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

Impact of climate change on surface water potential in Borkena watershed

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

By: Solomon Arega

, **May, 2018**
Jimma, Ethiopia

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

Impact of climate change on surface water potential in Borkena watershed

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

By: Solomon Arega

ADVISOR: Dr.Ing Tamene Adugna

CO-ADVISOR: Mr. Wakjira Takala

May, 2018

Jimma, Ethiopia

DECLARATION

I Solomon Arega Getahun, declare that this thesis is my own original work and that it has not been presented and will not be presented to any other university for similar or any other degree award.

Name	Signature	date
Solomon Arega		

We the undersigned, certify that we read and hereby recommend for the acceptance by Jimma University a thesis entitled: **The impacts of climate change on surface water potential in Borkena watershed** in partial fulfillment of a degree of masters of Science in hydraulic engineering.

Name	Signature	date
1. Dr.Ing Tamene Adugna (Adviser)	……………………..	……………………
2. Mr. Wakjira Takala (Co Advisor)	………………………	……………………

ABSTRACT

Nowadays, the world climate change is acquiring series issue against surface water potential. Climate change affects stream flow timing through the temperature increase and change for precipitation. Changes in the duration of rainy season can affect river flow. Therefore, this study, evaluate the impacts of climate change on surface water potential of Borkena River, under the newly representative concentration pathway scenarios RCP4.5 and RCP8.5. The study used high-resolution dynamical downscaled climate data and new climate scenarios. Dynamically downscaled daily rainfall and temperature data were obtained from international water management institute, and all meteorological data (maximum and minimum temperature, precipitation, humidity wind speed and sunshine hour) were collected from national meteorology agency. The downscaled future climate data have undergone bias correction before any analysis. Then Current evaporation data estimated by FAO recommended Penman – Monteith method while future evapotranspiration was estimated by Hargreaves method. Hydrological engineering center of hydrological modeling system model used to examine the effect of climate change on stream flow. The hydrological model calibrated from 2003 – 2010 and validated from 2011 -2015. The performance of the model assessed by Nash – Scatilffe (NSE= 0.714 & 0.615), coefficient of determination (R^2 = 0.777 & 0.652) and relative volume error (RVE = 4.0% & -13%) during calibration and validation process respectively. According to Mann–Kendall trend test the projected climate variable (temperature, annual rainfall and evapotranspiration) showed on increasing trend. The projected average maximum temperature will be increasing by 1.169^0c and 1.512^0c for RCP4.5 and RCP8.5 in the middle term period (2041 – 2070) relative to base line period respectively. In addition, the precipitation indicates that increase by 7.119% and 7.99%mm in the future period (2041-2070) under RCP4.5 and RCP8.5 respectively. Average annual stream flow volume will increase up to 13.13 % and 15.44% under RCP4.5 and RCP8.5 scenarios for the middle term period respectively. The impact of climate change analysis was control on surface water potential (runoff volume) in hydrological model.

Key words: Borkena River, Climate change, HEC-HMS, RCPs, Trend Analysis,

ACKNOWLEDGEMENT

First and foremost, thanks to the Almighty God and his mother St. Merry for gifts to me their unlimited care. I thank my advisor Dr. Ing. Tamene Adugna, for his useful comment and ideas to guide and support my thesis work. I also thank my co- advisor Mr. Wakjira Takala for his illuminating and timely comments in all steps of my work.

I would like to thank all my friends especially my friend Wudneh Temesgen for his valuable

I would like to acknowledge the National Meteorology Agency and Ministry of Water, Irrigation and Electricity for providing me the required data and information to fulfill this research work. I thank the CORDEX program for downscaled data based on CMIP5 simulation.

Finally, I would like to extend thanks to my families especially to my wife Helen Yimane and my sister Tiruwork Gugsa for their encouraging and supporting help through my study.

TABLE OF CONTENT

Contents

LIST OF TABLE

LIST OF FIGURE

LIST OF ABBRIVATION

AGCM	Atmospheric Global Climate Model
AIM	Asia pacific Integrated Model
AIMES	Analysis Integration and Modeling for the Earth System
AOGCM	Atmospheric and ocean Global Climate Model
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
CCCM	Camp Coordination and Camp Management
CMIP3	Coupled model Inter-comparison project phase three
CMIP5	Coupled model Inter-comparison project phase five
CO_2	Carbon dioxide
CORDEX	Coordinated Regional Climate Downscaling Experiment
DEM	Digital Elevation Model
ECHAM5	European Center Hamburg Version 5
GCM	General Circulation Model
GHGs	Greenhouse gases
HadGEM2-ES	Hadley Global Environment Model2-Earth System
HEC-HMS	Hydrological Engineering Center of Hydrological Modeling system
IGBP	International Geosphere-Biosphere Programmer’s
IIASA	International Institute for Applied System Analysis
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water resource Management Institute
MESSAGE	Model for Energy Supply Storage and General Environmental impact
MK	Mann-Kendall
MoMIE	Ministry of Water, Irrigation and Electricity
NMA	National Meteorology Agency
NOAA	National Ocean and Atmospheric Administration
NZCC	New Zealand Climate Center
RCM	Regional Climate Model

RCP	Representative Concentration Pathway
SRES	Special Report on Emission Scenario
SRTM	Shuttle Radar Topography Mission
TFRCD	Task Force on Regional Climate Downscaling
USACE	United States Army Corps of Engineers
USACE TRM	United States Army Corps of Engineers Total Research Management
UNDP	United Nation Development Program
UNESCO	United National Educational, Scientific and Cultural Organization.
US-ACE	US Army Corps of Engineering
WCRP	World Climate Research Program
WGCM	Working Group on Coupled Modeling

1 INTRODUCTION

1.1 Background

Climate change is change in average surface temperature and change in atmospheric circulation in the size and pattern of natural climate variation globally (NOAA, 2007). Evidence of observed climate change impacts is strongest and most comprehensive for natural system. In many regions of the world, changing precipitation or melting snow and ice are altering hydrological systems; affect water resources in terms of quantity and quality (IPCC, 2014).

Global warming due to the enhanced greenhouse effect is likely to have significant effect on the hydrologic cycle (IPCC, 1996). The first assessment report of the intergovernmental panel on climate change (IPCC) finds, beyond reasonable doubt, that the earth's climate is warming, since the 1950s; the rate of global warming has been unprecedented compared to previous decade's millennia. The IPCC find with 95% certainty that human activity, by increasing concentrations of greenhouse gases in the atmosphere, has been a dominate cause of the observed warming, since the mid-20 centuries. The first assessment report presents strong, evidence warming over land across Africa has increased over the last 50 – 100 years. Data from 1950 onwards suggests that climate change has changed the magnitude and frequency of same extreme weather events in Africa already. Ethiopia is situated in the health, livelihoods and food security of people in Africa have been affected by climate change (IPCC, 2014). The Northeast of Africa it is influenced by the Northeast, to the Southwest monsoons bringing moisture from the Indian and Atlantic Oceans (Yilma, 2005). Since annual rainfall amounts decreases from the south to the north topography as well strongly influences the rainfall.

The temperature in Ethiopia increased at about 0.2^0c per decade. The increase in minimum temperatures is more pronounced with roughly 0.4^0 c per decade. Precipitation on the other hand, remained fairly stable over the last 50 years when average over the country Ethiopian's GHG emissions are dominated by agriculture, which contributes 80% of the total GHG emissions (Marius, 2009). This reflects the fact that livestock farming goes together with high methane emission. In the addition to agriculture, the energy sector (heating, cooking and transport) contributes to the total GHG emission with 15%, 95% of the energy consumption is satisfied by biomass source (mainly wood); petroleum and electricity are of minor importance (Marius, 2009).

Climate model projections under the SRES A2 and B1 scenarios over Ethiopia show warming in all seasons across the country, which may cause a higher frequency of heat waves as well as higher rates of evaporation (Conway, 2011).

Over the Awash River basin, a temperature increase 2.4^0 C and 3.0^0 C respectively is projected by the CCCM and GFD3 show a 5% increase in temperature, while CCCM indicate a 2% decrease with doubling of CO2. As the report of that, the general warming simulated by all GCMS under CO2 doubling would result in a substantial decrease in annual runoff over the Awash River basin (Kinfe.H, 1999). Borkena River is one of the main tributaries of Awash River basin, found in South Wollo, and have been chosen as study area for this research. Some high intensity could produce local floods, but most heavy runoff come from highland humid regions of Awash river basin causing lowland inundation and sedimentation lowland region. Thus, it is important to assess the impact of climate change on surface water. This research aims to generate climate scenarios for precipitation, temperature and evapotranspiration over the Awash River basin representative catchment to assess climate change impacts on the catchment. The precipitation and temperature scenarios were generated from dynamically CMIP5 climate model output to the fine resolution for hydrologic model used bias correction methods.

1.2 Statement of the problem

Climate fluctuation can affect the use of agriculture land associated with irrigation system. On the other hand, climate change that increase overall water availability either could be beneficial or could increase the risk of flood (Arnell, 1999). The change on temperature pattern can significant impact surface water resources by the resulting in change hydrological cycle. The hydrological cycle change can have a direct effect on the quantity of evapotranspiration quantity and quality of runoff components (Alemu, 2011). Although, the spatial and temporal which clearly magnifies its impact on agriculture, industry and urban development.

Awash River basin is one of the most utilized rivers in Ethiopia; serves as drinking water, hydropower industrial consumption, irrigation and disposal of wastewater (Laijenogo, and Rolald, 2013). It has annual flow 4.6 billion m^3 (3.75% Ethiopia’s total freshwater flow). Borkena catchment is one of sub-basin of Awash River basin in which no principal investigation were conducted before independently. However, some studies were conducted on Awash River basin, which includes Borkena catchment. Still needs investigation of climate change impact of the basin in so many ways with new plausible climate scenarios in specified on 0.50 latitude × 0.50 longitude grids, as well as land use and land cover information. RCPs also allow the modeling of climate system response to human activities as they include information on a range of long lived GHGs, including emissions of radiative active gasses and aerosols, land use and socioeconomic condition (Van Vuuren, 2011).

This study targeted to address the impact of climate change on sub - basin level and understanding the general trends of the future climate variables such as temperature, precipitation and evapotranspiration and in what this affects the surface water flow potential. Therefore, more information needed about impact of climate change on future water resource development for different sector, such as agriculture, hydropower and health. The newly developed pathway scenario RCP4.5 & RCP8.5 and rainfall – runoff hydrological model HEC-HMS4.2 were used in the study.

1.3 Objective of the study

1.3.1 General objective

The general objective of this study is to evaluate the impact of climate change on stream volume of Borkena watershed.

