as: class1(0-10%). Class2 (10-25%), and class3 (25-9999%). Maximum value of slope in SWAT data base has a deffault value of 9999%. From land slope classiffication about 64.81% of the watershed area has slope 0-10%,23.1% of the area has 10-30%, and the rest 12.09% has 25-78% slope.

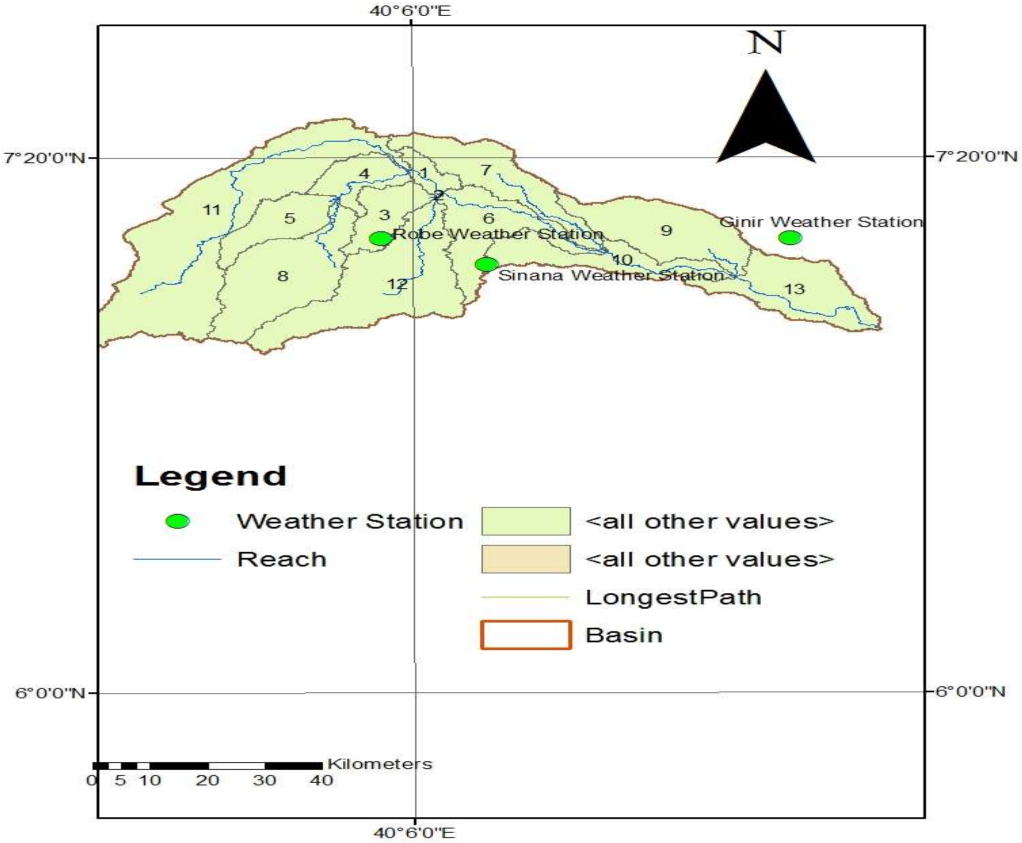

Figure 4.13. Sub-basin delination in the Weyb watershed by SWAT model

Table 4.5. Major soil of Weyb watershed and areal coverage

No.	Soil unit name	Soil unit code	Area [ha]	Percentage catchment area (%)
1	Chromic Cambisol	CMx	52855.24	12.54
2	Dystric Cambisol	CMd	75257.57	17.85
3	Eutric Cambisol	CMe	20564.47	4.88
4	Haplic Luvisol	LVh	72401.70	17.17
5	Vertic Luvisol	LVv	40063.73	9.50
6	Calcaric Cambisol	CMc	8063.79	1.91
7	Leptosol	LP	26628.50	6.32

8	Eutric Vertisol	VRe	84026.42	19.93
9	Regosol	RG	34281.81	8.13
10	Calcic Vertisol	VRk	7449.74	1.77

Table 4.6. Major land use of Weyb watershed and areal coverage.

Land use	SWAT codes	Area (ha)	% of watershed
Agricultural land-close-grown	AGRC	147,152.6	35.6
Agricultural land-generic	AGRL	58,713.2	14.2
Range-grasses	RNGE	42,079.5	10.2
Forest-mixed	FRST	29,632	7.2
Residential-med/low density	URLD	117.9	0.03
Residential-low density	URML	2723	0.66
Range-brush	RNGB	68,450.5	16.6

4.4.1.2. Sensitivity analysis

The SWAT model considered the twenty seven flow parameters for the analysis of sensitivity from which 21 of them were found to be relatively sensitive. Among the sensitive flow parameters, ground water flow were the most sensitive. Base flow alpha factor (Alpha_ Bf)[days], Threshold water depth in the shallow aquifer for flow (Gwqmn)[mm], Soil evaporation compensation factor (Esco), Initial curve number(II) value(Cn2), Soil depth(Sol_Z)[mm], Threshold water depth in the shallow aquifer for "revap"(Revapmin)[mm Available water capacity (Sol_Awc)[mmwater/mm soil] and Ground water "revap" coefficient (GW_Revap),(Sol_k)[mm],(GW_DELAY)[days] were found to be the most sensitive hydrological parameters for the summulation of stream flow in the Weyb watershed. A brief description of each hydrological parameters are listed in the SWAT model user's manual (Neitsch et al .,2005).

4.4.2. SWAT model calibration and validation

4.4.2.1. Model calibration

Model calibration followed sensitivity analysis.

The authomatic base flow separation technique based on the daily stream flow data measured at the outlet of the watershed indicated that about 63%of the total water yield is contributed from subsurface water source.

The model was run for a period of nine years January 1, 1993 to December 31, 2005. The calibration was therefore performed for a period of eight years (January 1, 1993 to December 31, 2000) on monthly and daily bases.

