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Evaluating the Potential Impact of Climate Change on the Hydrology of Ribb Catchment, Blue Nile Basin, Ethiopia

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ABSTRACT

Varies scientific findings indicate there is climate change which affects a given hydrology and, hence, water availability. To quantify its impact on the specific catchment scale since spatial and temporal variability of climate change impact, this study was carried out at Ribb catchment, Blue Nile Basin Ethiopia. Bias corrected Regional Climate Model (RCM) projection data set for Nile Basin studies at Representative Concentration Pathway (RCPs) (RCP4.5 and RCP8.5) were used for trend analysis and future stream flow generation. It were analyzed for three time horizons on 2020s (2011-2040), 2050s (2041-2070), 2080s (2071-2098). A baseline period (1976-2005) was used as a reference. Trends of future temperature and precipitation change were checked by Mann-Kendall trend test. SWAT was calibrated (R^2=0.83 and NSE=0.74) and validated (R^2=0.72 and NSE=0.71). Mean annual minimum temperature is found to increase by 2.45 ^{0}c at RCP4.5 and 4.64 ^{0}c at RCP8.5 scenarios and maximum temperature could increase by 2.41 ^{0}c and 5.15 ^{0}c at RCP4.5 and RCP8.5 scenarios, respectively, on 2080s. Mean monthly maximum and minimum temperature also showed increasing trend. The highest increase in maximum temperature was found in July whereas the maximum increase in minimum temperature in January. Average monthly and annual precipitation changes vary in magnitude but consistent trend was not found. As a result, mean annual stream flow could potentially reduce from 42.78m^3/s to 40.24m^3/s and from 42.78m^3/s to 37.58m^3/s on RCP4.5 and RCP8.5 scenarios, respectively, on 2080s. On monthly time scale, decreases in stream flow were found from March to August whereas slight increase from September to February. With respect to individual months, June flows were found to have maximum impact in both scenarios (63.3% at RCP8.5 and 55.45% at RCP4.5 scenarios). The least impacted month was August based on RCP8.5 scenario which is decreased by 6.64 % and April based on RCP4.5 scenario which is reduced by 1.21%. Looking at total volume, July showed a maximum decrease on both scenarios which is reduced by 21.08 m^3/s at RCP4.5 scenario and 51.22 m^3/s at RCP8.5 scenario. Maximum increase found in October with 10.31m^3/s and 11.26m^3/s at RCP4.5 and RCP8.5 scenarios respectively. Besides, a potential decrease at seasonal stream flow was shown in summer and spring whereas may increase slight during autumn and winter. Future stream flow of Ribb River is decreased annually and monthly since increased on future temperature and reduced of rainfall.

Keywords: SWAT, Scenarios, RCP, Climate change, Bias correction

Résumé

Les résultats scientifiques varient selon les changements climatiques qui affectent une hydrologie donnée et, par conséquent, la disponibilité de l'eau. Pour quantifier son impact sur l'échelle spécifique du bassin versant depuis la variabilité spatiale et temporelle de l'impact du changement climatique, cette étude a été réalisée dans le bassin versant de Ribb, dans le bassin du Nil Bleu en Éthiopie. Les données de projection du modèle climatique régional (MCR) corrigées en fonction des biais pour les études du bassin du Nil conduites sur un sentier de concentration représentatif (RCP) (RCP4.5 et RCP8.5) ont été utilisées pour l'analyse des tendances et la génération future des flux de cours d'eau. Il a été analysé sur trois horizons temporels différents des années 2020 (2011-2040), 2050 (2041-2070) et 2080 (2071-2098). Une période de référence (1976-2005) a été utilisée comme référence. Les tendances des variations futures de la température et des précipitations ont été vérifiées par le test de tendance de Mann-Kendall. SWAT a été calibré (R^2 = 0,83 et NSE = 0,74) et validé (R^2 = 0,72 et NSE = 0,71). On a constaté que la température minimale annuelle moyenne augmentait de 2,45 ^{0}c à RCP4,5 et de 4,64 ^{0}c à des scénarios RCP8.5 et que la température maximale pourrait augmenter de 2,41 ^{0}c et à 5,15 ^{0}c à des scénarios RCP4.5 et RCP8.5, respectivement, à 2080 °c. Les températures maximales et minimales mensuelles moyennes ont également montré une tendance à la hausse. La plus forte augmentation de la température maximale a été constatée en juillet alors que la hausse maximale de la température minimale a été constatée en janvier. Les variations mensuelles et annuelles moyennes des précipitations varient en ampleur, mais aucune tendance constante n'a été trouvée. En conséquence, le débit annuel moyen pourrait potentiellement passer de 42,78 m^3/s à 40,24 m^3/s et de 42,78 m^3/s à 37,58 m3 / s dans les scénarios RCP4.5 et RCP8.5, respectivement, à 2080 °c. Sur une période de temps mensuelle, les débits ont diminué de mars à août, alors qu'ils ont légèrement augmenté de septembre à février. En ce qui concerne chaque mois, les flux de juin ont eu un impact maximal dans les deux scénarios (63,3% à RCP8,5 et 55,45% à RCP4,5). Le mois le moins touché a été août sur la base du scénario RCP8.5 qui a été réduit de 6,64% et celui d'avril sur la base du scénario RCP4.5 à 1,21%. En ce qui concerne le volume total, le mois de juillet a montré une diminution maximale dans les deux scénarios, qui a été réduite de 21,08 m^3/s avec le scénario RCP4.5 et de 51,22 m^3/s avec le scénario RCP8.5. Augmentation maximale constatée en octobre avec 10,31 m^3/s et 11,26 m^3/s avec les scénarios RCP4.5 et RCP8.5 respectivement. En outre, une diminution potentielle du débit saisonnier a été observée en été et au printemps, alors qu'elle pourrait augmenter légèrement en automne et en hiver. Le débit futur de la rivière Ribb est diminué chaque année et tous les mois car il a augmenté la température future et réduit les précipitations.

Mots-clés: SWAT, scénarios, RCP, changement climatique, correction du biais

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ACRONYM

AOGCM………………Atmosphere-ocean General Circulation Model

AR5…………………….Assessment Report

CMIP5………………….Coupled Model Intercomparison Project Phase 5

CORDEX……………….Coordinated Regional Climate Downscaling Experiment

GCM…………………...General Circulation Model

HRUS………………….Hydrological Response Units

IPCC……………………Intergovernmental Panel on Climate change

RCPs……………………Representative Concentration Pathways

SWAT…………………..Soil and Water Analysis Tool

SWATCN…………… Soil And Water Analysis Tool_ curve Number

SWAT-CUP……………SWAT-Calibration and Uncertainty program

WMO………………….World Metrological Organization

MOWE………………..Ministry of Water and Energy

ABBREVIATION

ALPHA_BNK…………...…Base flow alpha factor for bank storage

CANMX……………………Maximum canopy storage

CN2………………………...Initial SCS CN II value

BIOMIX……………………Efficiency of soil biological mix

ESCO……….…………..Soil evaporation compensation factor

REVAPMN………………..Threshold water depth in the shallow aquifer for “revap”

RCHRG_DP……………......Deep aquifer percolation fraction

GW DELAY……………….Ground water delay

GWQMN…………………..Threshold water depth in the shallow aquifer for flow

GW_REVAP………………Ground water “revap” coefficient

SOL_AWC………………....Available water capacity

CHAPTER 1: INTRODUCTION

1.1. Background

Changing of climate refers to an alteration in climate states or variables due to different interior or exterior factors which is recognized in variability of its behaviors at average level. Some of external factors include change in solar energy and vulcanization which happen naturally that contributes for change of climate. However, Human beings are the leading factor to influence nature and contribute to climate change (IPCC, 2007).

Surface and ground water resources in regional and global scale are affected by climate change (Xu and Singh, 2004). Increased in temperature and precipitation changes can alter regional water balances and hydrological regimes (Poitras et al., 2011 and Bolch et al., 2012). Due to its severity at regional and international level, climate change issue becomes a priority field of studies to find out best solutions which can alleviate current situation (Lettenmaier et al., 1999 and Fowler et al., 2007).

Temperature of the earth surface is dependent on the incoming and reflected solar radiation. The incoming radiation passes through atmosphere and heats earth surface. Emitted radiation form earth surface absorbed by some gases form atmosphere and re-emitted downwards and warms the lower parts of atmosphere. The important function of atmosphere is being endangered by speedily increasing concentrations of greenhouse gases above the natural level while also new greenhouse gases. This will add further warming which could threaten sustainability of the Earth (Jenkins, 2005).

Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, AR5) showed world mean surface temperature warmed by 0.85^0C from 1880 to 2012. The beginning of 21^{st} century has been the warmest on record (IPCC, 2013). This increase of world temperature leads higher evapotranspiration which causes to alter global precipitation situation (Paparrizos et al., 2016 and Urrutia and Vuille, 2009). Rise of temperature also affects the occurrence, property, distribution and movement of water resources and causes higher occurrence or frequency of hydrological events such as floods and droughts in catchment and basin level.

Global climate changes impact over in future by increasing of temperature and variability of rainfall also studied by Trenberth et al., (2003); Alexander et al., (2006); Kharin et al., (2013) and Van Vuuren et al., (2011). They showed the occurrence of climate change through used Representative concentration pathways (RCPs) scenarios, which are current scenarios used for the IPCC AR5, for future climate change projection based on the Coupled Model Intercomparison project (CMIP5).

Climate change impact is becoming a serious issue in our continent, Africa. IPCC reports showed increasing trend of temperature and decreasing of rainfall in most parts of Africa. It indicated African countries are highly affected by climate change due to over dependency on agriculture which is highly susceptible for climate change. Africa is one of the most vulnerable regions to weather and climate variability (IPCC, 2007). Shongwe et al., (2010) studied the projected climate change in mean and extreme precipitation in Africa.

Ethiopia is one of the East African Countries and evidently showed climate change; it becomes a great issue. Variability of rainfall pattern and increase of temperature were verified by researchers at the Blue Nile basin level (Abdo, 2008; Zerihun, 2009; Nile, 2016 and Gebremariame, 2009).

Blue Nile/Abbay Basin is one of the largest basin in Ethiopia with high population pressure, degradation of land and highly dependent on agricultural economy (Tsegay, 2006). Increase in population growth, economic development and climate change have been proven by IPCC, (2007) to cause rise in water demand, necessity of improving flood protection system and drought. Lake Tana sub-basin is the main sources for Blue Nile River and there water resources are an important input for different water development projects and livelihood support of the people in the basin. Ribb catchment is the selected catchment in Lake Tana sub-basin in which currently, multipurpose water resources development projects are proposed and constructed. So it is critical to determine hydrological responses to climate change for sustainability of projects and looking for possible mitigation measures.

Research works were done at Lake Tana, sub-basin level but it is inadequate in spite of supporting large population and target area for flow to Blue Nile River. This study is therefore aimed to evaluating the potential impacts of climate change on the hydrology of Ribb catchment through simulation the stream flow of different time horizons using temperature and precipitation data by SWAT model. Bias corrected RCM temperature and precipitation data set for Nile basin studies was used for model input.

1.2. Statement of Problem

Climate change has a diverse effect on the socioeconomics of Ethiopia and its effect will continue if proper mitigation and adaptation measures are not in place. It is because the economy of the country is dependent on agriculture which is sensitive for climate change. Similarly, many parts are arid and semiarid which are susceptible to desertification and drought. The national meteorological statistics Agency report (NMSA, 2001) marked the climate change is serious issue for Ethiopia which needs special attention.

IPCC reports, the main evidences for climate change impacts, showed climate change is a serious issue in Africa. However, these reports were provided on large scale perspective (Africa). The extents of temperature and precipitation changes vary spatially and temporally (Aerts and Droogers, 2004). Therefore, it is important to look impacts at small scale i.e national and catchment level.

The previous scientific studies conducted at Blue Nile basin and Lake Tana sub-basin level were mainly used global climate models (GCMs) data of third phase of Coupled Model Intercomparison Project (CMIP3) downscaled to local level. These Regional Climate Models used for impact assessment were based on Special Report on Emission Scenarios (SRES) of A2 and B2. Currently, Representative Concentration Pathways (RCPs) are used for impact assessment. Using of these RCPS scenario showed a better agreement with observed climate data (Fikadu et al., 2018).

Likewise, estimating future stream flow using projected changes of local scale climate variables is necessary to properly plan for future climate conditions impact adoption. Planning for sustainable utilization of water resources based on climate change impact assessment is critical for Ethiopia since dependent on agriculture which is highly vulnerable for climate change. In spite of the implication and significance of Lake Tana, its basin for continues settlement of the people, only little is done in planning for future climate change impact assessment at Lake Tana basin (Gebremariam, 2009).

Moreover, Ribb River is among the main tributaries of Lake Tana, the origin of the Blue Nile. Many African countries that are downstream could potentially be impacted with changes in Ribb River flow. But, effects of climate change in water resource analysis and management at Lake Tana basin has not been adequately addressed (Setegn et al., 2011). To fill the aforementioned gaps with scientific solutions and studies, understanding climate change impact on hydrology is vital for developing sustainable mitigation measures. Therefore, this master thesis aimed at evaluating the potential impact of climate change on the hydrology of Ribb catchment and understands its implication for water resources management.

1.3. Research Objectives

1.3.1. Main Objective:

The main objective this thesis work was evaluating the potential hydrological impact of climate change on Ribb River catchment, Blue Nile Basin, Ethiopia.

1.3.2. Specific Objectives

1. Representing catchment hydrology through calibration and validation of Soil and Water Assessment Tool (SWAT).
2. Bias correction of Regional Climate Model (RCM) data with RCP scenarios to catchment level stations.
3. Evaluate future trend of temperature and precipitation using bias corrected RCP4.5 and RCP8.5 scenarios data.
4. Quantifying the potential impact of climate change on future stream flow relative to the present situation.

1.4. Research Questions

a. How much SWAT model could accurately simulate stream flow to see future climate change impact?
b. How much the bias correction method is downscale RCM data to the station level observed data?
c. What is the general future trends of maximum, minimum temperature and precipitation variations one could expect compared to present situation?

d. How temperature and precipitation change reflect on stream flow of Ribb River in future?

1.5. Research Hypothesis

- The Soil and Water Assessment Tool (SWAT) model able to simulate the stream flow of the river effectively.
- Bias correction method matched observed and model projection data with the acceptable level.
- Maximum and minimum temperature shows an increasing but decreasing trend of precipitation in future.
- Stream flow of the River could decrease and/or exhibit shift in seasonality due to changes in temperature and precipitation.

1.6. Significant of the Study

Planning and implementation of projects for a sustainable water use depends on understanding potential changes in future flows. Projects implemented without such type of study have a high probability of failure. Water resources project planning and implementation in Ethiopia at much local level may not consider such factors. Effective use of water resources is the main option to have food security in developing countries like Ethiopia. Therefore, this study is helpful in providing insight on trends of climate variables change in Ribb catchment and their potential effects on stream flow of the river. Generally, this thesis work has the following significances.

- Contributes to the body of knowledge in understanding impact of climate changes in future and its implication on Ribb River flow.
- Provides information that could be useful for institutions and local governments for the implementation of projects and integrated water resource management activities.
- It will used as a stepping stone for other researchers and scientists to carry out further studies.
- Provides application methodology to other readers in using climate change data, models, as well as hydrological models.

1.7. Thesis layout

This thesis work contains five chapters. Chapter one is an introduction which provides background of study on general overview of climate change; statement of problem, which states about gaps existing literature that motivated this work; main and specific objectives, scope and significant of the study. Chapter two is literature review. It covers overview and evidences of climate change in the world, Africa, Ethiopia and specifically in the study area; overview on hydrological models mainly SWAT and its applicability in the world in general to the study area in specific and lastly the GCM and CORDEX Africa RCMs data. Chapter three goes through the methodology which has area description, methods and materials used. Under area description location, land use and land cover, soil type, elevation, and information about meteorological and gauge stations, climatic condition of study area and stream flow information are covered. Overall procedures followed for this study; data availability, use, quality checking are included on method part. Chapter four presents result and discussion which contains data quality test results; SWAT modeling; bias correction and accuracy checking; trend analysis of climate variables and assessing of climate change impact on stream flow. Chapter five provides conclusion and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

2.1. An Overview about Climate Change

Average global temperature has risen by about 0.74 ^{0}C between 1906 and 2005. This climate change has happened in two phases, which was from 1910s to 1940s and more strongly from the 1970s to the 2005 (IPCC, 2007).

2.2. Evidences for Climate Change

The main evidence which indicates the presence of global climate change in past, present and future is IPCC reports provided in different time periods. These reports depend on the findings of scientists working on it based on tangible evidences.

IPCC reports had been providing valuable information starting from First Assessment Report (FAR IPCC, 1990) to current Fifth Assessment Report (AR5 IPCC, 2013). Most reports were used their own scenarios, which are different to each other and/or are slightly similar a, for future climate change. However, all the reports have the same final destination, which is there was climate change in past, there is climate change currently and there will climate change in future.

All previous reports marked change of climate variables which contributes to climate change. Concentration of Co_2 in the atmosphere would double in 2100 and average temperature will also increase between 1.4 to 5.8 ^{0}c on the same year. Due to risen in temperature, snow melt would be significantly accelerated which would contribute the rise of sea level and changing rainfall pattern up to 20%. Observations on past centuries showed changes are occurring in the different amount, intensity, frequency and types of precipitation (IPCC, 2007).

Previous IPPC projections on climate change variables such as Co_2 concentration, global average temperature and sea level rise is well fitted as expected. However, projections on increase of CH_4 and N_2o concentrations are not on the right ranges of projection, which is smaller than the expected/projected one (IPCC, 2013).

The presences of future climate change at global scale also confirmed by different scientists and researchers. This climate change is expressed mainly by variability of rainfall and continued increment of temperature (Trenberth et al., 2003; Alexander et al., 2006 and Kharin et al., 2013). Average temperature is projected to increases over 1^0c under a low-emission scenario (RCP2.6) and over 4^0c on extreme scenario (RCP8.5) (Knutti and Sedlacek, 2013).

2.3. Impact of Climate Change on Hydrology and Water Resources

Higher concentration of Greenhouse gases in atmosphere causes increase of both minimum and maximum temperature and variability of rainfall distribution and amount (Houghton et al., 2001).Water cycle components such as precipitation and runoff; timely and spatial distribution of water and quantities are affected by climate change.

Third IPCC report (IPCC, 2001) showed global warming affects water availability. Changing of climate variables mainly temperature and precipitation are indicators of climate change. An increase of temperature leads increase of evaporation which causes water imbalance between surface and atmosphere. Changing in precipitation has negative impact on surface hydrology and water resources. Change in temperature and precipitation also causes for the occurrence of flooding and droughts also affect the hydrology and water resources of a region. Climate change impact therefore affects discharge of rivers. Among many influences affecting stream flow, the weather parameters especially precipitation is the main factor.

Climate change impact on water resources and hydrology can also manifest through increased temperature and precipitation changes which can alter regional water balances and hydrological regimes (Poitras et al., 2011 and Bolch et al., 2012).

2.4. Previous and Projected Future Climate Changes in Ethiopia

2.4.1. Historical Climate Change

Ethiopian National Meteorological Services Agencies (NMSA) conducted studies through used 42 meteorological stations across the country and showed the country had both dry and wet years over the past 50 years (NMSA, 2001). Climate change trends are spatial. Trend analysis on annual rainfall of the country showed reduced tend in northern and southern parts and increasing trend in central parts of the country which indicates rainfall trend are not uniform across the country.

Similarly, NMSA study showed there are changes of very warm and very cold seasons and years. However, general trend showed there is an increase in both minimum and maximum temperature over the last 50 years.

2.4.2. Future Climate Change Projection

Researchers and scientists projected future climate change of Ethiopia in addition to the generalized IPCC reports for Africa. Conway and Schipper, (2011) reported future climate change using medium to high SRES emission scenario of annual warming across Ethiopia could be 0.7 to 2.3 ^{0}c and 1.4 to 2.9 ^{0}c in 2020s and 2050s respectively. The potential future climate change shown variability of rainfall and increase in temperature at Lake Tana basin level (Abdo, 2008; Zerhun, 2009; Nile, 2016; and Gebremariam, 2009).

IPCC report indicates climatic conditions of East Africa in future could get noticeably warm. By taking average results of the whole climate models, since different results in each model, shows temperature increases by about 4^{0}c at the end of the 21$_{st}$ century. Individual model projection showed temperature increase exceeding 6^{0}c by the same period. However, future projections of precipitation don’t shown consistent trend. It is more complex to state and conclude either it will increase or decreases (IPCC, 2013).

2.5. Climatological Baseline

For projection about future climate change impacts requires a baseline data. This information has to be a measurable report of changes. The first stage of future climate change projection is needed to have starting point information about historical climate change of the region which is referred to as climatological baseline. Baseline information of climate change needed to define observed climate with climate change information on the region helps us to create a climatic scenario. It is used as a reference period to scenario construction and from which future climate change model is calculated (Houghton, 2001).

Selection of baseline period is not random, it is dependent on a specific criteria. Based on (Carter, 2007) findings criteria for selecting baseline period are listed below.

- Ability to represent for present day and recent average climate in the region in which the study is conducted.
- Adequate duration to comprise ranges of climatic variations and weather conditions.
- High quality data for accurate future projection.
- Covering a period for which data on all climatological variables available adequately distributed over space and readily available

2.6. Global Climate Models (GCM)

The interaction of complex processes on earth and atmospheric system leads climate change worldwide over time. This complexity challenges to make a simple reasoning on climate change study. To alleviate such a challenge computer modeling is a best solution and have been developed to simulate climate system and interaction between system components mathematically (Dibike and Coulibaly, 2005).

General circulation models (GCMs) are computer programs that simulate the Earth's climate via mathematical equations that describe atmospheric, oceanic and biotic processes, interactions, and feedbacks. Modern climate models are composed of a system of interacting model components, each of which simulates a different part of climate system (Bader et al., 2008). Atmospheric state is described by such variables as temperature, pressure, and humidity, winds, water and ice condensate in clouds. Ocean General circulation models (OGCMs) solve the primitive equations for global incompressible fluid flow analogous to the ideal-gas primitive equations solved by atmospheric GCMs (Bader et al., 2008). Combinations of these two components forms an atmosphere-ocean coupled general circulation model (AOGCM) and these GCMs are composed of many grid cells that represent horizontal and vertical areas on Earth's surface. Therefore, GCMs are primary tools that provide reasonably accurate global, hemispheric and continental scale climate information and are used to understand present climate and future climate scenarios under increased greenhouse gas concentrations.

2.7. Emission Scenarios

Projection of future climate change in the region is relied on various evidences of human activities on earth surface. Scientists working in this field are using differs indications to perform it in the most accurate and precise way. Climate scenario working by using a plausible indication of what future could be looks like over decades or centuries, given a specific set of assumptions. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the behaviour of the climate system over long time scales.

Climate change scenarios are also reasonable trajectories of different aspects of future that are constructed to investigate potential consequences of anthropogenic climate change (Houghton, 2001). Scenarios of different rates and magnitudes of climate change provide a basis for assessing risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems (IPCC, 2007).

Scenarios are alternative images of how future might unfold, in order to consider how robust different decisions or options may be under a wide range of possible futures Wayne, (2013) and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties.

IPCC published a set of climate change scenarios though time based on different reasonable scientific evidences. The first and second sets of scenarios called SA90 and IS92 were published since1990 and 1992 respectively. IPCC also released the third and fourth generation of projections called Special Report on Emission Scenarios (ERES) since 2000 then used for the Third and Firth Assessment Report, (TAR) and (AR4). ERES had provided common reference points for a great deal of climate science research in last decade. Current scenarios called Representative Concentration Pathways (RCPs) are the latest generation of scenario process which is used in the Assessment Report Five (AR5) in a better way than SRES.

2.7.1. Representative Concentration Pathways (RCP) Scenarios

IPCC AR5 had used new projections of future climate change to prepare the 2013s report which were more detail and models have become more advanced. Climate scenarios used in IPCC reports also have changed over time to reflect the state of knowledge of climate change studies. Ranges of climate change projections from model results provided and assessed in the first IPCC assessment in 1990 to those in the 2007 AR4 provides an opportunity to compare projections with actually observed changes, thereby examining deviations of the projections from observations over time (IPCC, 2013).

RCP scenarios are the latest generation that provides input to climate models, which are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. These scenarios provide a quantitative description of concentrations of climate change pollutants in the atmosphere over time, as well as their radioactive forcing in 2100.

Four main scenarios have been defined with different targets of radioactive forcing in the year 2100: RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6. Numbers refer radioactive forcing in W/m2 in 2100. Differences in radioactive forcing between these scenarios are relatively small up to 2030, but become very large by the end of 21st century and dominated by Co_2 forcing.

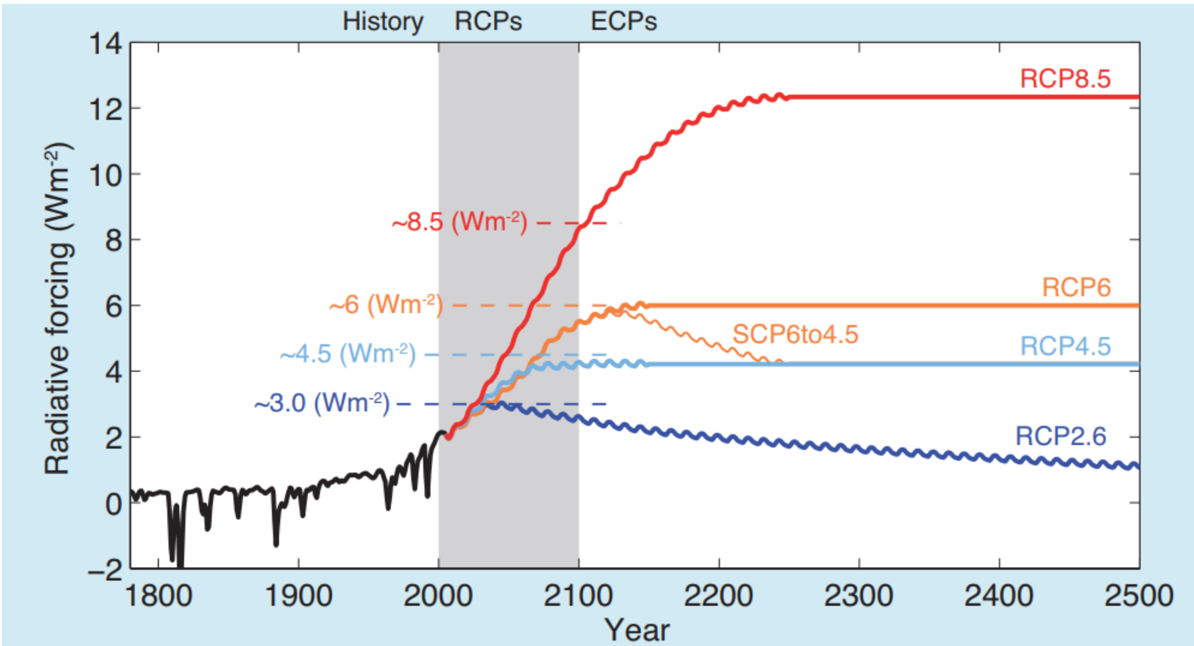


Figure 1: Radioactive forcing for RCPs and extended concentration pathways (IPCC, 2013)

- **RCP 8.5**: It is considered increasing greenhouse gas emissions over time. It will reach over 8.5 W/m2 by 2100 and will continue to rise onwards after some time.
- **RCP 6.0**: total radioactive forcing is stabilized after 2100 without adopting any technologies and strategies to reduce greenhouse gas emissions.
- **RCP 4.5**: total radioactive forcing is stabilized before 2100 by applying ranges of technologies and strategies for reducing greenhouse gas emissions.
- RCP 2.6: radioactive forcing peaks at approximately 3 W/m2 before 2100 and then declines to approx. 2.6 W/m2 in 2100. In order to reach such a forcing, greenhouse gas emissions have to be reduced substantially over time. One increasing and stabilization scenarios: RCP4.5 and RCP8.5were used for this study.

2.8. CORDEX-Africa RCM

CORDEX Africa RCM data is supported by the World Climate Research Programme to foster global partnership to generate an ensemble of high-resolution historical and future climate projections at regional scale. Downscaling in this approach is based on predictions and climate scenarios in Coupled Model Intercomparison Project Phase 5 (CMIP5). A purpose of CORDEX-Africa is to promote international downscaling coordination and facilitate easier analysis by scientists and end-user communities at local level of regional climate changes (Trzaska and Schnarr, 2014). Africa is one of the most vulnerable regions to weather and climate variability (IPCC, 2007). Thus, CORDEX-Africa is one of special concerns of CORDEX program. Importance of fully exploiting CORDEX-Africa multi-Global Climate Model (GCM)/multi-RCM ensemble has been strongly emphasized. This helps to assess climate change signal and possibly to identify and quantify the sources of uncertainty (Dosio and Panitz, 2016). CORDEX-Africa provides projected climate outputs at a relatively higher spatial resolution (50 km by 50 km).

2.9. Hydrological Modelling

Modeling is principles of getting output by providing inputs. Several empirical, physically based or conceptual models could be used for hydrological and related studies. Approach of empirical models is based on defining important factors through field observation, measurement, experiments and statistical methods (Petter, 1992). This model has its own advantage to predict hydrology of a specific area but it is place dependent and needed a long term data which considered as a disadvantage (Elirehema, 2001). Other type of model is physical based model which is working based on knowledge of fundamental processes and incorporate the laws of conservation of mass and energy (Petter, 1992). These physical processes is not static, it varies temporally and spatially. This model plays a major role in analyzing impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds.

The whole amount of precipitation is not transfer directly to runoff. There are many physical processes which determine transformation of precipitation to surface runoff. Hydrological models are useful tools to define these processes. Many hydrological models are designed and implemented to simulate the rainfall runoff relationships under various spatial and temporal dimensions. Central emphases of these models are to establish a relationship between various hydrological components such as precipitation, evapotranspiration, surface runoff, ground water flow with infiltration and percolation. Many of these hydrological models describe canopy interception, evaporation, transpiration, snow-melt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated subsurface flow.

2.9.1. Types of Hydrological Modelling

Hydrological models are classified in to different categories based on various parameters. It is divided in to three major categories based on process description (Cunderlik, 2003). These are lumped, semi-distributed and distributed models.

1. **Lumped Models:** parameters in this model do not vary though out the basins. Response of the basin is evaluated at outlet of the catchment without considering response of individual sub-basins. Parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. Using of this model is not common for hydrological studies due to aforementioned reasons.
2. **Distributed Models.** On this model parameters vary spatially which is chosen for users. It attempts to incorporate data concerning spatial distribution of parameter variations together with computational algorithms to evaluate influence of this distribution on simulated precipitation-runoff. This model require large amount of (often unavailable) data which is considered as a disadvantage. And also physical processes are model in detailed which is used to provide an accurate and precise result.
3. **Semi-Distributed Models:** it shared behaviors of lumped and distributed models. Parameters vary from basin to basin and not required large amounts of data. Its structure is more physical based than structure of lumped models which is considered as an advantage. SWAT (Arnold et al., 1993), HEC-HMS (USACE, 2001), HBV (Bergstrom, 1995) are considered as semi-distributed models.

2.9.2. Hydrologic Model Selection

Many hydrological model structures are available in each model classes. When conducting hydrological and other studies using these models, choosing of appropriate models which can fit the purpose of study with right time and budget and in accurate way is a challenging part of research. Having specific criteria is required to choosing an appropriate model. Beven, (2000) recommended four criterions for choosing a fitting model structures as listed below.

I. Think through the model is freely available since to address economic issue. It also needed to be easily understandable.

II. Output of the model have to fit to our objective of study with in the most accurate and precise way.

III. Prepare a list of assumptions made by the model and check 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.

IV. Number and type of data inputs required. Make a list of inputs required by model and make sure whether all required data by model can be provided within time and capital.

Based on the above selection criteria, SWAT model were used for this study.

2.9.3. Soil and Water Assessment Tool (SWAT) Model

It is physically based semi-distributed watershed model operating on a daily time step and uses a modified Soil Conservation Service-Curve Number (SCS CN) method to calculate runoff. It was developed by the United States Department of Agriculture Agricultural Research Service (USDA ARS) and Texas A&M AgriLife Research to predict the impact of various land uses and management practices on water, sediments, and agricultural chemical yields in large complex watersheds over long periods of time (Neitsch et al., 2009). The model allows to user to quantify relative impact of management, soil, climate and vegetation changes at sub-watershed level (Arnold, 1998). This type of model is preferred for isolating hydrologic response from a single variable, such as land cover and land use change (e.g. management decisions.

Water balance is a driving force for things happened in the watershed. To simulate by model, hydrologic cycle must follow what is happening in the watershed to accurately predict movement of sediments (Neitsch et al., 2009). Hydrology is simulated in two major ways:

- Land phase, which controls sediment, nutrient and pesticides loading to each channel from sub-basins, and
- Water or routing phase that controls the movement through the channel network to the watershed outlet (Neitsch et al., 2009).

Hydrologic cycle is simulated by SWAT based on the following water balance equation (Arnold, J.G. et al., 1998).

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{Qw}) \ldots\ldots\ldots\ldots\ldots 1$$

SW_t: final soil water content (mm)

S_{Wo}: initial soil water content on day i (mm H2O), t is the time (days)

R_{day}: amount of precipitation on day i (mm H2O)

Q_{surf}: amount of surface runoff on day i (mm)

E_a : amount of evapotranspiration on day i (mm H2O)

W_{seep}: amount of water entering vadose zone from soil profile on day i (mm H2O)

Q_{Qw} : amount of return flow on day i (mm H2O).

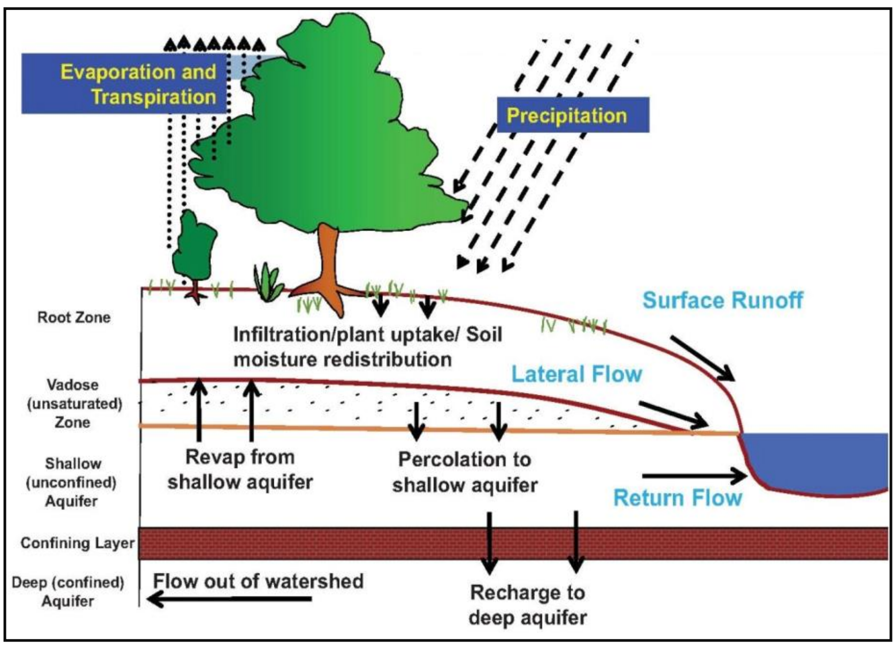


Figure 2: Hydrological cycle that SWAT considers during modeling

2.9.4. Reasons for Selecting SWAT Model

Each hydrological model has its own specification to choose. For this study SWAT model is chosen due to the following reasons:

- It is used worldwide for climate change and land use change impact on hydrology.
- It simulates major hydrological process in the watersheds

- It is less demanding and easily accessible input data, and
- It is readily and freely available which can access and work on it easily.