1.3.2 Specific objective

- ✓ To assess the trend of future rainfall, temperature and evapotranspiration under RCP4.5 and RCP8.5 climate scenarios.
- ✓ To evaluate future change of rainfall, temperature and evaporation with respect to the baseline period under both RCP4.5 and RCP8.5 scenario.
- ✓ To examine the effect of climate change on stream flow volume of the study area.

1.4 Research question

1. What is the trend of future rainfall, temperature and evapotranspiration of the study area?
2. What will be climate change on the study area under CMIP5 climate model output?
3. What are the effects of climate change on the stream flow volume of the study area?

1.5 Significance of the study

Results of this study will contribute to water resource management and planning efforts in Borkena River. Evaluation of climate changes scenarios will help to understand new insight about water resource management problem and to develop necessary solution for the problem.

1.6 Scope of the study

This study focus on the impact of climate change on the surface water in the Borkena watershed and so it did not include groundwater aspects and land use land cover change impact on surface water potential in the basin.

2 LITERATURE REVIEW

2.1 Climate change

Climate change is a long term in statistics of the weather, including it average. That means it could show up as a change in climate normal for a given place and time of year, from one decade to the next. The global climate is currently changing. The last decade of the 20th century and beginning of the 21th have been the warmest period in the entire global instrument temperature record, starting in the mid-19th century (NOAA, 2007).

Climate change is having a significant impact on weather pattern, precipitation and the hydrological cycle, affected surface water availability, as well as soil moisture and ground water recharge (UNESCO, 2006). Climate change impact refers to effects on lives, livelihoods, water, health, ecosystems, economics, societies, cultures, services, and infrastructure due to the interaction of climate change or hazardous climate events occurring within a specific period and the vulnerability of an exposed society or system. Rather they are different probable scenarios that have been constructed based on assumption about population and world development (IPCC, 2007A). Different institutions using climate or circulation model ran these scenarios. The output from these models has uncertain change signals. The most recent scientific assessment by the intergovernmental panel on climate change (IPCC) concludes that, since the late 19th century, anthropogenically induced emission of gases such as carbon dioxide (CO_2) that trap heat in the atmosphere in the manner of a greenhouse have contributed to an increase in global mean surface temperatures of about 0.3 to 0.7^0c. Moreover, based on the IPCC's mid-range scenario of future greenhouse gases emission and aerosols and their best estimate of climate sensitivity, a future increase of 2^0c is expected by the year 2100 (IPCC, 2013).

2.2 Surface water

Surface water originates from rainfall and is a mixture of surface run off and ground water. It includes rivers, lakes and wetland, which may originate springs and collect run-off from the watershed. Natural water flow moving under the force of gravity along their channel filled by surface and underground runoff are called rivers (Khublaryan, 1994). It is the most important role in economics and the functioning of ecosystem. Major river water uses can be summarized as Source of drinking water supply, Irrigation of agricultural lands, Industrial and Municipal water supplies, Navigation and Fishing, Boating and body-contact recreation. A simple evaluation of surface waters availability for regional, national or trans-boundary use can be based on the total river water discharge. According to the size, the river are divided into large, medium and small. The large rivers are characterize by the basin area of 2000-50,000km^2, medium river basin area of 20,000-50,000km^2 and small river basin area of less than 2000km^2 (Khublaryan, 1994).

2.3 GCMs/CMIP5 climate model

Climate models are important tools for improving our understanding and predictability of climate behavior on seasonal, annual, decadal and centennial time scales. Models investigate the degree, which observed climate changes might be due to natural variability, human activity, or a combination of both. Their results and projections provide essential information to be better informing decision of national regional local importance, such as water resource management, agriculture, transportation, and urban planning. Climate modeling is already computationally intensive but increase-computing power would allow for more comprehensive simulations, better-represented parameterizing processes, and more accurate climate change projections at regional and local level (NOAA, 2007). Different regionalization techniques have been developed to enhance the regional information provided by GCMs and AOGCMs and to provide fine scale climate information. These techniques can be classified into three categories. High resolution and variable resolution time-slice atmosphere GCM (AOGCM) experiment, Nested limited area or regional climate model (RCMs), and Empirical/statistical and statistical/dynamical methods.

GCMs are considered the best in depicting future climate driven by anthropogenic forcing but they are too coarse for many impact assessment and studies, in particular downscaling method, affect the realism of the data. Choosing a downscaling technique is a trade-off between many factor, among them the capacity to illustrate realistic future climate, easiness to use and nature of climate information or data required for impact studies (Santaso, 2008). Several technical aspects in climate scenario constructions and handling have been briefly discussed.

Downscaling is the process of taking native-scale global climate model (GCM) results of global climate response to changing global atmospheric composition and post processing those through additional statistical or dynamical models to create a set of results at finer spatial scale that is more meaningful in the context of local and regional impact (IPCC, 2008).

The dynamic method typically uses the output of regional climate models, which are driven, by global models at the boundary of the regional model's domain. The output from this method is still at a coarser scale compared to what is required locally (Wilby, 2002). In the regional climate model (RCM) there is more convective large-scale precipitation over land and sea point throughout the seasonal cycle compare to the GCM. The RCM is also characterized by stronger vertical velocities than the driving GCM, mainly due to improved resolution of smaller scale feature of the dynamic and also its interaction with topography. The RCM does better than GCM in capturing the observed distribution of daily rainfall (Hudson, 2002).

Statistical downscaling is based on the view that regional climate is condition by two factors, such as the large climatic state and regional/local physiographic features. From this viewpoint, regional or local climate information is derived by first determining a statistical model, which relates large-scale climate variable or predictors to regional and local variable. Then the large-scale output of an AOGCM simulation is fed into this statistical model to estimate the corresponding local and regional climate characteristics (Mearns, 2003).

Climate modeling group from around the world, the world climate research programmer's (WCRP) working group on coupled modeling (WGCM), with input from the International Geosphere-Biosphere programmer's (IGBP); analysis integration and modeling of the earth system (AIMES) project, agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of the Coupled Model Inter-comparison project CMIP5 (Taylor et al, 2012). In the experiments collected under CMIP5, both models and scenario have changed with respect to CMIP3 making a comparison with earlier results and scientific literature they generated. The set of models used in AR4 (the CMIP3 model) have been superseded by the new CMIP5 models and the SRES scenarios have been replaced by four representative concentration pathway scenarios (RCPs). The archive of model simulations began being populated by mid-2011 and continued to grow during the writing of AR5 (Hibbard, 2007).

The world climate research program (WCRP) recently formed the task force on regional climate downscaling (TFRCD) coordinated regional climate downscaling experiment (CORDEX) aims to create a framework for evaluating and comparing the range of dynamical and statistical RCD techniques in use around the world. The general aim of CORDEX is, for a range of limited area regions to downscale a number of GCM climate scenarios/predictions derived from the CMIP5 set of integrations. Its initial focus on Africa (50-km grid spacing) that first Africa is especially vulnerable climate change, both because of the dependence many vital sectors on climate variability (e.g. agriculture, water management, health) and because of the relatively low adaptive capacity of its economies (Filippo et al., 2009)

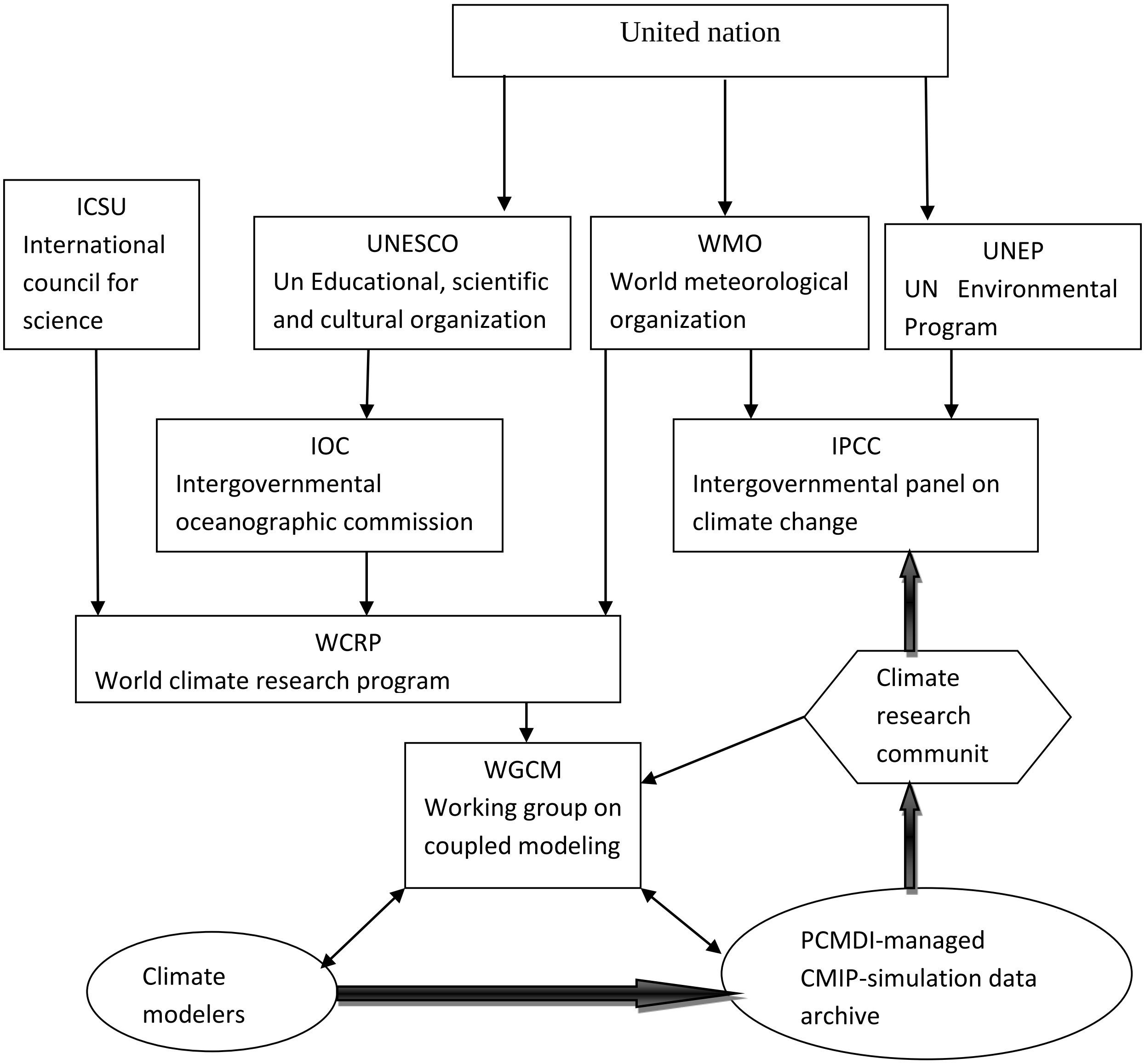

Figure 2.1: Relationships of CMIP5 to Organization Established to coordinate climate research activities internationally *(Taylor et al., 2012)*

2.4 Climate scenarios

Climate change scenarios are possible sequences and/or combination of plausible change in future climate. They used to assess the future consequences of climate change and assist the relevant authorities to formulated appropriate mitigation and prepare adaptive measures to accommodate these changes (Hudson, 2002). Scenarios have served as an important crystallizing function in climate change research in the past and will likely continue to do so in the past, and will likely continue to do so in the future (Detlef, 2013).