Model parameters were calibrated with SWAT-CUP which was very automated process, using SUFI-2 (Sequential Uncertainty Fittings version 2), an auto calibration tool which is embedded in SWAT-CUP of SWAT 2012 extension. The calibration processes considered 10 flow parameters (Table 4.7) and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The auto calibration processes significantly improved model efficiency. Table 4. 7. Illustrates the final calibrated and fitted values. The result from different statistical methd of model performance evaluation met the criteria with R^2, and ENS values of 0.55, 0.50, respectively.

An intensive hydrological calibration resulted in good SWAT predictive efficiency at the monthly time step when compared to measured flow data. The hydrograph of observed and simulted flow indicated that the SWAT model is capable of simulating the hydrology of Weyb watershed. Though rigorous calibration was undertaken for flow, there is still slight overstimation during the dry season flows of observed series both at calibration and validation periods.

Table 4.7. Calibrated flow parameter values and variation methods (imet)

Flow parameters	Lower and upper bounds	Calibrated values	Variation methods
Alpha_Bf;[days]	0.0-1.0	0.9	Replacement
Cn2	±25.0	-10.9	Multply
Esco	0.0-1.0	0.16	Replacement
Gw_Delay;[days]	±10.0	5.47	Addition
Gwqmn;[mm]	±1000.0	853.02	Addition
Revapmin;"revap"[mm]	±100.0	93.73	Addition
Sol_Awc; available water capacity [mm]	±25.0	15.42	multiply
Sol_Z;soil depth[mm]	±25	6.17	multiply
Sol_k;[mm]	±25	0.167	multiply
Gw_Revap[mm]	0.02-0.2	0.079	Addition

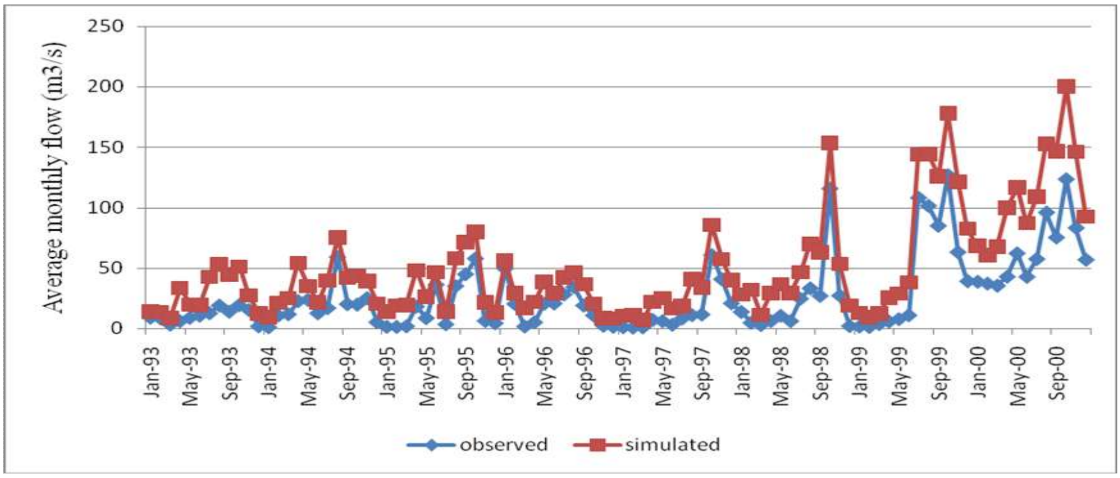

Figure .4.14. Hydrograph of observed and simulated monthly flow for the calibrationperiod(1993–2000) at the outlet of the subbasin 13, where Weyb gauging station is located.

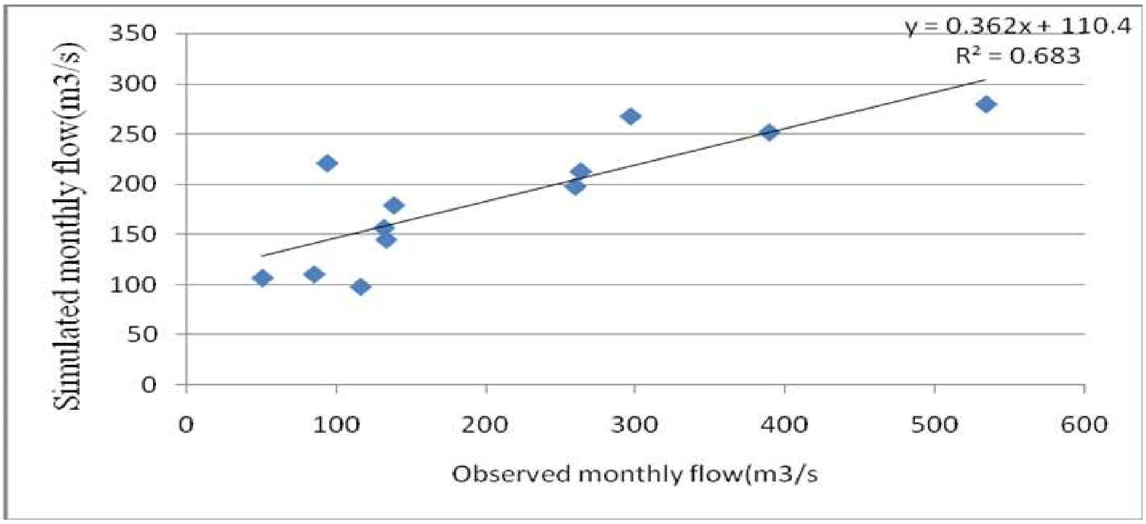

Figure. 4.15. Scatter plot of observed and simulated monthly flow for the calibration period.

4.4.2.2. Model validation

It was found that the model has strong predictive capability with r2, and ENS values of 0.58, and 0.57 , respectively. Statistical model efficiency criteria fulfilled the requirement of r^2> 0.6 and ENS > 0.5 which is recommended by SWAT developer (Santhi et al., 2001). This indicates that the model parameters represents the processes occurring in the Weyb watershed as good as possible given the quality of available data. It can be used to predict watershed response for various outputs.