2.9.5. Applicability of SWAT Model

SWAT is widely applied in many parts of the United States Peterson and Hamlett, (1998); Arnold et al., (1998); Benaman et al., (2005) and Heuvelmans et al., (2004). It was also validated for stream-flow and sediment loads (Santhi, et al., 2001).

SWAT also applied in many parts of Africa (Arnold et al., 2009). Evaluation of SWAT model in simulating of sediment yield and stream flow on Lake *Jebba* watershed in Nigeria showed satisfactory performance for stream flow and sediment yield predictions (Adeogun et al., 2015). It was also used in Northern Algeria with title of modeling of discharge and sedimentation using SWAT model in the *Harraza* basin (Faiza et al., 2016).

SWAT showed a good application performance in Ethiopia. Ayana et al., (2012) examined applicability of SWAT in estimating runoff and sediment yields in Fincha watershed. It was calibrated and validated frequently in Blue Nile basin (Asmamaw, 2013; Shimels, 2008; Awulachew et al., 2008; Kassa, 2007 and Setegn et al., 2008). Through modeling of Gumara watershed in Lake Tana basin (Awulachew et al., 2008) indicated that stream flow and sediment yield simulated with SWAT were reasonable accurate.

Applicability of SWAT on flow, sediment, Nutrient and impact of land use and climate change is also done by (Dessu and Melesse, 2012 and 2013; Dessu et al., 2014; Wang et al., 2006 and 2008a, b, c; Wang and Melesse, 2005 and 2006; Behulu et al., 2013 and 2014; Setegn et al., 2009a, b, 2010 and 2011; Setegn and Melesse, 2014; Mango et al., 2011a, b; Getachew and Melesse, 2012; Anwer et al. 2014 and Grey et al., 2013).

SWAT model also becomes popular to environmental managers. It is because it has been adopted as a component of the USA Environmental Protection Agency's Better Assessment Science Integrating Point and non-Point Sources software packages (Gassman et al., 2007).

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

It is a program designed to integrate various calibration/uncertainty analysis programs for SWAT using the same interface. The program guides input files necessary for running a calibration program. Each SWAT-CUP project contains one calibration method and allows running procedure many times until convergence is reached. It allows saving calibration iterations in iteration history for later use. SWAT CUP includes several techniques such as PSO, SUFI-2, GLUE, Parasol and MCMC. SUFI-2 (Sequential Uncertainty Fitting) is very convenient to use, but it needs good knowledge on parameters and their effect on outputs (Yang et al, 2008).

CHAPTER 3: METHODOLOGY

3.1. Study Area Description

3.1.1. Location

Ribb catchment is located in northwestern part of Ethiopia. The catchment stretches between 11°40'0'' - 12° 10'0'' N latitude and $37^0$30'0''- 38° 14'0'' E. It is part of Lake Tana basin; source of Blue Nile (Abbay) River. Blue Nile Basin is the largest basin in Ethiopia with high population pressure, degradation of land and highly dependent on agricultural economy (Tsegay, 2006). Total catchment area of Ribb (gauged and ungauged) is about 199,160 hectares (Garede et al., 2014). However, this study was conducted at gauged part of the catchment which has total area about 131,245.43 hectares. Ribb River is originated from the higher elevation of *Guna* Mountains, Southern Gonder.

Ribb catchment supports total number of population about 878,261 based on CSA, (2007) and about 89.7% of population lives in rural areas which mainly depend on agriculture.

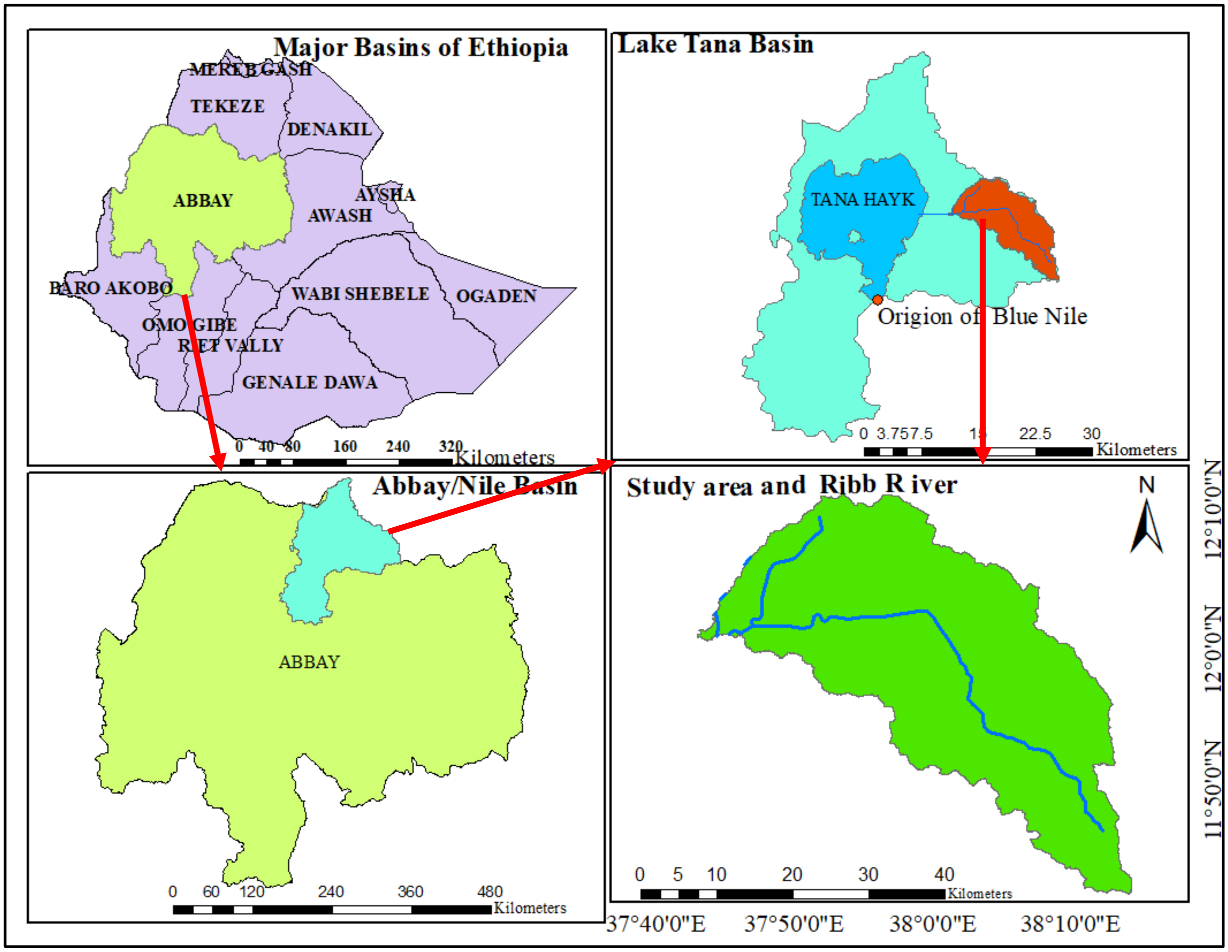


Figure 3: Geographic locations of the study area

3.1.2. Location of Gauge and Meteorological Stations

Stations found inside and near distances were used for this study. Since the study area has a diverse topographic features stations found in diverse elevation were used. Locations of stations were also at different direction to get an accurate representative data. The catchment has also tributaries which supply water to main Ribb River. Gauge station is found at the outlet of the catchment used to record stream flow of Main River (Ribb).

The study area/catchment was divided in to 29 sub basins with threshold area of given 2700 ha during watershed delineation using SWAT model.

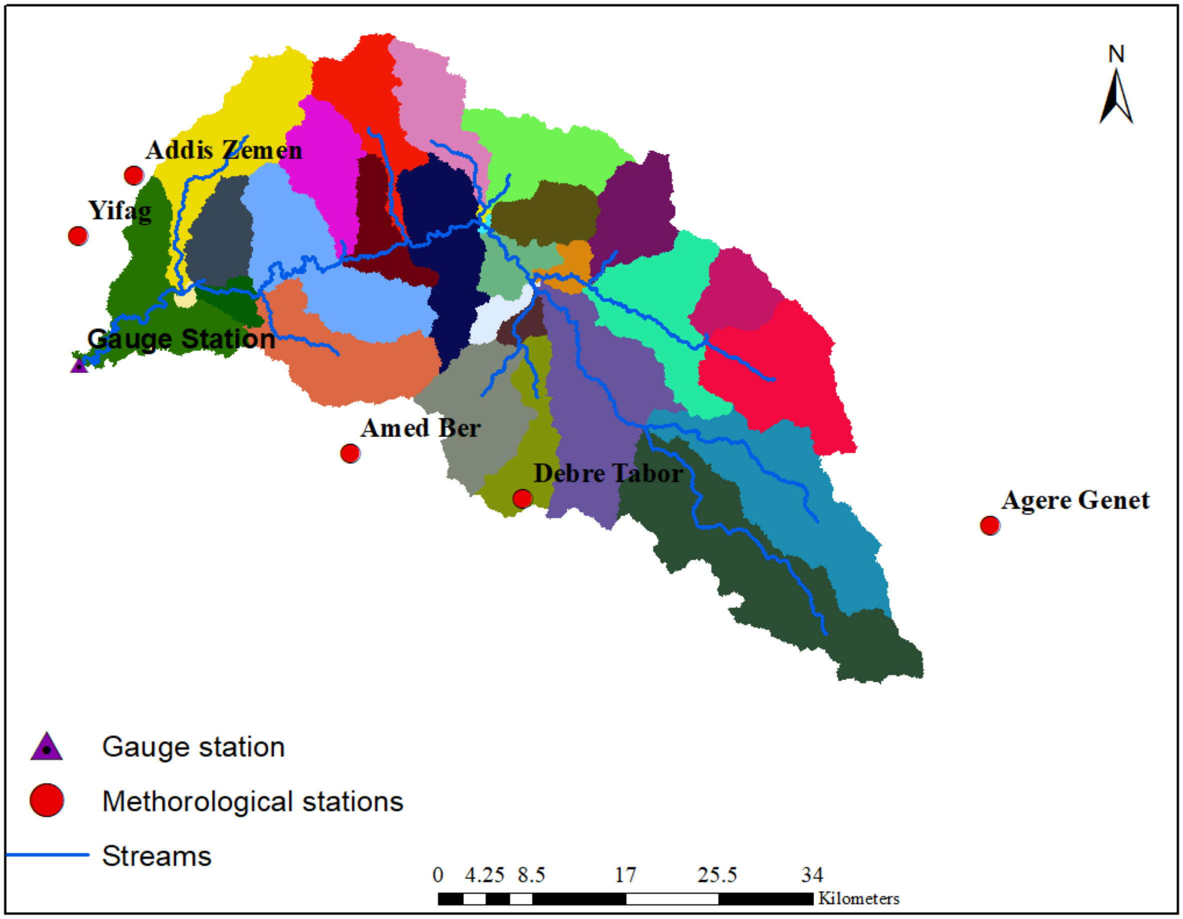


Figure 4: Locations of gauge and meteorological stations and sub-basins information

Table 1: Information about meteorological stations

No	Station Name	Latitude	Longitude	Elevation	Class
1	Debre Tabor	11.87	37.99	2612	4
2	Addis Zemen	12.12	37.77	1940	3
3	Amed Ber	11.91	37.89	2051	3
4	Yifag	12.08	37.73	1853	3
5	Agere Genet	11.8	38.3	3010	3

(Coordinates of stations were found http://www.ethiomet.gov.et/stations/regional_information/2)

3.1.3. Elevation

Topographic features of the area have an impact on runoff generation and velocity, rainfall pattern and temperature. Elevation of watershed was developed from ArcGIS10.4 version software by using 30m X 30m resolution DEM of the study area downloaded from STRM.

Higher elevation is found at southeastern part of the watershed, *Guna* Mountains and also north and northeastern tips. Lower elevation is found at western part of the catchment around *Fogera*. Large parts of the catchment are found below average elevation.

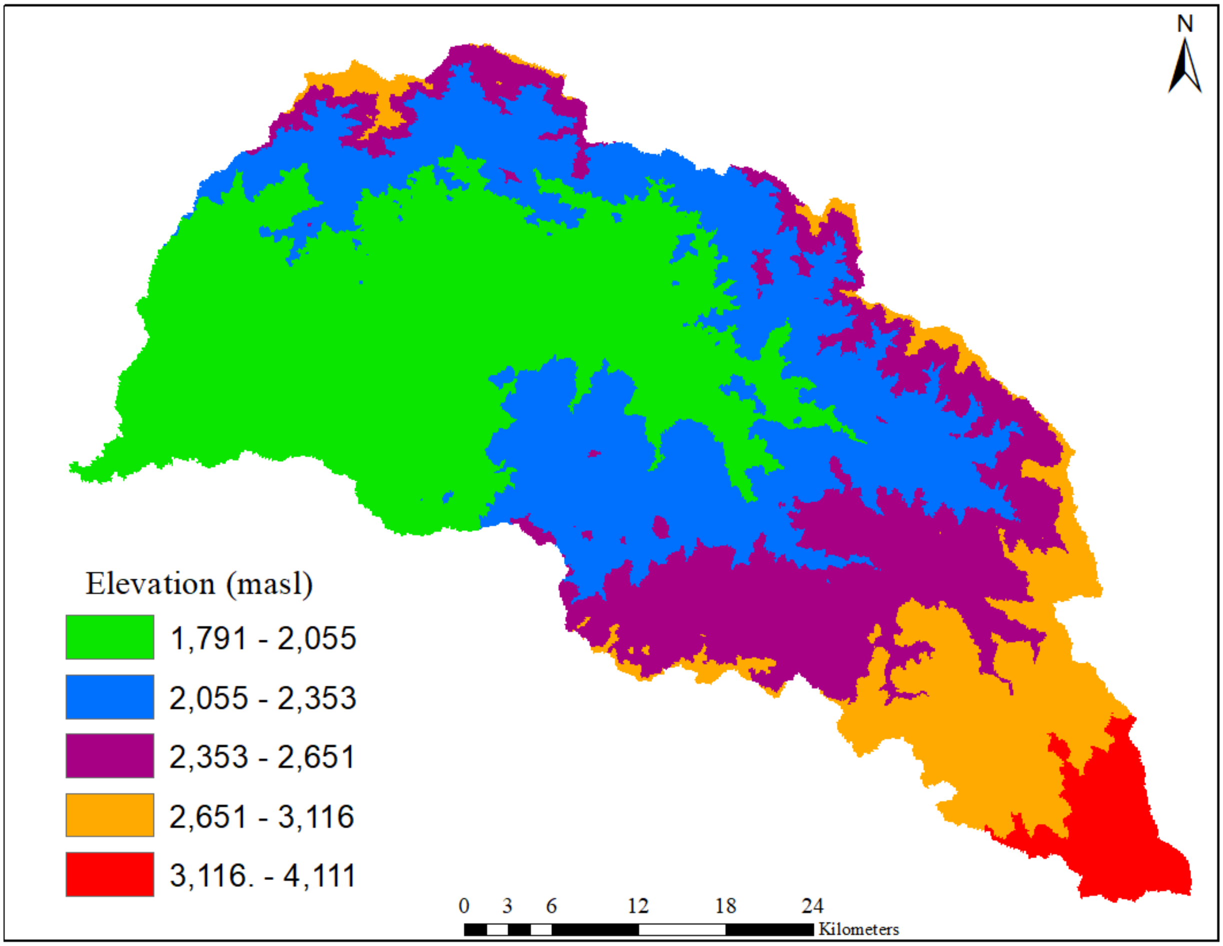


Figure 5: Elevation information of the study area

3.1.4. Slope

Slope is one factor affecting surface runoff amount and velocity at the watershed level. Ribb catchment has various slope features. DEM of 30x30m resolution was processed to determine slope of the catchment pixel by pixel then the average slope was determined.

Dominate slope was found from 15-30% which covers 30% of the total area. About 22.5 % of the area has slope greater that 30% and only 8% has a slope of 0 to 3.The study area is relatively steeply at northern and northeastern parts of the catchment (see figure below). Average topographic slope reduces to <1% at *Fogera* plain, around the outlet of the watershed.

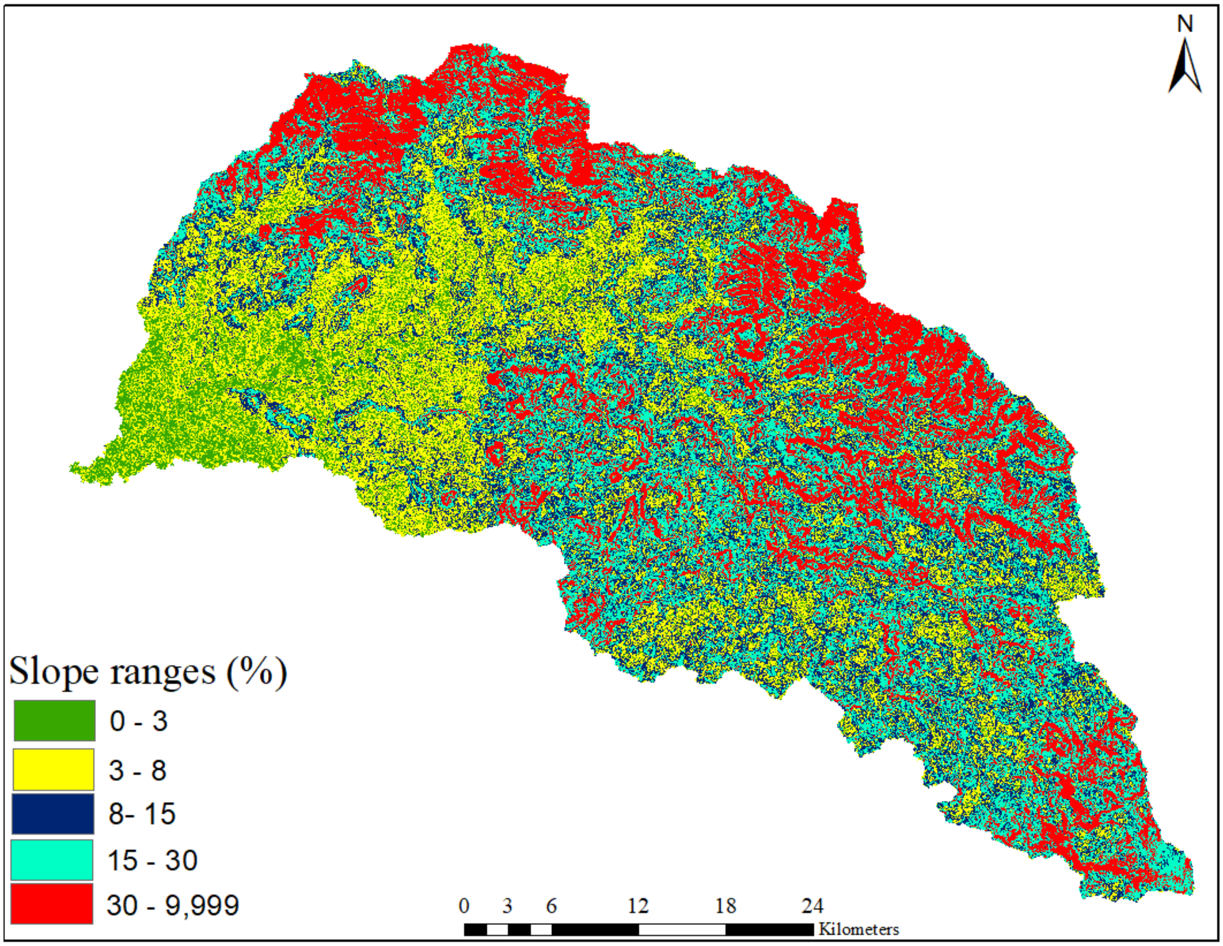


Figure 6: Slope information of the study area

3.1.5. Soil Types of the Study Area

Soil type is also another factor affecting runoff generation and velocity. Soil was an input data to model SWAT in a specific catchment to simulate stream flow. Soils in Lake Tana sub-basin are the mixture of delatic and recent river alluvial deposits and are heterogeneous (Dile et al, 2013). Since Ribb catchment is part of Lake Tana sub basin and varies in elevation and slope, it has variable soil types too. Major soil types found in the catchment were Alisols, Luvisols, Nitosols, Vertisols, Regosols, Cambisols, Fluvisols and Leptosols.

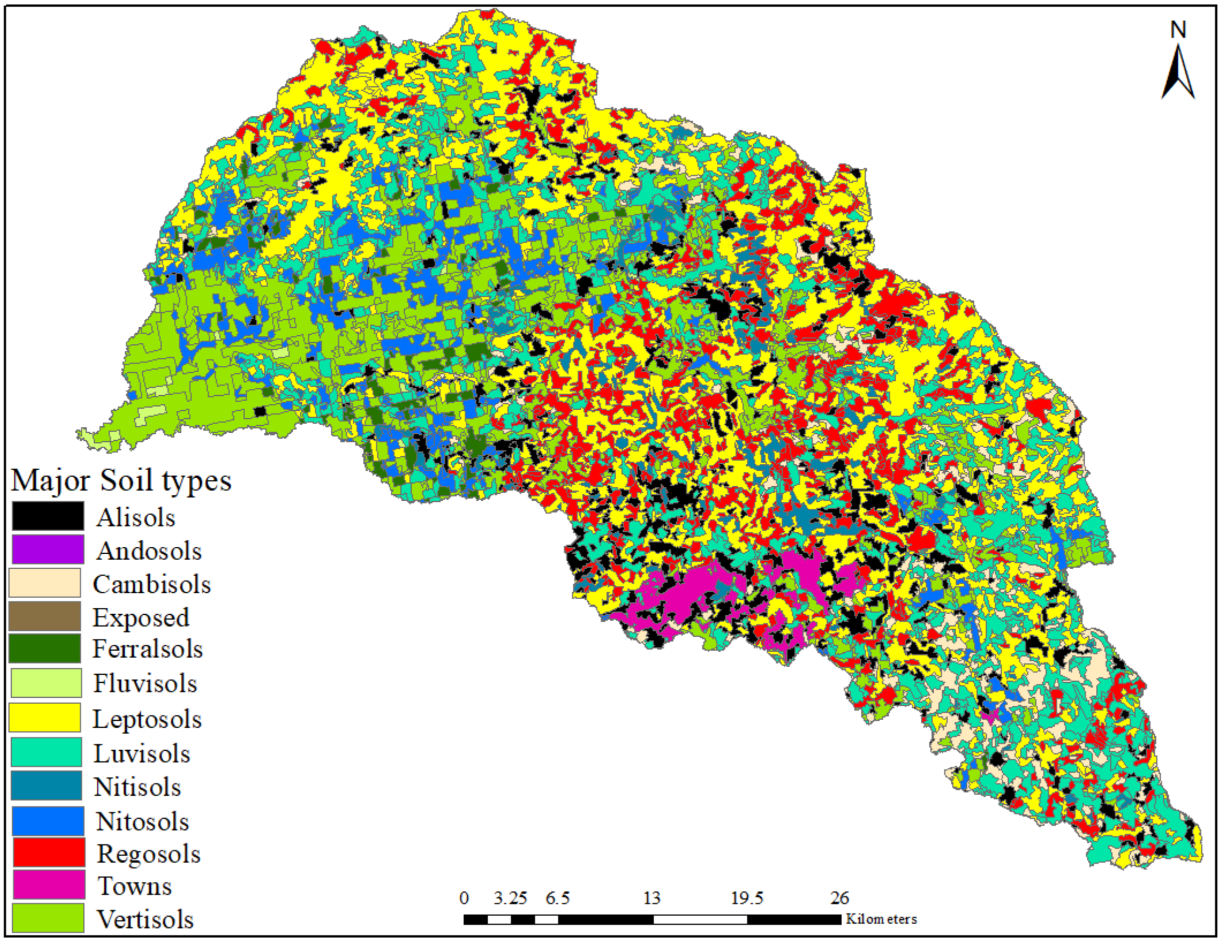


Figure 7: Major soil types in the study area

3.1.6. Land Use Land Cover

Land use affects the runoff, it should be considered for accurate hydrological studies. Land use is changed to agricultural use due to rapid population growth. Since the catchment is currently supports a lot of people, the dominant land is for agricultural purpose which covers about 95.5%. Garede et al., (2014) showed the same result of the catchment is dominantly used for agricultural purpose but the percentage of area coverage is different due to time difference of studies. (Gebremariame, 2009) also varified the land use of Ribb catchmnt is domimantly used for agiculture.

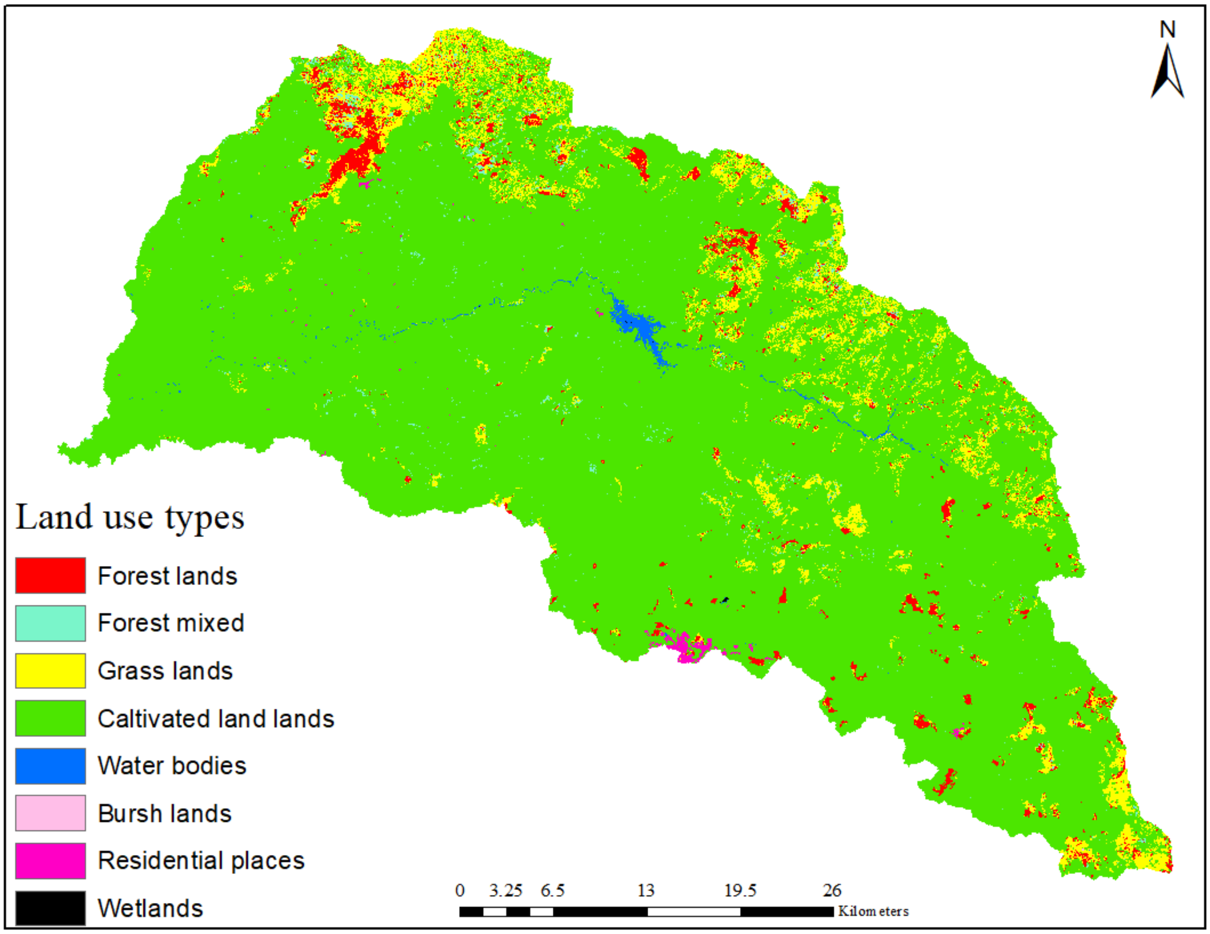


Figure 8: Land use Land cover of the study area

3.1.7. Climate

Climate of Ethiopia is mainly controlled by seasonal migration of Inter tropical Convergence Zone (ITCZ), its associated atmospheric circulation and topographic features. Traditional climate classification of the country based on altitude and temperature are: *Wurch* (cold climate above 3000m altitude), *Dega* (temperate like climate-highland with from 2500 to 3000 m altitude), *Woina Dega* (warm climate from 1500 to 2500m altitude), Kola (hot and arid type with less than 1500 m altitude) and *Berha* (hot and hyper-arid type) climate (NMSA, 2001). Majority of study area falls in *Woina Dega* climatic condition based on elevation. Some part is fall under Wurch and *Dega* climatic condition. Southeastern tips of the catchment (*Guna* Mountains*)* falls on Wurch climate condition.

a. Temperature

Temperature depends on elevation. Areas found in lower elevation are temperate regions while higher elevation areas are considered as tropical or cold reigns (Conway, 1999). Results obtained on this thesis work support Conway's result. Stations located at upper elevation showed lowest record and stations found in lower elevation showed highest record of both minimum and maximum temperature (look elevation of stations on table 1 above). Temperature is averagely falls by 5.8 ^{0}c by each 1000m (Conway, 200).

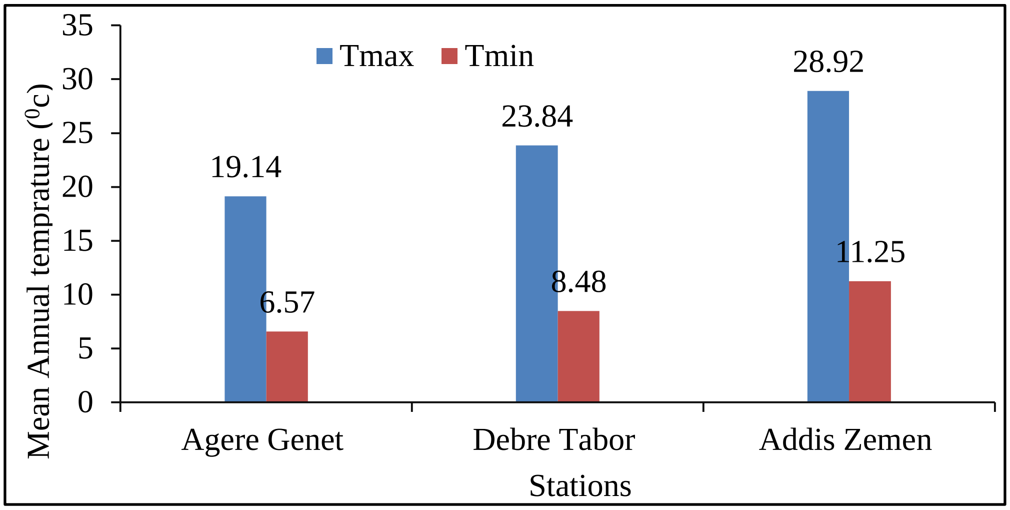


Figure 9: Mean daily observed maximum and minimum temperature data

Differences of minimum temperature between stations are lower than differences in maximum temperature. It seems spatial variability of maximum temperature is higher than minimum temperature.

All stations showed highest temperature record on March. April, February, October, November and December also showed the higher temperature records. Lowest temperature was recorded on August and July. In minimum temperature, maximum temperate was recorded on May and July and the lower record is showed on December, November and January.

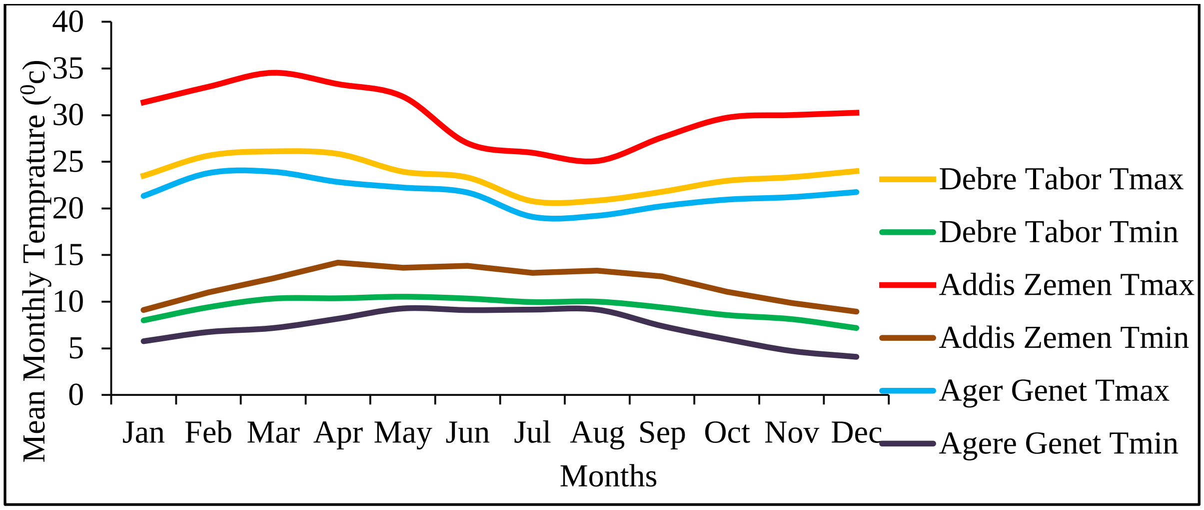


Figure 10: Mean monthly maximum and minimum temperature data

b. Rainfall

Rainfall also varies spatially, temporally and seasonally. Spatial variability of rainfall was also dependent on the elevation of the study area. Areas located in lower elevation get lower rainfall whereas higher rainfall obtained for areas located in higher elevation.

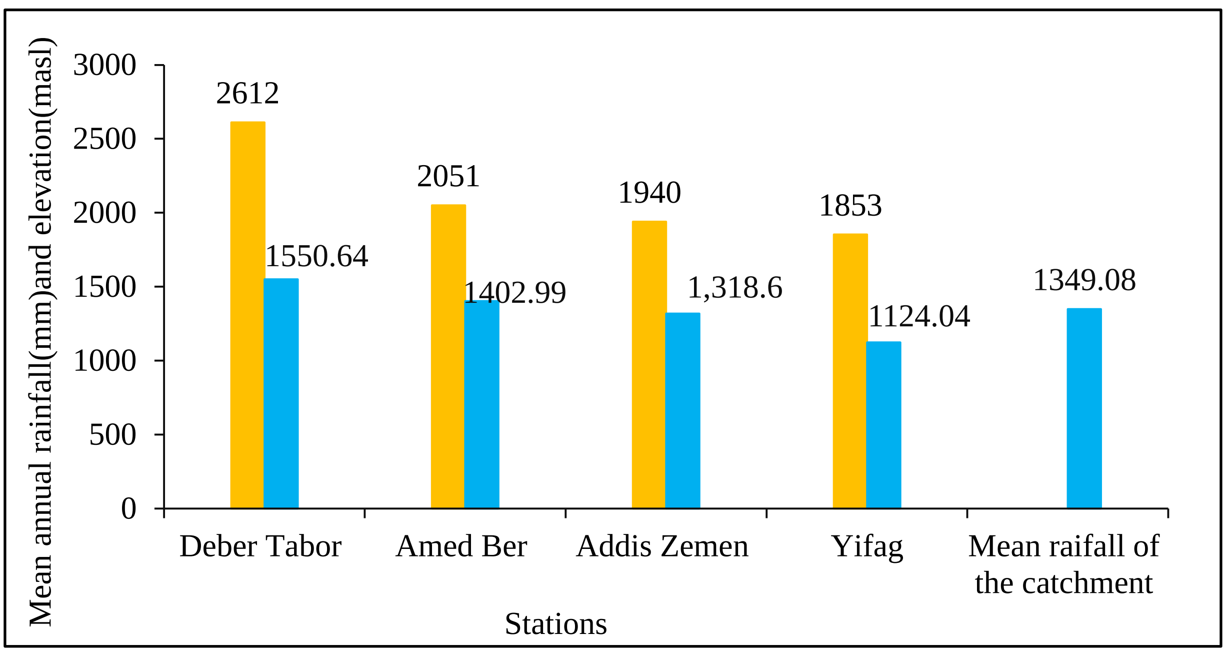


Figure 11: Mean annual rainfall and elevation of stations

As you have a look above (figure 11), rainfall of stations is not proportional with the elevation. As an example rainfall of Debre Tabor is not much different to Amed Ber when compared to rainfall of Amed Ber with Addis Zemen in relation to their elevation. It is due to other factors like temperature, the wind speed and direction.