If climate scenarios are available and reliable (that means they depict plausible future climate), there are always beneficial for picturing future climate and understanding its impact. They are also useful, probably more important, for testing the robustness adaptation response or policies, despite their uncertainties. Communication climate change scenario to under decision makers, resource manager and planner. In to describe the future climate condition in term of likelihood of occurrence that can be assessed by quantifying the uncertainties (Santaso, 2008).

Human GHG emissions are a model input although it is possible to including an economical/ technological sub model to provide these as well. Atmospheric GHG level is usually supplied as an input, though it is that reflects vegetation and oceanic processes to calculate such level. Future scenarios do not include unknown events, such as volcanic eruption or changes in solar forcing. These effects are believed to be small in comparison to greenhouse gas forcing in the long term, but large volcanic eruption for example, can exert substantial temporal cooling effect (IPCC, 2007A).

The IPCC special report on Emission scenario in replacing the old IPCC scenario (IS92) identifies 40 different scenarios following four families of story line. Six illustrative scenarios were drawn from these four families. That are A1F1 (fossil intensive), A1T (predominantly non fossil), A1B (balanced across energy source), A2, B1 and B2. All emission scenarios were designated as equally valid and probable.

2.4.1 Representative concentration pathway (RCPs)

Concentration or emission scenarios consistent with the RCPs drive the CMIP5 projections of climate change. For CMIP5, fours RCPs have been formulated that are based on range of projection of future population growth, technological development, and societal response. The labels for the RCPs provide a rough estimate of the radiative forcing in the year 2100 (relative to pre-industrial condition).

The radiative forcing in RCP8.5 is increase throughout twenty-first century before reaching level of about 8.5w/m^2 at the end of the century. In addition to this high scenario, there are two intermediate scenarios, RCP4.5 and a low so called peak and decay scenario, RCP2.6 in which radiative forcing reaching a maximum near the middle of the twenty-first century before decreasing to an eventual normal level of 2.6w/m^2.

The early identification of representative concentration pathway will facilitate coordination of new integrated socioeconomic, emission and climate scenarios. RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentration. In addition, the term pathways is to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as stabilization level, that is of interest. But also the trajectory that is taken over time to reach that outcome they are representative in that they are one of several different scenarios that have similar radiative forcing and emission characteristics (IPCC, 2007A).

A new set of scenarios, the representative concentration pathway (RCPs), was used for the climate model simulation carried out under the framework of the coupled model Inter-comparison project phase 5 (CMIP5) of the world climate research program. A large number of comprehensive climate models and ESMs have participated in CMIP5, whose result forms the core of the climate system projection (IPCC, 2013). The RCPs are named according to radiative forcing target level for 2100.

The RCP8.5: high range emission scenario since its possible development for high population number, high fossil/coal use. It was developed using the MESSAGE model and the IIASA integrated assessment framework by the international institute for applied system analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emission over the time.

The RCP6.0: medium rage emission scenario, its low-medium baseline scenario or high mitigation scenario. RCP6 developed by the AIM modeling team at the national institute for environmental studies in Japan. It a stabilization scenario in which total radiative forcing in stabilized shortly after 2100.

The RCP4.5: medium range emission scenario, its high mitigation scenario. It developed by the GCAM modeling team at the Pacific Northwest national laboratory's joint global change research institute in the united states. It is stabilization scenario in which total radiative forcing is stabilized shortly after 2100.

The RCP2.6: low range mitigation scenario. The IMAGE model team of the PBL Netherlands environmental assessment agency developed it. That lead to very low greenhouse gas concentration levels, it is a peak and decline scenario, its radiative forcing level first reaches a value of around 3.1w/m^2 by the midcentury and returns to 2.6w/m^2 by 2100. In order to reach such radiative forcing levels greenhouse gas emissions (and indirectly emission of air pollutions) are reduced substantially over time.

The radiative forcing estimates are based on the forcing of greenhouse gas and other forcing agents. The four selected RCPs were considered to be representative of the literature, and include one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenario (RCP8.5).

Table 2.1: Main characteristics of each regional concentration pathway.

Scenario component	RCP2.6	RCP4.5	RCP6	RCP8.5
Greenhouse gas emissions	Very low	Medium – low mitigation very low baseline	Medium baseline; high mitigation	High baseline
Agriculture area	Medium for crop land and pasture	Very low for both cropland and pasture	Medium for cropland but very low pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium- low	Medium	Medium	Medium-high

2.5 Hydrological Model

The use of hydrologic system analysis is to study the system operation and predict its output. Hydrologic model is an approximation of the actual system, its inputs and outputs are measurable hydrologic variables and it structure is a set of equations linking the inputs and outputs.

2.5.1 Hydrological model classification

Hydrological model divided in to two categories there are deterministic and stochastic model. Deterministic model does not consider randomness; a given input always produces the same output. A stochastic model has outputs that are at least partial random, one might say that deterministic models make forecasts while stochastic model make predictions. Deterministic hydrological models are divided in three groups: lumped, semi-distributed and distributed model. Based on these different modeling approaches, different software are developed for the hydrologic analysis and development of the corresponding flood hydrograph for given storm (Karamouz, 2013).

Lumped hydrological model: the most common models in hydrological analysis are the lumped model. The lumped hydrological models are usually based on the concept of the unit hydrograph, which is valid in the case of watershed being considered as a linear causative and time –invariant system. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based model, example of lumped model is IHACRES model.

Semi- Distributed Hydrological Model: in semi- distributed models, the study area can be divided in to different sub-basins to consider different parameters for their modeling. There is no limitation on the number of sub-basins, but by increasing the division numbers, the computational time effort will highly increase. They are two main types of semi-distributed model such as kinematic wave theory model (HEC-HMS) and probability distributed model (TOPMODEL). Kinematic wave theory model is uncomplicated version of the surface and subsurface flow equations of physically based hydrological model. Probability distributed model is reported for by using probability distributions of input parameters across the basin.

Distributed hydrologic model: the distributed models are commonly GIS based to empower them to include the spatial variation of model parameters and variables in high resolution. Generally large amount of data required for parameterization in each grid cell. The governing physical processes are modeled in detail, and they are used properly, the model is highest degree of accuracy, example of the distributed model is the watershed model system (WMS) (Juraj, 2003).

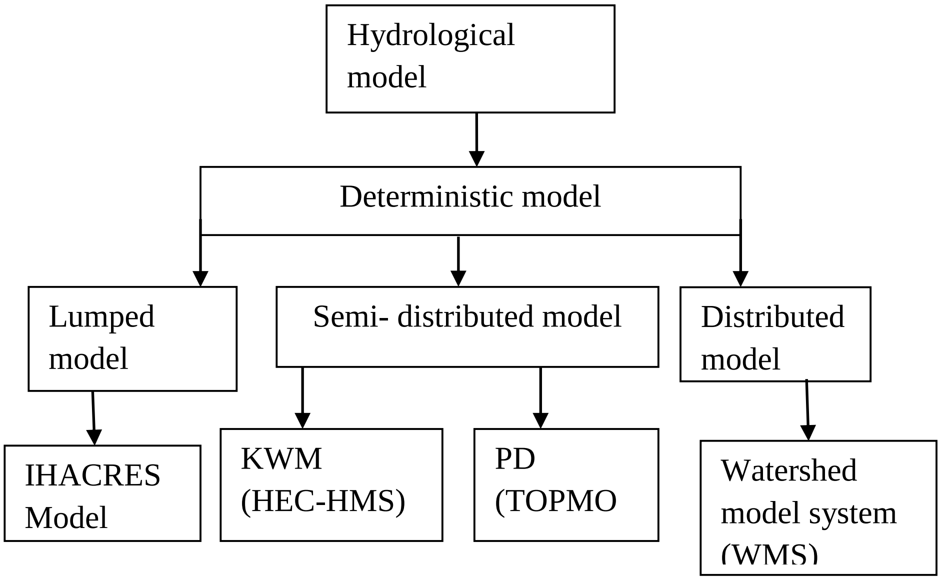

Figure 2.2: Classification of deterministic hydrological model. Source: *(Juraj, 2003)*

2.5.2 Semi-distributed model HEC-HMS4.2.1

The HEC-HMS is a popular model employed for rainfall-runoff analysis in dendrite watershed. This model is applicable in different geographic areas for different problem related to rainfall-runoff analysis. These problems vary from large basin water supply and flood hydrograph to small urban or natural watershed runoff analysis. The model output in the form of runoff hydrographs can be used directly or indirectly for study of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and system operation (Karamouz, 2013)

The hydrological modeling system (HEC-MHS) was designed to simulate the rainfall runoff processes in a wide variety of watershed types. It was anticipated that no single process model would be universally applicable. Therefore, it would be necessary to provide process models that could be used in dry climates, humid climates, and climates impacted by snow and ice, furthermore, more processes of the hydrologic cycle may not be necessary in all applications, for example, snow fall, accumulation, and melt are only necessary in arctic and alpine environments. They may or may not be necessary in temperate climates. Therefore, it would be necessary to design a software system where appropriate process models could be selected, including the possibility that certain processes would not be included at all. The HEC-HMS software was designed in the context of the study process typically used in the U.S. Army Corps of engineers (Scharffenber, 2010).

It is a numerical model that provides a variety of models to simulate watershed hydrological parameters such as runoff, infiltration losses and river routing to predict runoff and flow (Ford, 2008). It is a semi-distributed model that required model that requires physical data to anticipate hydrologic simulation and requires detailed data and more complex parameterization compare to the lumped conceptual model, which requires minimal input data. The main reasons using of HEC-HMS model are simplicity and widely acceptance, and is well-known rainfall-runoff simulation model.