The model validation results for monthly flow (Fig 4.15and 4.16) indicate generally a good fit between measured and simmulated output, and slight overestimation of the low flows and understimation of the peak flows were observed at the validation period which is better than calibration results. Since the model performed as well in the validation period, as for the calibration periob hence, the set of optimized parameters listed in table 4.4 during calibration proccess for Weyb watershed can be taken as the repesentative set of parameters for the Weyb watershed.

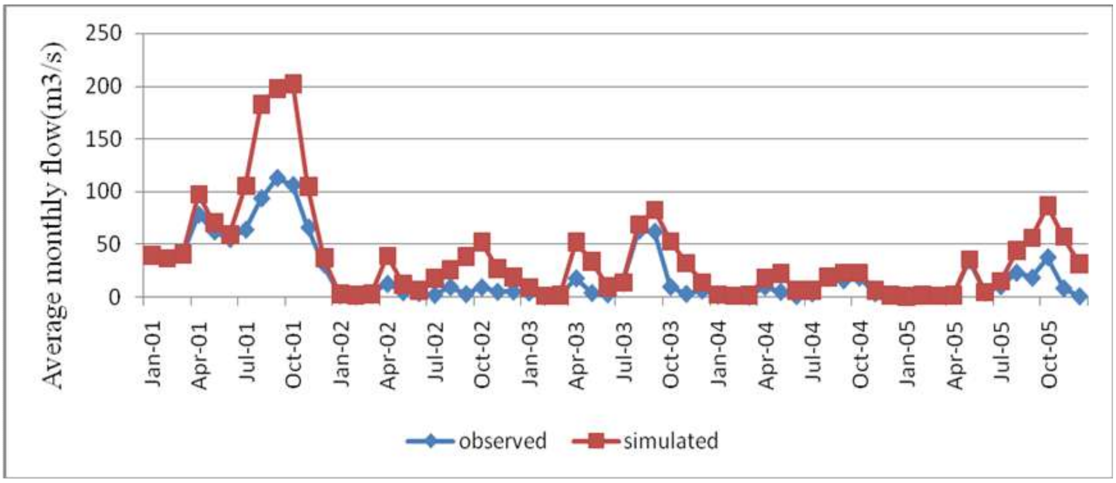

Figure.4.16.Hydrograph of the observed and simulated monthly flow for the validation period.

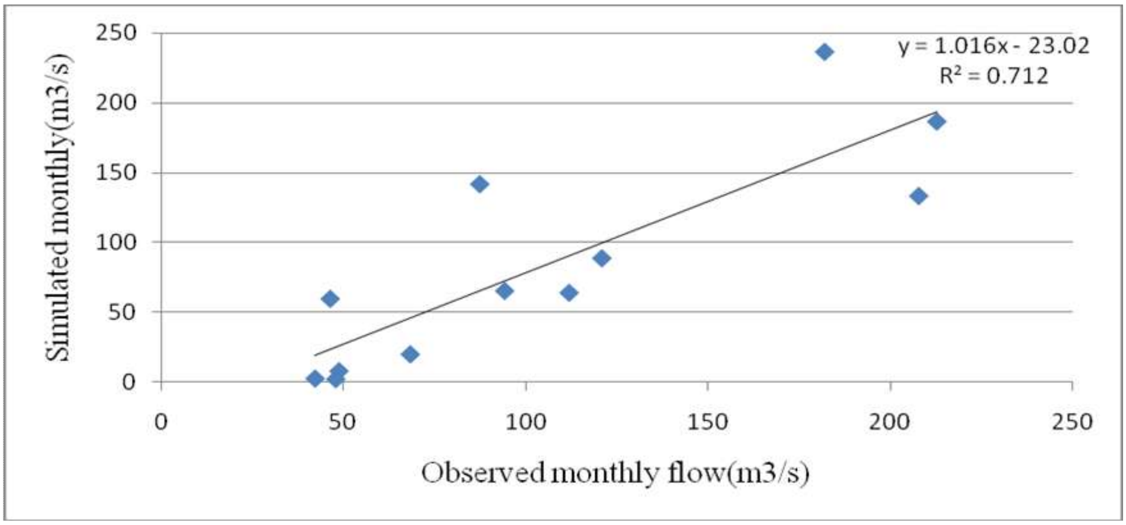

Figure .4.17. Scatter plot of observed and simulated monthly flow for the validation period.

There is some variation in statistical values among researchers, in this particular study too, this variation might be due to mainly spatial data used (predominantly land use land cover data),disparity in catchment sensitive parameters that affect calibration processes, uncertainty during data handling and due many more cases.

4.5. Water yield simulation

4.5.1. 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. Average annual basin values for different water balance components during a base simulation periods presented in Table 4.8 shows average annual watershed of the water balance components. From these components total water yield is the amount of streamflow leaving the outlet of watershed during the time step. The total water yield mathematically can be expressed as surface runoff plus lateral soil flow contribution to streamflow plus ground water contribution to streamflow minus water lost from tributary channels in the HRU via transmission through the bed. In a distributed model,it is possible to view the output as it varies across the watershed.

Table 4.8. Average annual water balances simulated for a base periods of 1993-2005.