Most part of the country gets high amount of rainfall on summer especially on August and July based on Ethiopian meteorological studies report. Mean monthly rainfall distribution also showed maximum rainfall on July except Debre Tabor station record, which showed the maximum records on August. It is an indication of rainfall monthly variability with in the specific catchment.

Study results obtained at Lake Tana sub basin and Blue Nile basins done by Conway,(2000); Kebede et al., (2006); Sutcliffe & Parks, (1999) and Tarekegn and Tadege, (2005) indicated hydrological year of the study areas are characterized by one main rainy season (summer) between Junes to September, in which 70% to 90 % of the annual total rainfall occurs.

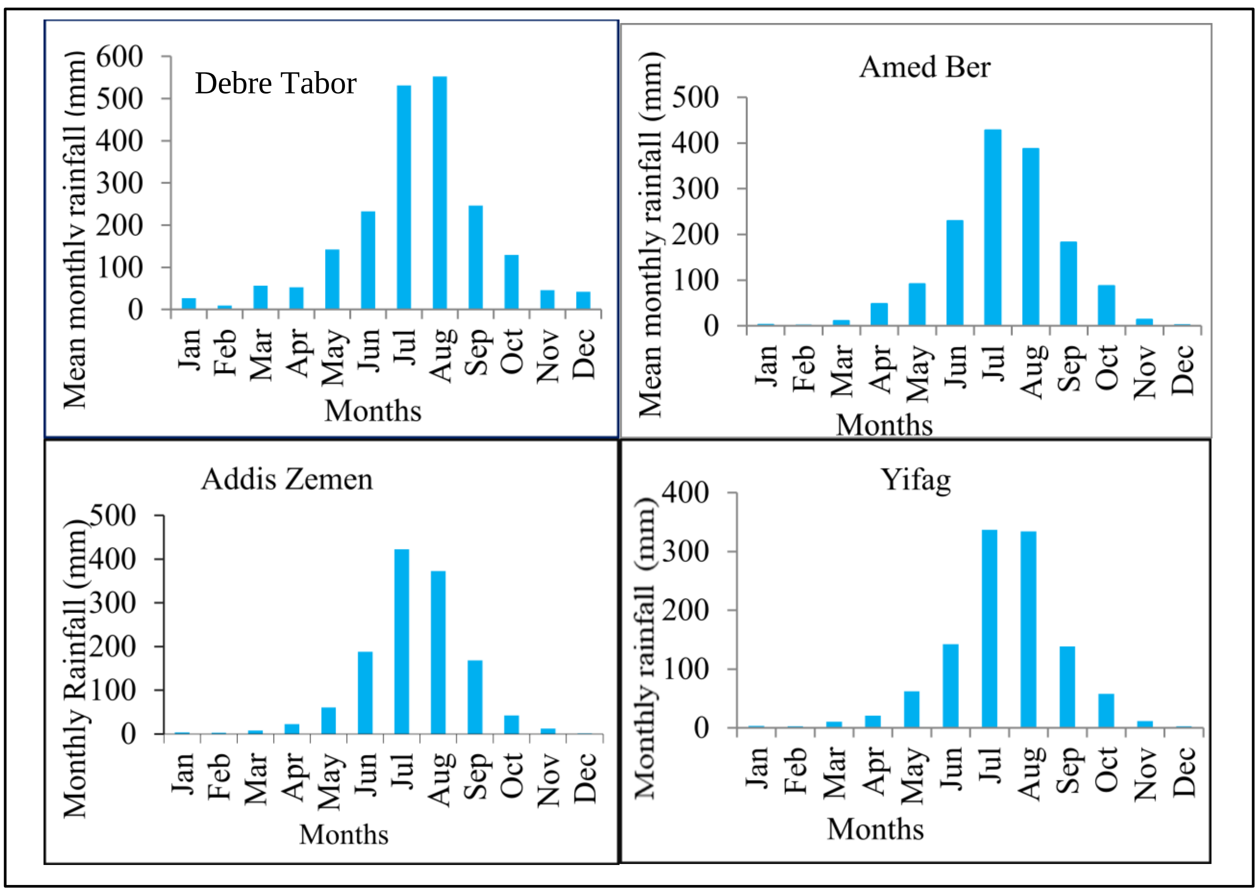


Figure 12: Distribution of mean monthly rainfall in the study area

2.1.8. Discharge Information and Data Screening

As suggested by Gordon et al.,(1992) the initial step taken during river discharge data screening was quick visual scan on data time series to detect gross errors such as erroneous peak flow, missed recordings, and flows of constant rate. Daily average discharge of Ribb River was about14.75 m3/s.

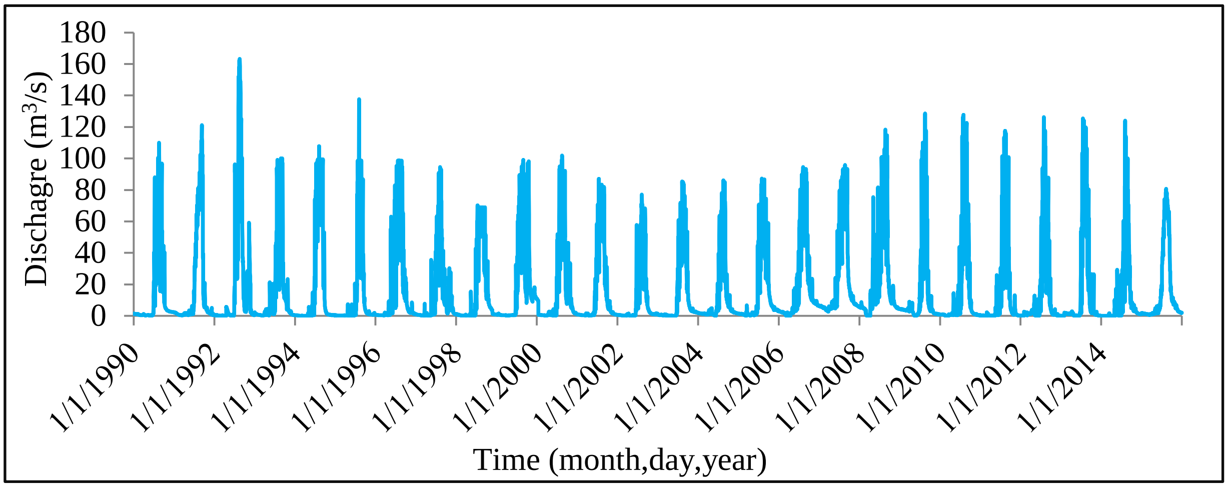


Figure 13: Daily stream flow of Ribb River

Stream flow generation depend on amounts of rainfall obtained.

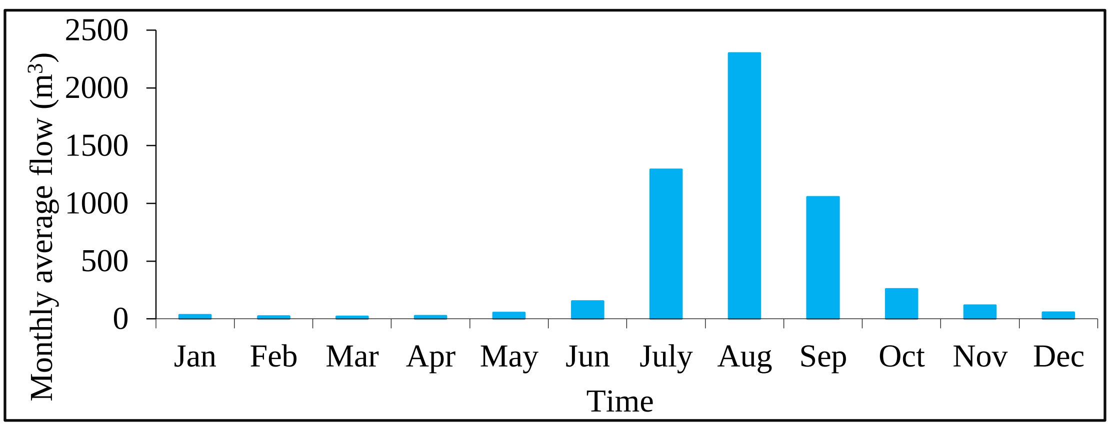


Figure 14: Monthly average discharge of Ribb River

Mean monthly flow is higher on August but higher rainfall was recorded on July in all satiations except Debre Tabor (Figure 12). It might be Debre Tabor station covered a large part of the study area and water loss by infiltration and deep percolation decreases from the beginning to end of rainy season which is associated with infiltration and the water holding capacity of soil.

3.2. Method and data availability

3.2.1. General Methods of the Study

Soil and Water Assessment Tool was calibrated and validated through used observed data to verify model capacity to simulate future stream flow acceptably. Daily projection precipitation and temperature data was generated by bias correction technique from RCM projection precipitation and temperature data set for Nile Basin studies. Trend analysis of bias corrected model temperature and precipitation data and climate change induced simulated stream flow changes was analyzed. It was done for future time horizons of 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-20098) from baseline and between successive time horizons through using two RCPs scenarios (RCP4.5 and RCP8.5).

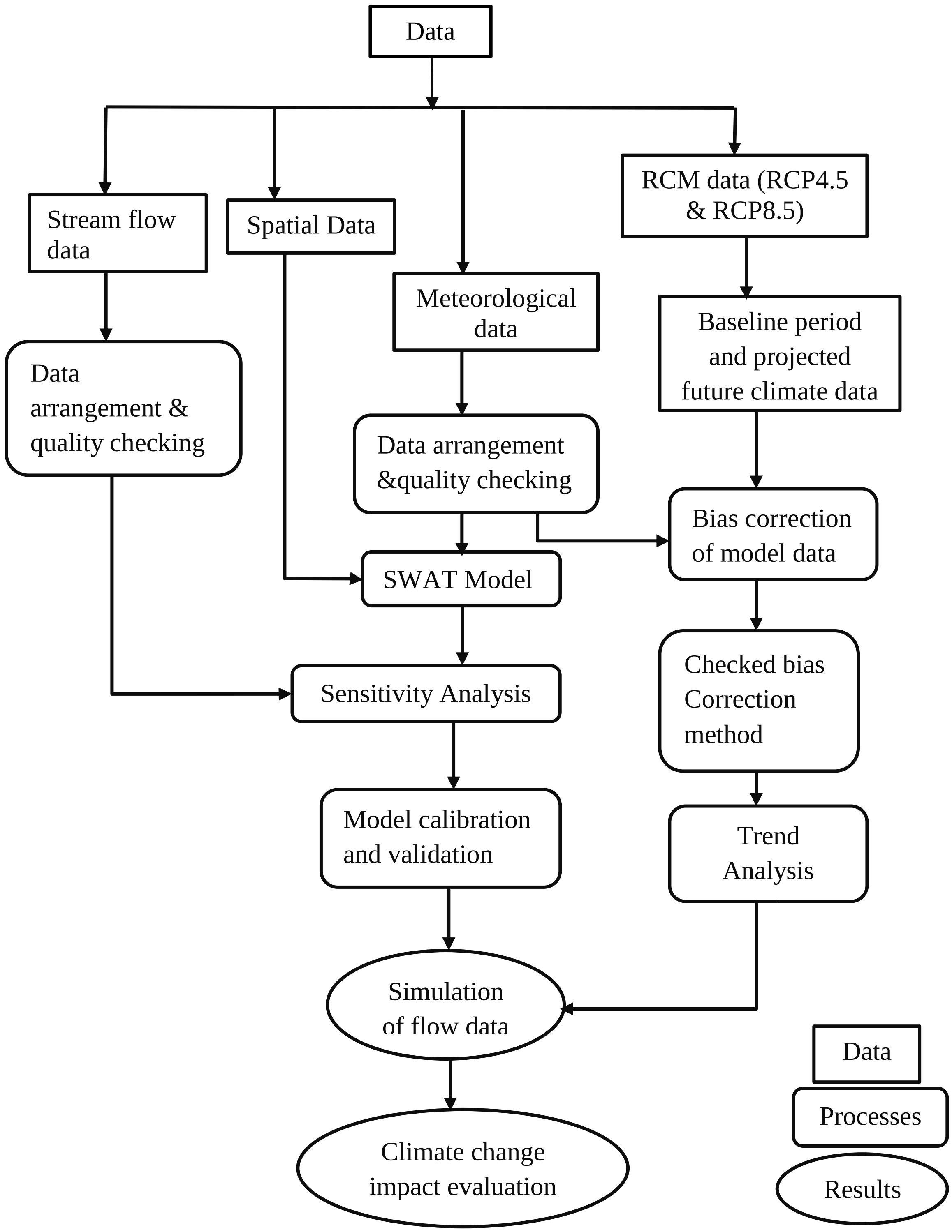


Figure 15 Flow chart of the general method

3.2.2. Data Availability

3.2.2.1. Meteorological data

Required meteorological data were rainfall, maximum and minimum temperature, wind speed, relative humidity and solar radiation. Solar radiation data was prepared from day time sunshine hour data using Angstrom method. Secondary meteorological data were collected from Ethiopian Metrological agency Addis Ababa and Bahir Dar branches. They were used for hydrological model (SWAT) development and bias correction of projected model data.

However, there was only Debre Tabor station found inside the catchment which had contained required data in a required quality and quantity. Taking only one station data was not rightly represented due to diverse topographic feature of the study area. To alleviate such a difficulty, additional data were collected from surrounded stations. Addis Zemen, Amed Ber and Yifag (only for SWAT modeling) stations rainfall data were used and temperature data of Addis Zemen and Agere Genet (only for SWAT modeling) stations. Debre Tabor was the only principal station which had wind, relative humidity and sunshine hours.

Selection of representative surrounding metrological stations depends on availability of required climatic variables, length of record period, distance from the catchment as well as selection of base period used for analysis of present and future climate, length of historical model outputs.

Additionally, all selected surrounding stations do not have full required data. Among statins only Debre Tabor and Addis Zemen contains required baseline temperature and rainfall data from 1976 to 2015. Taking of only two stations data also not fairly represent the entire area due to the aforementioned reason of having a diverse topographic feature of the study area. Therefore, to reduce uncertainties of stream flow projection in future time horizons data diversification of used stations and RCM data was needed. Therefore, average aerial precipitation method was used to generate rainfall data for Amed Ber station since it has only rainfall data from 1986 to present.

I. Estimating average aerial precipitation data

Average aerial precipitation was prepared by using Theissen Polygon method in ArcGIS10.4 to fulfill rainfall data of Amed Ber station. This was done through using the following formula.

$$P_{mean} = \frac{(\sum_{i=1}^{m} p_i A_i)}{A_{Total}} \text{......................2}$$

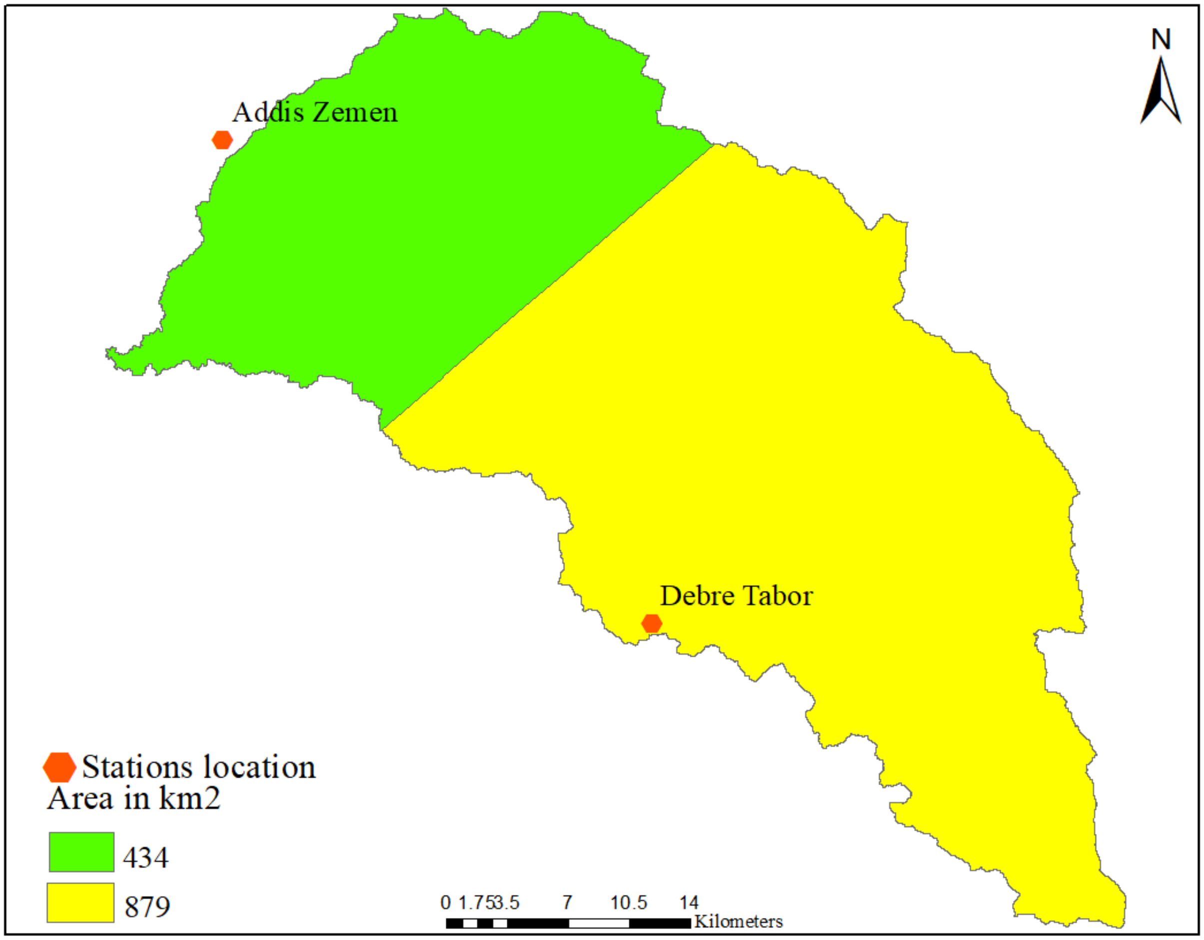


Figure 16: Area contribution of Addis Zemen and Debre Tabor stations to prepare average areal precipitation for Amed Ber station

Since temperature is not spatially varies like precipitation data, only two stations data (Debre tabor and Addis Zemen) were used for future stream flow generation.

II. Preparation of weather generator data

Weather generator, an input for SWAT model, was prepared and used to provide data for stations having missing data. Weather generator files needs at least 20 years of records to prepare (Arnold et al., 2013). Wind data of study area also required in addition to rainfall and temperature data. Therefore, Debre Tabor station data were used to prepare weather generator.

Weather generator was prepared manually through using PCPSTAT and dewPOINT2.0 version programs by using 21 year rainfall, temperature and wind data. By preparing this weather generator, SWAT weather generator in the database is replaced by importing the newly prepared weather generator.

III. Preparing solar radiation data

Solar radiation data is also one input data for SWAT. Angstrom method was used to prepare solar radiation by using the following formula.

$$R_S = \left(a_s + b_s \frac{n}{N})a_s\right) R_a \text{……………………………}3$$

Where

R_S solar or shortwave radiation $\left[\frac{MJ}{m2\ \ day}\right]$]

R_a extraterrestrial radiation $\left[\frac{MJ}{m2\ \ day}\right]$

a_s regression constant. expressing the fraction of extraterrestrial radiation reaching the earth

on overcast days $(n = 0)$

$\frac{n}{N}$ relative sunshine duration

$a_s + b_s$ fraction of extraterrestrial radiation reaching the earth $(n = N)$

n actual duration of sunshine(hours)

N maximum possible duration of sunshine or day time hours(hours)

The daylight hours,N, are givenby:

$$N = \frac{24}{\pi} \omega_s$$

$$R_a = \frac{24(60}{\pi} G_{sc}\, d_r[\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)]$$

Where:

R_a extraterrestrial radiation $\left[\frac{MJ}{m2\ \ day}\right]$

G_{sc} = solar constant = 0.0820 $\left[\frac{MJ}{m2\ \ min}\right]$

d_r inverse relative distance Earth_Sun(equation___)

ω_s sunset hour angle

φ latitude[rad]equation

δ Solar declination (equation_) [rad]

φ, [Radians) = $\frac{\pi}{180}$ [decimal degree]

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{360} J - 1.39\right)$$

The sunset hours angle, ω_s, is given by:

$$\omega_s = \arccos[- \tan(\delta) \tan(\delta)$$

$$\omega_s = \frac{\pi}{2} - \arctan \frac{- \tan(\delta) \tan(\delta)}{\sqrt{X}}$$

$$R_s = k_{RS} \sqrt{(T_{max} - T_{min}})R_a \text{-------------------}4$$

Where

R_a extraterrestrial radiation $\left[\frac{MJ}{m2\ \ day}\right]$

T_{max} maximum air temprature (0_c)

T_{min} minimum air temprature (0_c)

K_{RS} adjustment coefficient(0.16 … … .0.19) ($0_c^{-0.5}$)

for 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, kRs ≅ 0.16; for 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, kRs ≅ 0.19.

Table 2: Data availability for this study

Stations	Climate data			Data available
	RF	Tem	Wind, Rh & sunshine hours	Year
Debre Tabor	X	X	X	1976-2015
Addis Zemen	X	X	-	1976-2015
Amed Ber	X	-	-	1976-2015
Yifag	X	-	-	1988-2015
Agere Genet	-	X	-	1988-2015

- ✓ *F: Rainfall; Tem: temperature; Rh: Relative humidity*

Rainfall and temperature data from 1988 to 2015 were used for SWAT modeling and from 1976 to 2005 used as a baseline period data for stream flow generation.

3.2.2.2. Spatial data

Digital elevation model (DEM), land use/land cover, and soil map are spatial data inputs required for SWAT model development for hydrological studies.

DEM describes elevation of any point in a given area at a specific spatial resolution as a digital file. It is clear that spatial resolution of DEM is vital in properly representing the area and slope in sub-basins. So, 30 m by 30 resolution DEM was obtained from NASA Shuttle Radar Topographic Mission (SRTM) from the link below *(srtm.csi.cgiar.org/wpcontent/uploads/files/srtm_5x5/TIFF/srtm_44_11.zip).* It was required by SWAT to delineate the watershed with a number of sub watershed and hydrological response units (HRU). It is also used to analyze drainage pattern of the watershed, slope, stream length, width of channel and flow direction within the watershed.

Land use and soil data were collected from Amhara design and supervision works enterprise.

3.2.2.3. Stream flow data

Stream flow data was required for sensitivity analysis, calibration and validation of model simulation in SWAT_CUP. This data was collected from Ethiopia Ministry of Water, Irrigation and Electricity (WoMIE). Data from 1990 to 2013 was used for this study purpose.

Table 3: SWAT input data types, sources and uses

No	Data types	Source	Uses
1	Meteorological data	Ethiopia Meteorological agency, MoWE (Addis Ababa and Bahir Dar Branch)	Input for SWAT Model to develop the model and to bias correction of model projection data.
2	Flow data	Ethiopia Ministry of Water, Irrigation and Electricity	For sensitivity analysis and model calibration and validation
3	Spatial data	Online, Amhara Design and Supervision Works enterprise	Watershed delineation, land use land cover classification, HRU definition and slop classification.

3.2.3. Data Quality Checking

Studies of Engineers and hydrologists on water resources development and management mainly rely on meteorological and hydrological data. Some date required data, in the acceptable level, may be lost due to different reasons such as malfunctioning of measuring instruments, absence of recording by any causes etc. So, filling missing data should part of research work. Also accurate result is not found only by filling of missing data. There are also many errors from recorded data during reading, coding, managing etc. In the principles of hydrology, data should be stationary, consistent, homogeneous and free from trend when we use it for frequency analysis and hydrological modeling (Dahmen and Delft, 1989). Data quality check was done for rainfall, temperature and stream flow data according to data availability.

3.2.3.1. Filling missing data

The presence of missing on climate and hydrology data is common and a serious of problems by producing bias in study results. No matter how much the system is well designed, recorder is professional and measuring instrument is accurate there are missing on meteorological and hydrological data. It is mandatory to fill missing data when a hydrological basin analysis needs a time series continuous data (Surur, 2010).

The issue is how to deal with missing data since impossible to recover actual missing values. Hydrology and related science researchers are usually faced a problem of choosing appropriate missing data handling technics. Missing data affects validity and reliability of results (McKnight et al., 2007). Using inaccurate missing data filling technique also has its own problems on result accuracy. To perform a good analysis and simulation by using long time series data, handling this problem by using accepted missing data filling method is a pre-request.

Many methods are employed to fill missing based on amount of missing data. Arithmetic mean, Normal ratio, Regression and distance power method are commonly used. Choosing an appropriate method is dependent on different parameters such as simplicity, length of missing data and accuracy. Missing data of stations is more than 10% and it is user familiar of normal ratio method which is used for this study. The equation is:

$$P_{X=}\frac{N_X}{n}\left(\frac{P_1}{N_1}+\frac{P_2}{N_2}+\frac{P_3}{N_3}\dots\dots..\frac{P_n}{N_n}\right)\dots\dots\dots\dots\dots\dots\dots 5$$

Where: P_x : value of missing data and N_x : normal precipitation of station in question ; P_1, P_2, P_3 and P_n : recorded precipitation values of the nearest stations 1, 2, 3 and nth stations, respectively, for n observation stations; and N_1, N_2, N_3 and N_n are normal precipitation of 1, 2, 3 and n_{th} stations, respectively.

Missing rainfall and temperature data were filled based on the data availability.

3.2.3.2. Data homogeneity and consistency test

Homogeneity test is highly encouraged to get acceptable results. Due to numbers of reasons stations and gauge data might be have heterogonous. Quality and reliability of data to be used in modeling of hydrology and water resources processes should be tested statistically.

Outcome of homogeneity test is a "decision"; either Ho is rejected leads to data heterogeneity or accepted (data homogeneity). Rejecting the null hypothesis means accepting the alternative hypothesis and it directs there is a date at which there is a change in data or heterogeneity of time series data. So, Pettitt's test developed by Alexandersson in 1986 to detect a change in a series of rainfall data was used. The rainfall, temperature and stream flow data were passed through homogeneity test based on the available data.

Time series of hydro-meteorological data should also consistent if periodic data are proportional to an appropriate simultaneous time series (Chang et al., 1974). Double mass curve analysis for checking consistency of a hydrological and meteorological data records were considered to be an essential tool. The consistency of rainfall data were checked for this study.

3.2.3.3. Trend test of hydro-meteorological data

Mann, (1945) and Kendall, (1970) non-parametric test was used to investigate existence or non-existence of trend in data planned to use for this purpose.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0. Outcome of a test is a decision; either Ho is rejected or accepted. Rejecting H_o means accepting the alternative hypothesis, and it directs the presence of trend of time series data (Arun et al., 2012). P-value is computed using exact method either one or two tailed.

Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, statistic S is incremented by 1. On other hand, if data value from a later time period is lower than a data value sampled earlier, S is decreased by 1. Net result of all such increase and decrease yields final value of S.

Mann-Kendall S Statistics is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{Sign}(xj - xi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

$$Sign(xj - xi) = \begin{cases} 1 \text{ if } xj - xi > 1 \\ 0 \text{ if } xj - xi = 1 \\ -1 \text{ if } xj - xi < 1 \end{cases}$$

A positive and negative value of S indicates an upward and downward trend respectively (Arun et al., 2012).

Variance of the data is computing by using the following formula.

$$E(S) = 0, \mathrm{Var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(i)(i-1)(2i+5)}{18} \ldots..7$$

Where: ti is considered as number of ties up to sample i.

Software used for performing statistical Mann-Kendall test is Addinsoft's XLSTAT2016 which was used for this study. It was tested at 95% confidence level for precipitation, both maximum and minimum temperature and stream flow data. Two tailed test was used.

3.2.4. Soil and Water Assessment Tool (SWAT)

SWAT has been updated to recent version ArcSWAT 2012 which is an ArcGIS 10.x extension. In ArcSWAT, watershed is delineated into a number of sub-basins, which are further divided into Hydrological Response Units (HRUs) that consist of homogeneous land use, slope, and soil characteristics. Subdividing of watershed into HRUs enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. Runoff is predicted separately for each HRU and routed to obtain total runoff for the watershed which increases accuracy of load predictions (Winchell et al., 2009). By delineating the watershed, user is able to reference different areas of the watershed to one another spatially. For each sub-basin input, information is grouped into the following categories: climate; groundwater; HRUs; ponds/wetlands; and the main channel draining the sub-basin (Neitsch et al., 2009).

Rainfall data from Addis Zemen, Debre Tabor, Amed Ber and Yifag station whereas temperature data from Debre Tabor, Addis Zemen and Ager Genet were used for SWAT input. The remaining required meteorological data were obtained only from Debre Tabor station.

3.2.4.1. SWAT model setup

Working on SWAT has process which are project setup, watershed delineation, hydrologic response unit (HRU) definition, writing up the input table, editing SWAT input(if necessary) and finally SWAT simulation or run the SWAT model.

Watershed delineation was done by watershed delineator tool in ArcSWAT interface of ArcGIS Digital Elevation Model (DEM) of a target area as input. It allowed delineating the watershed and sub-basins. It was done due to outlining the target area of the study.

Land use land cover and soil map was imported to SWAT2012 database and loaded for land use and soil classification of the study area since having their own impact on runoff generation. Slope classification was done since it has its effect on stream flow generation.

Collected and arranged meteorological data from 1988 to 2015 and location of meteorological stations were prepared based on ArcSWAT 2012 data input format and then loaded accordingly under writing up section for stream flow generation.

SWAT was then run monthly by providing two year warming period out of 28 year data (1988 to 2015). Simulation result was saved since used for SWAT_CUP input for sensitivity analysis and model calibration and validation. See the detailed procedure from SWAT user manual.

3.2.5. Model Sensitivity, Calibration and Validation Analysis

3.2.5.1. Model sensitivity analysis

Parameters are many which affect hydrologic system of a specific catchment. But all parameters are not equally affects runoff generation. Some parameters are more sensitive but some of them might not have any effect or have only a little effect.

Therefore, sensitivity analysis was carried out to determine the number of optimized parameters to obtain a good fit between SWAT simulated and observed data. It helps to know the relative ranking of which parameters are mostly affect output due to input variability van Griensven et al., (2002) which reduces uncertainty of model out puts and provides parameter estimation guidance for model calibration and validation.

Sensitivity analysis can be local and global (Haan, 2002). In local sensitivity analysis, the effect of each input parameter is determined separately by keeping other model parameters constant. In global sensitivity analysis all model inputs are allowed to vary over their ranges at same time. Global senility is based on use of probabilistic characteristics of input random variables.

Sensitivity analysis was undertaken by using SWAT-CUP through used global sensitivity design method. SWAT-CUP uses t-test and p-value to rank sensitive parameter that corresponds to greater change in output response. A t-stat provides a measure of sensitivity (larger in absolute value of t-stat are more sensitive) and p-values determined significance of sensitivity. A value close to zero has more significance in p-value. To improve simulation result and thus understood behavior of hydrological system in Ribb catchment, sensitivity analyses were conducted using 23 flow parameters which were selected though reviewing different paper works which were done at Blue Nile and specifically Lake Tana sub-basin. Sensitivity analysis was done by 15 year flow data (1990 to 2004).

No	Parameters	Description	Min	Max
1	ALPHA_BF	Base flow alpha factor [days]	0	1
2	BIOMIX	Efficiency of soil biological mix (dimensionless)	0	1
3	CANMX	Maximum canopy storage (mm)	0	10
4	CH_K2	Channel effective hydraulic conductivity (mm/hr.)	0	15
5	CH_N2	Manning's n value for main channel	0	1
6	CN2	Initial SCS CN II value	-0.15	0.15
7	EPCO	Plant up take compensation factor	0	1
8	ESCO	Soil evaporation compensation factor	0	1
9	GW_DELAY	Ground water delay (days)	-30	60
10	GW_REVAP	Ground water "revap" coefficient (days)	-0.036	0.2
11	GWQMN	Threshold water depth in the shallow aquifer for flow (mm	-1000	1000
12	REVAPMN	Threshold water depth in the shallow aquifer for "revap" (mm)	-750	750
13	A_SOL_ALB	Most soil albedo	-0.25	0.25
14	SOL_AWC	Available water capacity (mm water/mm soil)	-0.2	0.2
15	SOL_K	Saturated hydraulic conductivity (mm/hr)	-0.15	0.15
16	SOL_Z	Soil depth (mm)	-0.15	0.15
17	SURLAG	Surface runoff lag time (days)	0	10
18	TLAPS	Temperature laps rate (^{0}c/km)	0	50
19	CH_COV	Chanel cover factor	0	1
20	CH_EROD	Channel erodibility factor	0	1
21	ALPHA_BF_D	Base flow alpha factor [days]	0	1
22	ALPHA_BNK	Base flow alpha factor for bank storage	0	1

23	RCHRG_DP	Deep aquifer percolation fraction	0	1

Table 4: Default parameters used for sensitivity analysis

3.2.5.2. Model calibration and validation

Model calibration and validation was conducted by using selected sensitive parameters obtained during sensitivity analysis. Monthly observed flow data was divided in to two for calibration and validation. Data from 1990 to 2004 was used for calibration whereas to validation from 2005 to 2013. Model calibration is modification of input parameters and comparison of predicted output with observed values until a defined objective function is achieved (James and Burges, 1982).

There are different calibration processes in SWAT_CUP such as SUFI_2, Parasol, and GLUE. But calibration process in SWAT_CUP using SUFI_2 algorithm is commonly used in Tana sub basin and Blue Nile system and showed best fitted result for *Gilgel Abay*, *Gumara*, *Ribb*, and *Megech* catchments (Setegn et al., 2009a). In addition, SUFI-2 parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data.

3.2.6. Model Performance Evaluation

Model performance is evaluated for the extent of its accuracy (Goswami et al., 2005). Level of goodness of fit of models has been evaluated by objective function that measures level of agreement between observed and SWAT model output data. For this study, the following two objective functions have been used.

3.2.6.1. Nash-Sutcliffe (NS) efficiency criterion

It measures normalized statistic that indicates how well a plot of observed with simulated data fits 1: 1 line and determines relative magnitude of residual variance compared to measured data variance.

$$N_{S=}1-\frac{\sum_{i=1}^{n}(Q_{Simu}(i)-Q_{observed})2}{\sum_{i=1}^{n}(Q_{obser}(i)-Q_{obser\,mean})2}\text{.................... ....8}$$

Q_{simu} is simulated flow; Q_{obser} observed flow and Q obser is observed flow average.

Range of NSE lies between 1.0 (perfect fit) and -∞. An efficiency of lower than zero indicates mean value of observed time series would have been a better predictor than the model.

The differences between observed and predicted values are calculated as squared values which considers as a drawback. As a result larger values in a time series are strongly overestimated whereas lower values are neglected (Legates and McCabe, 1999). For quantification of runoff predictions, this leads to an overestimation of the model performance during peak flows and an underestimation during low flow conditions.

3.2.6.2. Coefficient of determination (R^2)

It estimates combined dispersion against single dispersion of observed and predicted series. Range of R^2 lies between 0 which means no coloration at all and 1 means dispersion of prediction is equal to observation.

$$R^2=\frac{\sum_i(Q_m-\overline{Q_m})(Q_{S,J}-\overline{Q_S)2}}{\sum_i(Q_{m,j}-\overline{Q_m})2\ \sum_i(Q_{S,J}-\overline{Q_S)2}}\text{.........................9}$$

Q_m: measured discharge, Q_s: simulated Stream, Q_M bar: average measured discharge and Q_s: average simulated discharge.