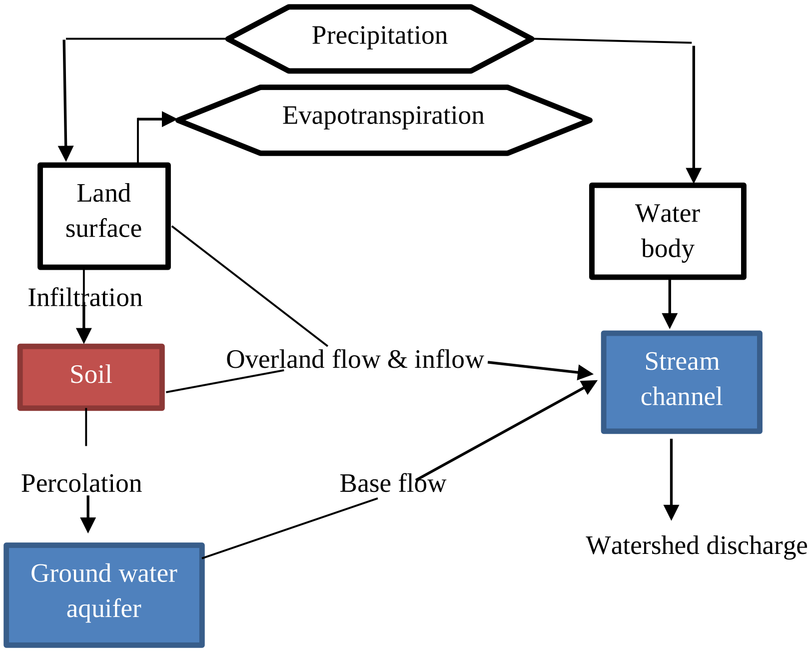

Figure 2.3: Typical HEC-HMS4.2.1 representative of watershed runoff. Source: *(USACE, 2000)*

3 MATERIALS AND METHODS

3.1 Study Area description

3.1.1 Location

The Awash River basin is located in central Ethiopia and flow through 5 regional states at an altitude of about 3000m above sea level. The total length of the river is about 1200km and its catchment area is 113700km^2. Borkena River is located in the North-eastern part of Ethiopia. It is one of the main tributaries of the Awash River basin. It is drain from the mountainous chains escarpments found in the northern plateau which is adjacent to the Afar rift down to south-eastern direction and joining the Jara River, it finally enters the Awash River (Sahele, 2001). As show Figure 3.1 the river basin lies in the east part of Ethiopia between 12^{0}0` and $6^{0}$20`N and 39^{0}32` and $40^{0}$0`E.

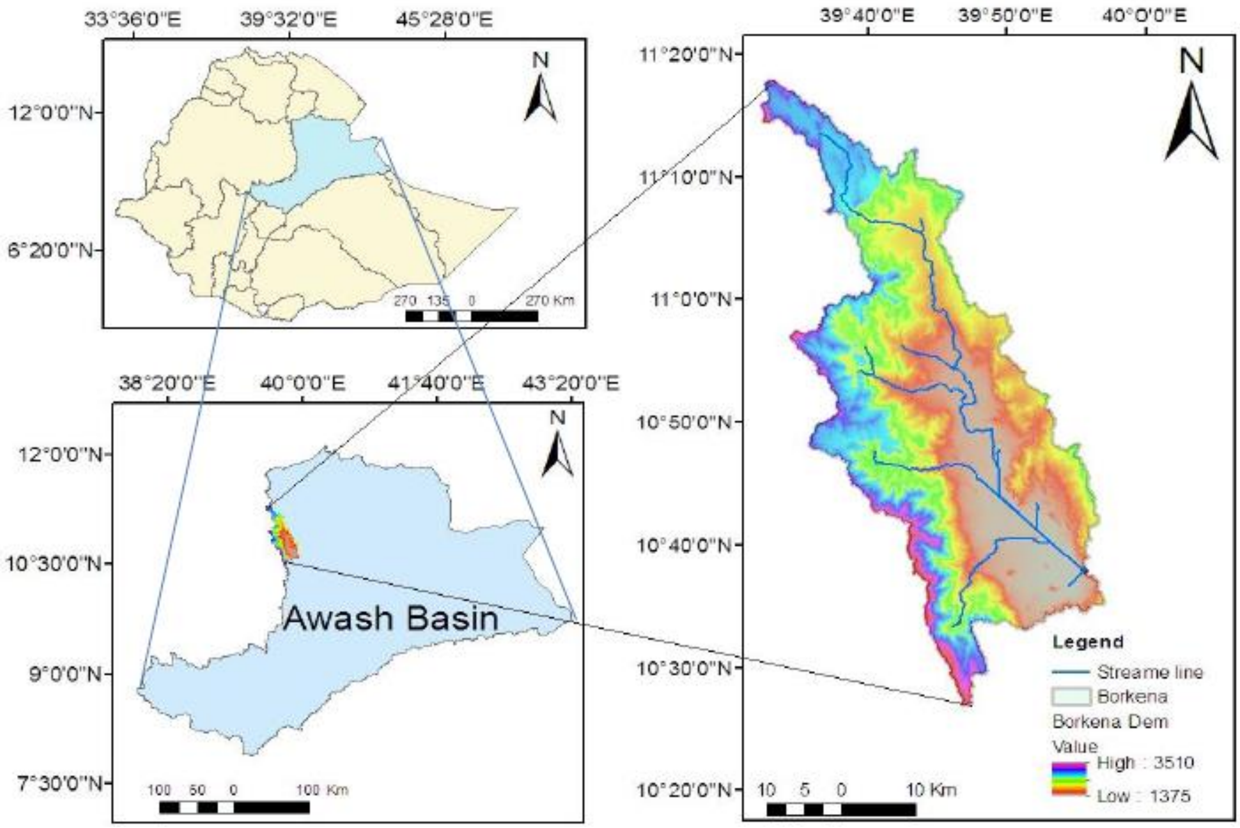

Figure 3.1: Description of the study area.

3.1.2 Climate of the study area

The climate of the study area is varying between sub-humid and sub-tropical, and according to the local classification of climate, which is mainly based on altitude variation, the climate is classified as “Dega and Weyna Dega”. The main annual rainfall over the catchments is 1028mm and most of which is concentrated in the big rainy months that lasts from July to September and contribute about 84% of the annual rainfall. The mean monthly temperature considering the kombolcha meteorology station varies between 16.1^0c to 22.1^0c which corresponds to December June respectively. Monthly mean sunshine hour and relative humidity varies between 5.0 to 8.5 and 40.1% to 64.3% respectively with rainy seasons being humid and have lower sunshine hour. The sub humidity area covers about 50.3% and the subtropical aerial coverage is about 49.7% of the total catchment area (Sahele, 2001).

3.1.3 Land use and land cover

More over the use of woods for fuel consumption and as a construction material is influencing the land use and land cover pattern of the area. Mainly for these reasons, the catchments are being degraded from time to time. The vegetation covers of the area including eucalyptus, acacia and juniper trees over a small area and bushes and shrubs cover the larger area proportion (Sahele, 2001).

3.2 Data collection

3.2.1 Climate data

All observed weather data used in the study were collected from the national meteorology service of Ethiopia (NMA). It is the head office is Addis Ababa and it is the branch office is Kombolcha. The dataset covers the reference period of 1986-2016. Although use the national observation network including several rainfall gauge and synoptic stations. Daily time series of five climate variable (minimum and maximum temperature, relative humidity, wind speed, and sunshine hour), and daily time series of rainfall data collected form NMA.

The RCM-GCM simulations were performed in the framework of the CORDEX-Africa project. Climate data that were downscaled regionally were gate from International Water Management Institute (IWMI). RCM groups produced the datasets. Each dataset consists of historical runs and projections based on the emission scenarios RCP4.5 and RCP8.5.

3.2.2 Hydrological data

Daily stream flow data from selected sub basins were used for calibration and validation of hydrological model (HEC-HMS) for hydrologic impact analysis. Borkena River daily discharge covering the references period 2003-2015 were collected from ministry of water, irrigation and electricity (MoWIE).

Table 3.1: Data collection and source.

Data type	Data source	Period	Description
Climate	National meteorology agency	1986-2016	Daily precipitation, minimum and maximum temperature, average wind speed and humidity
Hydrology	Minister of water, irrigation and electricity	2003-2015	Daily and monthly flow data

3.3 Methodology

After collecting the necessary data for the research delineation of the study area, determination of basin characteristics and analysis stream flow and rainfall data have been made. The data used in this research are DEM data, Hydrological and Meteorological data, and RCM data. ARC-GIS are to obtain hydrological and physical parameters and spatial information of the catchment. The HEC-GeoHMS and HEC-HMS model are used to analysis the given data. The digital elevation model (DEM) of the study area prepared was from shuttle radar topography mission (SRTM) which have a resolution of 30m×30m. Digital elevation model (DEM) used automatically to delineate the watershed boundaries. After delineating the watershed boundary, different useful basin data such as area, slope, mean elevation, and maximum flow distance are calculated. In addition, locates all flow paths overall terrain model, which make it possible to examine flow patterns in different point of the basin. The longest flow path in each sub-basin, which used for estimation of the time of concentration, is also calculated. The DEM processed by using Arc-GIS 10.3 to extract the map and the stream layer of the study area. The DEM and stream layer are also used as input for HEC-GeoHMS, which is an extension of Arc-GIS 10.3 interface.

Bias correction was done for both observed and RCM climate data. The output from HEC-GeoHMS, Bias corrected observed climate data (rainfall and evapotranspiration) and observed flow data are used as input for HEC-HMS to calibrate and validate. On the other hand, the bias corrected RCM data given to the calibrated and validated rainfall-runoff hydrological model (HEC-HMS) which have been made for future flow data. Mann-Kendall trend test has been used for determination of climate change trend in the study area. Mann-Kendal trend analysis of time series consists of the magnitude of trend and its statistical significant.