Water balance components	Amount in(mm)
Precipitation; Precip	1006.80
Surface runoff ; Sur_Q	83.24
Lateral soil flow contribution; Lat_Q	13.56
Ground water contribution to streamflow; GW_Q	212.46
Revap or shallow aquifer recharges	20.56
Deep Aquifer Recharges	174.12
Total water yield; Twyld	309.03
Percolation out of soil; Perc	435.80
Actual evapotranspiration; ET	518.7
Potential evapotranspiration; PET	606.8

4.6. Climate change impacts on stream flow

Before attempting to simulate runoff for future scenarios at desired locations, the SWAT model was intended to be calibrated and validated using observed stream flow data at the catchment. Due to the variations in the projected precipitation and temperature in both space and time different hydrological impacts are likely caused by the climate change. The final objective of downscaling is to generate an estimate of meteorological variables corresponding to a given scenario of future climate. These meteorological variables are used as basis for hydrological impact assessment. Simulation of 1986–2005 period was used as a base period against which the change in future climate is evaluated. Daily precipitation and minimum and maximum temperature in SWAT are adjusted on monthly basis using results from the RCM for the future three periods of thirty years: 2020s (Near_term), 2050s (Mid_term), and 2080s (Far_term) for two scenarios. Historical or base period was then rerun with the adjusted climate inputs.Other climate variables as wind speed, solar radiation, and relative humidity were assumed to be constant throughout the future simulation periods. Simulated monthly stream flow for the future time horizons exhibited larger variation in some months relative to the baseline period but generally it shows a double peak mode due to the bimodal type of rainfall in the area. The analysis of future monthly stream flow indicated that there is a decreasing percent change for all the months except for from March to June for both RCP 4.5 and RCP 8.5 scenarios in near, intermediate and far future periods. In case of RCP4.5 a decrease on the months of Jan (in all the time slice), Feb (at the Near_term and Mid_term), Oct (at the Far_term), Nov (at the Far_term) and Dec (in all the time slice) and an increment on the rest of the months and future time slices was observed (Fig 4.17). The variance in monthly stream flow was insignificant on the month of Feb (at the Far_term time slice), Mar (at the Near_term), May (at the Far_term), and Nov (at the Near_term and Mid_term) in RCP4.5 scenario. In case of very high emission level (RCP8.5) there has been a decrease of stream flow on the months of Jan (at the Near_term and Mid_term) and Feb (at the Near_term and Mid_term time slice and Dec (in all the time slice) and an increase on the rest of the months and future time slices was observed (Fig 4.18). As compared to base period, the variance in monthly stream flow was very minor on the month of Jan (at the Far_term), Feb (at the Far_term), Mar (at the Near_term time slice), May (at the Far_term), Oct (at the Mid_term and Far-term) and Nov (in the Mid_term) in RCP8.5 scenario.

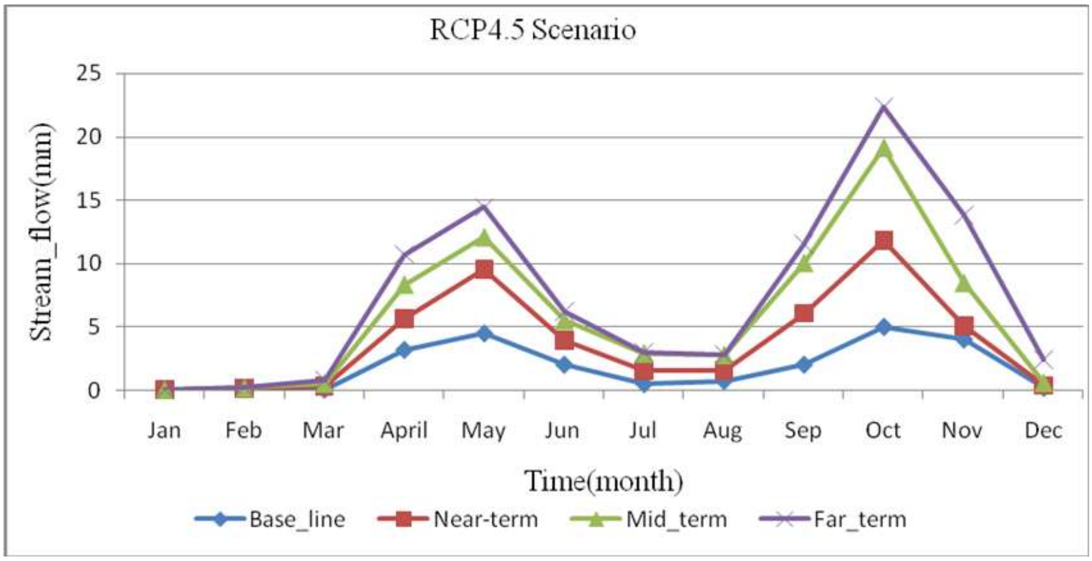

Figure.4.18: Mean monthly stream flow simulated for base-line and future climate for RCP 4.5 scenarios

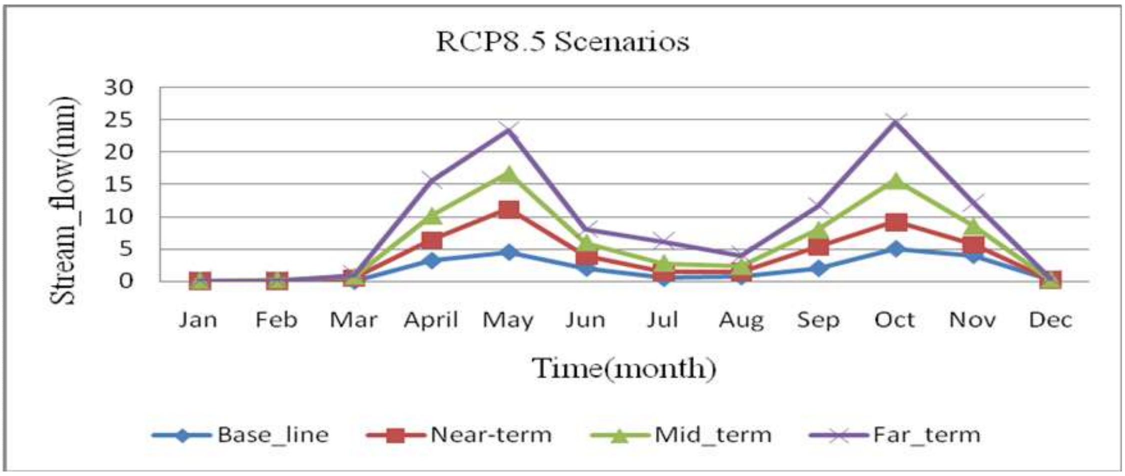

Figure.4. 19:Mean monthly runoff simulated for present and future climate for RCP 8.5 scenarios

4.6.1. Climate change impacts on monthly,seasonal and annual stream flow

As it has been observed from Table 4.8 below which shows the change of stream flow in percent for the three future time series (2010-2039),(2040-2069) and 2070-2099) with respect to the base period for both RCP 4.5 and RCP 8.5 scenarios. Table4.8 below revealed that the percentage change from base period on the months of Jan, Feb, Nov and Dec the generated total stream flow decreases pointedly for all the three time slice and RCP scenarios with exceptions in time slice of near_term on Oct and Far-term on Feb for both very high and an intermediate scenarios.