Table 5: Performance rates of NSE and R2

Performance	NSE	R2	PBIAS
Very good	0.75<NSE≤1	0.75< R^2≤1	PBIAS ≤±10
Good	0.6<NSE≤0.75	0.6< R^2≤0.75	±10≤PBIAS <±15
Satisfactory	0.36<NSE≤0.6	0.36< R^2<0.6	±15≤PBIAS<±25
Bad	0<NSE≤0.36	0.25 < R^2 ≤ 0.5	± 25 < PBIAS ≤ ± 50
In appropriate	NSE<0	R^2<0	±50 ≤PBIAS

(Source: Moriasi et al., (2007), Van Liew et al., (2003) and Fernandez et al., (2005))

3.2.7. General Circulation Models (GCMs)

GCMs data are based on coarse information performed at atmosphere, ocean and earth surfaces. Due to using this course input the output of the model also coarse. But to project future climate changes in accurate way, higher resolution information or model result data is highly demanded and advisable to use. Using of GCM data affects result of climate variables prediction at local or catchment level. Accuracy of GCM increased from first to current fifth generation.

Downscaling technique is one commonly used mechanism to correct errors from model data. It allows fine scale information derived from GCM or RCM output and smaller scale climate results from an interaction between global climate and local physiographic details.

3.2.8. Climate Change Projections Data Set for Impact Studies in Nile Basin

Nile Basin Initiative partnership was prepared climate change projections data set for Nile basin studies. This partnership was established for the aims of provision of well vetted climate change projection data at appropriate spatial and temporal resolution for key target end users and provision of scenarios of hydrology of the Nile Basin for various climate change projections (Assefa T., 2019), which is one of the goal among different tasks. The downscaled RCP4.5 and RCP8.5 scenarios historical and future projection precipitation and temperature data from SMHI-RCA4 (RCM) by 0.25 degree resolution which is derived from MPI-M-MPI-ESM-LR (GCM) were used for this study. This NetCDF Meta data were stored in matlab data file by.*mat format. It was opened based on altitude and longitude of target place (grids) used for this study and changed to excel format by using the matlab software**.**

Grid point selection

Selection of Grids to extract required data was carried out based on area contribution, distance to stations and correlation between grid and stations data. Location of grids and stations were overlapped on shape file of study area using ArcGIS10.4. Three Grids (grid2, grid6 and grid7) were selected to extract precipitation and temperature data based on the above criteria.

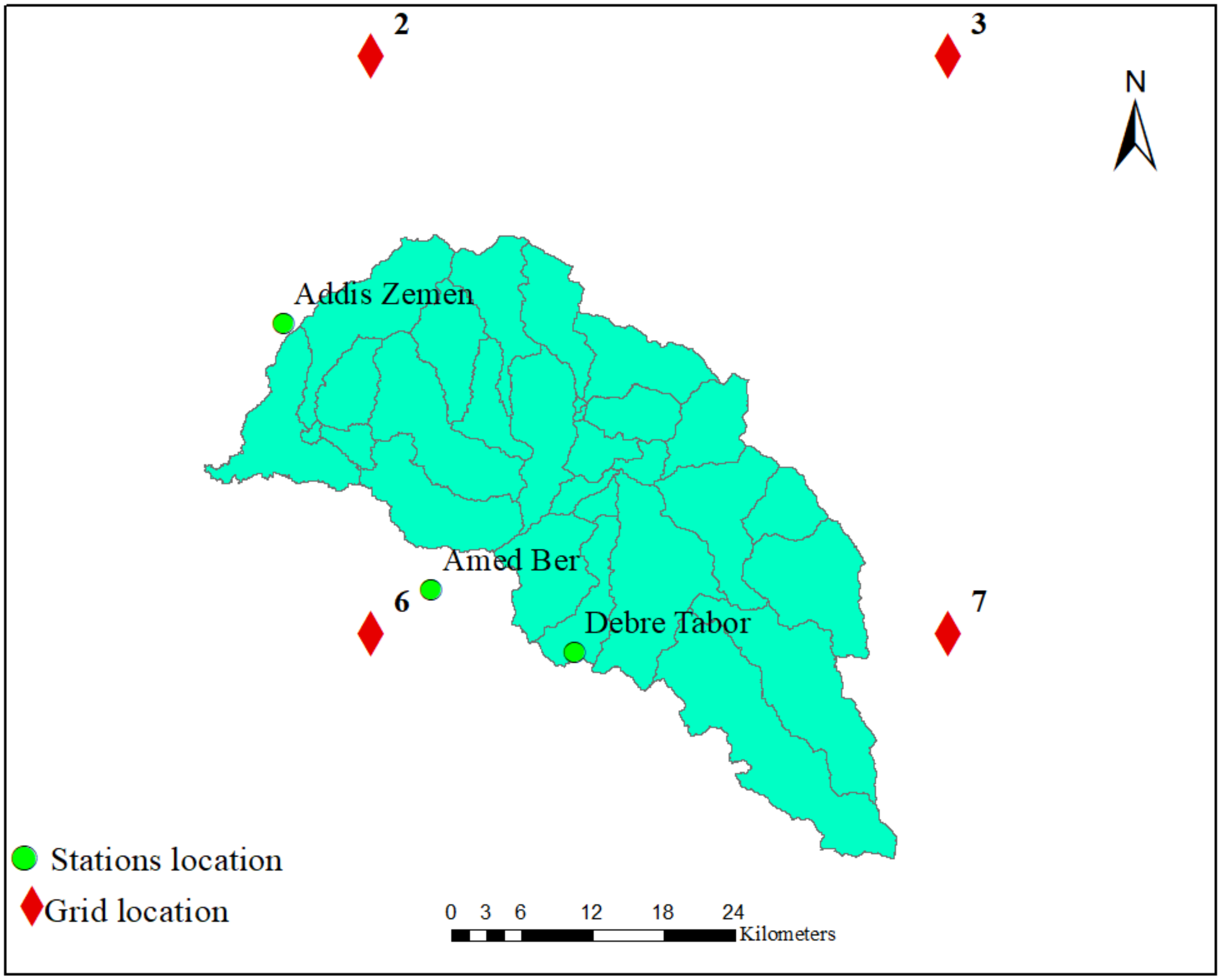


Figure 17: Location of stations and grids which extract data

Bias correction

Climate change projection data set for impact studies in Nile Basin has finer resolution but it is still required further bias correction by specific nearest meteorological stations observed data since shown differences when checked the historical model and observed data. It is since climate change variables especially precipitation has high spatial variability nature that should be bias corrected for the sake of getting an acceptable result. So, precipitation and temperature data was further downscaled in to station level by using bias correction method.

There are various methods used for bias correction in hydrological studies. Linear scaling, power transformation, variance of scaling and quantile mapping are among common methods. Linear-scaling approach was used for this study due to its simplicity and suitability for bias correction at daily bias of precipitation and temperature data (Nigatu, 2013). Precipitation and temperature model data are corrected by multiplier and additive terms, respectively, through using the following formulas.

$$P_{corrected,m,d} = P_{uncorrected(RCM),m,d} \text{ x } \left\lfloor \frac{\mu(P_{observed,m}}{\mu(P_{uncorrected,m}} \right\rfloor \text{..........10}$$

$$T_{corr,m,d} = T_{uncorr\ (RCM),m,d} + \lfloor \mu(T_{Obs,m}) - \mu(T_{uncorr,m} \rfloor \text{.........11}$$

Where: $T_{corr,m,d}$: Corrected temperature on specific month and day

μ : mean value

Bias correction was carried out by two ways after selecting grids closest to each meteorological station.

The first way was by taking nearest station observed data to each extracted model projection data on grid. Observed baseline precipitation data (1976 to 2005) of the three stations namely Debre Tabor, Addis Zemen and Amed Ber were used to correct historical and projection precipitation data extracted from grid7, grid2 and grid6, respectively, (see figure 17 above). Similarly, observed baseline temperature data (1976 to 2005) obtained from Debre Tabor and Addis Zemen stations were used for bias correction of historical and future projection temperature data extracted from grid7 and grip2, respectively. It is due to taking of only one station and grid data was not representative the entire study areas since having diverse topographic features of the catchment. Bias corrected model data in this way was used to simulate stream flow of Ribb River for future climate change impact analysis.

The second way of bias correction was through taking representative model projection data from grids and observed data obtained from station based on their area contribution. Area contributed by each station and grid was classified by using Theissen polygon on the ArcGIS10.4. By dividing the area enclosed by each station and grid it was considered the enclosed area by one station and grid get the same amount of precipitation and temperature. This method gives weight to station data in proportion to space between stations (IHMS, 2006). It was done by applying the formula found below. This bias corrected representative data was used for trend analysis of temperature and precipitation in three time horizons: 2020s (2011-

2040) ,2050s (2041-2070), 2080s (2071-2098) by taking baseline period (1976 -2005) as a reference.

$$P_{Average} = \frac{(\sum_{i=1}^{m} p_i A_i)}{A_{Total}}$$

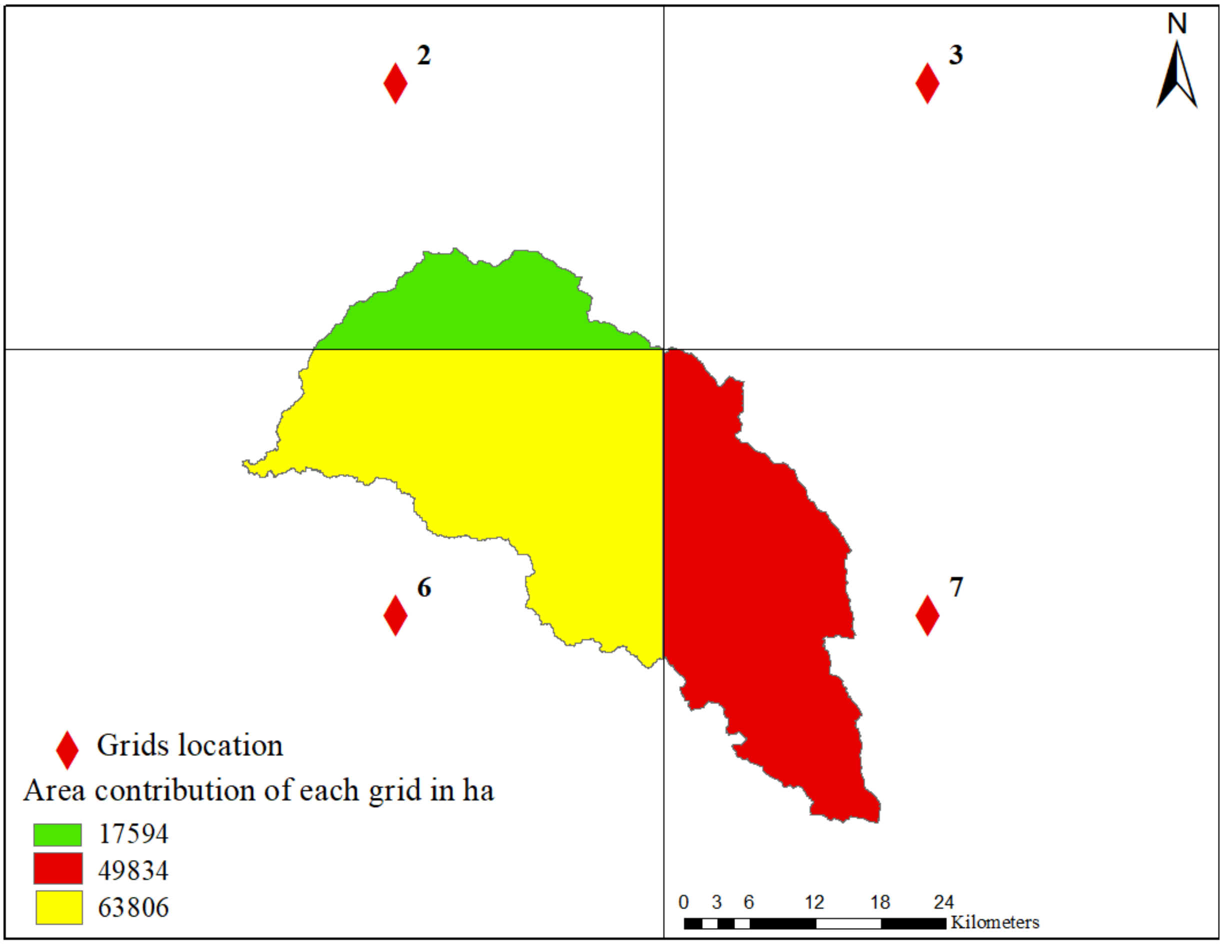


Figure 18: Area contribution of grids to prepare representative model projection baseline and future precipitation data

As you have a look from (figure 18) above, grid6 covers largest and grid2 covers smallest area. Area contributed by grid3 is very small so it is excluded during preparation of representative average precipitation data.

During preparing representative rainfall data used as baseline for bias correction of extracted data from grids, Debre Tabor covers a largest area than other stations (look figure 19 below). It is likely suggest that the prepared representative rainfall data shared more rainfall natures of

Debre Tabor station than Addis Zemen and Amed Ber. Once stations were set by using Theissen polygon shown above (Figure 19), representative precipitation was prepared based on their area contribution.

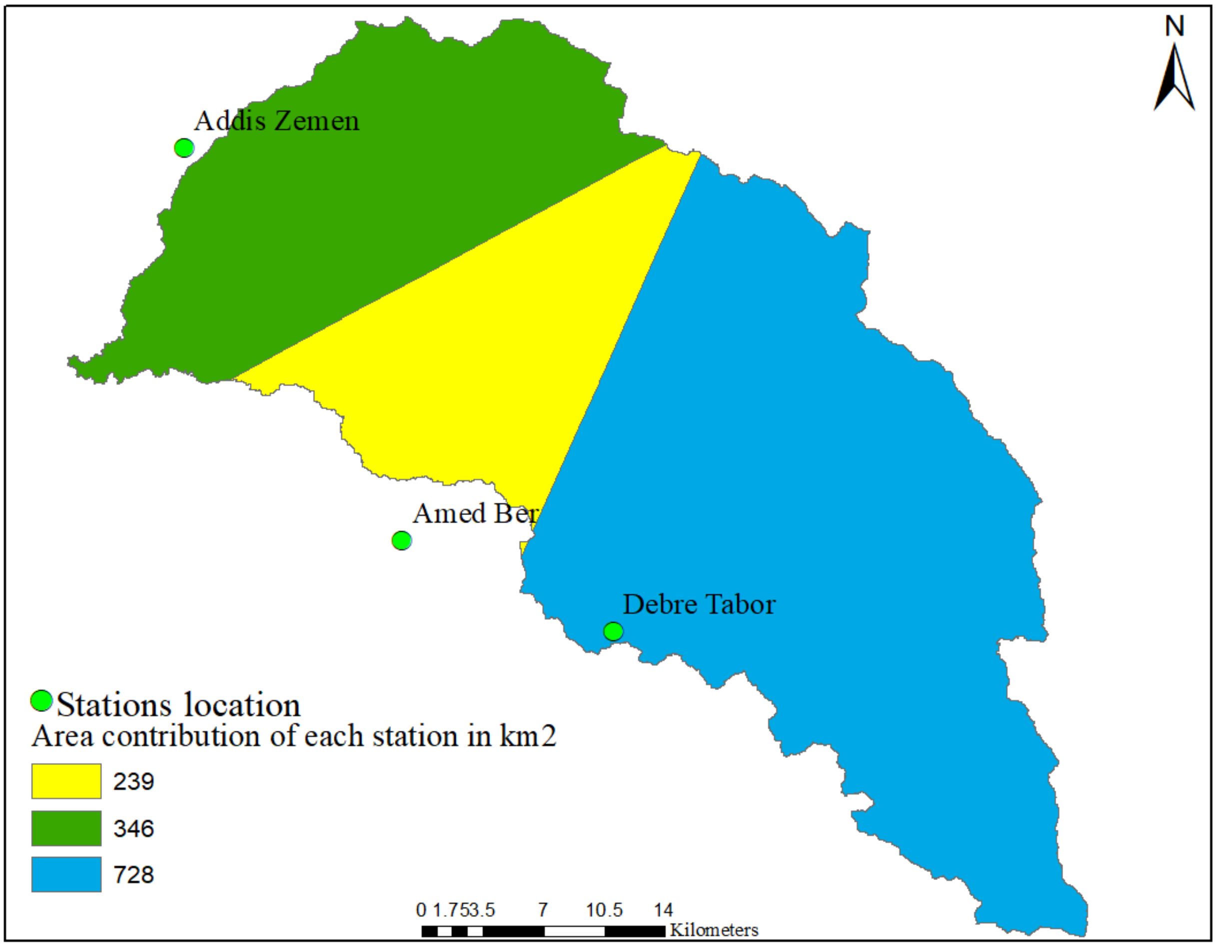


Figure 19: Area contribution of stations to prepare representative baseline precipitation data

Baseline period representative temperature data were also prepared based on area contribution of the two used stations (Debre Tabor and Addis Zemen) like the one done to prepare historical representative precipitation data.

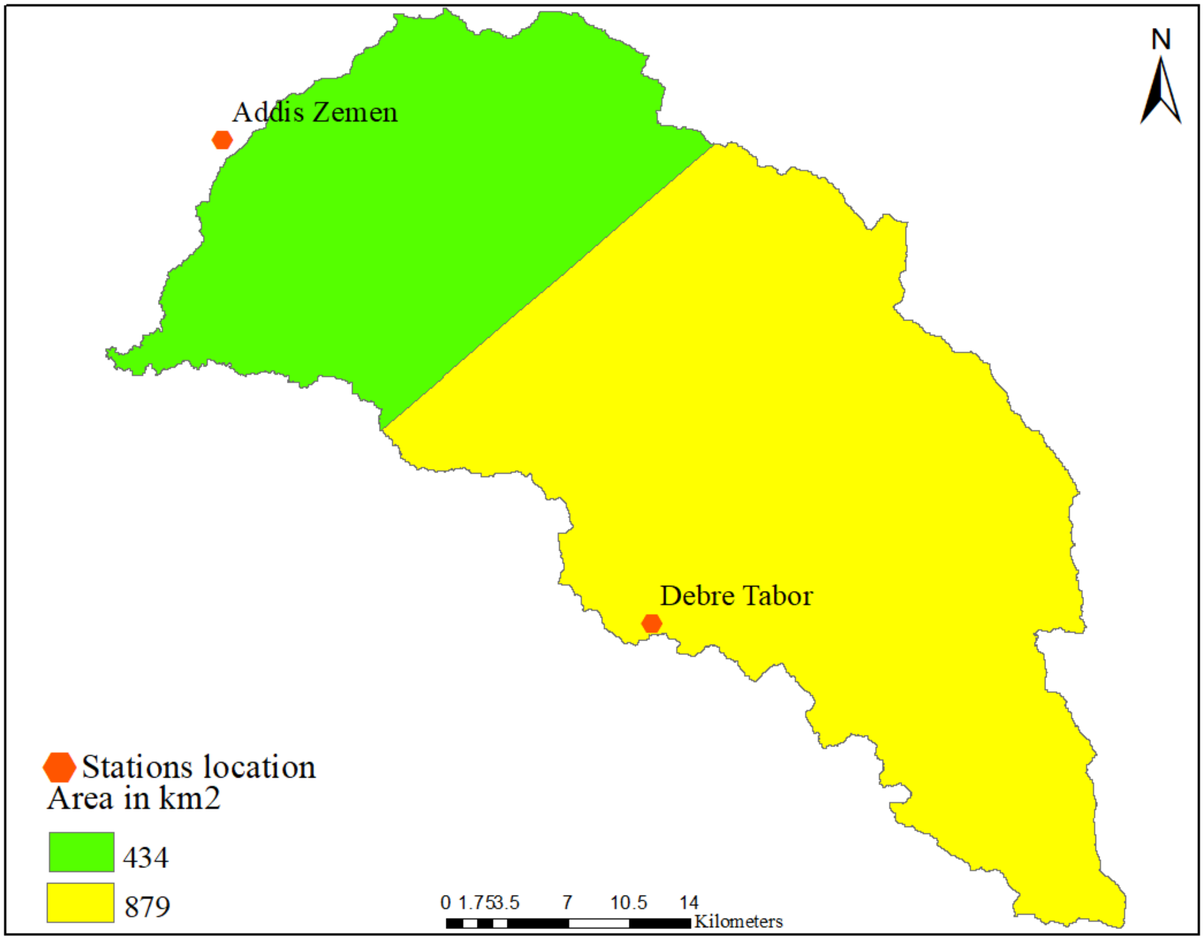


Figure 20: Area contribution of stations to prepare representative baseline temperature data

Based on above information (Figure 20), the prepared representative temperature data is most likely looks Debre Tabor than Addis Zemen since area coverage differences between them.

Area contributions of grid2 and grid6 used to prepare the representative future projection temperature data was done by the same approach shown above.

- ✓ *Both historical and future projected data were then bias corrected following the same approach stated above.*

Accuracy of bias correction method was checked through using mean values of observed and bias corrected model data, Coefficient of determination (R^2), Nash-Sutcliffe (NS) Efficiency and percent of bias (PBIAS).

3.2.9. Impacts of Climate Change on Stream Flow

Analyses climate change impacts on Ribb River stream flow was the main objective of this thesis work. It is very crucial for reduction of risks and optimizing the benefits. It is due to expected climate change having significant impacts on stream flow of Rivers. So, analyzing of future flow condition is important for drought studies, design of water supply systems. It also helps for estimation of safe water withdrawal and classification of stream potential regulating waste disposal to streams (Riggs, 1985).

Stream flow of Ribb River was generated on three time horizons: 2020s (2011-2040) ,2050s (2041-2070), 2080s (2071-2098) and baseline period (1976 -2005) used as a reference. It was done through SWAT model by using as input of bias corrected precipitation data extracted from grid2, grid6 and grid7 and temperature data extracted from grid2 and grid7 (Look on figure 17 about grids). Changes due to climate change impact on generated stream flow were analysis on annual, monthly, seasonal bases and peak maximum and mean minimum flow of the river. Annual stream flow was analyzed by taking mean values of each time horizons and looked change of stream flow from baseline period to 2080s and also between successive time horizons. Stream flow was also analysis on monthly change bases of different time horizons in both scenarios. It was also focused from the baseline to 2080s and also between each successive. Seasonal variation of stream flow was given under consideration which was done through focusing four seasons of the country (summer, autumn, winter and spring). Since distraction and construction of un necessary structures due to lack of information on minimum and peak stream flow, mean annual and monthly maximum and minimum stream flow of the study area were analyzed.

3.3. Materials Used

Table 6: Materials used for this study

No	Materials	Purpose
1	ArcGIS 10.4	Geo-referencing, rectification, and other various spatial analysis
2	ArcSWAT2012	SWAT model development, run execution, present results using reports and maps
3	XLSTAT2016	For data quality testing (Homogeneity test and trend analysis) of meteorological and flow data
4	Google Earth Pro.	Helps to cross check the recorded coordinates of the metrological and gauge stations, to cross check the land use features of the study area.
5	PCPSTAT	Used to prepare weather generator, SWAT database input data
6	DEWPOINT02	To prepare weather generator input data
7	SWAT_CUP2012	Used for model calibration and validation
8	Mintab 18	used to stack the climate and flow data as a SWAT input format
9	UTM Convertor	used to convert the coordinates of the stations and gauge station from latitude and longitude to UTM and UTM to latitude and longitude
10	Medley	used to insert biography and references
11	Matlab	Used to open *.mat format future RCM data set for Nile Basin studies and convert to excel format to make it possible to use.

CHAPTER 4: RESULT AND DISCUSSION

4.1. Quality Analysis of Stream Flow and Observed Climate Data

Data quality test were done to verify the accuracy and readiness of data to use to SWAT model and used as a base period data for future climate change impact projections. It was done based on data availability of meteorological and gauge stations.

4.1.1. Homogeneity Test

Homogeneity of rainfall, temperature and flow data for this study was checked using the statistical homogeneity test software called Addinsoft's XLSTAT2016. Tests presented in this tool were corresponding to alternative hypothesis. XLSTAT2016 was evaluated p value by using a Monte Carlo method at 95% confidence interval. As computed p value is greater than significance level alpha value, 0.05, one has accepted null hypothesis, and rejects alternative hypothesis which is indicated data is homogenous or no any heterogeneity. But if a computed P-value is less than a significant level Alpha it is an indication to reject a null hypothesis and accept other one which indicates data is not homogeneous.

Homogeneity test result of rainfall, temperature and flow data produced using pettitt's test in XLSTAT2016 showed all data are homogeneous.

Table7: Pettitt homogeneity test results with parametric values a) precipitation b) temperature and c) stream flow data

a

Parameter	Stations			
	Debre Tabor	Amed Ber	Addis Zemen	Yifag
K	129	123	133	62
t	1982	2004	2004	2001
p-value	0.31	0.36	0.28	0.70
alpha	0.05	0.05	0.05	0.05

b	Stations					
	Debre Tabor		Addis Zemen		Agere Genet	
Parameter	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
K	181	91	181	171	30	26
t	1998	1992	1996	2006	2008	2008
p-value	0.06	0.72	0.06	0.08	0.051	0.06
alpha	0.05	0.05	0.05	0.05	0.05	0.05

C	Gauge Station
Parameter	Ribb Near Addis Zemen
K	167
t	1978
p-value	0.63
alpha	0.05

4.1.2. Consistency Test of Rainfall Data

Testing of data consistency is a hydrologist and engineers principal task before use data for modeling. When meteorological data are consistent; it indicates readiness of data to use for hydrological modeling. It is a common practice to verify relative consistency with double-mass curve. Relative consistency of time series from different stations is often irrelevant, and data in these series can very suitable for independent use if they are absolutely consistent and homogeneous. Nevertheless, it is still a good idea to verify whether the areas covered by certain stations are in the same hydrological regions or not.

For this study consistency of observed rainfall data from four stations were checked by using double mass curve. Cumulative of all stations rainfall data with cumulative of individual stations data were plotted. The plot of double mass curve indicates reasonable degree of consistency, with no discernible change of slop for any of sites and the R^2 is approximately 1 for all stations. This consistency check was indicated data is well fitted and enough consistent.

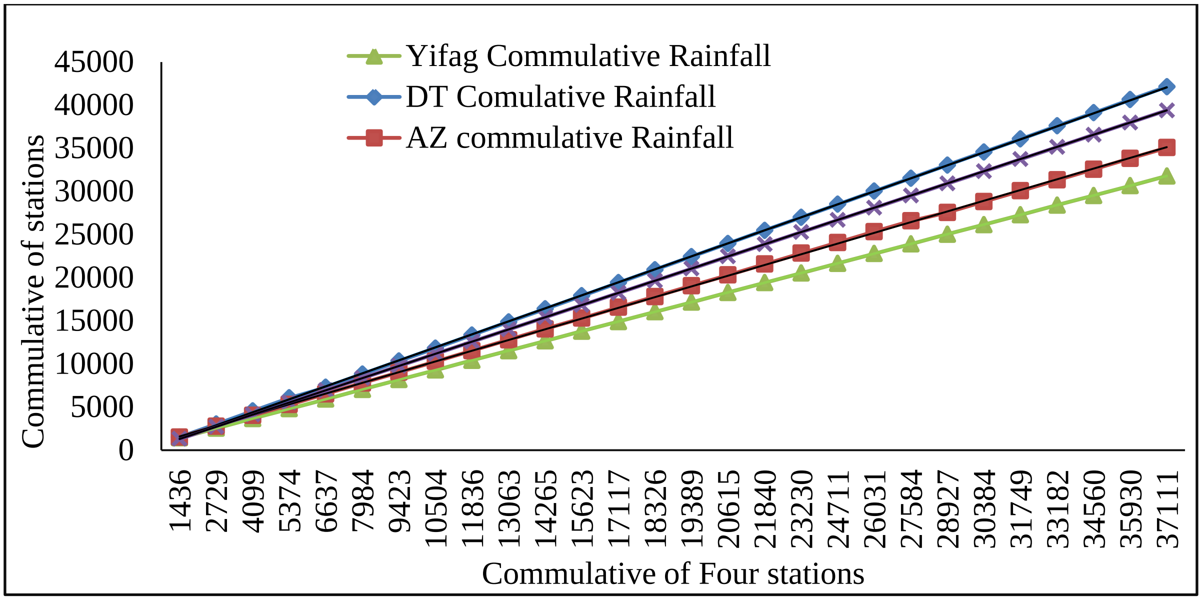


Figure 21: Rainfall data consistency result using double mass curve

- *AZ =Addis Zemen; DT= Debre Tabor; AB= Amed Ber*

4.1.3 Trend Test of Observed Data

Trend analysis of observed rainfall and temperature data of all used stations for this study were evaluated by using Mann-Kendall trend test in XLSTAT2016. The algorithm of this method is based on the principle of when computed P-value is greater than Alpha value; data has no significant trend (Arun et al., 2012). When the reverse is happened; data have a significant trend, however, it is not mean that there is not any change under these situations but it means change is minor. Minor increasing and decreasing trend is based on S value. When S value is negative and positive but P value is greater than Alpha value, it is an indication of minor decreasing and increasing trend on data respectively.

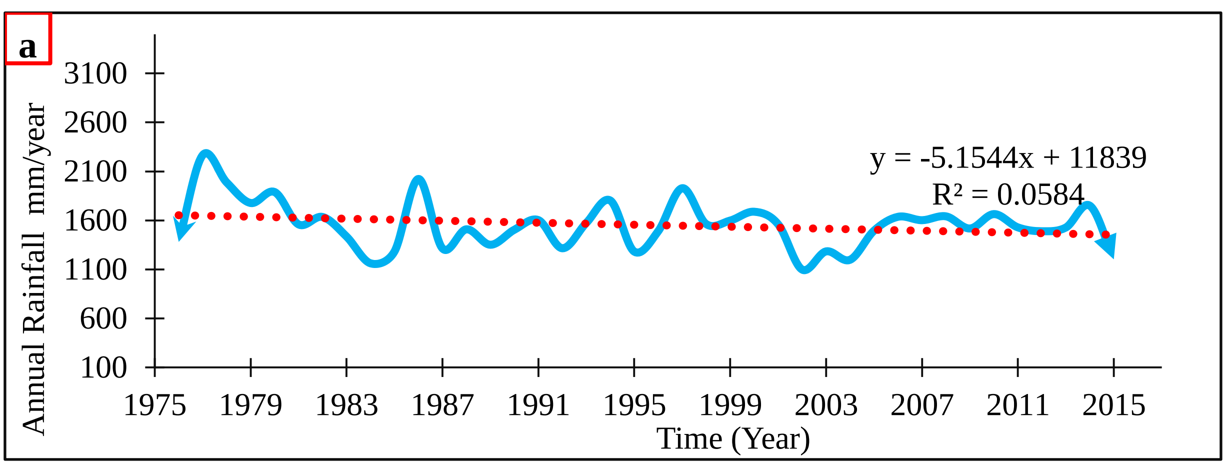
a. Rainfall

Trend test result of rainfall data showed no significant trend. There is also lacks slight consistent increasing or decreasing trend. Rainfall data obtained at Debre Tabor and Yifag stations showed a slight decreasing trend and Addis Zemen and Amed Ber stations data showed minor increasing trend.

Different researches were conducted at Blue Nile basin level for trend analysis. Some findings concluded there is no significant trend on rainfall but others concluded there is a trend. As an evidenced of Seleshi and Camberlin, (2005) study result on trends of extreme seasonal observed rainfall over the period (1965-2002) with a decreasing trends found in summer (June-September) and spring (March-May) seasons. From majority of studies considering total observed precipitation trends, in annual basis over the period from (1990- 2010) in different parts of Blue Nile basin showed no significant change in annual precipitation (Conway, 2000; Seleshi and Zanke, 2004; Cheung et al., 2010 and Gebermical et al., 2013). However, (Jury and Funk, 2013) from (1948-2006) and (IPCC, 2013) in last century showed decreasing trends. Result obtained from this study also shown the same results of the upper findings of not significant and consistent trend in the rainfall of Ribb catchment.

Table 8: Mann Kendall trend test results of observed rainfall data

No	Parameters	Stations			
		Debre Tabor	Amed Ber	Addis Zemen	Yifag
1	Kendall's tau	-0.09	0.17	0.05	-0.06
2	S	-68	133	38	-25
3	Var(S)	0	0	0	0
4	p-value (Two-tailed)	0.44	0.12	0.67	0.67
5	alpha	0.05	0.05	0.05	0.05



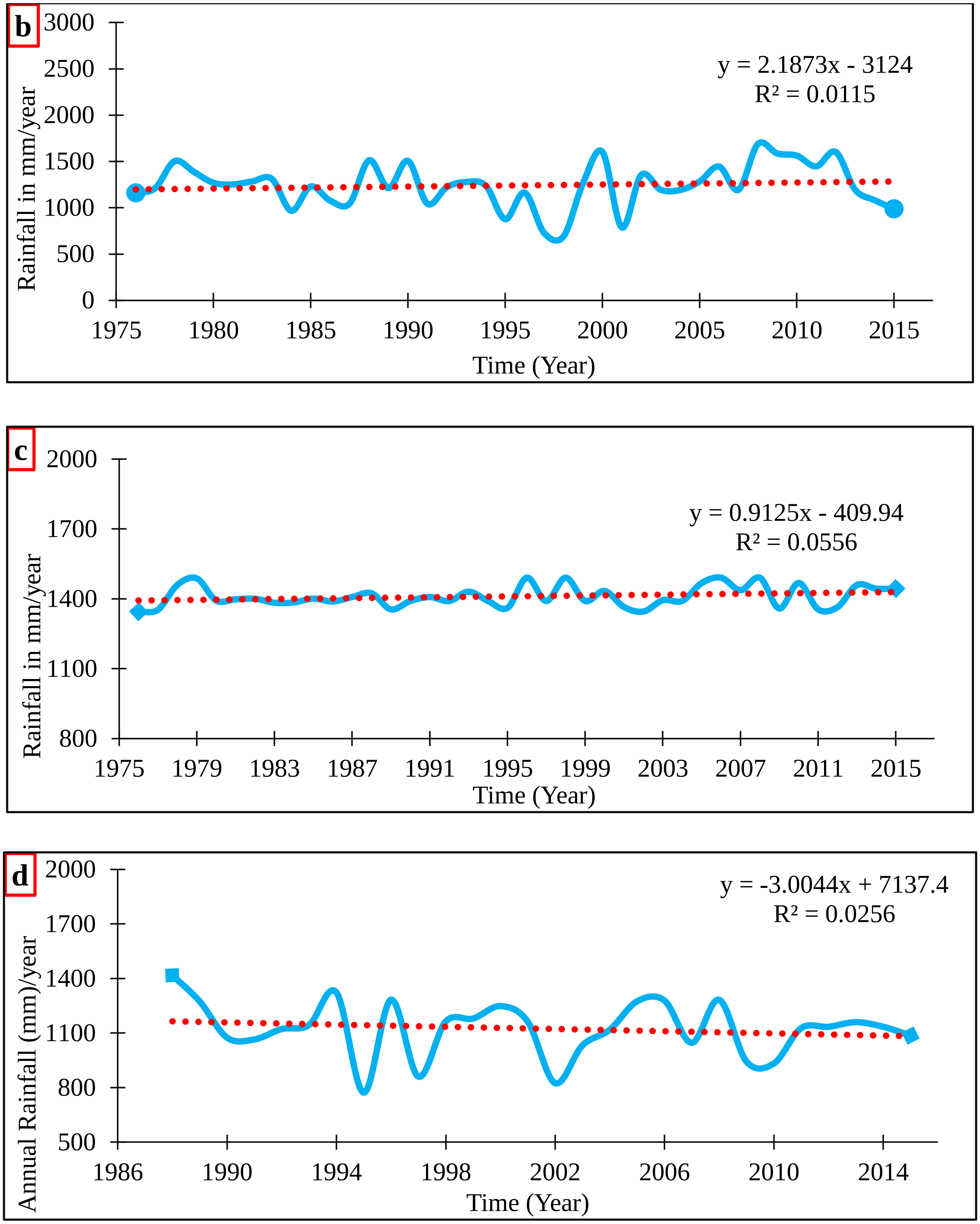


Figure 22: Trend test analysis results of observed rainfall a) Debre Tabor b) Addis Zemen c) Amed Ber d) Yifag

b. Temperature

Research findings on global, Ethiopian and Blue Nile Basin level indicated temperature has increased trend. According to Ethiopian economic association (EEA, 2008) report on past four decades average annual temperature has been increasing by 0.37^0c per decades with in the majorities of warming occurring during second half of 1990s. IPCC, (2013) report also shown climate change could found in East African countries. As Ethiopia is part of this region, temperature change is expected.