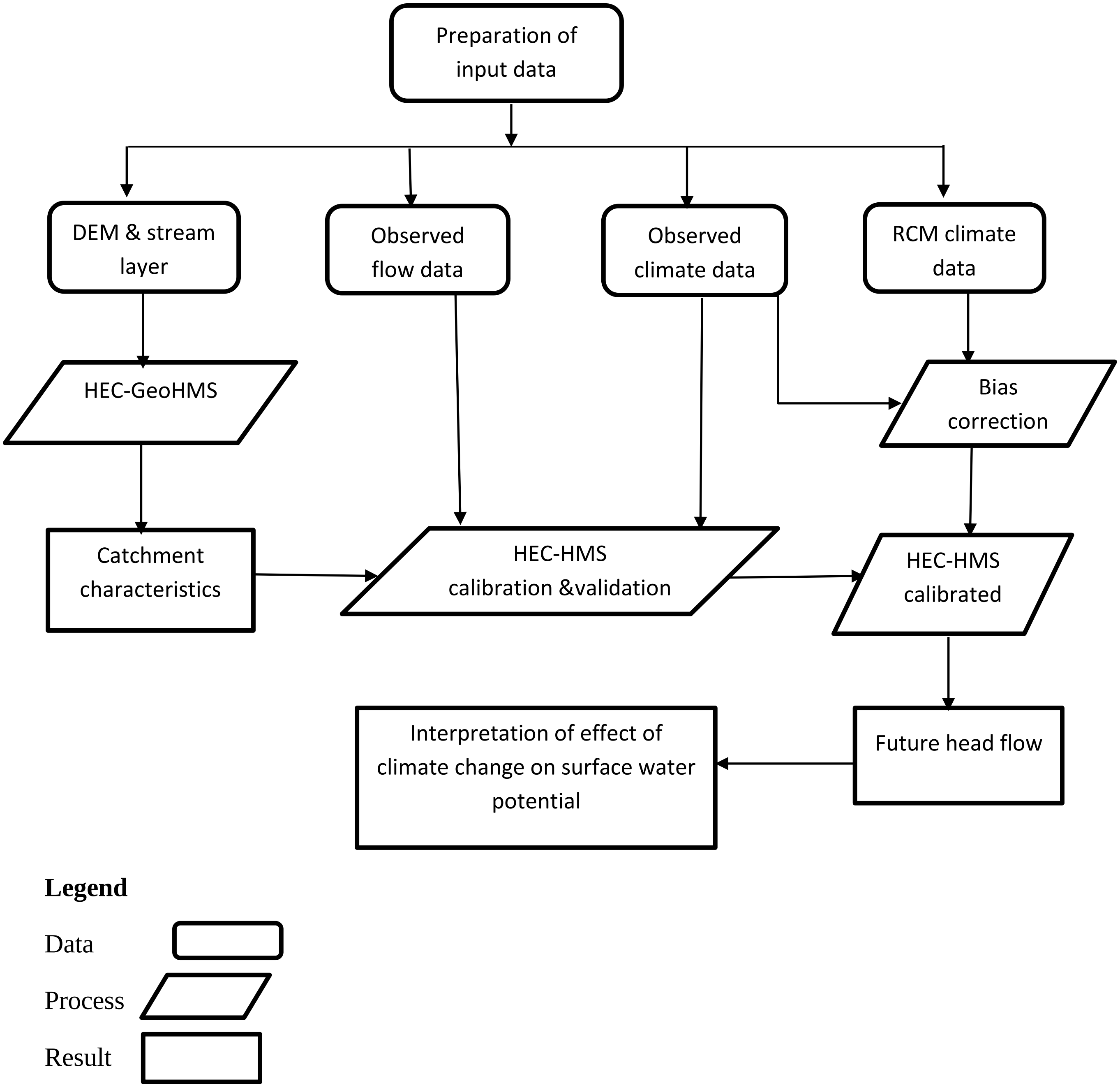

Figure 3.2: General methodology flow chart used in the study.

3.4 Data analysis and Processing

3.4.1 Meteorological data analysis

Meteorological data is input in HEC-HMS model to simulate the hydrological condition of the river. The main problem in water resource potential assessment, especially in developing country is the availability of meteorological and hydrological data in quantity and quality. The result of any research depends on data resource. In this research, meteorological data available at eight stations located in and around the study area. Three meteorological stations are principal (first class) and five stations are third class meteorological station. (In detail appendix A table A-1)

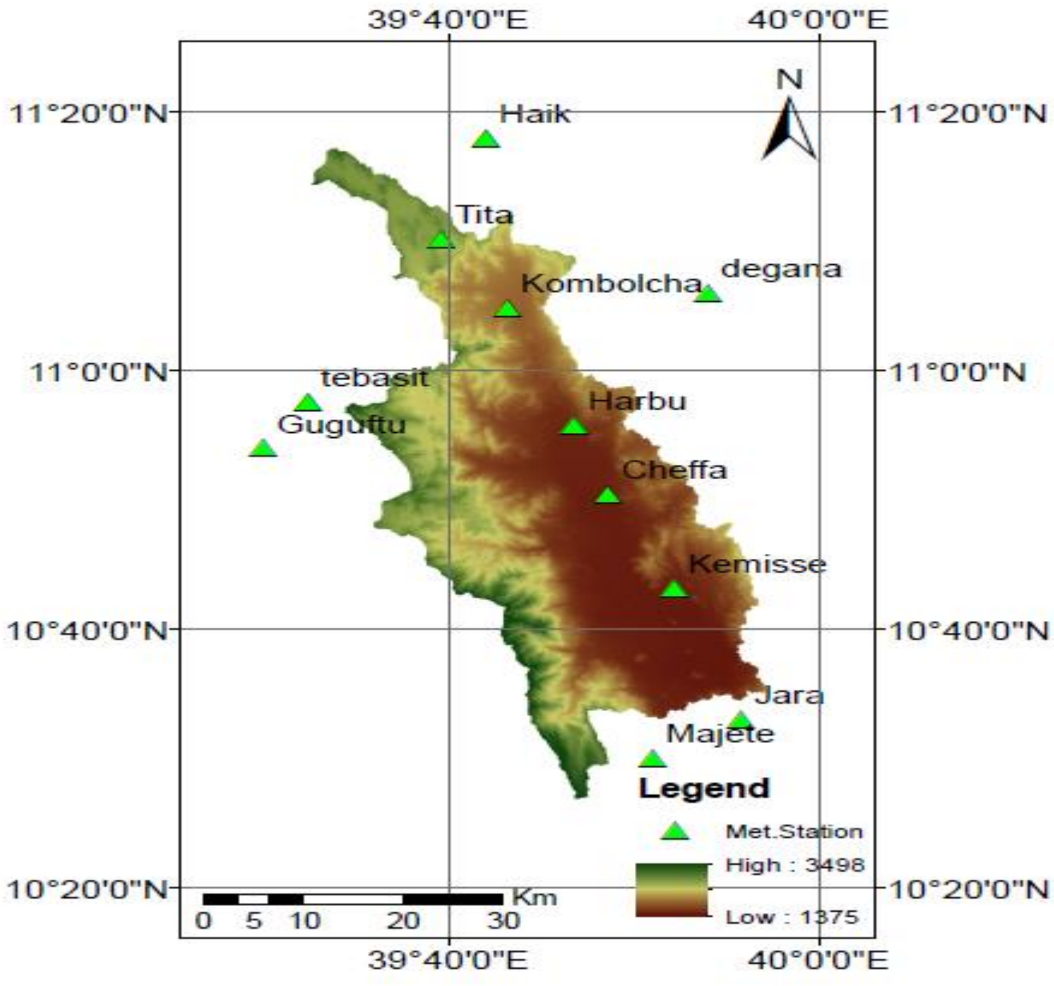

Figure 3.3: Selected climate stations of Borkena River.

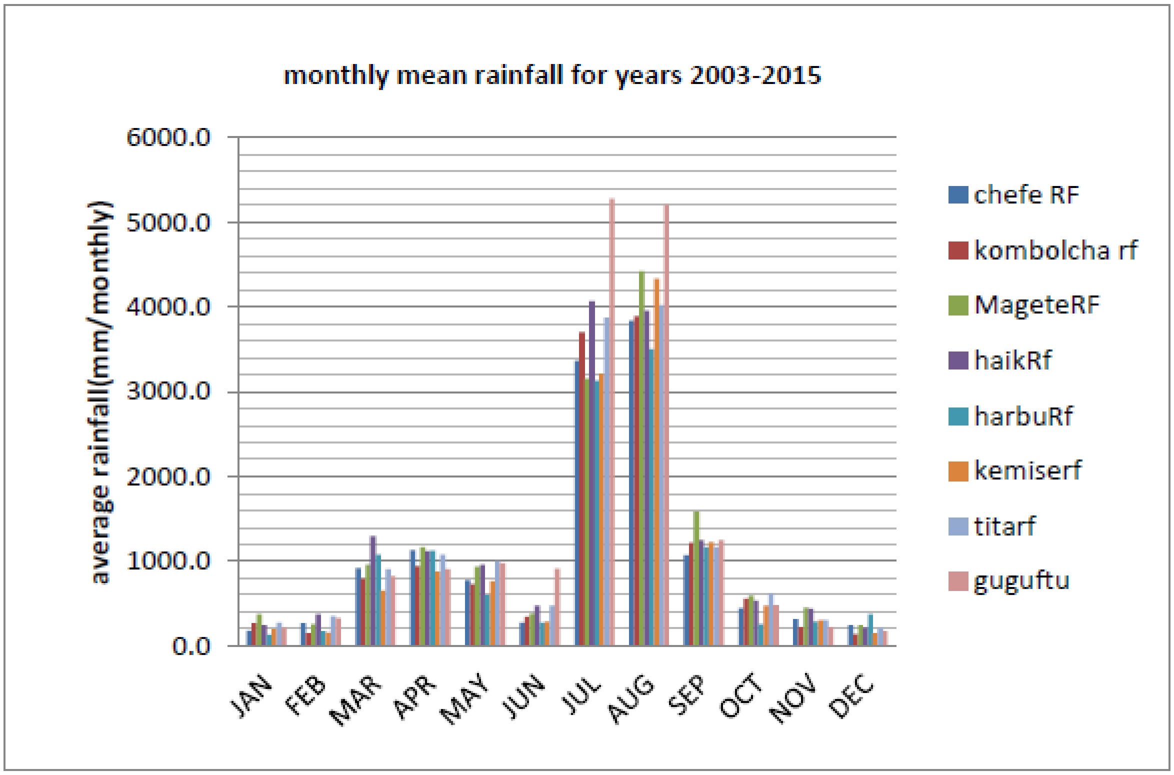

Figure 3.4: Monthly average rainfalls of selected stations (mm/monthly).

3.4.2 Filling missed data

Due to the absence of observer or instrument failure, meteorological data records occasionally are incomplete. In such a case, one can estimate the missing data by using the nearest station meteorological data and hydrological data. For this research, station which has below 10% missed recording of meteorology data were filled by Arithmetic mean method and more than 10% missed recording of the data were filled by inverse distance weight interpolation (IDW) method.