The months March as well as July might shows a biggest increase of total stream flow almost greater than 60% and 52% respectively for all time slice and for all RCP scenarios with exception of near_term time slice on the month of March for very high and an intermediate emission scenarios; future stream flow may also rise, mainly, on the month of Jun, Apr, Aug and Sep. The highest decrease of monthly mean daily stream flow might be observed on the month Jan by 38.69%, 51.71%, 51.26%, and 42.66%, 44.03%, 45.11% and 35.73%, 37.07%, 18.02% (on Dec) in the time slice of near, mid and fa_termr respectively for all RCP scenarios.

Table 4.9. Average monthly, seasonal and annual stream flow in the three future time horizon from the base period simulation under two RCP scenarios in percent (%)

Month	RCP 4.5			RCP 8.5		
	2020(%)	2050(%)	2080(%)	2020(%)	2050(%)	2080(%)
Jan	-42.66	-44.03	-45.11	-35.73	-37.07	-9.10
Feb	-53.22	-33.33	12.11	-51.95	-18.62	79.97
Mar	-13.44	60.23	143.32	-10.57	75.47	212.32
Apr	28.84	37.09	26.71	36.81	40.11	38.80
May	21.03	11.85	-4.82	28.05	17.44	5.08
Jun	15.32	43.06	76.36	23.64	55.62	110.54
Jul	54.24	63.48	66.79	59.98	68.83	77.06
Aug	28.96	27.56	24.50	31.79	27.76	28.11
Sep	16.32	26.66	37.97	15.92	26.35	49.56
Oct	16.15	5.91	-18.22	28.27	-0.26	-2.25
Nov	6.38	-7.50	-28.66	9.47	-14.94	-14.19
Dec	-30.19	-37.53	-46.18	-25.57	-33.78	-18.02
Dry season	-29.92	-30.60	-26.96	-25.94	-26.10	9.67
Intermediate	12.94	38.06	60.39	19.48	47.16	91.69
Wet season	28.92	30.90	27.76	33.99	30.67	38.12
Annual	3.98	12.79	20.40	9.18	17.24	24.49

Future seasonal average daily stream flow might be decrease in dry season(for example, in the month of Nov, Dec, Jan and Feb) by 0.15mm (29.92%), 0.19mm (30.60%), 0.22mm (26.96%) (RCP4.5) and 0.12mm (25.94%), 0.18mm (26.10%), 0.01mm (+9.67%) (RCP8.5) in near, mid and far_term respectively, but increase an intermediate season (Mar, Apr, May and Jun) by 0.25mm (12.94%), 0.49mm (38.06%), 0.63mm (60.39%) (RCP4.5) and 0.34mm (19.48%), 0.59mm (47.16%), 0.98mm (91.69%) (RCP8.5) in near, mid and far_term respectively as well as increase in wet seasons (Jul, Aug, Sept and Oct) by 0.63 mm (28.92%), 0.66mm (30.90%),0.57mm (27.76%) (RCP4.5) and 0.75mm (33.99%), 0.64mm (30.67%), 0.82mm (38.12%) (RCP8.5) in near, mid and far_term respectively as revealed in Fig 4.19, Fig 4.20, Fig 4.21,Fig 4.22 and Table 4.8, likewise the mean annual percentage change from base period of stream flow found to be increased by 3.98%, 12.79%, 20.40% (RCP4.5) and 9.18%, 17.24%, 24.49% (RCP8.5) in near, mid and far_term respectively. As we can see from the results above that there has been high monthly and seasonal variation of stream flow as compared to the annual variation for all the two RCP scenarios and upcoming time slices. However, the average annual stream flow possibly increased in the ranges 9.18-24.49% (RCP8.5), 3.98-20.40% (RCP4.5).The results also point out that the annual potential evapotranspiration has been revealed a decrease by 13.31% (RCP8.5), 14.48% (RCP4.5).