This study result at Ribb catchment level had shown maximum and minimum temperature change in past records (1976 to 2015). Change was showed increased trend in all stations data used for this study as a representative of the catchment. However, this increasing trend is still not significant since computed P value is greater than alpha value in all stations except maximum temperature recorded at Addis Zemen. Therefore, maximum temperature around the outlet of the catchment has a significant increased trend while the remaining part of the catchment has not significant increased trend but showed a slight increased trend in all parts of the catchment as shown in the table below.

Table 9: Mann-Kendall trend test result of maximum and minimum temperature data

No	Parameter	Stations					
		Debre Tabor		Addis Zemen		Agere Genet	
		Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
1	Kendall's tau	0.21	0.06	0.23	0.15	0.09	0.24
2	S	162	46	180	116	34	92
3	Var(S)	0	0	0	0	0	0
4	p-value	0.06	0.60	0.04	0.18	0.52	0.07
5	alpha	0.05	0.05	0.05	0.05	0.05	0.05

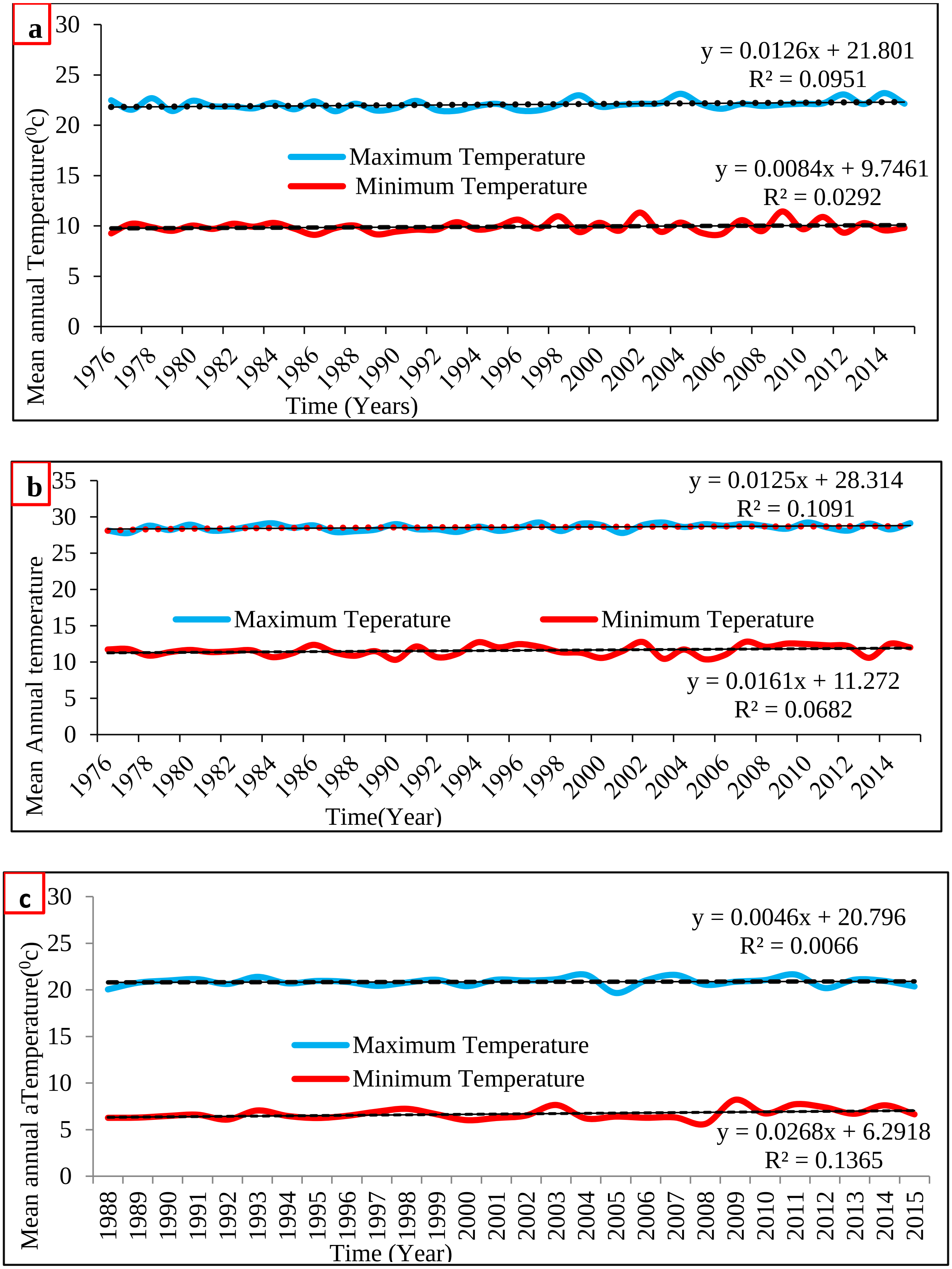


Figure 23: Mann-Kendall trend test results of maximum and minimum temperature a) Debre Tabor b). Addis Zemen c) Agere Genet

c. Stream flow

Historical stream flow data showed a minor decresing trend. It is since temerature and rainfall of the catchment showed slight incresing and decresing trend respectively. As shown from area desciption part of this study land use of the study area also changed to agricultural lands which affects stream flow pattern. Commulative effects of afformentioned and other factors causes a sightly decresing trend of stream flow from the river.

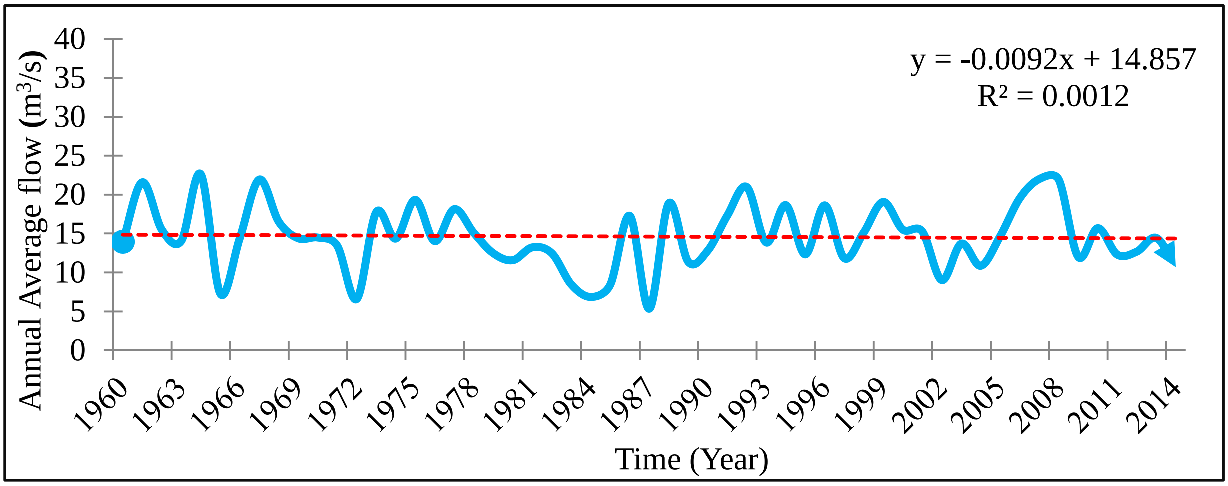


Figure 24: Trend test result of stream flow

Table 10: Mann-Kendall trend test result of flow data

Parameter	Parameter values
Kendall's tau	-0.05
S	-75
Var(S)	18975
p-value	0.59
alpha	0.05

4.2. Modelling of SWAT on the Catchment

Modeling of SWAT should priority task to know model capability and efficiency to simulate stream flow acceptably.

4.2.1. SWAT Model Setup Result

Based on watershed delineation topographic report which was obtained during watershed delineation, maximum elevation of Ribb catchment was 4111 meter above sea level while minimum elevation was 1792 meter above sea level. Mean elevation and standard deviation was 2277.57 and 391.08 meter above sea level respectively.

Monthly simulating results of SWAT by using 28 year meteorological data (1988 to 2015) by providing 2 year warm up period was shown below.

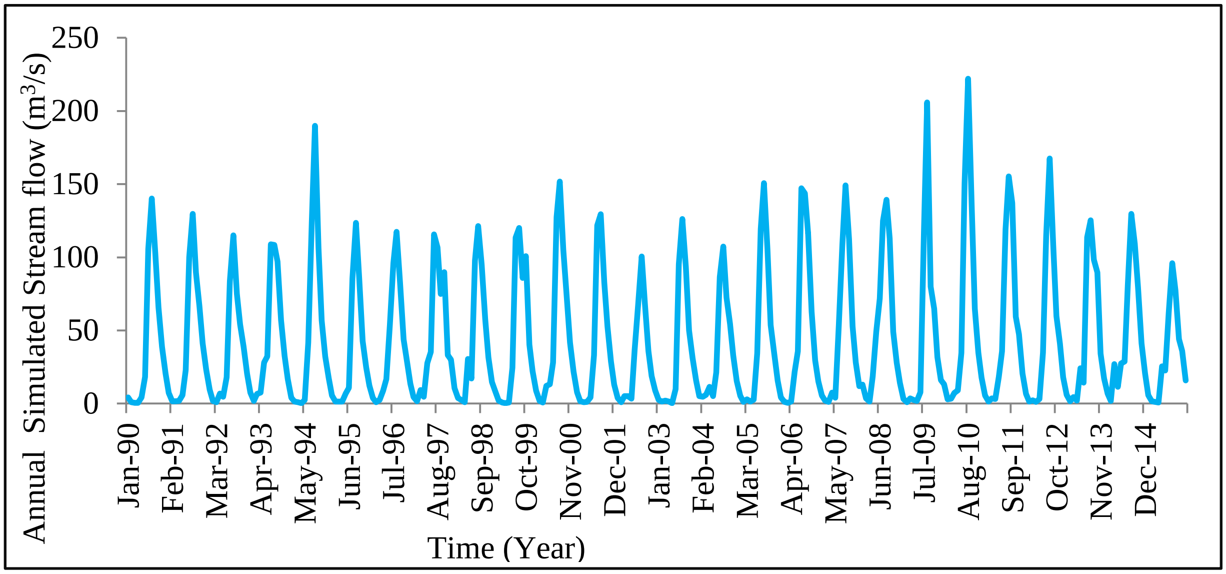


Figure 25: SWAT simulated stream flow

This result was used as an input for SWAT_CUP to sensitivity analysis and model calibrate and validate.

4.2.2. Sensitivity Analysis

Sensitivity analysis is a process of selecting powerful parameters which can significantly affect model simulated result. Working of model calibration and validation with the entire parameters are labor intensive and time consuming. That is why sensitive analysis should carry out as a prerequisite for calibration and validation.

This sensitivity analysis process was done by using SWAT-CUP software of SUFI-2 project type to get acceptable results by using default parameters. Sequential Uncertainty Fitting Algorithm (SUFI-2) is very advantageous since it combines optimization with uncertainty analysis and can handle large number of parameters (Abbaspour, 2011).

Six iterations by 50, 300,500,800, 1000 and 1200 number of monthly simulations using 15 year (1990 to 2004) flow data was conducted then an accepted NSE=0.74 and R^2=0.79 was obtained on final iteration. It is very good in terms of NSE and good based on R^2 results based on Moriasi et al., (2007); Liew et al., (2003) and Fernandez et al., (2005) parameters performance ranking.

Monthly simulation was carried out instead of daily simulation since SWAT generated and observed stream flows were not well correlated to each other. This is because of Ribb River observed flow data was not perfectly recorded since overflown at rainy season (SMEC, 2007). Besides, based on field visit information, recording system of the river was traditional until 4 years ago which causes getting less accurate flow data and the river is affected by sedimentation *(See the attached picture from appendix I).*

Research study results showed monthly simulation gives a good model performance result (R^2 and NSE) result than daily one. Climate change impact evaluation on Blue Nile reservoirs study result of (Habtom, 2009) using A2 and B2 scenarios and HBV-model provides best result on monthly simulation than daily simulation.

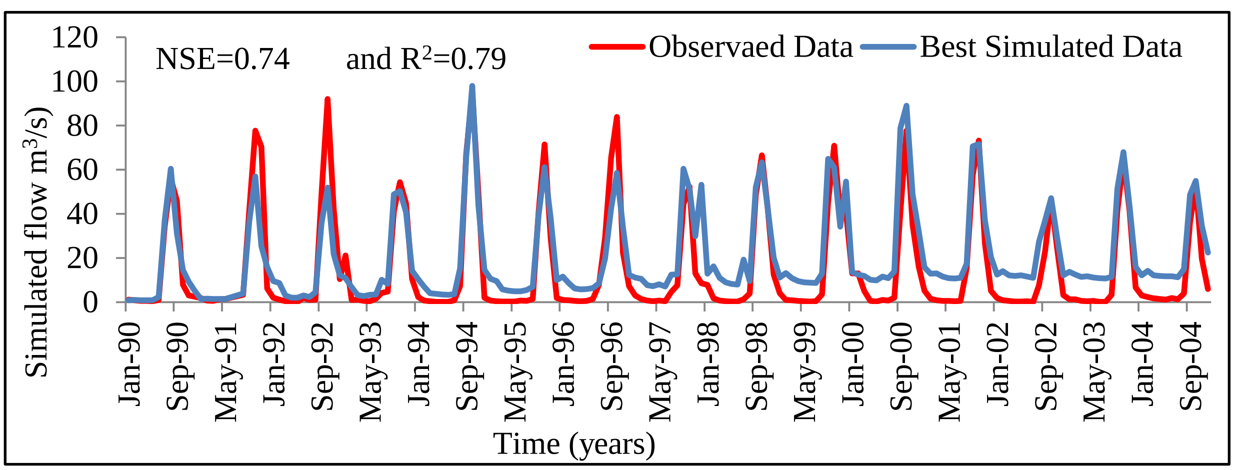


Figure 26: Observed and best simulated flow during sensitivity analysis using default parameters

As you have a look on above (figure 23), observed and best simulated flow showed best correlation. But there was overestimation of model on minimum flow than observed data mainly from 1994 onwards. There is also model underestimation of peak value on 1991 and 1992 and 1995 and 1996. These are due to aforementioned reasons of traditional recording approach of the river cause to less accurate record, affecting by sedimentation and overflow of the river during summer season.

Parameter sensitivity and ranking were measured by using t-Stat, which is coefficient of a parameter divided by its standard error. P-values are used to determine the significance of sensitivity. Parameters having a significant effect are a larger absolute t-Stat and lower p-values. Based on above concepts, eleven (11) sensitive parameters namely: A__GW_DELAY.gw, R__CN2.mgt, A__GWQMN.gw, V__GW_REVAP.gw, V__RCHRG_DP.gw, A__CANMX.hru, V__ALPHA_BNK.rte, A__REVAPMN.gw, A__REVAPMN.gw, R__SOL_AWC.sol, V__ESCO.hru, V__BIOMIX.mgt were selected *(See the attached graph at appendix A.*

Research studies at Blue Nile Basin level was used various sensitive parameters. However, Gebiaw et al., (2015) and Nile, (2015) were used similar parameters of this study result which were used as an evidence of selecting right parameters.

Table 11: Ranks of sensitivity of parameters

N_o	Parameter Name	t-Stat	P-Value	Sensitivity Rank
1	A__EPCO.hru	-0.05	0.96	23
2	V__TLAPS.sub	-0.18	0.86	22
3	V__CH_COV .rte	-0.23	0.81	21
4	R__SOL_ALB .sol	-0.38	0.70	20
5	V__CH_EROD .rte	0.64	0.52	19
6	V__SURLAG.bsn	0.89	0.37	18
7	R__SOL_K .sol	-1.23	0.22	17
8	V__CH_K2.rte	1.39	0.17	16
9	V__ALPHA_BF.gw	-1.48	0.14	15
10	V__ALPHA_BF_D.gw	-1.55	0.12	14
11	R__SOL_Z.sol	1.56	0.12	13
12	V__CH_N2.rte	2.07	0.04	12
13	V__BIOMIX.mgt	-2.78	0.01	11
14	V__ESCO.hru	-3.44	0	10
15	R__SOL_AWC.sol	3.63	0	9
16	A__REVAPMN.gw	-4.15	0	8
17	V__ALPHA_BNK.rte	-4.70	0	7
18	A__CANMX.hru	6.88	0	6
19	V__RCHRG_DP.gw	-7.29	0	5
20	V__GW_REVAP.gw	15.63	0	4
21	A__GWQMN.gw	16.62	0	3
22	R__CN2.mgt	-25.18	0	2
23	A__GW_DELAY.gw	30.85	0	1

Table 12: Parameters with minimum and maximum default and new values after sensitivity analysis

		New value		Default value	
N_o	Parameters	Min	Max	min	Max
1	v__ALPHA_BF.gw	0.14	0.71	0	1
2	v__BIOMIX.mgt	-0.29	0.57	0	1
3	a__CANMX.hru	2.04	7.35	0	10
4	v__CH_K2.rte	-0.08	9.97	0	15
5	v__CH_N2.rte	0.29	0.88	0	1
6	r__CN2.mgt	-0.06	0.11	-0.15	0.15
7	a__EPCO.hru	0.44	1.32	0	1
8	v__ESCO.hru	0.36	1.09	0	1
9	a__GW_DELAY.gw	-2.8	51.62	-30	60
10	v__GW_REVAP.gw	0.07	0.29	-0.04	0.2
11	a__GWQMN.gw	-337.97	986.31	-1000	1000
12	a__REVAPMN.gw	-852.23	215.98	-750	750
13	r__SOL_ALB.sol	-0.42	0.03	-0.25	0.25
14	r__SOL_AWC.sol	-0.04	0.27	-750	750
15	r__SOL_K.sol	-0.02	0.23	-0.15	0.15
16	r__SOL_Z().sol	-0.23	0.02	-0.15	0.15
17	v__SURLAG.bsn	3.84	11.52	0	10
18	v__TLAPS.sub	-11.03	29.66	0	50
19	v__CH_COV.rte	0.41	1.23	0	1
20	v__CH_EROD.rte	0.31	0.94	0	1
21	v__ALPHA_BF_D.gw	0.33	0.98	0	1
22	v__ALPHA_BNK.rte	-0.5	0.5	0	1
23	v__RCHRG_DP.gw	-0.3	0.57	0	1

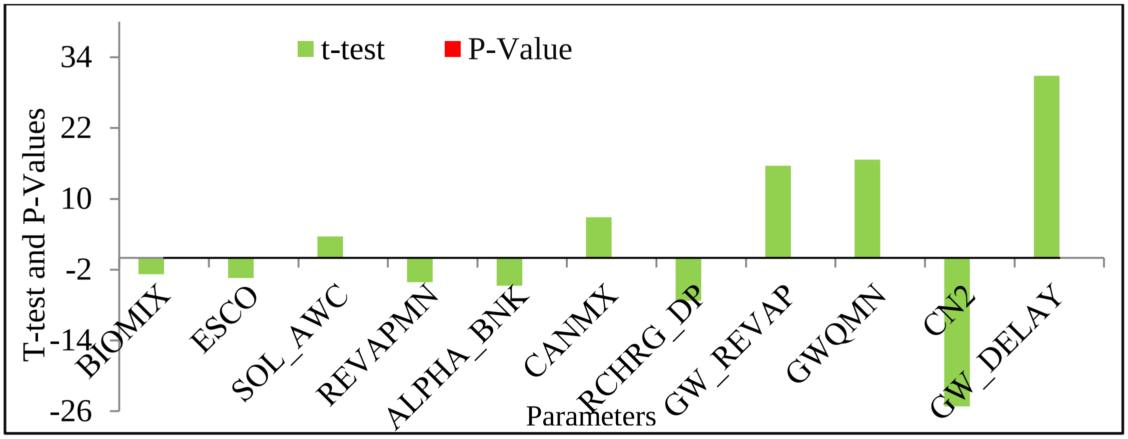


Figure 27: Selected most sensitive parameters

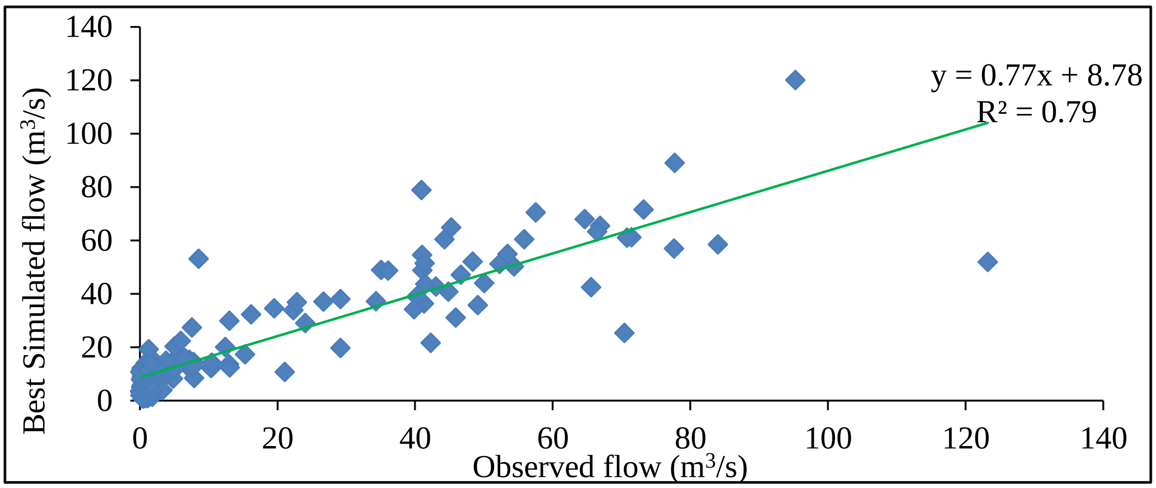


Figure 28: Scatter plot of observed and simulated flow during sensitivity analysis

4.2.3. Calibration and Validation of SWAT Model

Model calibration is an important task to improve result of model simulation and result verification by validation. It is a process of altering parameters which help to improve models predictive accuracy. Calibration and validation are supported by sensitivity analysis as shown above which avoids performing calibration by non-effective parameters. Parameters selected after sensitivity analysis were used for calibration and validation of model.

Four iterations with 100, 250,400, 500 and 600 number of simulations were conducted for model calibration until gotten acceptable results using flow data from 1990 to 2004. At final iteration, accepted values, R^2=0.83 and NSE=0.72, were obtained which is very good based on R^2 and good based on NSE results.

Model validation was provided an acceptable result after 4 iterations with 100, 200, 300 and 400 simulations which were 0.71 and 0.72 of R^2 and NSE respectively though used flow data from 2005 to 2013.

However, many research findings at Blue Nile Bain level shown better NSE and R^2 results during calibration and validation. It is due to aforementioned reasons of Ribb River is overflown in summer rainy season (SMEC, 2007) and was used traditional measuring instrument until 4 years ago as well as the river is affected by sedimentation. Due to that observed and SWAT simulated flow were a bit far apart (model over estimation than observed data).

Table 13: Most sensitive parameters selected for calibration and validation

		Global sensitivity		
Number	Parameter	T-Stat	P-Value	Rank
1	V__BIOMIX.mgt	-2.78	0.01	11
2	V__ESCO.hru	-3.44	0	10
3	R__SOL_AWC.sol	3.63	0	9
4	A__REVAPMN.gw	-4.15	0	8
5	V__ALPHA_BNK.rte	-4.70	0	7
6	A__CANMX.hru	6.88	0	6
7	V__RCHRG_DP.gw	-7.29	0	5
8	V__GW_REVAP.gw	15.63	0	4
9	A__GWQMN.gw	16.62	0	3
10	R__CN2.mgt	-25.18	0	2
11	A__GW_DELAY.gw	30.85	0	1

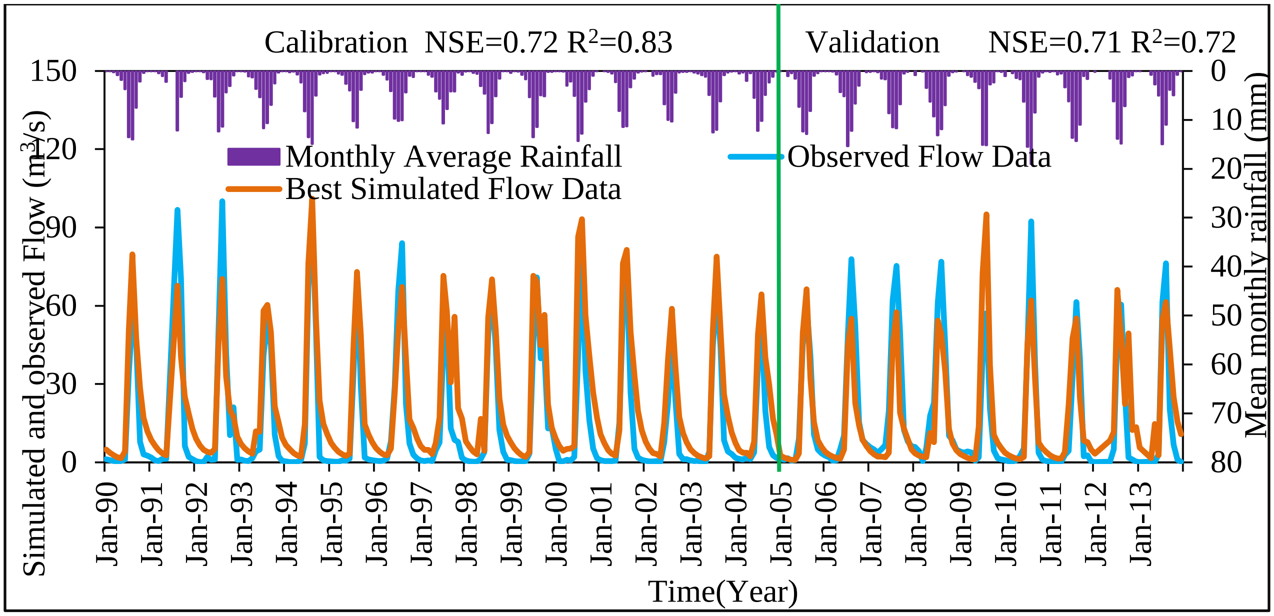


Figure 29: Hydrograph of model calibration and validation results

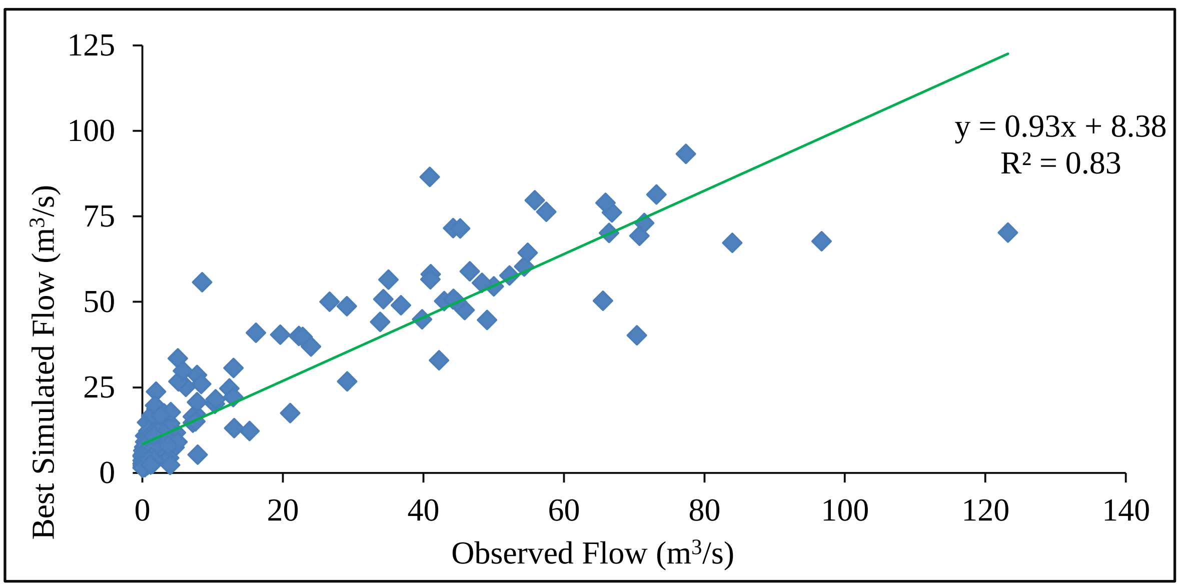


Figure 30: Scatter plot of observed and simulated data during model calibration

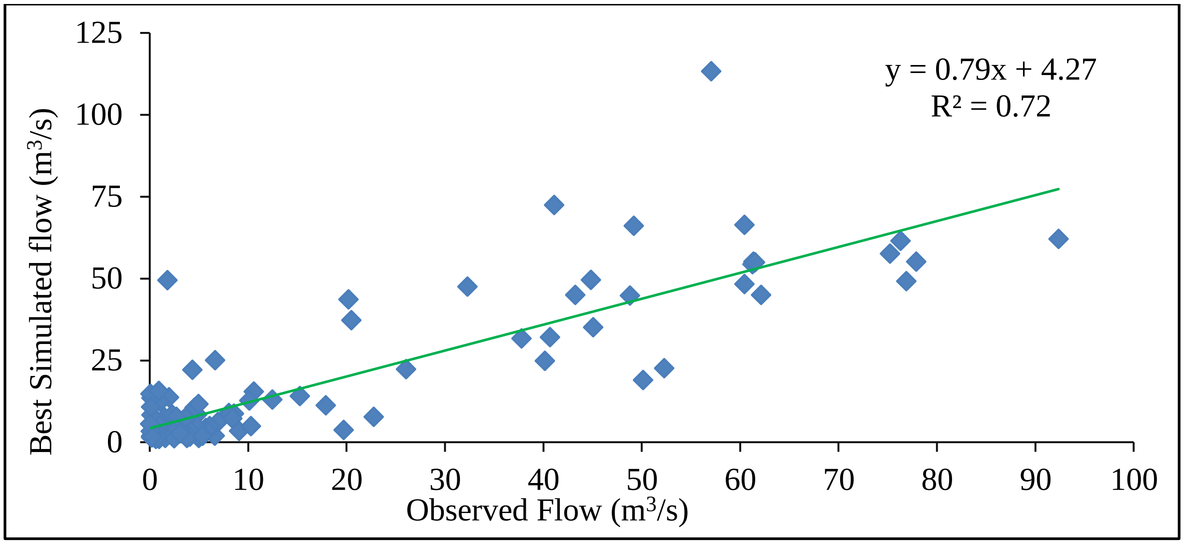


Figure 31: Scatter plot of observed and simulated data during model validation

4.3. Bias Correction of Model Projection Data

Historical model data were not fitted baseline observed data. Existences of similar bias were also assumed in downscaled future climate change scenarios data. Therefore, Historical (baseline) and future projected two scenarios (RCP4.5 and RCP 8.5) data were bias corrected by following the same bias correction approaches using linear scaling method.

Linear scaling bias correction method was used to match monthly precipitation and temperature observed and model historical data. Results of bias corrected model data were tested by mean values of corresponding observed and bias corrected model data, Coefficient of determination (R^2), Nash-Sutcliffe (NSE) Efficiency and percent of bias (PBIAS).

4.3.1. Precipitation

Bias correction was initially done by using each stations data to the nearest corresponding grids data to use for future stream flow generation as stated from the method part. Mean values of stations baseline observed data and corresponding grids (Debre Tabor with Grid7, Amed Ber with Grid6 and Addis Zemen with Grid2) bias corrected precipitation data were showed similar results. Coefficient of determination (R^2), Nash-Sutcliffe (NSE) Efficiency and percent of bias (PBIAS) also showed best agreement as shown in table below.

Table 14: Agreement between baseline period observed and bias corrected model precipitation data (1976 to 2005)

No	Station	Corresponding Grid Number	R^2	NSE	PBIAS
1	Debre Tabor	7	1	1	-0.05
2	Addis Zemen	2	1	1	0.17
3	Amed Ber	6	1	1	-0.01

See the sample of Excel sheet work attached at Appendix B.

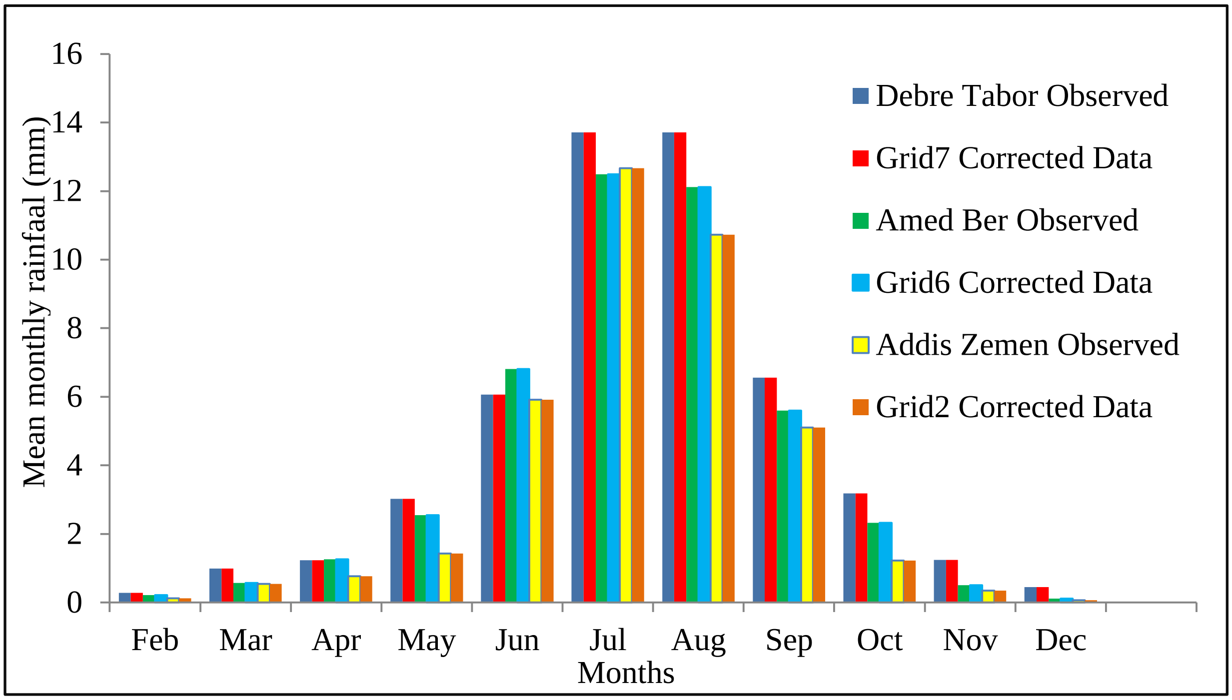


Figure 32: Agreement of mean monthly baseline period observed with corresponding bias corrected mode precipitation data (1976-2005)

Representative baseline model and observed precipitation data was prepared based on their area coverage of stations and grids using Theissen polygon method. Then precipitation data was bias corrected again. Result was evaluated by comparing mean, R^2, NSE and PBIAS like the one did before. Mean values of aerial based representative observed, raw (uncorrected) model and bias corrected model data were 1413.60, 1415.29 and 1413.60 respectively which showed a good agreement between them. R^2, NSE and PBIAS results also showed a very good agreement between baseline observed and bias corrected model data.