Arithmetic mean (AM) method: If the normal annual rainfalls at surrounding gauges are within 10% of the normal annual precipitation at the stations concerned, then the arithmetic mean procedure could be adopted to estimate the missing data (Chow, 1988).

$$P_{m=}{}^{1}/_{n}\left[\sum_{i=1}^{n} Pi\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where

Pm = estimate for the target station m

Pi = rainfall values of rain gauges used for estimation

n = number of surrounding station

Inverse Distance Weighting (IDW) method: In this method, the weight for each station is assumed inversely proportional to its squared distance of the target station from the neighboring station with data (Lam, 1983).

$$Px = \frac{\sum_{i=1}^{m} \frac{1}{di^2} pi}{\sum_{i=1}^{m} \frac{1}{di^2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..3.2$$

Where

P_x = estimate of rainfall for the ungauged station

P_i = rainfall values of rain gauges used for estimation

di = distance from each location the point being estimated

N = number of surrounding station

3.4.3 Station data record check for consistency

Double mass curve technique is often used to test the consistency of rainfall record by plotting the cumulative annual rainfall at station x against the current cumulative values of mean annual rainfall for a group of surrounding station for the number of year of record. From the plot, the year in which a change in regime or environment has occurred is indicated by the change in slope of the straight line plot (Ragunath, 2006). The rainfall records of the station X are adjusted by multiplying the recorded values of rainfall by the ratio of slopes of the straight line before and after change in environment.

$$P_{a=} \frac{b_a}{b_o} P_o \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.3$$

Where

Pa = adjusted precipitation

Po = observed precipitation

bo = slope of graph at time Po was observed

ba = slope of graph to which records are adjusted

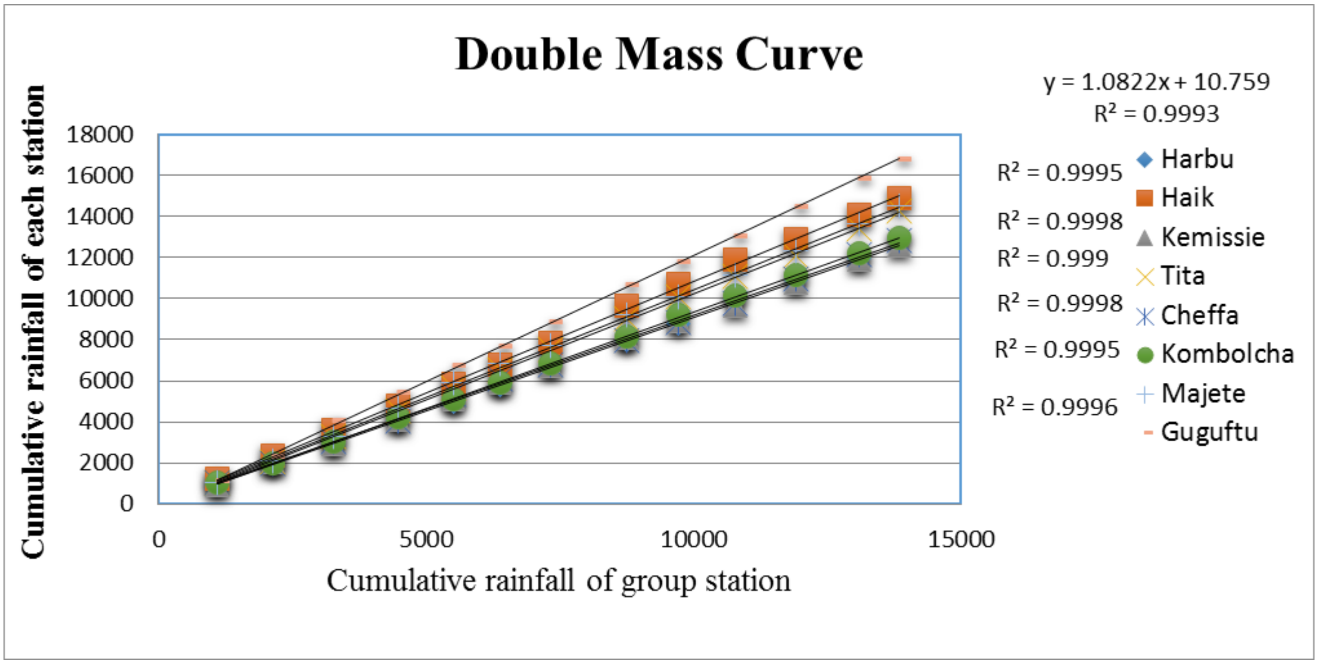

Figure 3.5: Borkena river catchment selected Meteorological station rainfall consistency checking result.

3.4.4 Testing of homogeneity

Homogeneous data are process that could potentially affect the data must remain constant for the complete time period. The results of non-dimensional from data analysis show in Figure 3.6 to all sub-basins. The non-dimension of the month's value was calculated:

$$P_n = 100 * \frac{\overline{P_n}}{\overline{P}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..3.4$$

Where

P_n = non- dimensional value of rainfall for month n.

$\overline{P_n}$ = over year averaged monthly rainfall at station n

$\overline{P}$ = over year average yearly rainfall of the station.

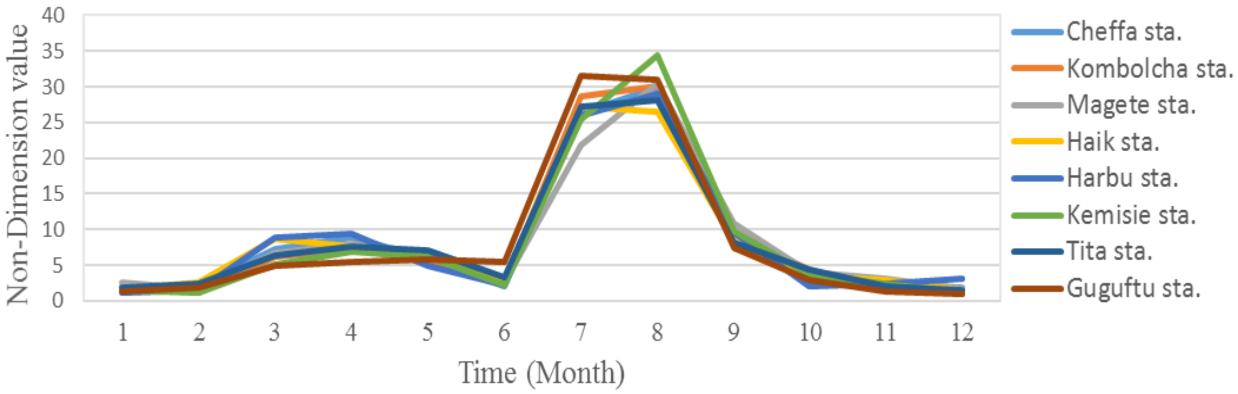

Figure 3.6: Homogeneity test for selected stations in Borkena watershed.

3.4.5 Estimating Areal rainfall

It is important to have accurate rainfall information in a catchment for hydrological data analysis. However, rainfall varies in space and it is expensive to install and maintain a very dense rain gauges network to completely cover all the catchments. As result, only a limited number of gauge are installed and there are large gaps between the gauges. For assessing rainfall in a catchment, we need to determine the average rainfall over the catchment, so that the total amount of rainfall estimated by Thiessen polygon method.

The Thiessen polygon method is the most popular method used in practical engineering problems. The polygon plotted by computer software (ArcGIS). Thiessen area formed around each station by plotting the perpendicular bisectors of the lines connecting station use ArcGIS. The average rainfall computed by Thiessen polygon method used as input to the HEC-HMS model for calibration and future simulation. The relative weight for each gauge is determined from the corresponding area. If the area within the catchment assigned to each gauge is Ai, and its rainfall is Pi, the areal average rainfall for the catchment is

$$Pav = \frac{1}{A}\sum_{i=1}^{n} AiPi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

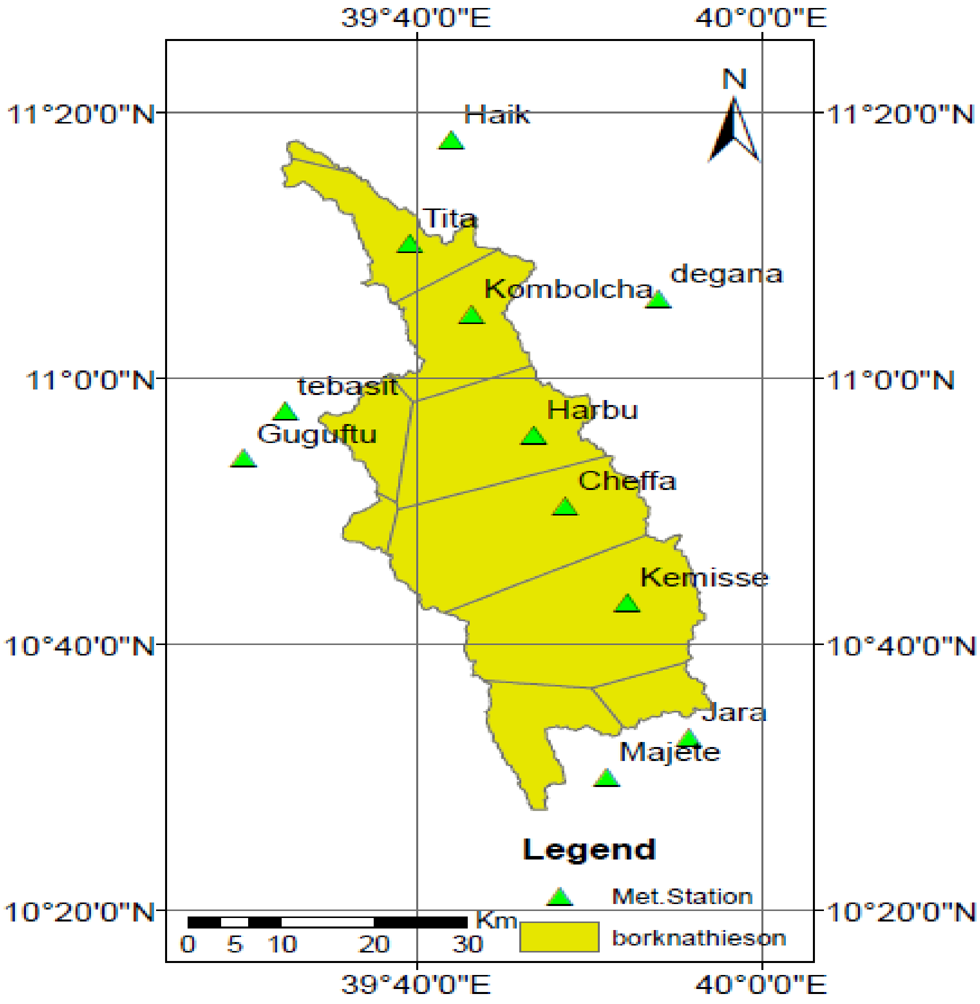

Figure 3.7: Borkena catchment areas Thiessen polygon for the selected meteorological station.

3.5 Basin evapotranspiration

Evapotranspiration (ET) is two processes of water loss from land to atmosphere, evaporation and transpiration. Evaporation is the process by which water from open water surface, on soil surface water on leaves and branch of a plant escapes as vapor to the atmosphere through the transfer of heat energy. On the other hand, transpiration is consists of vapor of liquid water (moisture) within plant and subsequent loss of water as vapor through leaf stomata (ADSWE.A.D, 2012).