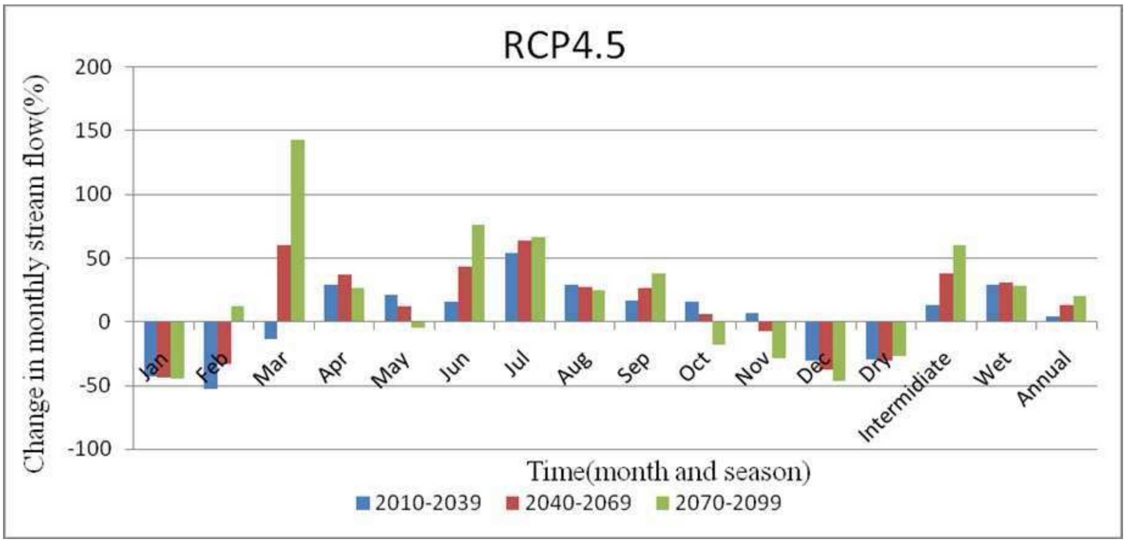

Figure4. 20: monthly and seasonal stream flow percentage change from the baseline for RCP 4.5 scenario

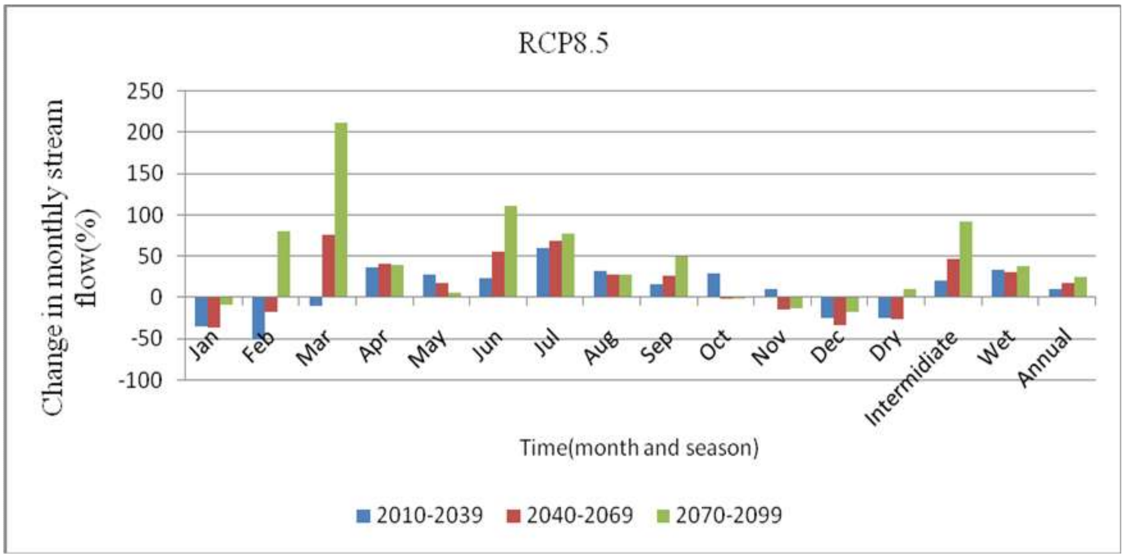

Figure.4. 21: Monthly and seasonal stream flow percentage change from the baseline for RCP 8.5 scenario

There was good relationship between runoff change and precipitation change. There were some exceptional months, which showed increased stream flow while the precipitation decreased, and vice versa or the other way round due to the hydrological response of the catchment.

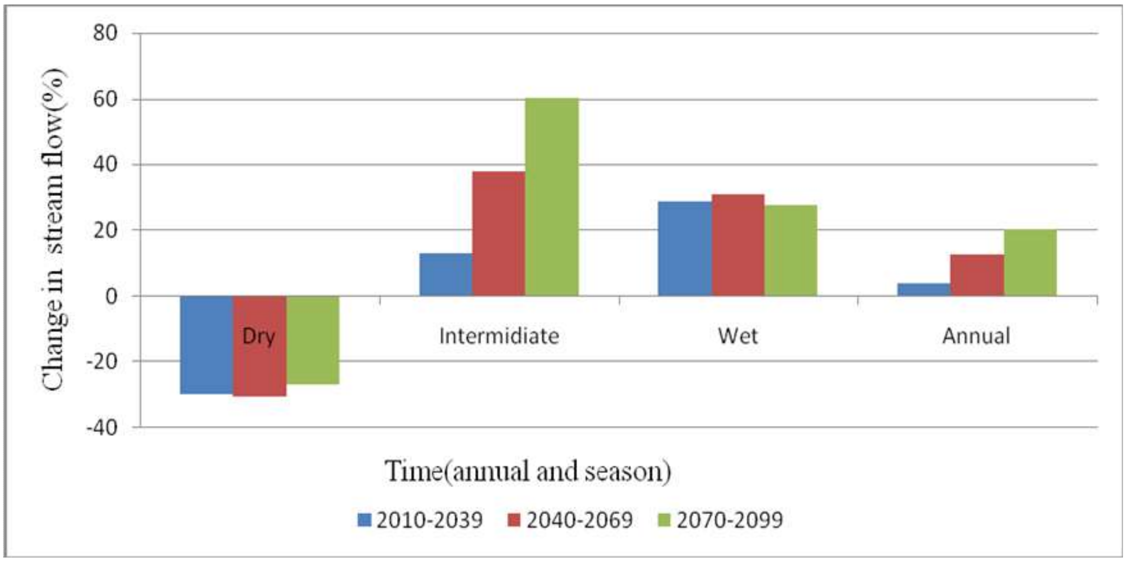

Figure.4. 22: Seasonal and annual percentage change stream flow relative to the baseline for the three time slices of RCP 4.5