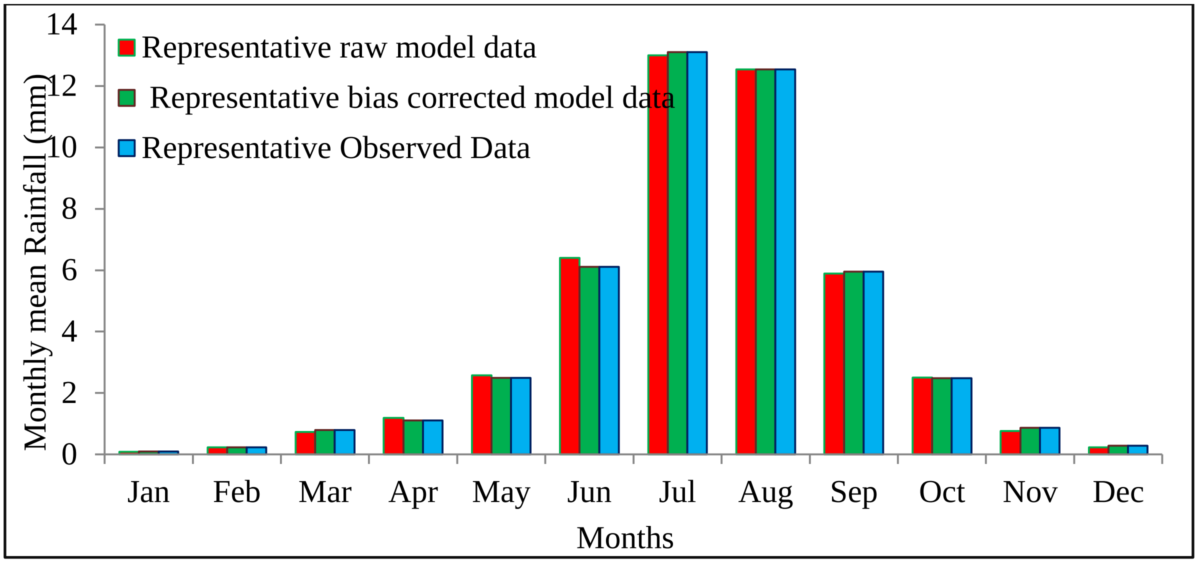


Figure 33: Correlation of representative observed, uncorrected and bias corrected baseline precipitation data (1976-2005)

4.3.2. Temperature

Like precipitation data observed and bias corrected baseline maximum and minimum temperature model data shown very good agreement. Mean annual representative minimum temperature of raw model data, observed and bias corrected model data were 10.57 ^{0}c, 10.52 ^{0}c, 10.52 ^{0}, respectively, whereas representative maximum temperature with the same order could 22.35 ^{0}c, 24.77 ^{0}c and 24.77 ^{0}c. NSE, R^2 and PBIAS results also showed a very good agreement of observed and bias corrected model maximum and minimum temperature data with values of 1, 1 and 0 respectively.

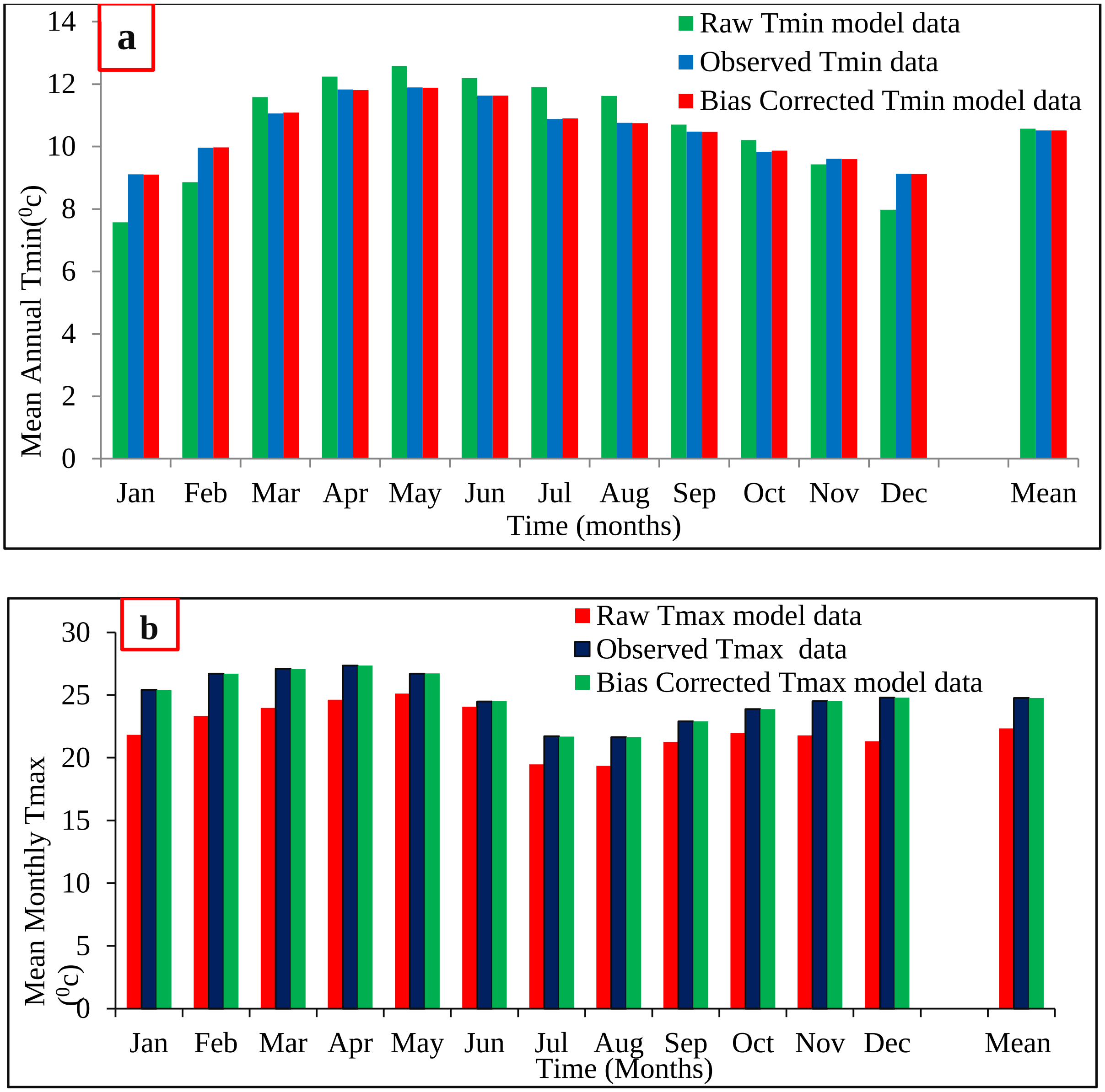


Figure 34: Agreement between baseline bias uncorrected and corrected model and observed (1976-2005) representative temperature data a) Minimum and b) maximum Temperature

✓ *Tmin: minimum temperature; Tmax: maximum temperature*

Raw model data was not shown a good agreement with observed data as shown from above (figure 34). It was underestimated than observed data in maximum temperature of all months and minimum temperature on January, February, November and December. Overestimation was shown on the remaining months on minimum temperature. It can therefore possible to conclude future projections on maximum temperature change are underestimated and up and down estimation on minimum temperature.

Using of these data without bias correction alters results of hydrologist studies by overestimating or underestimates of stream flow. So, it was clearly showed that bias correction should carry out when using projected climate change projection data for Nile Basin studies.

- ✓ *Future projected precipitation and temperature data were also bias corrected through flow the same approach of baseline climate data bias correction method by using observed data as a reference.*

4.4. Trend Analysis of Projected Future Climate Data

Trend analyses of future climate variables (precipitation and temperature) were done through using bias corrected representative model projection data. It was done on annual and monthly bases through using Mann-Kendall trend test on 95% confidence interval. As mentioned at data quality checking part of this study (section 4.1), Mann-Kendall trend test result of positive value S indicates upward (increasing) tend and negative value indicates a downward (decreasing) trend in tested time series data. When the computed P-value is greater than alpha value, it is an indication of no significant trend on climate change variables and the reverse is true when the p values are greater than alpha values. It should also put in mind that there will be a minor change even if the computed P value is greater than alpha value depending on S values. Trend was analysis on three time horizons 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2098) and baseline period (1976 to 2005) as a reference.

4.4.1. Trend Analysis of Projected Future Temperature Change

4.4.1.1. Projected temperature future mean annual trend analysis

a. Maximum temperature

Results of trend test indicated increasing of projected maximum temperature in both RCP4.5 and RCP8.5 scenarios. Mean annual maximum temperature of baseline period was 24.76^{0}c. But it increases by 1.27 ^{0}c, 2.18 ^{0}c and 2.41 ^{0}c on 2020s, 2050s and 2080s time horizon respectively at RCP4.5 scenario from baseline period. Maximum temperature at RCP8.5 scenario could increase by 1.46, 2.90 and 5.15 ^{0}c on 2020s, 2050s and 2080s time period, respectively. This result supports Knutti and Sedlacek, (2013) finding said “the average temperature is projected to increases over 4^{0}c on extreme scenario (RCP8.5)”.

Table 15: Projected mean annual maximum temperature statistics Mann-Kendall trend test

	Scenarios					
	RCP 4.5			RCP 8.5		
Parameter	2020s	2050s	2080s	2020s	2050s	2080s
Kendall's tau	0.32	0.45	0.07	0.11	0.51	0.60
S	137	197	28	47	225	226
Var(S)	0	0	0	0	0	0
p-value	0.014	0.0003	0.60	0.42	0.0001	0.0001
alpha	0.05	0.05	0.05	0.05	0.05	0.05

Maximum temperature shown significantly increasing trend on 2020s and 2050s at RCP4.5 scenario and on 2050s and 2080s at RCP 8.5 scenario whereas only minor increasing trend on 2080s at RCP4.5 scenario and on 2020s at RCP8.5 scenario.

b. Minimum temperature

Like maximum temperature, minimum temperature also showed significant increasing trend in all time horizons at both scenarios except on 2080s time period at RCP4.5 scenario. Mean minimum temperature on baseline period was 10.52 ^{0}c. This could increase by 1.19, 2.09 and 2.45 ^{0}c on 2020s, 2050s and 2080s, respectively, at RCP4.5 scenario from baseline period whereas it could increase by 0.83, 2.46 and 4.64 on 2020s, 2050s and 2080s time period, respectively, at RCP8.5 scenario.

Table 16: Projected mean annual minimum temperature statistics Mann-Kendall trend test

	Scenarios					
	RCP 4.5			RCP 8.5		
Parameter	2020s	2050s	2080s	2020s	2050s	2080s
Kendall's tau	0.44	0.36	0.02	0.30	0.6	0.64
S	191	155	6	131	261	242
Var(S)	0	0	0	0	0	0
p-value	0.0005	0.0053	0.9	0.02	0.0001	0.0001
alpha	0.05	0.05	0.05	0.05	0.05	0.05

Mean annual maximum and minimum projected temperature trend test result showed increasing tendency in future time horizons as shown from the above tables. However, the magnitude of change is not similar at both scenarios of same time horizon and entire successive time horizons. Based on RCP8.5 projection data, future maximum temperature could increase rapidly than minimum temperature from baseline period. It could also increase rapidly than RCP4.5 projection data. However, RCP4.5 scenario projected data showed both maximum and minimum temperature increase with the comparable rate within the same time horizon.

Based on RCP8.5 scenario projection data maximum and minimum temperature could increase by 5.15 and 4.64 ^{0}c, respectively, whereas maximum temperature by 2.41^{0}c and minimum temperature of 2.45^{0}c based on RCP4.5 on 2080s.

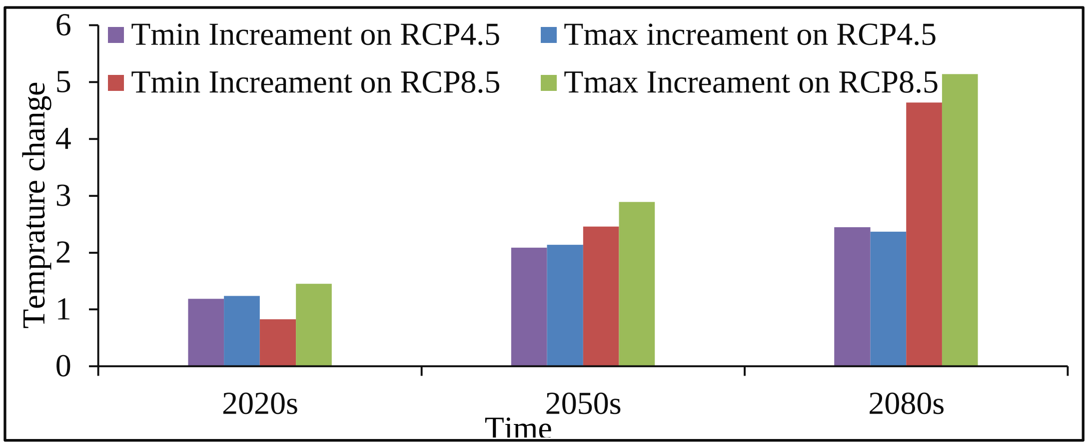


Figure 35: Temperature change on 2020s, 2050s and 2080s from baseline period

Similarly, magnitude of temperature changes also various between successive time horizon (Present, 2020s, 2050s and 2080s). Temperature found a highest magnitude of increase on 2080s based on RCP8.5scenario. Magnitude of increase becomes increased from 2020s to 2080s between successive time horizons. The highest magnitude of maximum and minimum temperature change could 2.25 ^{0}c and 2.18 ^{0}c respectively on 2080s. Lowest magnitude of increase could be by1.45 ^{0}c and 0.83 ^{0}c of maximum and minimum temperature respectively on 2020s. But RCP4.5 scenario showed a decreasing magnitude of increase from 2020s to 2080s between successive time horizons. The highest magnitude of increase showed on 2020s which could be1.24 ^{0}c and 1.19 ^{0}c on maximum and minimum temperature respectively. The lowest magnitude of increase found on 2080s which was 0.23 and 0.36 on maximum and minimum temperature respectively.

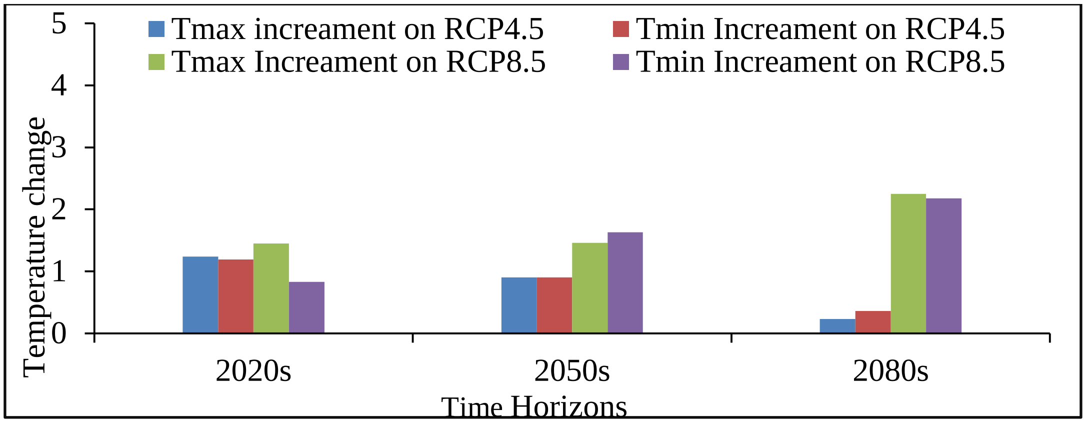


Figure 36: Temperature change magnitude between successive time horizons: 2020s (baseline to 2020), 2050s (2020 to2050) and 2080s (2050 to 2080)

Tmax: maximum temperature; Tmin: minimum temperature

As a general remark even if there are differences on magnitude of increase between and within the same scenarios on maximum and minimum, both scenarios showed maximum and minimum temperature increased in future.

Besides, temperature change was shown relatively the same magnitude of increase on both scenarios until the beginning of 2070s but increasing trend becomes vary onwards. After 2070s, both maximum and minimum temperatures could continue to increase in a higher rate based on RCP8.5 data than RCP4.5.

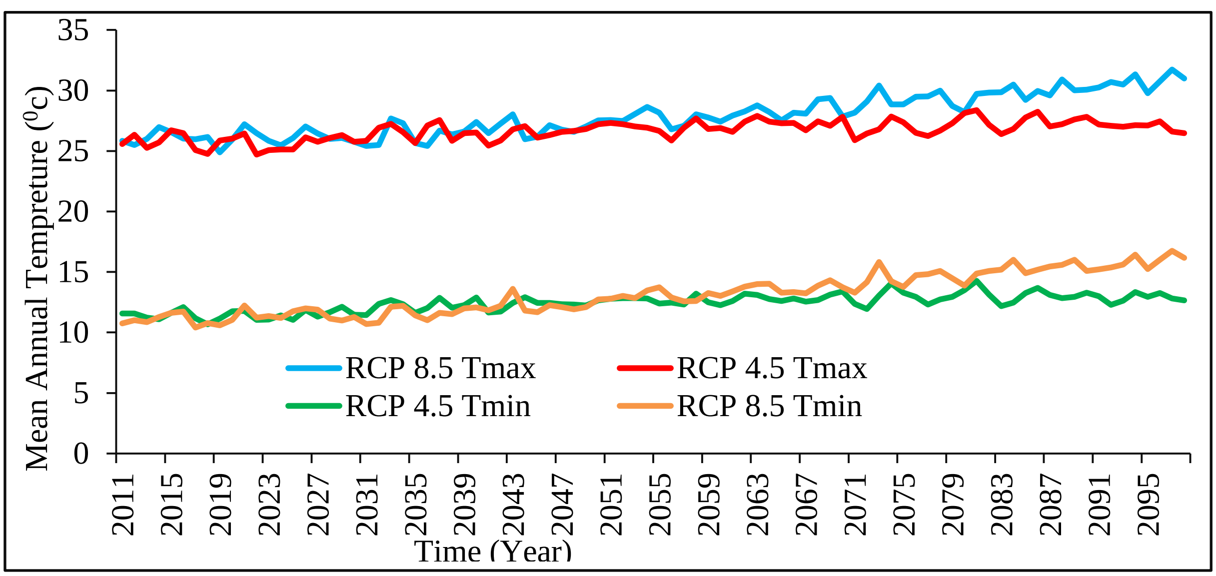


Figure 37: Mean annual projected maximum and minimum future temperature change rate

✓ *Tmax: maximum temperature; Tmin: minimum temperature*

Graphical temperature trend test results of each time horizons are attached at appendix C.

4.4.1.2. Projected temperature future mean monthly trend analysis

Trends of temperature change also checked at monthly bases for the sake of having clear information on climate change. Both monthly maximum and minimum temperature change was checked out at different time horizon and in each month level with respect to successive time horizons by using two scenarios data.

a. Maximum temperature

Mean monthly maximum temperature at the study area could increase between successive time horizons on both scenarios. Baseline and 2080s temperature showed the lowest and highest magnitude of records respectively in all months on both scenarios. Increasing order of used time horizons were baseline, 2020s, 2050s and 2080s.

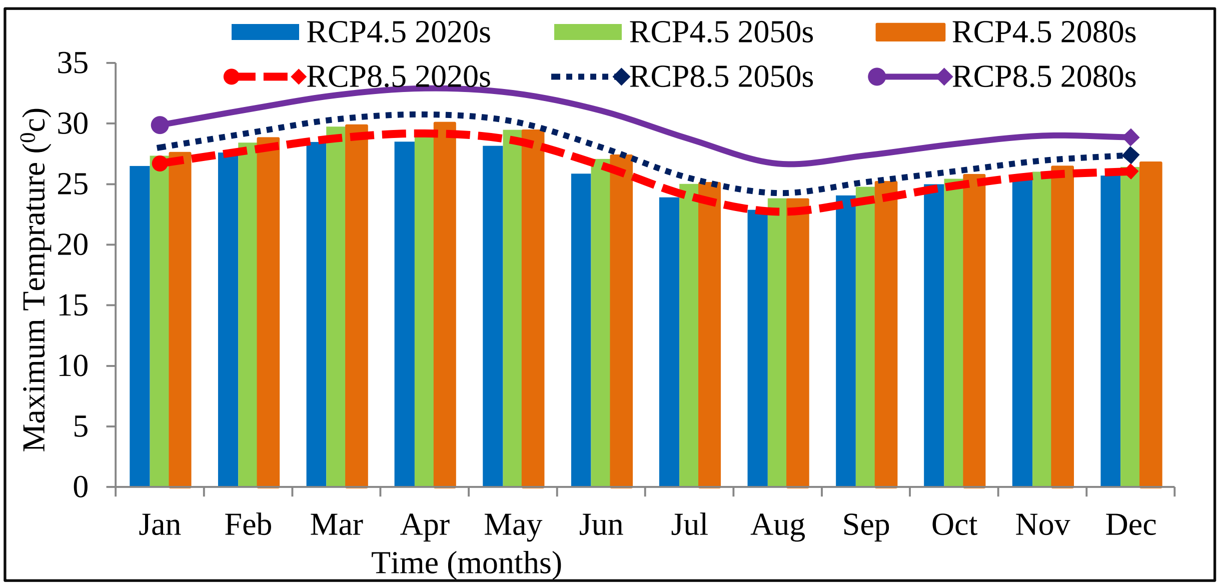


Figure 38: Mean monthly trend test of maximum temperature at RCP4.5 and RCP8.5 on 2020s, 2050s and 2080s

Magnitude of change on mean monthly maximum temperature could not equal in all month from baseline to 2080s. Based on both scenarios data, the highest magnitude change of maximum temperature showed in July. Then magnitude of change become lower and lower until December which has a lowest magnitude change at RCP8.5 scenario and October the lowest magnitude change at RCP4.5. Magnitude of change becomes raised again from January until to reach the highest magnitude change on July on both scenarios. Besides, RCP8.5

scenario showed the largest magnitude of increase than RCP4.5 within the same month because RCP 4.5 scenario is stabilization and incremental scenario of RCP8.5. The maximum and minimum magnitude change on maximum temperature at RCP8.5 scenario could reach 7.02 ^{0}c and 4.02 ^{0}c in July and December, respectively, on 2080s whereas highest and lowest magnitude change of maximum temperature found 3.36 ^{0}c and 1.83 ^{0}c at RCP4.5 scenario in July and October respectively.

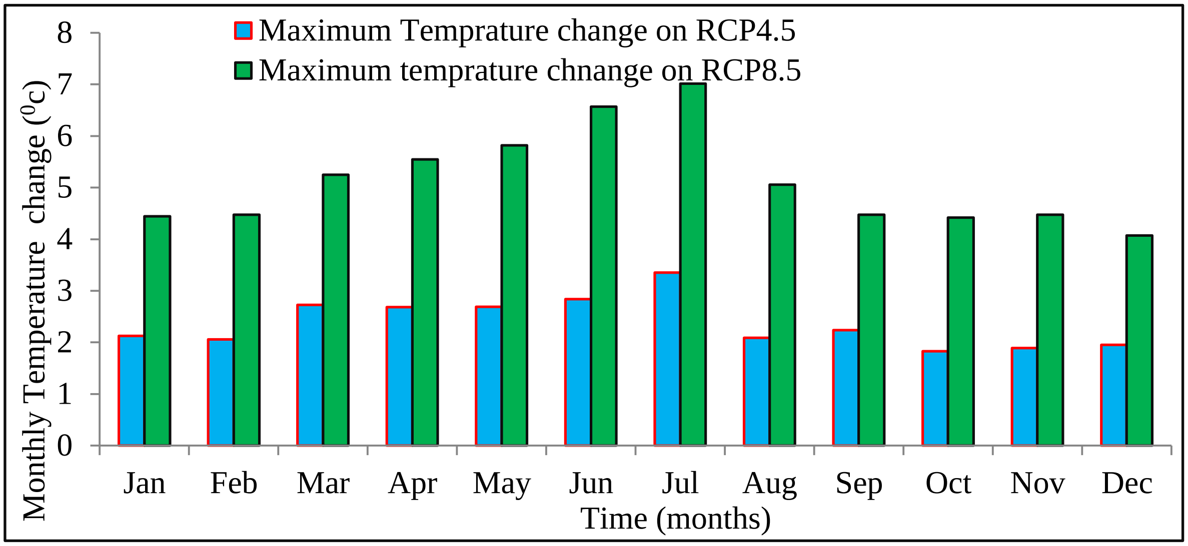


Figure 39: Mean monthly maximum temperature change from baseline period to 2080s

As shown from area description part of this study, the lowest mean monthly maximum temperature was recorded on July in all stations. However, when look up the magnitude change of maximum temperature in future projected model data, July could be the first one. The lowest magnitude future temperature change shown on December based on RCP4.5 scenario projection data. But it was among the months which were shown the maximum temperature records historically. The remaining months also reflected the same trend of the above idea. Based on this finding it may possibly conclude that the months which were showed lower historical temperature record will show maximum magnitude temperature change in the future.

b. Minimum temperature

Magnitude change of mean monthly minimum temperature could increase between consecutive time horizons and from baseline period in both scenarios like maximum temperature. Mean monthly baseline and 2080s minimum temperature showed the lowest and highest records respectively in all months in both scenarios. It is an indication of change in minimum temperature in future. Magnitude of increasing of mean monthly minimum temperature has the order of baseline, 2020s, 2050s and 2080s in all months in both scenarios (see graph 40 below).

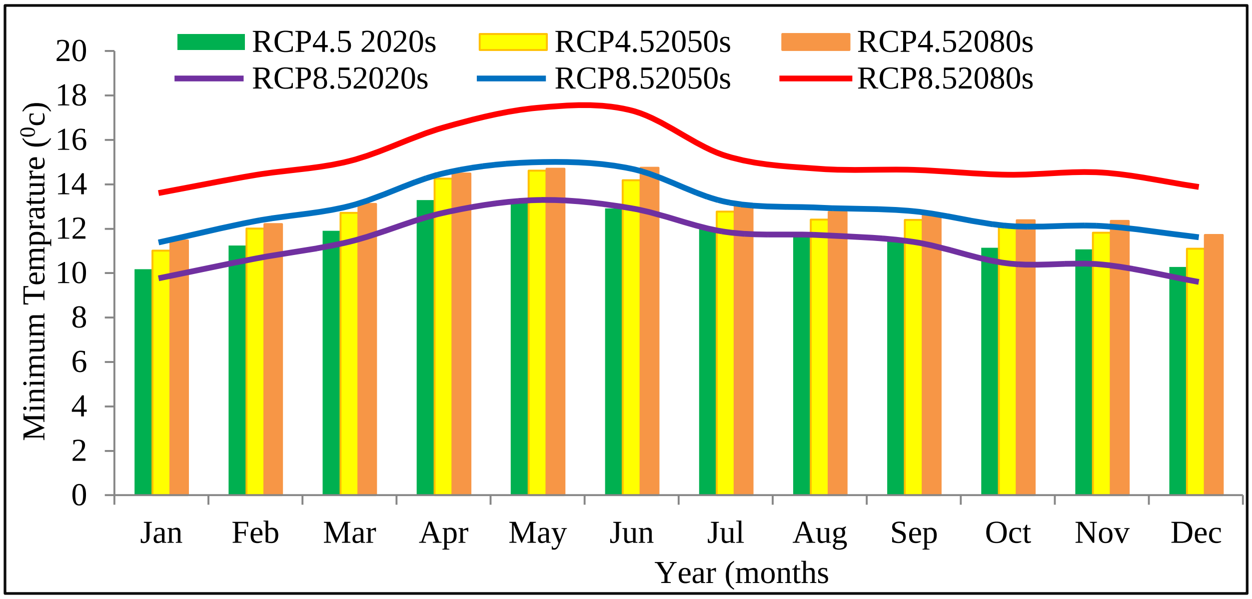


Figure 40: Mean monthly minimum temperature change on 2020s, 2050s and 2080s.

Magnitude of change of mean monthly minimum temperature varies between months from baseline to 2080s. Some months showed a peak change whereas lowest change in some months.

The highest magnitude change is shown in January on 2080s from baseline period which was 6.05 and 3.90 ^{0}c at RCP8.5 and RCP4.5 scenarios respectively. Maximum magnitude change also showed in December which was 5.93 and 3.75 at RCP8.5 and RCP4.5 respectively. The lowest magnitude change of mean monthly minimum temperature is found in August which is 3.08 and 1.14 ^{0}c at RCP8.5 and RCP4.5 scenarios respectively. However, magnitude of change is not equal in both scenarios. RCP8.5 scenario showed the higher magnitude of change than RCP4.5 within the same months as shown on the following graph.

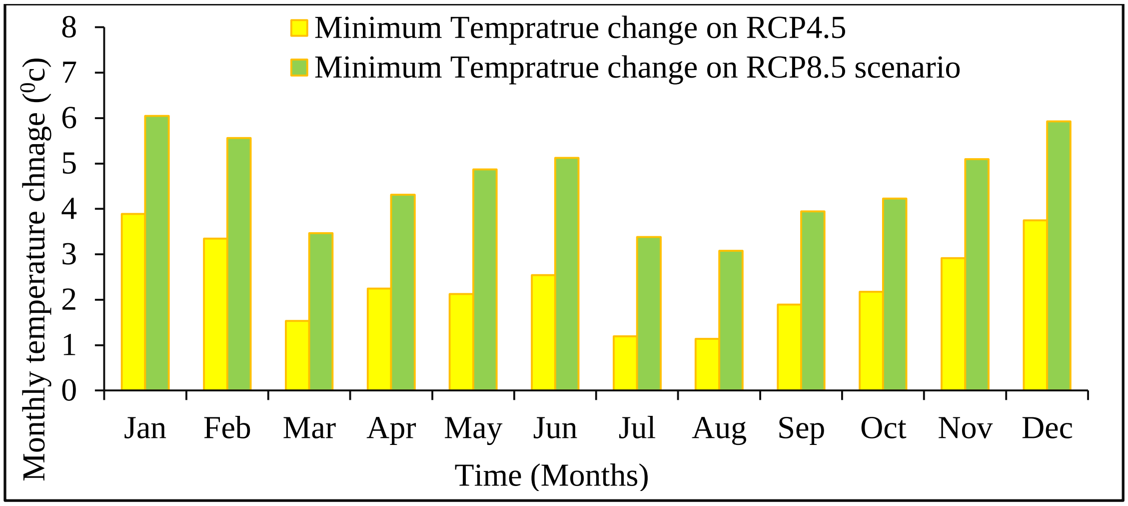


Figure 41: Mean monthly minimum temperature change in both scenarios from baseline to 2080s

Like maximum temperature, months showed maximum records from observed data showed minimum magnitude change in future but months showed minimum records historically found maximum magnitude change in future. From the upper minimum temperature trend analysis, January and December showed maximum magnitude change of minimum temperature on 2080s from the baseline period which was among months having lowest temperature records from historical data information whereas August was among the months showed maximum records of minimum temperature from the past records but it showed the minimum magnitude temperature change in the future.

Different researches including IPCC assessment reports showed increase of temperature in the future. An example of researches showed annual and monthly temperature change includes (Abdo, 2008) on his thesis work at *Gilgel Abay* catchment entitled with assessing climate change impact on hydrology at *Gilgel Abay* catchment, Blue Nile basin, Ethiopia; (Gebremariame, 2009) on his study of assessing climate change on the net basin supply of lake Tana water balance and (Habtom, 2009) on study of evaluation of climate change impact on upper Blue Nile Basin Reservoirs and others. This thesis result also supports their findings.

4.4.2. Trend Analysis of Projected Future Precipitation Change

Projected annual precipitation showed slightly decreasing trend in both RCP4.5 and RCP8.5 scenarios in all time horizons except on 2020s time period projection of RCP 8.5 scenario showing slightly increasing trend.

Table 17: Mean annual projected rainfall statistics Mann-Kendall trend test result

	Scenario					
	RCP 4.5			RCP 8.5		
Parameter	2020s	2050s	2080s	2020s	2050s	2080s
Kendall's tau	-0.07	-0.16	-0.27	0.06	-0.19	-0.1
S	-29	-71	-102	27	-83	-36
Var(S)	0	0	0	0	0	0
p-value	0.62	0.21	0.051	0.65	0.12	0.49
alpha	0.05	0.05	0.05	0.05	0.05	0.05

Precipitation of the catchment would have a slight decreasing trend but there could not see the significant change. As you have a look on table above computed P-value is greater than Alpha value which is an indication that there could not see significant decreasing trend in future. But negative S values in both scenarios of all time horizons except on 2020s at RCP8.5 scenario showed slightly increasing of precipitation in future.

Even if precipitation could show a slightly decreasing trend in future time horizons as showed above (Table 17) it is highly variable temporally and spatially. It has not a consistent increase or decrease trend. It increases in one year and becomes decreased next year(s) then decrease etc. This is due to complicated nature of precipitation processes and topographic features of the study area. Variable nature of rainfall is verified by researchers. Bates et al., (2008) stated "climate model simulation of precipitation has improved over time but it is still a problematic". Thorpe, (2005) also added that "rainfall predictions have a larger degree of uncertainty than those for temperature". This highly spatial and temporal variability of rainfall leads to complex to see climate change impacts in future by using short period of data. Annual rainfall of the study area is ranging from less than 1000mm/year to greater than 2500mm/year as shown at below (figure 42). It is an indication of rainfall variability with time.

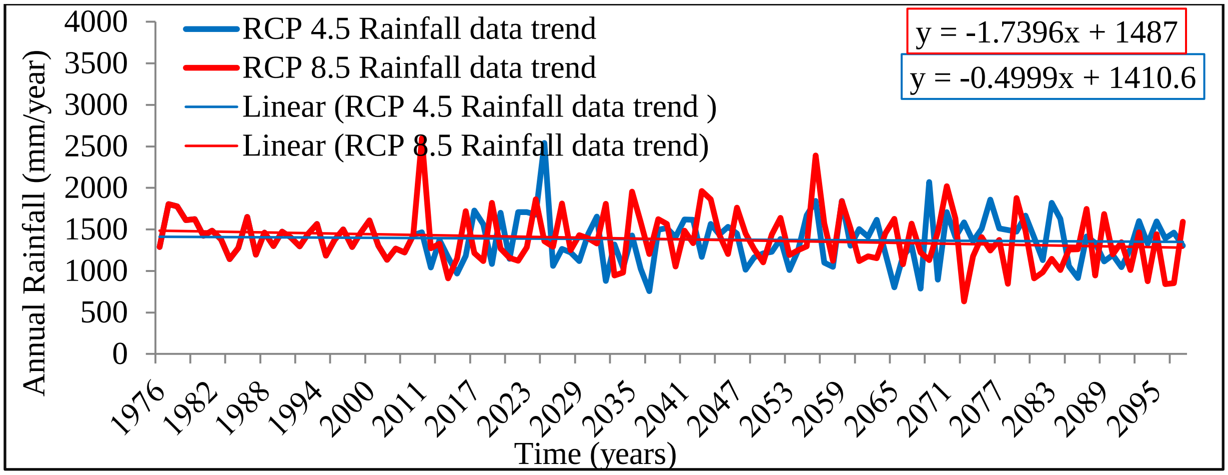


Figure 42: Annual trend analysis test result of precipitation data (1976-2098)

The result of this study showed mean monthly precipitation of Ribb catchment is also varies. As shown at below (figure 43) mean monthly precipitation could increase on April, August, November and December whereas decrease on March, May, June, July and September in all time horizons at RCP4.5 scenario on 2080s from current situation. Mean monthly precipitation of January, August, September and November showed an increased trend and decrease trend in May, June and July in all time horizons of RCP 8.5 scenario on 2080 from the baseline period. Rainfall of the catchment on the remaining months doesn't show a consistent trend.