There are different methods for estimate potential evapotranspiration (ETo) using observed data. The methods vary depends on climate variables required to estimation. For this research, potential evapotranspiration has been calculated using penman – Monteith. This equation used as input to the HEC-HMS model for calibration and simulation. Potential evapotranspiration calculated by using ETo calculator software from observed data which uses FAO. The penman – monteith method equation given by:

$$\mathrm{ET_{o=}}\ \frac{0.408\Delta(\mathrm{R_n}-\mathrm{G})+\ \gamma\frac{900}{\mathrm{T}+273}\mathrm{U_2}(\mathrm{e_s}-\mathrm{e_a})}{\Delta+\gamma(1+0.34\mathrm{U_2})}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.3.6$$

Where

ETo = reference evapotranspiration rate (mm/d)

T = mean air temperature

U_2= wind speed (m/s) at 2m above the ground

Rn = net radiation flux (MJ/m^2d)

G = sensible heat flux in to the soil (MJ/m^2d)

e_s= saturation vapor pressure, kPa

e_a = actual vapor pressure, kPa

Δ = slope of the pressure curve kPa/^{0}c

γ = psychometric constant, kPa/^{0}c

The future ET was estimated by using Hargreaves method. Climate model have only rainfall, minimum and maximum temperature data. Therefore, for the study it is suitable to use Hargreaves method, which is temperature, based used to estimate future evapotranspiration. The Hargreaves equation is;

$$\mathrm{ET_{o=}}\ 0.0023\mathrm{Ra}(\mathrm{T_{max}}-\mathrm{T_{min}})^{0.5}\left(\frac{\mathrm{T_{max}}-\mathrm{T_{min}}}{2}\right)+17.8\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots3.7$$

Where

ETo = estimated by the Hargreaves equation mm/day

Ra = extraterrestrial radiation MJ/m2day

Tmax = maximum air temperature (^{0}C)

Tmin = minimum air temperature (^{0}C)

3.6 Bias correction

Bias correction methods are often applied with in climate impact studies to correct the climate input data provided by regional climate models for systematic statistical deviations from observation data. The downscaled and bias corrected CMIP5 data is an input for calibrated the HEC-HMS model. The calibrated HEC-HMS model is used to assess the effect of climate change on stream flow generation for the basin. Bias correction methods adjust the long-term mean by adding the average difference between the simulated and observed data over the historical period to the simulated data or by applying an associated multiplicative correction factor.

3.6.1 Precipitation bias correction

The precipitation data downscaled by used power transformation, which corrects the CV (coefficient of variation) as well as the mean. In this nonlinear each daily precipitation amount P is transformed to a corrected P* using

$$P^{*} = aP^{b} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .3.8$$

The effect of sampling variability is reduced by determining the parameter a, and b for daily rainfall data of the all years (Leander, 2007). The determination of b parameter is done iteratively. It was determined such that the CV of the corrected daily precipitation matches the CV of the observed daily precipitation. In this way, the CV is only a function of parameter b according to

CV (P) = function (b), P is precipitation with the determined parameter b, the transformed daily precipitation values are calculated using

$$P^{*} = \ P^{b} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.9$$

The parameter “a” is determined such that the mean of the transformed daily values corresponds with the observed mean. The resulting parameter “a” depends on b. the parameter b depends only on the CV and is independent of the value of parameter a.

Table 3.2: Precipitation bias correction the value of a and b parameter for each sub-basin.

RCP4.5					
Sub-basin 1		Sub-basin 2		Sub-basin 3	
Parameter a	Parameter b	Parameter a	Parameter b	Parameter a	Parameter b
1.477944	0.7752	0.760368	0.93018	0.500785	0.500785
1.160811	0.853941	0.331184	1.292001	0.21988	0.21988
4.893447	0.416574	1.595564	0.811852	1.594426	1.594426
2.32985	0.416574	1.018419	0.741303	0.672081	0.672081
0.722029	0.506775	0.307134	1.200404	1.015139	1.015139
0.023791	0.9822	0.013142	1.91033	0.005766	0.005766
0.286247	1.871454	0.060191	1.701907	0.070133	0.070133
0.127075	1.436257	0.032847	1.852833	0.047519	0.047519
0.095183	1.562683	0.037467	1.595486	0.076422	0.076422
0.559433	1.42683	0.437242	1.002756	0.95249	0.95249
1.396304	0.708007	0.435904	1.044429	0.972146	0.972146
0.349675	1.178234	0.009367	2.257063	0.070266	0.070266

3.6.2 Temperature bias correction

For correcting the daily temperature difference technique is used. The correction of temperature only involves shifting and scaling to adjust the mean and variance (Leander, 2007). For sub basin, the corrected daily temperature T was obtained as

$$T^* = \bar{T}_o + \frac{\sigma T_o}{\sigma T_u}(T_u - \bar{T}_o) + (\bar{T}_o - \bar{T}_u) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.10$$

Where

T* = corrected daily temperature

$\bar{T}_o$ = mean observed temperature

$\bar{T}_u$ = uncorrected mean daily temperature from CMIP5 output data

T_o = observe temperature from NMA data set

T_u = uncorrected daily temperature from CMIP5

Table 3.3: Temperature bias correction the value of mean temperature and standard deviation for RCP4.5

Maximum temperature						
Sub-basin	Observed		RCP4.5		RCP8.5	
	Mean (^{0}c)	Stdv (^{0}c)	Mean (^{0}c)	Stdv (^{0}c)	Mean (^{0}c)	Stdv (^{0}c)
Sub-basin 1	27.04	2.19	21.07	3.06	22.04	3.59
Sub-basin 2	27.08	1.89	19.89	2.88	20.85	3.40
Sub-basin 3	30.07	3.67	23.95	3.17	24.90	3.62
Minimum temperature						
Sub-basin	Observed		RCP4.5		RCP8.5	
	Mean (^{0}c)	Stdv (^{0}c)	Mean (^{0}c)	Stdv (^{0}c)	Mean (^{0}c)	Stdv (^{0}c)
Sub-basin 1	11.56	2.98	9.29	4.33	10.30	4.67
Sub-basin 2	10.93	2.51	8.98	4.21	9.96	4.52
Sub-basin 3	13.19	3.19	11.96	4.37	12.99	4.72

3.7 Trend analysis

In this research trend analysis has been computed by using non-parametric Man-Kendall trend test. Mann-Kendall is to determine the fact of a mathematical sequence; consistently increasing and never decreasing or consistently decreasing and never increasing trends in series of climate data or hydrological data. It is a non-parametric test, which means it works for all distribution (i.e. your data does not have to meet the assumption of normality) but your data does should have no serial correlation. (Pohlert, 2018). The null hypothesis for this test is that there is no monotonic trend in the series. The alternate hypothesis is that trend exists. This trend can be positive, negative or non-null. The Mann-Kendall test statistic calculated according to

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(Xj - Xk) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.11$$

$$sign(x) = \begin{cases} 1\ if\ x > 0 \\ 0\ if\ x = 0 \\ -1\ if\ x\ < 0 \end{cases}$$

The mean of S is E(S) = 0 and the variance σ^2 is

$$\sigma^2 = \frac{\{n(n-1)(2n+5) - \sum_{j=1}^{p} tj(tj-1)(2tj+5)\}}{18} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.12$$

Where p is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group. The statistic S is approximately normal distributed provided that the following Z-transformation is employed

$$Z = \begin{cases} \frac{S-1}{\sigma} \; if\ S > 0 \\ 0 \; if\ S = 0 \\ \frac{S+1}{\sigma} \; if\ S > 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.13$$

The statistic S is closely related to Kendal's Ʈ as given by

$$T = \frac{S}{D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.14$$

Where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j\,(t_j - 1)\right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots 3.15$$

Magnitude of trend (Sen's slope)

This test computers both the slope, that means linear rate of change and intercept according to Sen's method. First a set of linear slopes is calculated as follows

$$d_k = \frac{x_j - x_i}{j - i} \; for\ (1 \leq i < j \leq n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.16$$

Where: d is the slope, x denoted the variable, n is the number of data, and i, j are indices.

Sen's slope is then calculated as the median from all slopes: b = median $d_{k.}$ the intercepts are computed for each time step t as given by

$$a_t = X_t - b * t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.17$$

And the corresponding intercept is as well the median of all intercepts. This function also computes the upper and lower confidence limits for Sen's slope.

3.8 Hydrological analysis

In this specific study, stream flow data of swamp flow gauge station have used for data analysis. The stream flow data was used for calibration and simulation of the hydrologic model HEC-

HMS4.2.1. The stream flow data covered for the period of 2003-2015. There are some periods with missed and short gauge records in stream flow data. Therefore, we must fill missed data and extend the short record before using the data. Missing flow data records are filled by making correlation between the station with missing data and any of select station with the same hydrological feature and common data periods.

Table 3.4: Equation relating the swamp flow gage with the Robit flow gage station.

Flow gage station	Jewoha gage station	Robit gage station
Swamp Borkena outlet	0.6121	0.7895
		Linear correlation equation $Y = 0.6507x + 2.0357$

Y= missed flow value at swamp gage, x = flow value at Robit gage for the same time period.

Table 3.5: Hydrological station for study area.

Station name	Drainage area (km^2)	Latitude	Longitude
Swamp Borkena outlet	1735.0	10.38	39.56

3.9 Hydrologic model

3.9.1 Hydrologic model selection criteria

There are different criteria which can be used selecting the 'right'' hydrological model. Criteria are depending on the project objective, which means each project has its own specific requirement and needs. The criteria of Juraj M. Cunderlik (Juraj, 2003) used for selecting the hydrological models are:

- Required model outputs important to the project and therefore to be estimated by model
- Hydrologic processes that need to be modeled to estimate the desired output adequately
- Availability of input data
- Price

Based on the above criteria, hydrological engineering center's modeling system (HEC-HMS) is selected as the best modeling tool, because of their simple structure, fast set up calibration, minimum data requirement and easy use. The current version of HEC-HMS4.2.1 a highly flexible package used for this study.

3.9.2 Description of HEC-HMS model

The US Army Corps of Engineering (US-ACE) Hydraulic Engineering Center HEC-HMS (Hydrologic modeling system) model designed to simulate the precipitation-runoff processes of dendritic watershed **system**. HEC-HMS designed to be applicable in a wide range of geographic area for solving the widest possible range of problem. This is including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, flood plain regulation, and systems operation (Scharffenber, 2010).

3.9.3 HEC-HMS set up

HEC-HMS software must have the following component before it can be run, such as basin model, a meteorological model and control specification.

The Basin model and basin model features: were created in the form of a background map file imported to the HEC-HMS from the data derived through HEC-GeoHMS for model simulation

The Meteorological model: the meteorological component has been used to model observed precipitation and evapotranspiration in the basin using the user weighting method and specified evapotranspiration model.