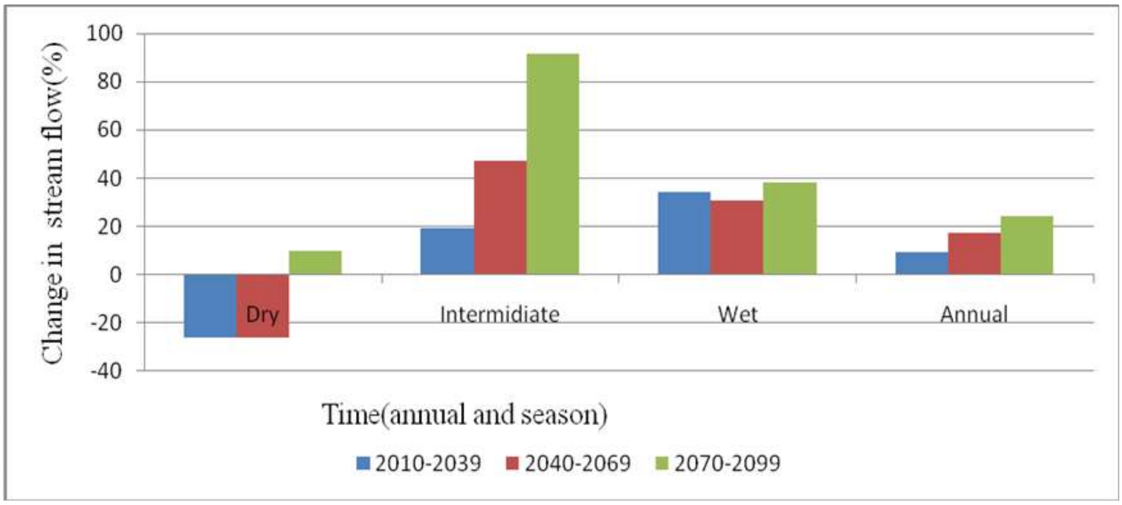

Figure.4.23: Seasonal and annual percentage change stream flow relative to the baseline for the three time slices of RCP 8.5

It has been discussed in Faramarzi et al. (2013), Setegn et al. (2011) that stream flow is sensitive to rainfall variability and this is in agreement with our study increase in rainfall results stream flow to increase. Accurate for this findings too where an increase of annual rainfall (Fig.4.21 and 4.22) in upcoming period tends in the direction of rising annual stream flow; the reason, probably, is that the annual potential evapotranspiration (PET) tends to decreases in all the two scenarios.

As far as future projection in this study in general, the decrement of stream flow in all months on the dry season might cause water shortage mainly in the lowland region, and greater increment of water availabilityin intermediate and rainy seasons might cause flooding to some flood prone region of the study area.

So,variability of stream flow which will result from climate change in the watershed affects the livelihood of people in the upper part of the watershed and also all inhabitants at the far downstream areas in Somalia whose life depends on the flow of Weyb River. Therefore, in order to alleviate these challenges (draught in some region and flooding in other corner) sustainable-integrated water resources management approach is paramount important.

5. CONCLUSION AND RECOMMENDATION

The conclusion and recommendation of the study is presented in this section.

Issues of the potential impacts of climate change remain a threat in future development activities especially in developing countries like Ethiopia. Hence it is important to assess the impact of climate change on hydrology of Weyb watershed. In this study, hydrological impacts of climate change on Weyb watershed were evaluated in response to the RCP 4.5 and RCP 8.5 scenarios. Variance scaling and power transformation bias correction methods was used to improve the simulation output of RCA4 regional climate model with high correlation to the observed data.

Hydrological model (SWAT) was used to simulate runoff. Hydrological impact of climate change between baseline period and future time windows was investigated using two climate scenarios. Based on the result of these two scenarios (i.e. RCP 4.5 and RCP 8.5) conclusion and recommendation of this study are presented as follows.

5.1 Conclusions

The projected maximum and minimum temperature shows an increasing pattern for all future time horizons for both RCP 4.5 and RCP 8.5 scenarios, but precipitation shows variable change all future time horizons for both RCP 4.5 and RCP 8.5 scenarios. Most of the projected maximum and minimum temperatures are within the limits of the expected projection carried by the latest Inter Governmental Panel on Climate Change (IPCC) (2014).The average annual maximum temperature will be increase in (2010-2039) by 1.2°C and 1.3°C,in (2040-2069) by 1.1°C and 1.4°C in (2070-2099) by1.4°C and 0.2°C for RCP 4.5 and RCP 8.5 scenario respectively. The average annual minimum temperatures will also increase in (2010-2039) by 1.5°C and 0.7°C, in (2040-2069) 0.1°C and 0.6°C in(2070-2099) by 0.1 °C and 0.7 °C for RCP 4.5 and RCP 8.5 scenario, respectively.

The projected areal precipitation experiences a mean annual increase for all the three time horizons (i.e. 2010-2039,2040-2069 and 2070-2099) for both RCP 4.5 and RCP 8.5 scenario. In the future annual precipitation is expected to increase by 0.9% 0.89% and 0.87% at (2010-2039), (2040-2069) and (2070-2099) respectively under the RCP 4.5 scenario. For the RCP 8.5 scenario is expected to increase by 0.86% ,0.84and 0.89% respectively for the (2010-2039), (2040-2069) and (2070-2099) when compared to the base line period.

The SWAT model is calibrated and validated on stream flow observed at the Sof_umer gauging station during the 1993-2005 base-line period. The model performance is evaluated using the Nash-Sutcliffe model Efficiency (NSE), and the coefficient of differentation (R^2). The statistics indicate that for calibration NSE,and R^2 are 0.50, and0.60, and for validation are NSE,and R^2 0.58 and 0.57, respectively. These values indicate that a good adjustment of the modeled to the observed stream flow for both calibration and validation period is achieved.

Climate change impact on stream flow of Weyb River was analyzed on a monthly, seasonal and annual basis. The stream flow is expected to change according to temperature and precipitation changes. The coming decades may thus bring less runoff (indicated by the simulated 3.98% , 12.79% and 20.4% increase in mean annual runoff in the 2010-2039, 2040-2069 and 2070-2099 time horizon respectively) for RCP 4.5 scenario. For the RCP 8.5 scenario is expected to increase by 9.81% ,17.24and 24.49% respectively for the (2010-2039), (2040-2069) and (2070-2099) when compared to the base line period.