Mean monthly precipitation showed a decreasing trend in May, June and July at both scenarios in all time horizons on 2080s from baseline period whereas increasing trend showed in August and November in all time horizons and in October on 2050s and 2080s of both scenarios. It could not show a consistent increasing and decreasing trend in the remaining months.

This result supports master's thesis result of Abdo, (2008) studied on Lake Tana Sub-basin. This result is also has similar pattern with deBoor, (2007) working on the impact of climate change on rainfall pattern on Ethiopian Highlands. His finding clearly marked rainfall will decrease on May, June and July which is fitted the finding of this study. His study also showed precipitation found to increase on September, October and November which is also more or less similar to this study result. Habtamu, (2009) thesis study result also showed similar result.

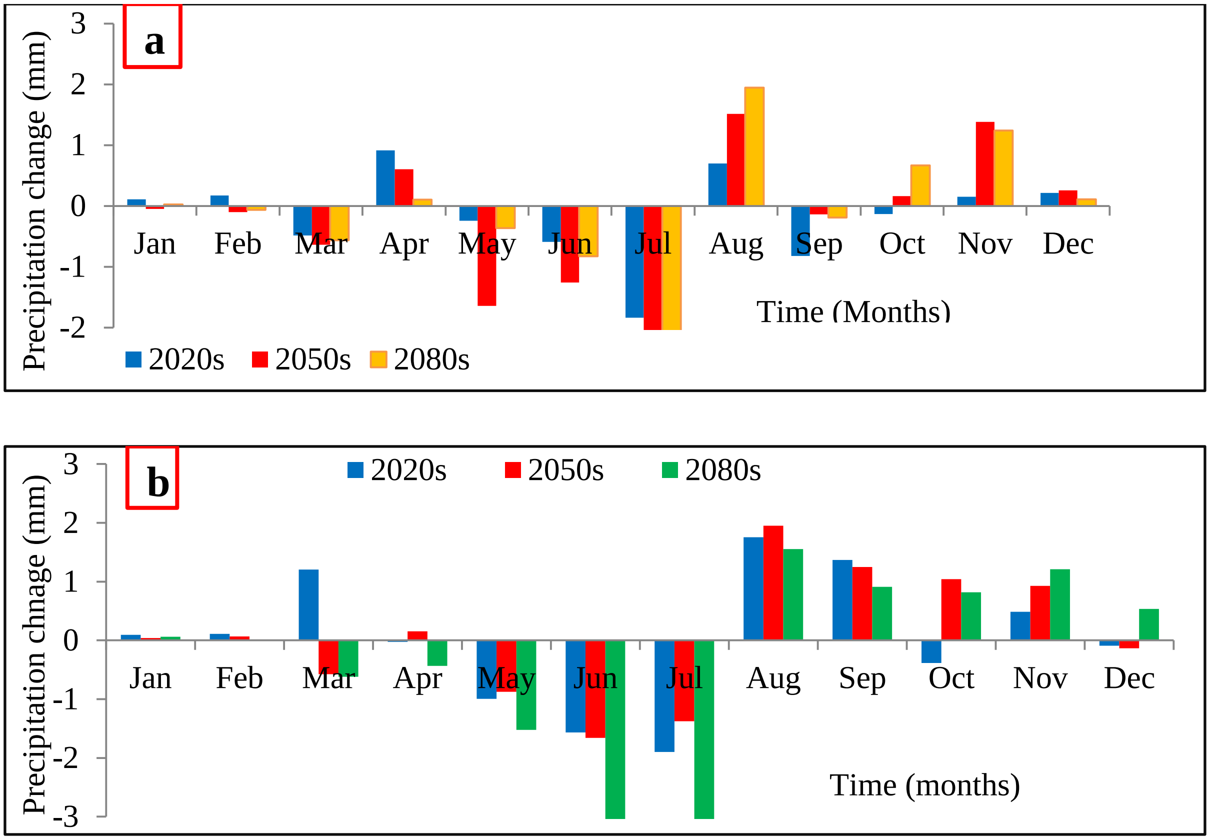


Figure 43: Mean monthly precipitation change at 2020s, 2050s and 2080s on a) RCP4.5 b) RCP 8.5 scenarios.

4.5. Impacts of Future Climate Change on Stream Flow

The ultimate goal of this research work was to evaluate the potential impacts of climate change on the hydrological system of Ribb River. Evaluation of climate change impact on stream flow should a pre-request of performing any projects in Specific River and any water bodies as well. Projects without such type of feasibility study have high probability to failure. Since many factors leading to decrease stream flow, rivers flow should project through estimating factors change in future.

Based on this fact, Ribb River stream flow was simulated to four time horizons as stated above by using bias corrected model temperature and precipitation data set for Nile Basin studies of RCP4.5 and RCP8.5 scenarios. Simulate stream flow of Ribb River was analysis annually, monthly and seasonally.

4.5.1. Impacts of Climate Change on Future Annual Stream Flow

Stream flow of Ribb River showed a decreasing trend from baseline to 2080s. As we have seen from temperature and precipitation trend analysis section of this study (section 4.4), annual rainfall of the catchment could slightly decrease from baseline period to 2080s on both scenarios. But both annual and monthly minimum and maximum temperature found increasing which causes decreasing of stream flow generation. Mean annual flow of stream could decrease by around 6% and 12.14% at RCP4.5 and RCP8.5 scenarios, respectively, from baseline to 2080s. Stream flow found to decrease more based on RCP8.5 scenario than RCP4.5 scenario data since as we have seen from projected temperature future mean annual trend analysis section of this study (Section 4.4.1.1) temperature data of RCP8.5 scenario is increased more than RCP4.5 scenario.

Simulated mean annual stream flow of the river was $42.78m^3/s$ on baseline period. It could be $40.75m^3/s$, $40.83m^3/s$ and $40.24m^3/s$ at RCP4.5 scenario and $41.73m^3/s$, $43.42m^3/s$ and $37.58m^3/s$ at RCP8.5 scenario on 2020s, 2050s and 2080s time horizons respectively. This showed decreasing trend of stream flow from baseline to 2080s at both scenarios. Simulated stream flow on 2080s is lower based on RCP8.5 scenario data than RCP4.5. It is due to magnitude of temperature change at 2080s from baseline period and from each consecutive time horizon of RCP8.5 scenario was higher than RCP4.5 scenario as shown on previous sections (figure 35 and 36). Magnitude of temperature changes from baseline period onward to successive time horizons found to increase from 2020s to 2080s on RCP8.5 but decreasing on RCP4.5 scenario. It is meant that magnitude of temperature change is higher on 2020s than 2050s and 2080s based on the RCP4.5 scenario but the reverse is true at RCP8.5 scenario. Magnitude of temperature change on 2080s is higher than 2020s and 2050s based on RCP8.5 scenario but the reverse works on RCP4.5 scenario etc. It is since RCP8.5 is increasing and RCP4.5 is stabilization scenario. That is why simulated stream flow showed annual decreasing trend in future.

Stream flow would not show consistent trend of increase or decrease between consecutive time horizons due to highly variable nature of rainfall. As you have a look in the following figure (figure 44b) stream flow would decrease from baseline to 2020s but increased from 2020s to 2050s then decreased again from 2050s to 2080s on both scenarios. However, changes have different magnitude/rate.

As a general remark, stream flow of Ribb River could decrease from baseline period to 2080s in both scenarios (Figure 44a)

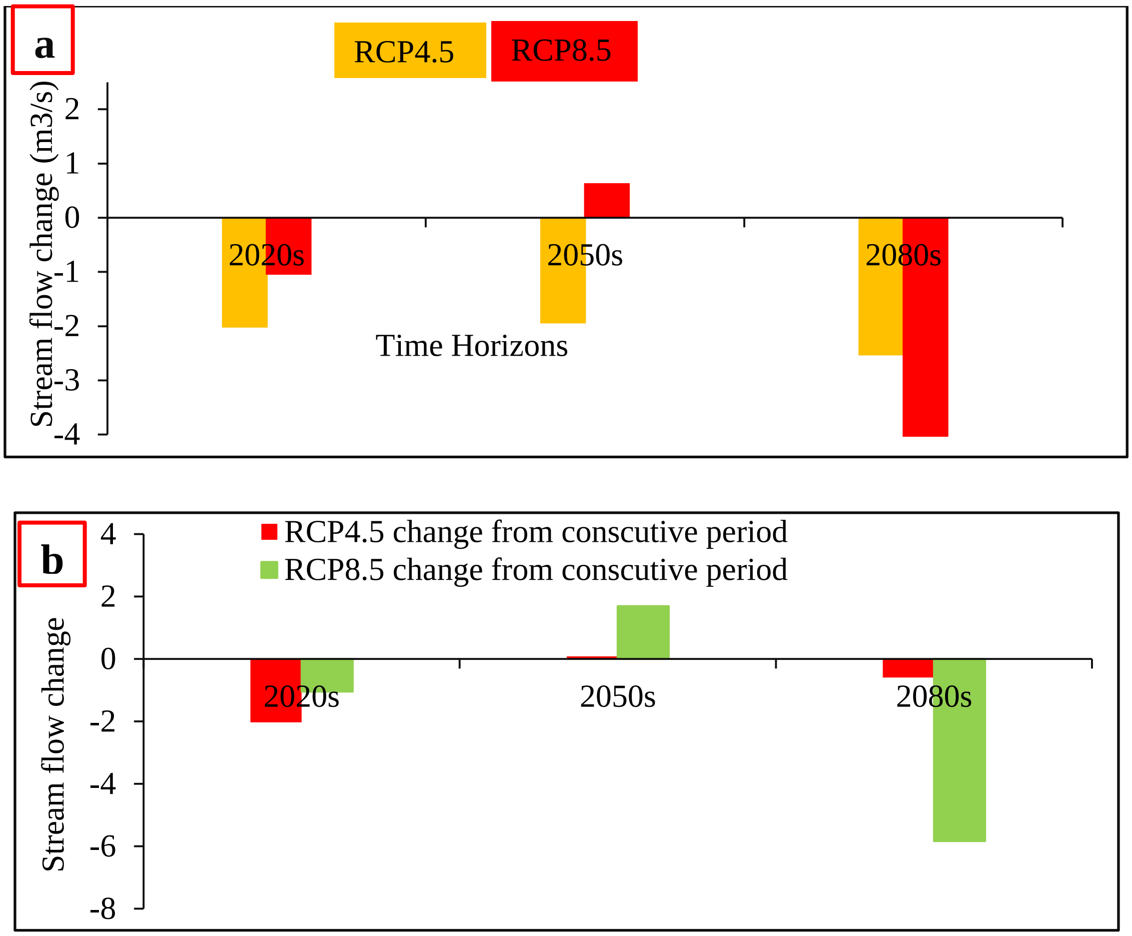


Figure 44: stream flow change a) from baseline and b) between consecutive time horizons

4.5.2. Impacts of Climate Change on Future Monthly Stream Flow

Simulated stream flow by using different hydrological model is depending on temperature, rainfall other inputs. Results of this study also confirms this fact months which showed a maximum magnitude change of temperature and decreasing of rainfall showed the lower stream flow generation.

Simulated stream flow would become decrease from March to August and starts to increase from September to February from baseline to 2080s. From March to July magnitude of maximum temperature change found to be higher than the remaining months in both scenarios as shown from monthly future temperature change trend analysis part of this study (section 4.4.1). The magnitude of minimum temperature change also moderate in these months whereas precipitation found to decrease for these months in future. Starting from September onwards, stream flow will become increased on both scenarios projection data. This increase of stream flow is due to magnitude of maximum temperature change becomes lower and precipitation becomes more or less increased.

However, December and January showed highest change of minimum temperature than other months but flow is still showed increasing. It is suggested lowest magnitude of maximum temperature change and increasing of rainfall. Simulated steam flow of Ribb River in the coming four time horizons (including baseline period) and both scenarios shown as follows.

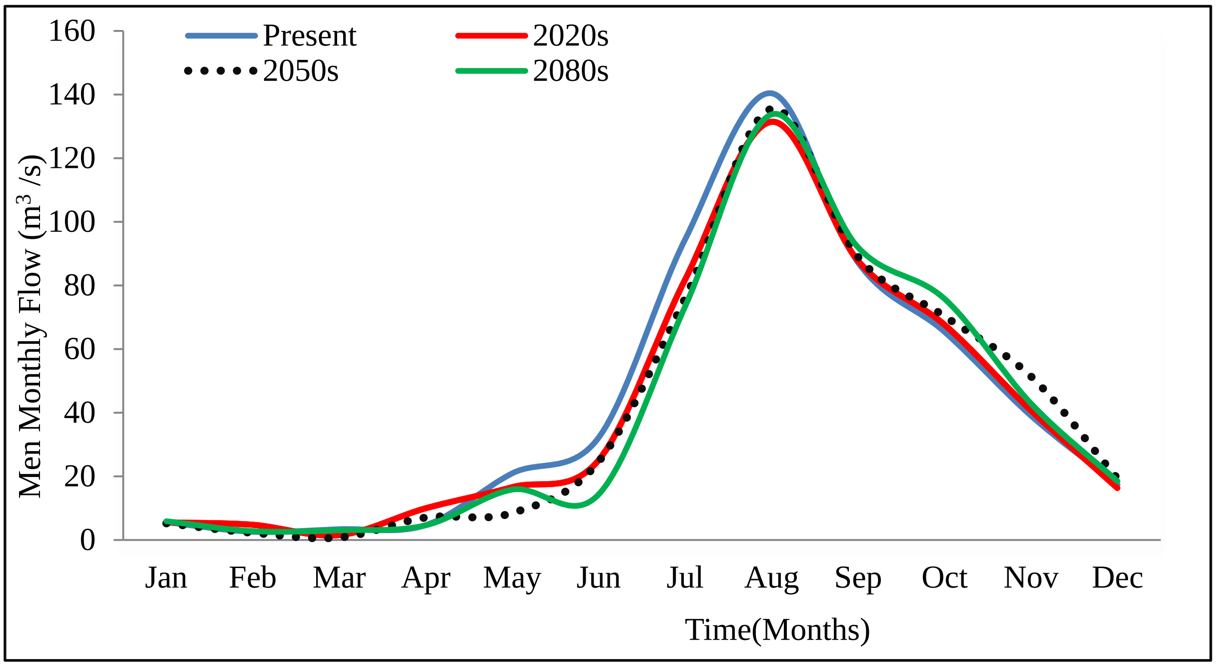


Figure 45: Hydrograph of future stream flow based on RCP4.5 scenario projection data

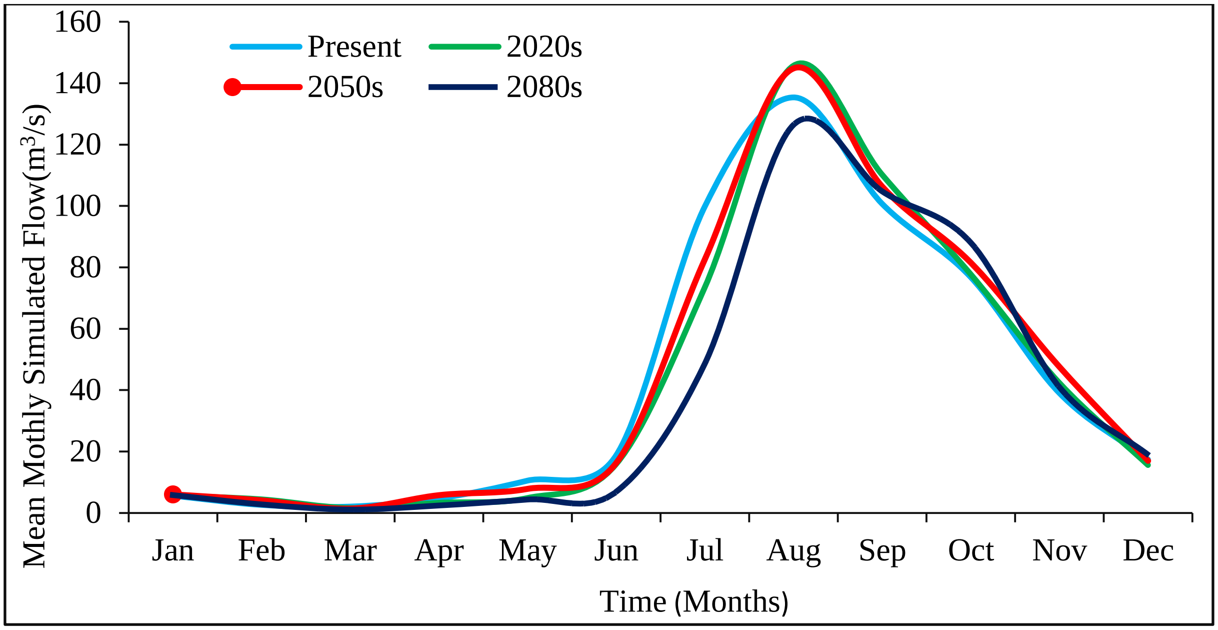


Figure 46: Hydrograph of future stream flow based on RCP8.5 scenario projection data

With respect to individual months stream flow change, June could show highest magnitude of decrease (63.3 % and 55.45% at RCP8.5 and RCP4.5 scenarios respectively) from baseline to 2080s. Higher magnitude of decrease of stream flow would also observe on May (24.38% and 58.64% at RCP4.5 and RCP8.5 scenarios respectively) and July 22.31% and 51.33% at RCP4.5 and RCP8.5 scenarios respectively. Minimum magnitude of decrease would observe on August based on RCP8.5 scenario which is found 6.64% and April (1.21%) based on RCP4.5 scenario. Decrease of stream flow on 2080s is higher on result obtained from RCP8.5 scenario data than RCP4.5 since higher temperature record on RCP8.5 scenario as stated above. Stream flow showed comparatively maximum increase on October (15.87% and 14.66% at RCP 4.5 and RCP8.5 scenarios respectively). Minimum increase would observe on September (6.06% and 4.01% at RCP4.5 and RCP8.5 scenarios respectively).

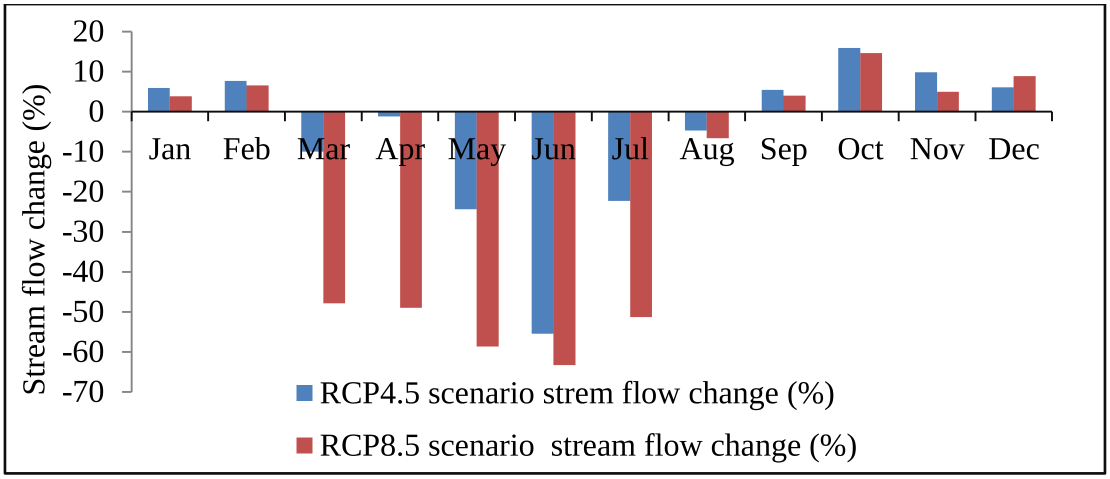


Figure 47: Mean monthly stream flow change on 2080s from baseline period

- ✓ Percentage change of mean monthly stream flow was obtained through multiplying the ration of different between 2080s and baseline period by 100.

In total volume decrease from baseline to 2080s, July is the first one in both scenarios. This total reduced volume is obtained by deducting baseline stream flow from stream flow obtained on 2080s. Total volume of water reduced in July found 21.08 cubic meters per second and 51.22 cubic meters per second at RCP4.5 and RCP8.5 scenarios respectively. Maximum increase could obtain on October which found to be 10.31 and 11.26 cubic meter per second in RCP4.5 and RCP8.5 scenarios respectively.

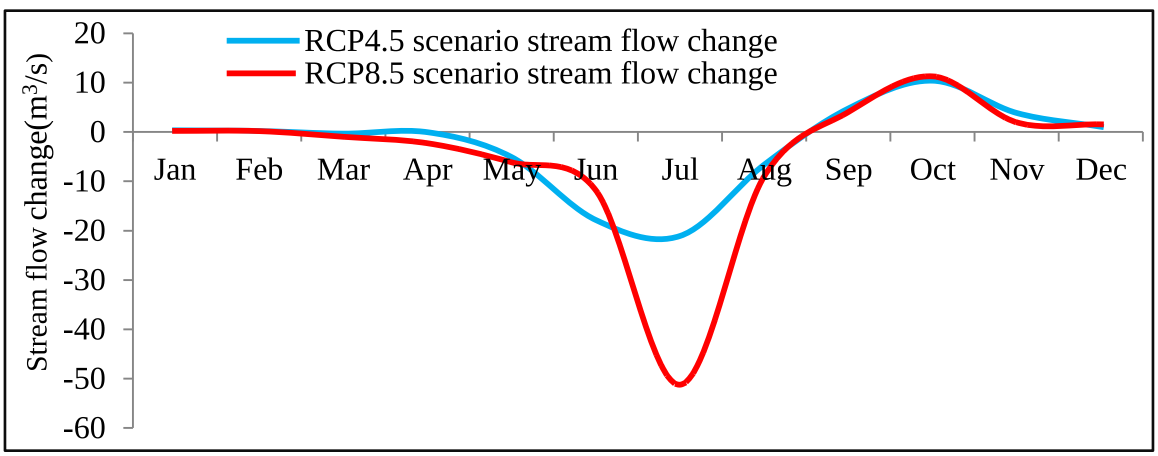


Figure 48: Mean monthly stream flow change on 2080s from baseline period flow

See the attached table on Appendix D for more information about mean monthly projected stream flow.

4.5.3. Seasonal Stream Flow Change Analysis

With respect to seasonal stream flow change of the river on 2080s from the baseline period, it would decrease at summer (June, July and August) and spring (March, April and May) seasons. But, it would increase at autumn (September, October, and November) and winter (December, January and February) seasons of the country in both scenarios (see on figure 49). The highest magnitude of decrease is showed at spring based on RCP8.5 scenario and summer based on RCP4.5 scenario. The highest magnitude of increase should observe on autumn than winter in both scenarios.

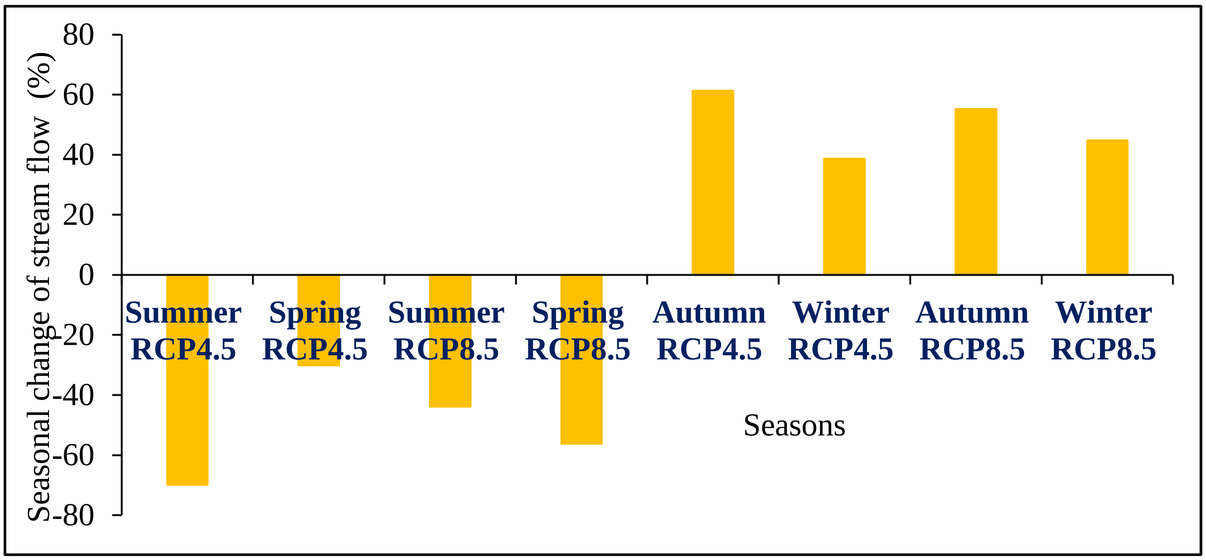


Figure 49: Seasonal stream flow change from baseline to 2080 at both scenarios

- ✓ Percentage of seasonal stream flow change was calculated by multiplying the rate of change on the target season by 100 and divided by the sum of seasons which have shown the same increasing or decreasing trend from seasons.

Stream flow would decrease by 69.87 and 30.13% on summer and spring seasons, respectively, based on RCP4.5 scenario whereas 43.82 on summer and 56.18 % on spring based on RCP8.5 scenario at 2080s from current situation. Stream flow would increase by 61.29 % and 38.71% on autumn and winter season, respectively, based on RCP4.5 scenario whereas 55.19% on autumn and 44.81 % on winter based on RCP8.5 scenario on 2080s from baseline period.

Rivers in Ethiopia are mostly used for agricultural and domestic water supply purpose at spring, winter and autumn but rainfed agriculture is commonly adopted at summer. Future water resources planning and implementing for irrigation projects on Ribb River is advisable on autumn and winter since slight increasing of stream flow in future which allows producing more than current situations. On spring and summer stream flow could decrease that shall construct reservoirs and other structures in the cause of different projects are planning to implement at Ribb River based on current stream flow information.

4.5.4. Maximum and Minimum Flow Change of Projected Future Stream Flow

Planning and implementing of projects at rivers should also base on future maximum and minimum stream flow for the sake of increasing life span, sustainability and profitability of projects. Peak/maximum stream flow causes distraction of constructed structures if the construction is based on the lowest peak stream flow information and peak flows are not under consideration. It is also caused to construct big structures over stream flow which leads unnecessary cost of construction. Knowing of future minimum stream flow is also helpful to know nature and type projects to implement on Specific River in future. So, knowing of minimum and maximum stream flows is helpful for future planning on rivers at all.

I. Monthly maximum and minimum stream flow change

As you have a look bellow (figure 50), monthly maximum/peak stream flow from baseline to 2080s showed the decreasing trend in January, February, March, April, May, June and July whereas increasing in August, October November and December at both scenarios. However, there is not the same result of RCP4.5 and RCP8.5 on September. The maximum stream flow is observed in August and therefore structures constructed in future should under consider peak flow could increase in August over than shown today.

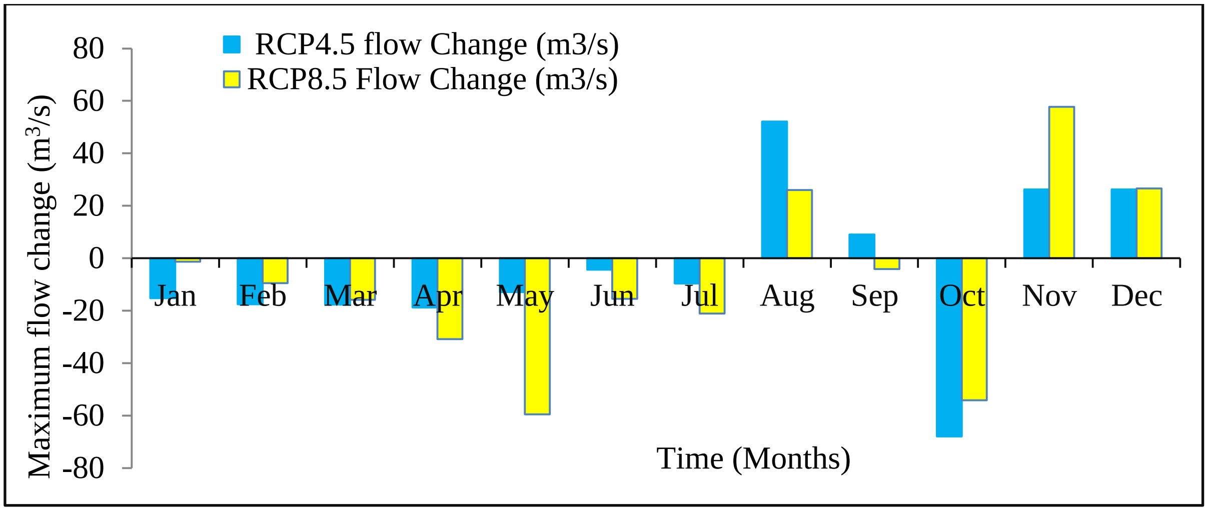


Figure 50: Monthly change of maximum stream flow from the baseline to 2080s at both scenarios

See the attached table on Appendix G for more information about maximum and minimum monthly future stream flow.

Besides, monthly minimum stream flow also would change through time. Results showed stream flow of the river could not show a significant change in January, February, March, April and May on both scenarios. It showed a slightly increasing trend on September which could be 6.44m^3/s and 2.65m^3/s at RCP4.5 and RCP8.5 scenarios respectively. However, it would show a decreasing trend in July, August, October, November and December at both scenarios. The maximum magnitude of decrease is found in July and August which is 24.70 m^3/s at RCP4.5 and 35.19 m3/s at RCP8.5 scenarios in July whereas by 22.45 m^3/s at RCP4.5 and 53.30 m^3/s at RC8.5 scenarios in August.

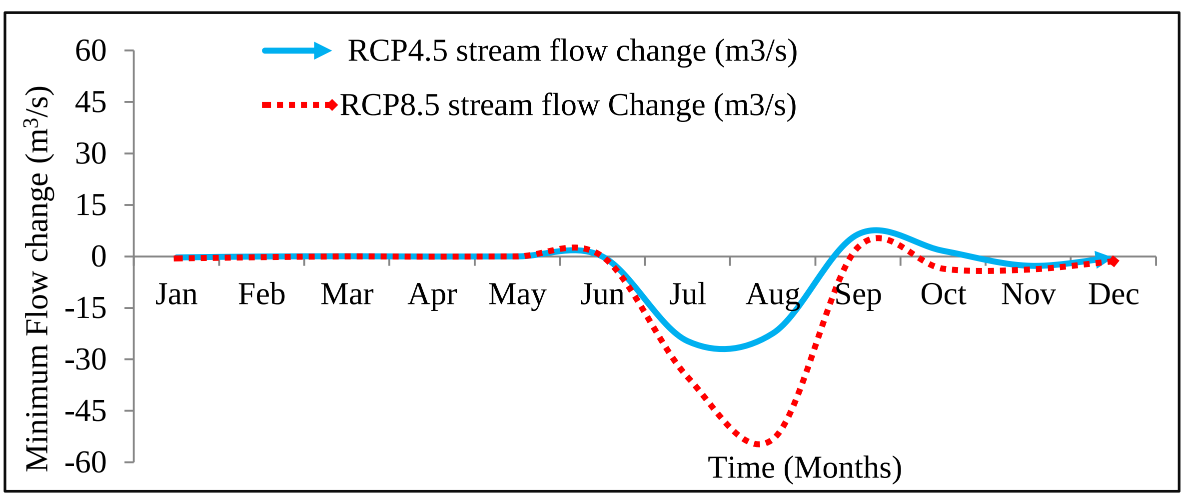


Figure 51: Monthly change of minimum stream flow from baseline to 2080s

II. Annual maximum and minimum stream flow change

Annual maximum stream flows of the river showed a decreasing trend in the future. Based on both scenarios simulation data it would become decrease from base line to 2080s. It was 294.60m^3/s on current situation and would be 234.8m^3/s, 269.5m^3/s and 236.8m^3/s on RCP4.5 scenario and 288.1m^3/s, 272.1m^3/s and 240.5m^3/s at RCP8.5 scenario on 2020s, 2050s and 2080s. Therefore, magnitude of annual peak stream flow showed decreasing trend between the consecutive time horizons at both scenarios except showed a slightly increasing trend from the 2020s to 2050s at RCP4.5 scenario.

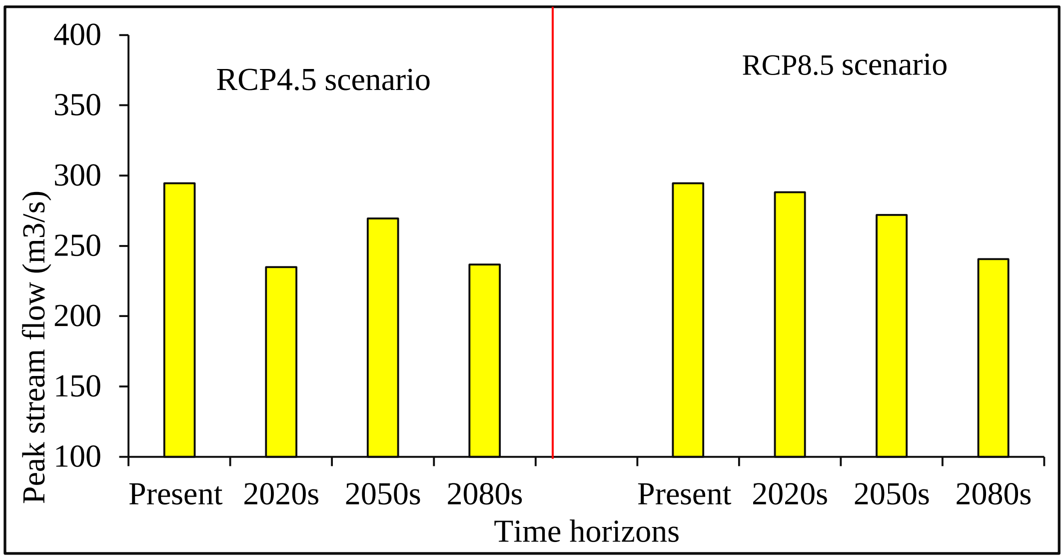


Figure 52: Annual maximum stream flow of Ribb River from the baseline to 2080s

See appendix E and F for more information about maximum and minimum annual stream flow.

Mean annual maximum stream flow would not show the consistent stream flow between the two time horizons. Based on this it is difficult for interpretation about the future situation.

Mean annual minimum stream flow also showed decreasing trend from baseline to 2080s in both scenarios. It would also show decreasing trend between consecutive time horizons except would show a bit increasing trend from 2050s to 2080s at RCP4.5.

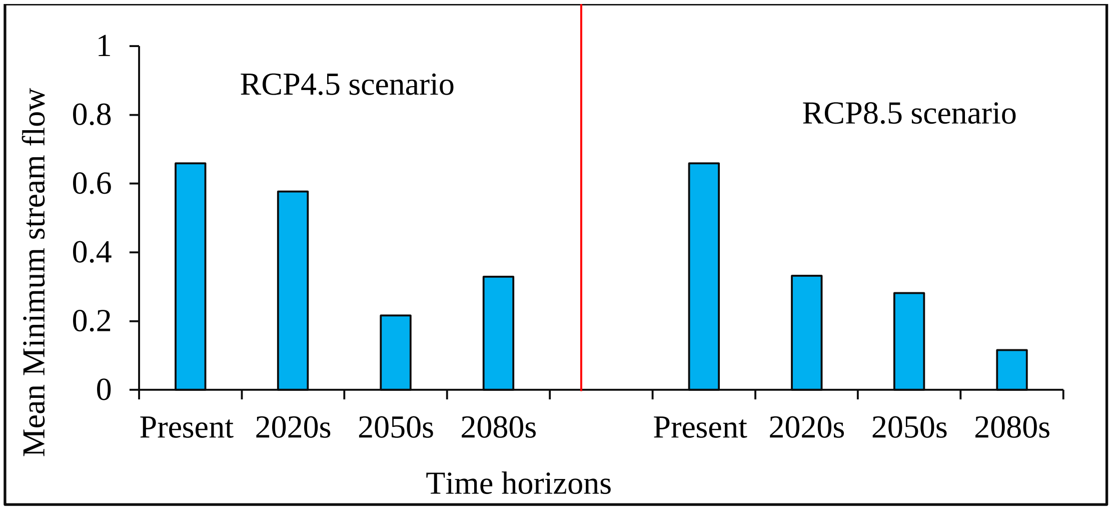


Figure 53: The mean minimum annual stream flow from the baseline to 2080s

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study evaluated the impacts of climate change on hydrology using bias corrected output of climate change projection data set for Nile Basin studies and hydrological model simulation approach of SWAT model. So the study reached on the following conclusions.