The Mann-Kendal trend test of downscaled precipitation shows significant increasing trend for RCP4.5 scenario; however, the trend was decreasing for RCP8.5 scenario. An increase of rainfall comparatively is higher in the intermidiate and wet season which could have positive impact on the study area. The main rainy season (wet) and intermediate rainy season indicate a increasing trend; on the other hand, the dry season showed an dicreasing trend. The mean seasonal streamflow might dicrease in dry season and increase in intermediate and wet seasons. The streamflow was found to be sensitive to the rainfall variability as a result the dicrease in rainfall at the dry season has resulted to an dicrease of streamflow at the same season and it has revealed increase of streamflow on the wet and intermediate seasons. Generally, there will be high seasonal and monthly variation of streamflow than on the annual basis. The change in the amount and distribution of rainfall and temperature would affect agricultural productivity and water utilizations in the study area.

These changes will certainly have implications on the social-economic development over the area, and will also impact on the flow of downstream. A significant conclusion from the study is that changes in precipitation have larger effects on stream flow of the watershed which need crucial integrated management activities.

5.2. Recommendations

- Flow data needed to properly model hydrological processes in the watershed are limited and the accuracy is not satisfactory. Hence, installing more and reliable flow gauging stations in the watershed will improve data availability and close monitoring of the data quality should also be given suitable importance to improve the water resources assessment in the future.
- The result of this study is based on one RCMs and two Representative Concentration Pathways (RCPs) were selected from 20 possible RCM from the fifth phase of the Coupled Model Inter comparison Project (CMIP5) downscaled over the Africa-CORDEX domain. However, it is often

recommended to apply different RCMs and Representative Concentration Pathways (RCPs) so as to make comparison between different models as well as to investigate a wide range of climate change scenarios that would result in different hydrological impacts. Hence this work should be extended in the future by including different RCMs and Representative Concentration Pathways.

- The model simulations considered only future climate change scenarios assuming all other things constant. However, in addition to fluctuations on temperature and precipitation, deforestation and population growth are among current trends over the watershed. Therefore, it is better to see the impacts of climate and land use changes over the Weyb watershed. Based on this finding, there is a concern that hydrological impact of climate change analysis using single hydrological model may lead to unreliable conclusion. In this regard, conducting multi model analysis is one way to reduce such uncertainty.

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7. APPENDICES

APPENDIX A: Definition of some important words

Forecast/ Projection: When a projection is designated "most likely" it becomes a forecast or prediction. A forecast is often obtained using physically- based models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Scenario: A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario but scenarios often require additional information (e.g. about the baseline or base year conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in the projection. Other terms that have been used as synonyms for scenario are "characterization", "storyline" and "construction".

Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.

Emission Scenario: projections of a potential future, based on a clear logic and a quantified storyline.

Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

Reference Scenario: is the type of scenario which is created from the current accounts year to show the behavior of the model output without intervention.

PcpSTAT: is a computer program that calculates statistical parameters of daily precipitation data used by the weather generator of the ArcSWAT model.

DewPOINT: is also computer program designed to calculate the average daily dew point temperature per month using daily air temperature and relative humidity data used by the weather generator of the ArcSWAT model.

APPENDIX B: Statistical analysis of daily precipitation data output of PcpSTAT and dew02 (1986 – 2005) of Robe for ArcSWAT Weather generator input Statistical Analysis of Daily Precipitation Data (1986 - 2005).

Input Filename = Roberainfall.txt
Number of Years = 20,
Number of Leap Years = 5,
Number of Records = 7305
Number of No Data values = 0

Table B-1. PCPstat output for arcswat Weather generator input statistical analysis of daily precipitation data (1986 - 2005)

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	20.94	2.9912	6.5672	0.0718	0.4675	3.85
Feb.	22.41	3.0038	5.6135	0.0877	0.5000	4.30
Mar.	61.43	4.7239	3.4920	0.2109	0.5991	10.85
Apr.	122.31	7.0848	2.7086	0.4093	0.6657	17.05
May.	74.07	4.7387	3.5931	0.3454	0.6456	15.80
Jun.	56.08	3.8780	3.3370	0.3433	0.5321	13.25
Jul.	92.87	6.4151	4.1726	0.4247	0.5857	16.05
Aug.	127.96	9.1511	5.8938	0.4933	0.6911	19.75
Sep.	110.04	5.4983	2.5797	0.4688	0.7475	20.40
Oct.	81.12	4.8253	3.3689	0.2591	0.7147	15.95
Nov.	32.60	3.6972	5.4680	0.1113	0.5161	6.20
Dec.	18.33	2.7555	7.8522	0.0778	0.4500	4.00

PCP_MM = average monthly precipitation [mm]
PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of a wet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

(written by Stefan Liersch, Berlin, August 2003)

This file has been generated by the program 'dew02.exe'

Input Filename = dew02.txt

Number of Years = 20.

Number of Records = 7305

Number of No Data Values

tmp_max = 0

tmp_min = 0

hmd = 2

Table B-2. Average daily Dew point temperature for period (1986 - 2005) output for arcswat weather generator input weather generator input

Month	tmp_max	tmp_min	hmd	dewpt
Jan	22.64	6	58.03	7.51
Feb	23.56	6.86	53.31	6.89
Mar	23.2	8.27	59.78	8.86
Apr	21.72	9.59	69.53	10.79
May	22.14	9.39	67.49	10.61
Jun	22.65	9	65.93	10.47
Jul	21.91	9	71.5	11.27
Aug	21.37	8.87	73.85	11.42
Sep	20.92	8.83	73.6	11.05
Oct	19.72	8.58	74.28	10.32
Nov	20.53	6.48	66.9	8.56
Dec	21.64	5.92	60.33	7.47

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]

dewpt = average daily dew point temperature in month [°C]

(written by Stefan Liersch, August, 2003)