Results of SWAT calibration and validation were verified that the model can effectively estimate future stream flow of Ribb River. Monthly stream flow data of the river were used to calibrate and validate the model using performance measuring parameters of coefficient of determination (R^2) and Nash Sutcliff (NSE). R^2 and NSE values were 0.72 and 0.83 for calibration and 0.71 and 0.72 for validation, respectively, which are deemed acceptable.

Climate change projections of RCM data set for Nile Basin studies were found to be biased and the dataset was bias corrected before it was used. A linear scaling method of bias correction was used for this study and was found to be effective in matching model data with observed data on a monthly time scale.

Historical and projected scenarios of annual maximum and minimum temperature data indicate an increasing trend but not consistent trend of change in rainfall was found in the study area. Mean annual maximum temperature could potentially increase by 1.27, 2.18 and 2.41 ^{0}c for 2020s, 2050s and 2080s time horizon, respectively, at RCP4.5 emission scenario from current condition. Increased in maximum temperature associated with RCP8.5 scenario were 1.46, 2.90 and 5.15 ^{0}c for 2020s, 2050s and 2080s time periods, respectively. The mean annual minimum temperature could also likely increase by 1.19, 2.09 and 2.45 ^{0}c on 2020s, 2050s and 2080s respectively at RCP4.5 scenario; and for RCP8.5 scenario those increases were 0.83, 2.46 and 4.64 for the respective 2020s, 2050s and 2080s time period at RCP8.5 scenario. Maximum magnitude changes were found with scenarios associated with RCP8.5 than RCP4.5. Monthly and seasonal changes were also found to be significant. Higher magnitude change of monthly maximum temperature were found in May, June, and July then this increase is smaller through December before it starts to rise again after January. Maximum changes in minimum temperature were found on December and January but there was no clear trend in rainfall amounts for all months. Summer rainfalls (May, Jun and July), however, showed a clear decreasing trend in both scenarios.

RCP4.5 and RCP 8.5 scenarios resulted in somewhat similar projection of future stream flow conditions. Stream flow changes were looked at monthly, seasonal, and annual time scales.

Annual stream flow showed a decreasing trend from the baseline to 2080s. The simulated mean annual stream flow was 42.78 m^3/s for the baseline period whereas is becomes 40.75 m^3/s, 40.83 m^3/s and 40.24 m^3/s at RCP4.5 scenario and 41.73 m^3/s, 43.42 m^3/s and 37.58 at RCP8.5 scenario for the corresponding 2020s, 2050s and 2080s time horizons, respectively. It showed a consistent decrease from the baseline to 2080s but a slight up and down between successive time horizons.

Based on the monthly simulated flow increasing trend are shown from September until February and decreasing trend from January until August. The maximum increase in magnitude is in October that showed an increase of 10.31 and 11.26 cubic meters per second in RCP4.5 and RCP8.5 scenarios, respectively. Whereas the maximum decrease was for July which is shown to be reduced by 21.08 and 51.22 cubic meters per second at RCP4.5 and RCP8.5 scenarios, respectively.

Based on seasonal change in river flow, summer flows are shown to have a potential decrease of 69.87 % and spring by 30.13% according to RCP4.5 scenario whereas a decrease of 43.82 % in summer and 56.18 % in spring is shown based on RCP8.5 scenario from baseline to 2080s. However, stream flow could increase by 61.29 % and 38.71% on autumn and winter season respectively based on RCP4.5 scenario and by 55.19% on autumn and 44.81 % on winter based on RCP8.5 scenario.

Monthly peak stream flow from the baseline to 2080s show a decreasing trend from January to July and October and increasing trend of August, November and December at both scenarios. The minimum stream flow did not show a significant change from January to May on both scenarios. Slightly increasing trend of minimum stream flow in September was found (6.44 and 2.65 m3/s on RCP4.5 and RCP8.5 scenarios, respectively). However, it showed a decreasing trend from July to December at both scenarios. Maximum decrease in magnitude was in July and August. The annual maximum stream flow shown decrease from baseline to

2080s at both scenarios. The mean annual minimum stream flow change also shows the decreasing trend in the future. Besides, both monthly maximum and minimum stream flow change have a decreasing trend into the future.

5.2. Limitation and Recommendations

A result reported in this study is based on a single RCM and two emission scenarios. Generalization of these findings may have to be confirmed by looking at additional RCM scenarios. This will also allow an understanding of uncertainties associated with General Circulation Models for the study area.

SWAT is found to be very important tool for simulating historical and future impacted hydrological processes at a watershed scale. However, in addition to climate change, future land use change will also play a critical role in stream flow generation. Impact of potential future land use change on stream flow for the study area was not within the scope of this research. Therefore, future studies may want to include both climate change impacts as wells as potential land use changes to have a complete picture of future stream flows.

Besides, there are also other factors affecting the stream flow generation such as soil type, evapotranspiration, solar radiation etc. that may also be impacted by climate change and were not explicitly included. Hence, the results of this study should be taken with care and be considered as an indicative for further studies than accurate predictions.

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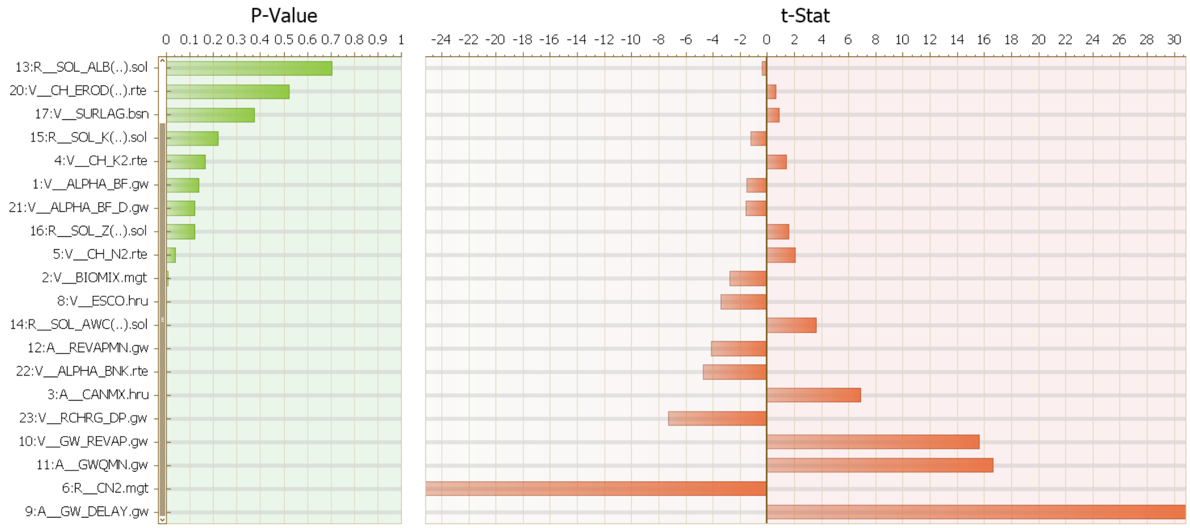
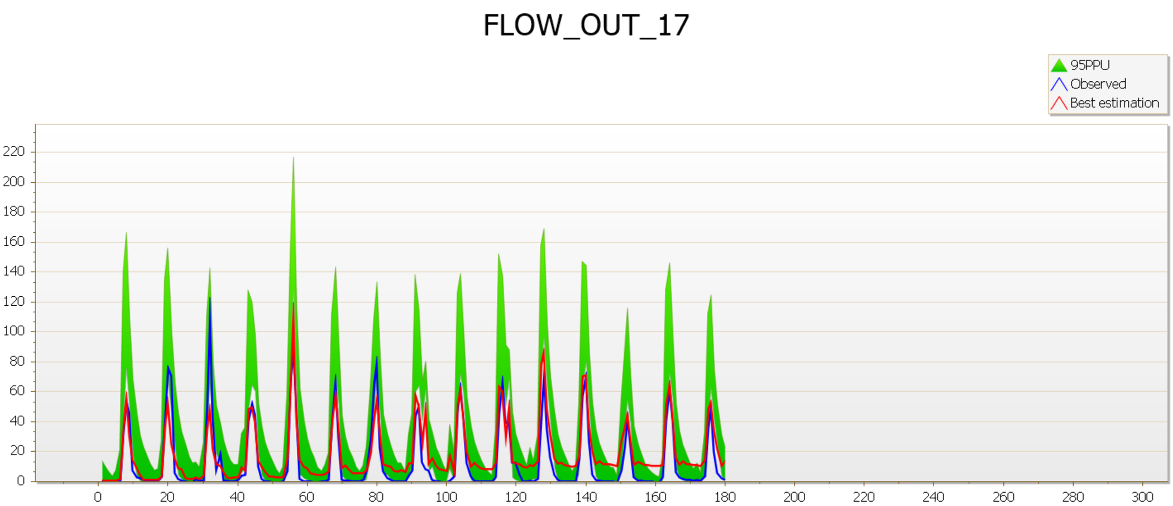
APPENDIXES

Appendix A: SWAT-CUP Sensitivity analysis result and sensitive parameters

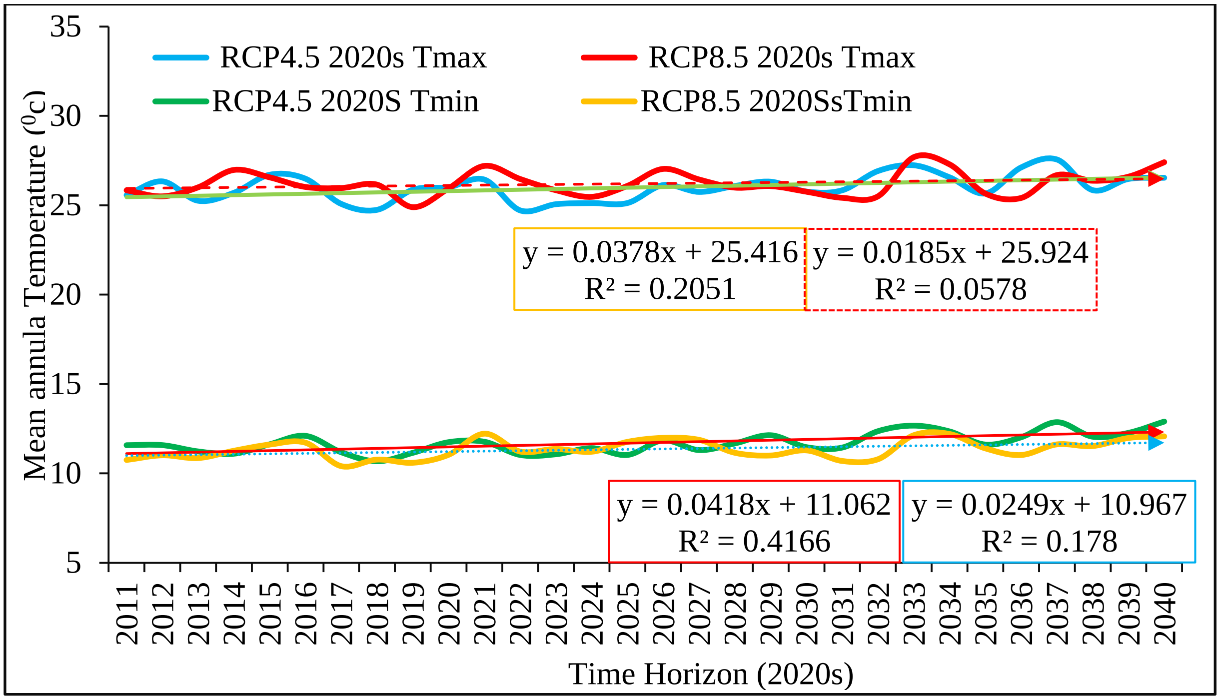


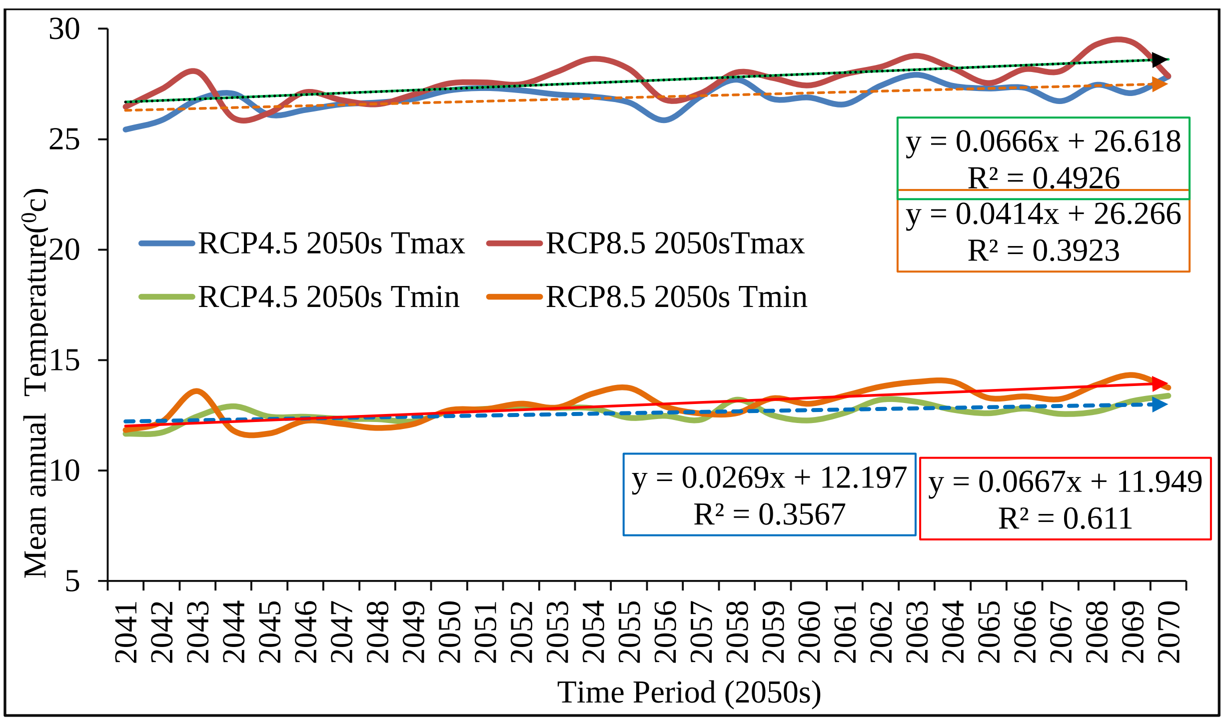


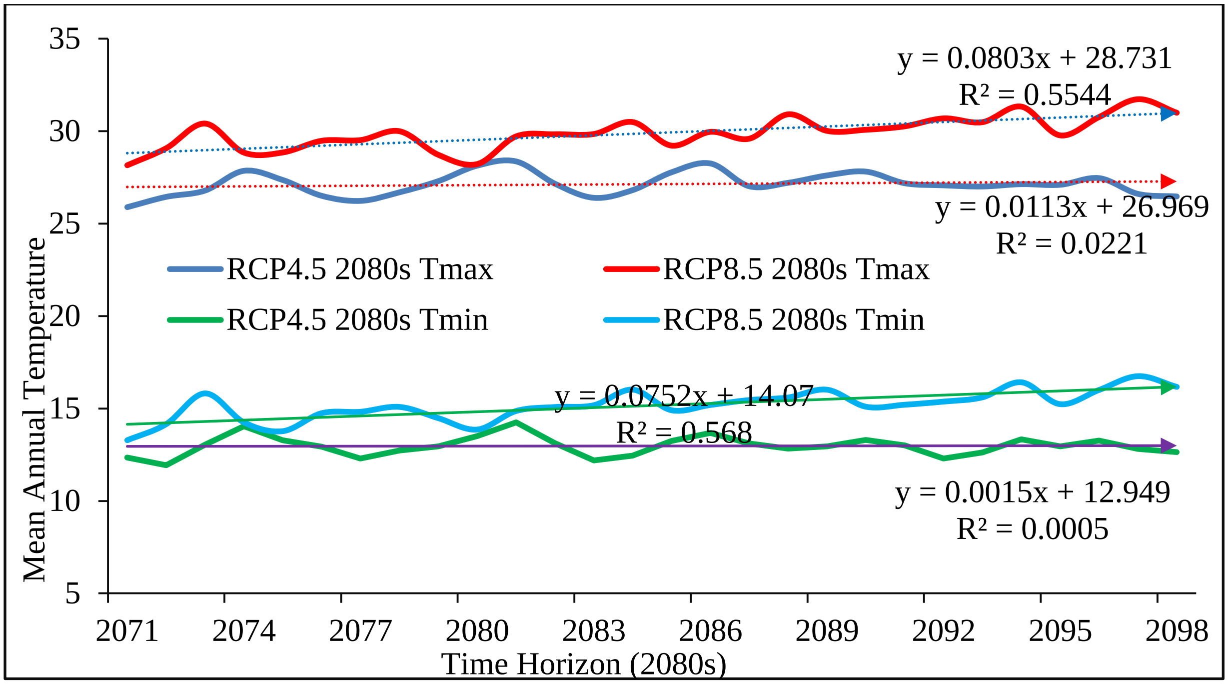
Appendix B: Excel sheet of calculating R2 and NSE and PBIAS for checking bias correction results accuracy

Months	Monthly mean Observed Rainfall (a)	Monthly mean of RCM Corrected Rainfall (b)	a-b	(a-b)^2	(a- a sum)^2	ABS(a-b)	a-a mean	(a-a mean)^2	b -bmean	(a-a mean)*(b-bmean)	((a-a mean)*(b-bmean))^2
Jan	0.145519713	0.145723896	-0.0002042	4.1691E-08	2545.899207	0.000204	-7.639469	58.36148082	-7.643058	58.38889959	3409.263595
Feb	0.283620283	0.277969001	0.00565128	3.1937E-05	2531.982025	0.005651	-7.501368	56.27052265	-7.510813	56.34136976	3174.349946
Mar	0.991696751	0.992344519	-0.0006478	4.196E-07	2461.224275	0.000648	-6.793292	46.14881055	-6.796437	46.1701789	2131.68542
Apr	1.236747487	1.236295625	0.00045186	2.0418E-07	2436.970034	0.000452	-6.548241	42.87945821	-6.552486	42.90725639	1841.032651
May	3.027331966	3.023545149	0.00378682	1.434E-05	2263.389398	0.003787	-4.757656	22.63529413	-4.765236	22.67135761	513.9904557
Jun	6.065565482	6.048379435	0.01718605	0.00029536	1983.531782	0.017186	-1.719423	2.956414946	-1.740402	2.992487273	8.95498008
Jul	13.71088698	13.75372105	-0.0428341	0.00183476	1360.985516	0.042834	5.925899	35.11627475	5.9649394	35.34762653	1249.454701
Aug	13.70720522	13.74250103	-0.0352958	0.00124579	1361.257182	0.035296	5.922217	35.07265278	5.9537194	35.25921766	1243.21243
Sep	6.560619809	6.534494703	0.02612511	0.00068252	1939.680531	0.026125	-1.224369	1.499078287	-1.254287	1.535709413	2.3584034
Oct	3.182290721	3.182075198	0.00021552	4.645E-08	2248.669056	0.000216	-4.602698	21.18482533	-4.606706	21.20327662	449.5789393
Nov	1.239837037	1.238798216	0.00103882	1.0791E-06	2436.665008	0.001039	-6.545151	42.83900551	-6.549983	42.87063232	1837.891116
Dec	0.45110273	0.451232649	-0.0001299	1.6879E-08	2515.155042	0.00013	-7.333886	53.78587807	-7.337549	53.81274471	2895.811493
Sum	50.60242417	50.62708047	-0.0246563	0.00410652	26085.40906	0.133567	-42.81744	1833.332812	-42.8383	1834.226113	3364385.434
Mean	7.784988335	7.788781611									

Appendix C: Trend test results of the projected future Temperature data on 2020s, 2050s & 2080s







35
30
25
20
15
10
5
Mean Annual Temperature
y = 0.0803x + 28.731
R² = 0.5544
y = 0.0113x + 26.969
R² = 0.0221
RCP4.5 2080s Tmax
RCP8.5 2080s Tmax
RCP4.5 2080s Tmin
RCP8.5 2080s Tmin
y = 0.0752x + 14.07
R² = 0.568
y = 0.0015x + 12.949
R² = 0.0005
2071
2074
2077
2080
2083
2086
2089
2092
2095
2098
Time Horizon (2080s)

Appendix D: Mean monthly projected stream flow a) RCP4.5 and b) RCP8.5 scenarios

a

Months	Baseline	2020s	2050s	2080s	Change from baseline	Change in %
January	5.58	5.54	5.24	5.91	0.33	5.91
February	2.59	4.76	2.25	2.79	0.20	7.71
March	3.40	1.54	0.76	3.07	-0.34	-9.98
April	4.68	9.95	7.07	4.63	-0.06	-1.20
May	20.95	16.57	8.49	15.84	-5.11	-24.38
June	32.20	25.06	24.64	14.34	-17.85	-55.45
July	94.49	81.75	75.99	73.40	-21.08	-22.31
August	140.38	131.40	135.53	133.75	-6.63	-4.72
September	87.20	87.75	88.95	91.96	4.76	5.45
October	65.42	67.66	70.32	75.81	10.38	15.87
November	39.06	40.73	51.41	42.90	3.84	9.84
December	17.41	16.32	19.32	18.46	1.06	6.06

b

Months	Baseline	2020s	2050s	2080s	Change from baseline	Change in %
January	5.58	5.67	6.04	5.79	0.21	3.81
February	2.59	4.39	4.06	2.76	0.17	6.54
March	2.05	1.59	1.36	1.07	-0.98	-47.88
April	4.68	3.27	5.74	2.39	-2.29	-48.95
May	10.50	4.84	7.80	4.34	-6.16	-58.64
June	18.70	15.88	16.23	6.86	-11.84	-63.30
July	99.79	73.44	82.60	48.57	-51.22	-51.33
August	135.38	145.69	144.83	126.40	-8.99	-6.64
September	100.75	110.24	106.31	104.79	4.04	4.01
October	76.82	77.76	81.52	88.09	11.26	14.66
November	39.06	42.36	47.55	41.00	1.94	4.98
December	17.41	15.58	16.94	18.95	1.54	8.86

Appendix E: SWAT Simulated annual maximum stream flow of Ribb River (m3/s)

Baseline	Present	2020s	RCP4.5	RCP8.5	2050s	RCP4.5	RCP8.5	2080s	RCP4.5	RCP8.5
1978	129.00	2013	157.80	122.10	2043	225.80	272.10	1973	159.60	141.51
1979	168.50	2014	109.40	115.70	2044	140.20	153.30	1974	149.70	147.90
1980	145.80	2015	119.00	106.90	2045	174.80	182.90	1975	166.70	166.90
1981	147.10	2016	178.30	180.70	2046	212.00	149.30	1976	207.00	174.60
1982	177.70	2017	200.70	217.80	2047	151.70	187.60	1977	165.30	157.90
1983	130.10	2018	118.00	168.00	2048	130.20	161.80	1978	144.80	120.57
1984	112.40	2019	106.00	158.00	2049	97.37	114.50	1979	198.40	240.50
1985	169.50	2020	157.60	111.00	2050	98.30	90.47	1980	207.60	210.70
1986	156.40	2021	184.50	206.70	2051	108.50	129.50	1981	162.20	122.10
1987	92.89	2022	127.90	174.90	2052	105.00	181.00	1982	149.40	118.70
1988	138.50	2023	147.80	136.80	2053	107.10	120.80	1983	159.40	113.90
1989	107.30	2024	180.50	119.10	2054	124.60	122.90	1984	137.80	88.06
1990	294.60	2025	234.80	203.20	2055	143.10	113.20	1985	134.70	155.10
1991	163.20	2026	102.80	127.51	2056	269.50	259.00	1986	87.01	160.60
1992	119.20	2027	158.60	197.70	2057	112.30	179.30	1987	168.20	179.00
1993	151.70	2028	125.60	173.80	2058	86.39	109.20	1988	190.80	126.90
1994	171.40	2029	136.20	132.50	2059	207.80	206.60	1989	87.24	109.10
1995	128.60	2030	147.50	163.50	2060	154.60	160.50	1990	97.45	100.10
1996	142.60	2031	173.50	124.50	2061	152.90	172.50	1991	93.63	156.70
1997	108.40	2032	71.81	243.00	2062	122.70	129.40	1992	125.00	100.20
1998	130.50	2033	160.00	171.10	2063	135.20	118.10	1993	206.60	146.90
1999	183.00	2034	103.00	92.71	2064	145.20	146.00	1994	182.70	135.61
2000	132.30	2035	141.60	288.10	2065	130.33	142.80	1995	169.50	137.20
2001	177.00	2036	96.11	183.60	2066	129.90	154.20	1996	151.00	101.80
2002	184.70	2037	145.09	158.20	2067	157.00	175.60	1997	236.80	192.69
2003	154.30	2038	134.80	169.30	2068	128.28	123.40	1998	147.40	136.70
2004	166.80	2039	157.10	124.80	2069	140.50	126.60			
2005	128.00	2040	142.20	134.10	2070	120.30	164.00			
Max flow	295		235	288		270	272		237	241
Mean	150.41		143.51	160.90		143.27	155.23		157.15	143.92

Appendix F: SWAT Simulated Annual minimum future Stream flow of Ribb River (m3/s)

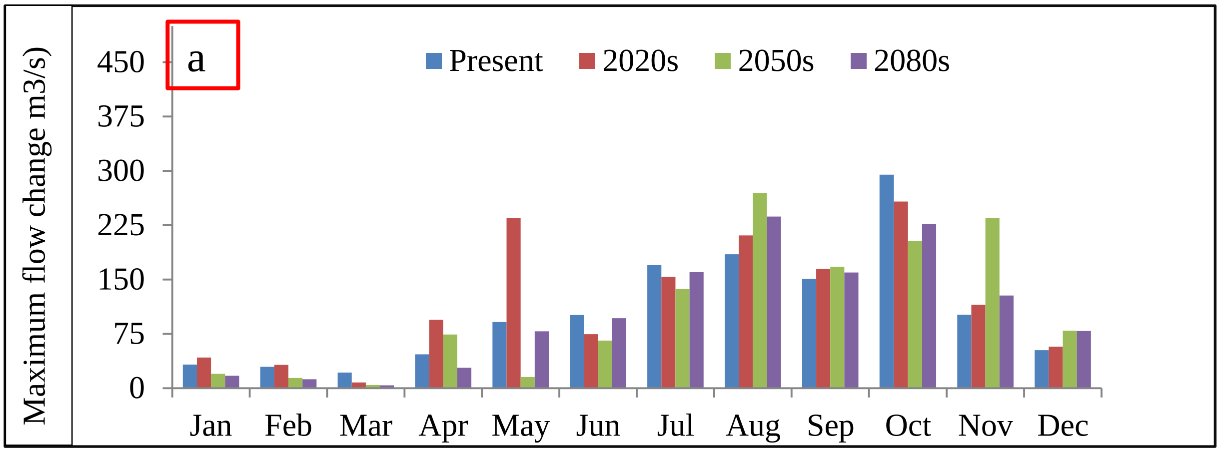
Baseline	Present	2020s	RCP4.5	RCP8.5	2050s	RCP4.5	RCP8.5	2080s	RCP4.5	RCP8.5
1978	0.53	2013	0.33	0.05	2043	0.86	0.11	1973	0.23	0.08
1979	0.41	2014	0.25	0.28	2044	0.18	2.05	1974	2.86	0.00
1980	0.18	2015	0.10	0.07	2045	0.05	0.22	1975	0.04	0.02
1981	1.26	2016	0.37	1.50	2046	0.14	0.10	1976	0.21	0.09
1982	1.21	2017	0.00	0.09	2047	0.25	0.07	1977	0.24	0.13
1983	1.67	2018	1.01	0.04	2048	0.00	0.10	1978	0.25	0.87
1984	0.09	2019	0.78	0.14	2049	0.09	0.14	1979	0.22	0.19
1985	0.88	2020	0.02	1.66	2050	0.00	0.39	1980	0.34	0.35
1986	1.76	2021	0.61	0.04	2051	0.22	0.26	1981	0.47	0.00
1987	0.31	2022	0.09	0.03	2052	0.29	0.12	1982	0.12	0.00
1988	0.00	2023	0.32	0.01	2053	0.07	0.06	1983	0.63	0.13
1989	4.14	2024	0.09	0.14	2054	0.10	0.11	1984	0.22	0.32
1990	0.06	2025	4.68	0.82	2055	0.14	1.22	1985	0.05	0.11
1991	0.17	2026	0.14	0.80	2056	0.49	0.02	1986	0.05	0.00
1992	0.56	2027	0.00	0.05	2057	0.76	0.45	1987	0.11	0.05
1993	0.11	2028	0.13	0.28	2058	0.06	0.15	1988	0.06	0.20
1994	0.56	2029	0.13	0.58	2059	0.00	0.13	1989	0.08	0.00
1995	0.09	2030	0.68	0.34	2060	0.61	0.00	1990	0.00	0.07
1996	0.26	2031	0.16	0.14	2061	0.06	0.15	1991	0.65	0.02
1997	1.20	2032	0.86	0.32	2062	0.31	0.19	1992	0.05	0.00
1998	0.72	2033	4.44	0.00	2063	0.64	0.29	1993	0.06	0.05
1999	1.35	2034	0.25	0.78	2064	0.00	0.06	1994	0.88	0.00
2000	0.08	2035	0.00	0.01	2065	0.01	0.70	1995	0.33	0.11
2001	0.29	2036	0.04	0.49	2066	0.00	0.15	1996	0.11	0.08
2002	0.15	2037	0.03	0.35	2067	0.04	0.01	1997	0.16	0.10
2003	0.14	2038	0.07	0.18	2068	0.48	0.38	1998	0.16	0.00
2004	0.16	2039	0.27	0.10	2069	0.02	0.26			
2005	0.11	2040	0.30	0.01	2070	0.20	0.01			
Mean flow	0.66		0.58	0.33		0.22	0.28		0.33	0.12

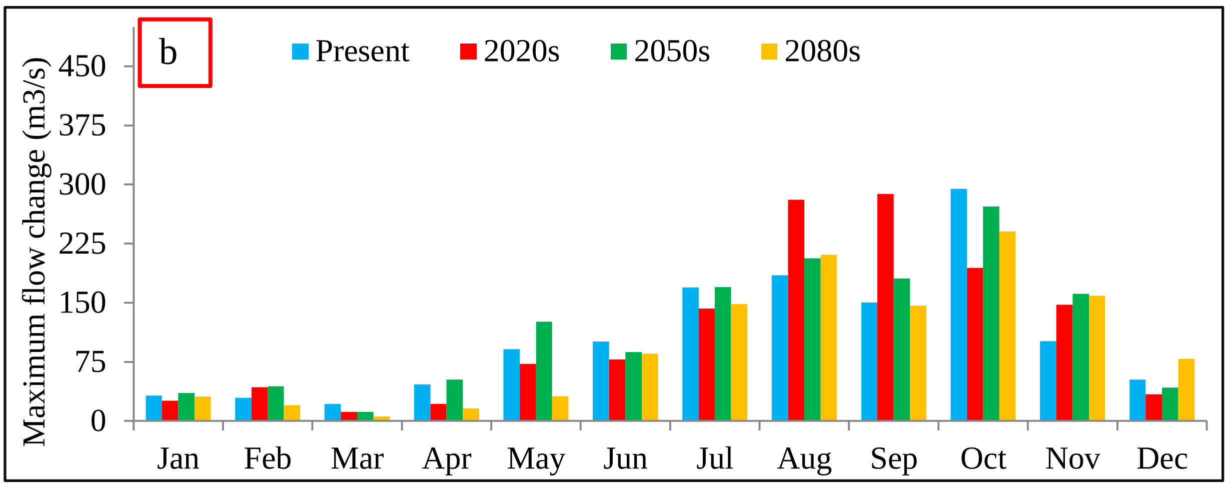
Appendix G: SWAT simulated monthly future stream flow (m3/s) a) Maximum b) Minimum

a	RCP4.5					RCP8.5			
Months	Present	2020s	2050s	2080s	Flow Change (m3/s)	2020s	2050s	2080s	Flow Change (m3/s)
Jan	32.25	42.10	19.63	17.00	-15.25	25.72	35.63	30.94	-1.31
Feb	29.54	32.16	13.99	12.03	-17.51	42.62	43.93	20.09	-9.45
Mar	21.50	7.87	4.02	3.81	-17.69	11.34	11.65	5.68	-15.82
Apr	46.64	94.40	74.14	27.84	-18.80	21.77	52.55	15.81	-30.83
May	91.00	234.80	15.08	78.12	-12.88	72.25	126.10	31.44	-59.56
Jun	100.90	74.15	65.52	96.53	-4.37	77.97	87.60	85.43	-15.47
Jul	169.50	153.20	136.40	159.90	-9.60	142.70	170.00	148.40	-21.10
Aug	184.70	210.60	269.50	236.80	52.10	280.70	206.60	210.70	26.00
Sep	150.50	164.30	167.50	159.60	9.10	288.10	181.00	146.40	-4.10
Oct	294.60	257.60	202.90	226.70	-67.90	194.20	272.10	240.50	-54.10
Nov	101.40	115.10	235.20	127.60	26.20	147.70	161.50	159.10	57.70
Dec	52.37	57.27	79.07	78.57	26.20	33.70	42.26	79.00	26.63

b	RCP4.5					RCP8.5			
Months	Present	2020s	2050s	2080s	Flow Change (m3/s)	2020s	2050s	2080s	Flow Change (m3/s)
Jan	0.98	0.25	0.57	0.72	-0.26	0.95	1.21	0.37	-0.62
Feb	0.30	0.07	0.35	0.27	-0.03	0.30	0.34	0.07	-0.23
Mar	0.06	0.09	0.02	0.11	0.05	0.07	0.11	0.07	0.00
Apr	0.08	0.02	0.02	0.04	-0.04	0.01	0.01	0.00	-0.08
May	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Jun	0.09	0.03	0.02	0.05	-0.04	0.00	0.13	0.05	-0.04
Jul	41.82	7.14	8.42	17.12	-24.70	0.10	7.91	6.63	-35.19
Aug	74.35	67.04	78.28	51.90	-22.45	53.19	90.47	21.05	-53.30
Sep	38.86	35.72	41.14	45.30	6.44	51.47	63.93	41.51	2.65
Oct	28.99	21.85	26.68	30.61	1.62	28.46	38.73	25.40	-3.59
Nov	16.75	10.68	15.82	14.03	-2.72	19.09	20.96	12.91	-3.84
Dec	4.14	1.74	4.37	3.77	-0.38	6.28	6.51	2.72	-1.43

Appendix H: Monthly change of maximum stream flow at a) RCP4.5 b) RCP8.5 scenarios on different time horizons





Appendix I: Field observation pictures in the study area

A). Sedimentation and overflow effect of Ribb River

B). the traditional stream flow measuring instruments used at Ribb River until 4 years ago

C). Land use of the study area is dominantly for agricultural/ cultivated land