Control specification model: determine the time pattern for simulation; it is feature consists of control time and date of ending and starting, as well as computational time step and time interval.

3.9.4 HEC-GeoHMS

HEC-GeoHMS is a geospatial hydrology toolkit for engineers with limited GIS experience. It is an extension package used in Arc GIS software (USAC, 2009). In this study, HEC-GeoHMS is used to derive river network of the basin and to delineate sub-basins from the digital elevation model (DEM) of the basins. In the sub-basins delineation process stream flow gauge swamp is used for Borkena river basin.

3.9.5 Analytical component of HEC-HMS

HEC-HMS consists of hydrological methods. It is consists canopy, surface, runoff – volume, direct– runoff and base flow. HEC-HMS gives flexibility to the user by providing each component with suit of methods. The user can choose a suitable combination of method depending on the available data, the purpose of modeling and the required spatial temporal scales. Some of the appropriate methods in the perspective of this study are describe below

Deficit and Constant loss: the method uses a single soil layer to account for continuous changes in moisture content. The initial deficit is the initial condition for the method. It is the amount of water required to fill the soil layer to the maximum storage. The maximum deficit specifies the amount of water the soil layer can hold specified as depth. An upper bound is the depth of the active soil layer multiplied by porosity. The constant rate is the percolation rate when the soil layer is saturated. The percentage of sub-basin which is directly connected to impervious area; all precipitation on that portion of the sub-basin becomes excess precipitation and subjected to surface storage and direct runoff. In the study makes used of the deficit and constant loss-rate methods.

Clark unit hydrograph transformation: the method is used to transform the excess rainfall to direct runoff at a given point outlet. It is a synthetic unit hydrograph method. That means the user is not required to develop a unit hydrograph through the analysis of past-observed hydrographs. Time versus area built into the program is used to develop the translation hydrograph resulting from a burst of precipitation.

Time of concentration: It is a maximum travel time in the sub-basin. It is used in the development of the translation hydrograph. Storage coefficient is used in the linear reservoir that accounts for storage effects.

Constant monthly base flow: It is allows the specification of a constant base flow for each month of year. It does not conserve mass within the sub-basin. It is intended primarily for continuous simulation in sub-basins where the base flow is nicely approximately by constant flow for each month.

Muskingum routing: The method uses a single conservation of mass approach to route flow through the stream reach. However, it does not assume that the water surface is level; by assuming a linear, but non-level. Water surface it is possible to account for increased storage during the rising side of a flood wave and decreasing storage during the falling side. By adding a travel time for the reach and a weighting between the influence of inflow and out flow, it is possible approximate attenuation. The Muskingum K is essentially the travel time through the reach. It can be estimated from knowledge of the cross section properties and flow properties. It may be calibration in some cases. The Muskingum X is the weighting between inflow and out flow influence; it ranges from 0.0 up to 0.5. In practical application values of 0.0 results in maximum attenuation and 0.5 results in no attenuation. Most stream reaches required an intermediate values found through calibration.

3.10 Model calibration and validation

In HEC- HMS has parameter each methods and the value of this parameter entered as input to the model to use the simulation hydrographs. The parameter estimated by observation and measurements of stream and basin characteristics. However, the required parameters cannot be estimated accurately, the model parameters are calibrated, that means in the presence of rainfall and runoff data the optimum parameters are found as a result a systematic search process that yield the best fit between the observed runoff data and the computed runoff. This method is called optimization. Optimization starts from initial parameter determine and adjusts them so that the simulated results match the observed stream flow as closely as possible.

The trial and error method: this method used to makes a subjective adjustment of parameter values in between simulation in order to reach at the minimum values of parameters that find the best fit between the observed and simulated hydrograph was employed to calibrate the model.

3.10.1 HEC-HMS model performance evaluation method

The method used to evaluate the performance of the model are the overall agreement between predict and measured runoff discharges, and the model ability to predict time and magnitude of hydrograph peak and runoff volume. HEC-HMS performance has been quantified for both calibration and validation in difference ways. There are root mean square error (RMSE), coefficient of determination (R^2) and Nash-sutcliffe efficiency.

3.10.1.1 Nash-sutcliffe efficiency (NSE)

It is a measure of efficiency that relates the goodness of-fit of the model to the variance of measure data. NSE can range from -∞ to 1. The value between 0.0 and 1.0 are acceptable level performance whereas the value less than or equal to zero indicates that the mean observed value is a better predictor than the simulated value which indicates unacceptable performance.

$$NSE = \frac{\sum_{i=1}^{n}[Q_o - Q_s]^2}{\sum_{i=1}^{n}[Q_o - \overline{Q}_o]^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.18$$

Where: Q_o = observed flow Q_s = simulated flow $\overline{Q}_o$ = average of observed flow

3.10.1.2 Coefficient of determination $\boldsymbol{R^2}$

The coefficient of determination R^2 defined as the squared value of the coefficient of correlation according to Bravais person. It has calculated as

$$R^2 = \frac{\sum_{i=1}^{n}\left[\left(Q_s - \overline{Q}_s\right)\left(Q_o - \overline{Q}_o\right)\right]^2}{\sum_{i=1}^{n}\left(Q_s - \overline{Q}_s\right)\left[\sum_{i=1}^{n}\left(Q_o - \overline{Q}_o\right)\right]^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.19$$

Where

Q_o= observed flow
Q_s= simulated flow
$\overline{Q}_o$= average of observed flow
$\overline{Q}_s$= average of simulated flow

The range of R^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all whereas a value of one means that the dispersion of the prediction is equal to that of the observed.

3.10.1.3 Relative Volume Error (RVE)

The value varies between -∞ and ∞. The best value is equal to zero or near to zero, this indicated there is not different between observed and simulated stream flow. However, at the time of simulation of discharge through the calibration period may wrong. Therefore, this objective function should be used in conjunction with the NS criteria as defined by equation

$$RVE = \frac{\sum_{i=1}^{n}\left(Q_{S,i} - Q_{O,i}\right)}{\sum_{i=1}^{n} Q_{O,i}} * 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.20$$

Where:

RVE = percentage error in total runoff volume

Q_s = simulation flow

i = the time step

Q_o = observed flow

An RVE value between +5% and -5% indicates a well performing model while error values between -5% and -10% indicate reasonable performance.

4 RESULT AND DISCUSSION

According to the objective of the research, the result and discussion presented in three parts. The first part presents the future temperature, precipitation and evapotranspiration trends, the second part will present the evaluation climate change of rainfall, temperature, and evaporation, finally the effect of climate change on the stream flow will examined and presented.

4.1 Future climate variables Trend analysis

4.1.1 Rainfall trend

This research, Mann-Kendall trend analysis has been used for historical and future data of precipitation and temperature from 1986-2015 for historical and from 2041-2070 for future period. The catchment average areal rainfall has decreasing trend for RCP4.5 and RCP8.5 scenarios of CMIP5 climate model. The trend is not significant for RCP4.5 scenario whereas, significant trend under RCP8.5 scenario. According to Mann-Kendall test result, the precipitation was decreasing trend by 4.58mm/annual over the historical period (1986-2015). In the future period (2041-2070), the Sen's slope estimate indicates precipitation will be decreasing trend to more than 12.12mm/annual under intermediate scenario RCP4.5. Under high emission scenario, RCP8.5 the basin precipitation shows a decreasing trend by 1.83mm/annual in historical period. In the future period (2041-2070s) the precipitation will decreased more than 0.46mm/annual. The general description of Mann-Kendall trend test result provided in table 4.1. For this study, CMIP5 model output projection of future precipitation informs that the mean annual precipitation trend generally shows decreasing trend tendencies over the basin under low medium and high emission concentration scenarios RCP4.5 and RCP8.5 in 2041-2070.

Table 4.1: Results of Mann-Kendall trend test for areal precipitation of the basin for future period.

Sub-basin	Mann –Kendal test for Historical						Mann-Kendall test for Future					
Borkena river	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs
	-75	-4.582	-0.17	-17	-1.826	-0.039	-95	-12.12	0.2^{ns}	-5	-0.45	0.01^{s}

S is Mann-Kendall statistics, Zs Mann-Kendall trend test, slope (Sen's slope) is the change mm/annual and it tells the magnitude of the trend per annual, ns is non-significant and s is significant trend at 0.05 significant level. A positive value of s indicates there is an increasing trend and a negative value is decreasing trend.

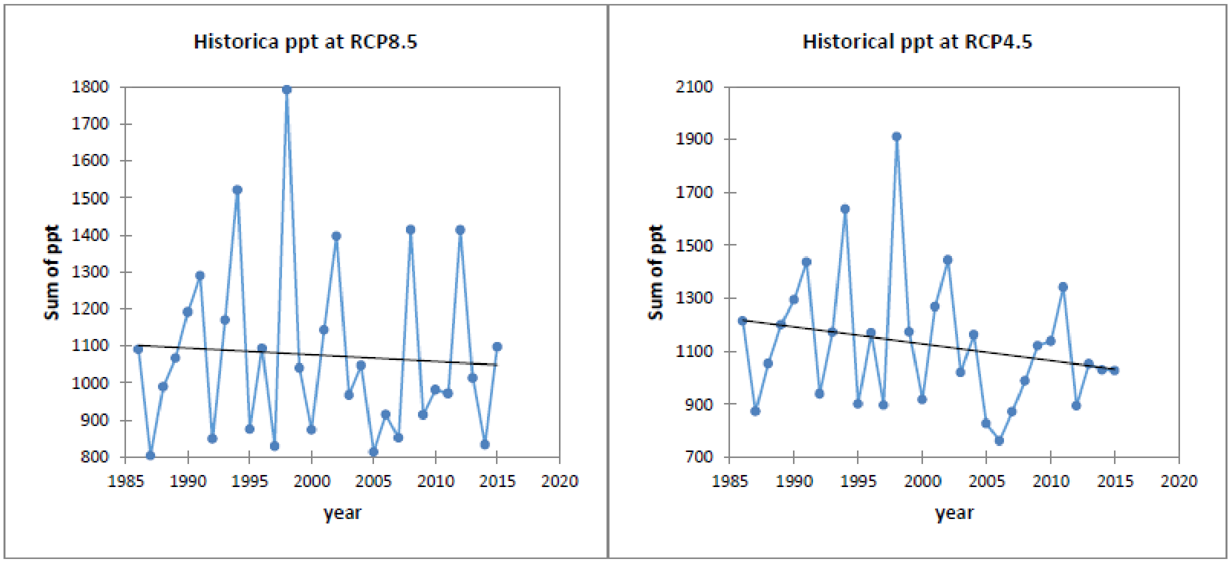

Figure 4.1: Trends of annual precipitation for the Borkena River basin in historical period under RCP4.5 & RCP8.5.

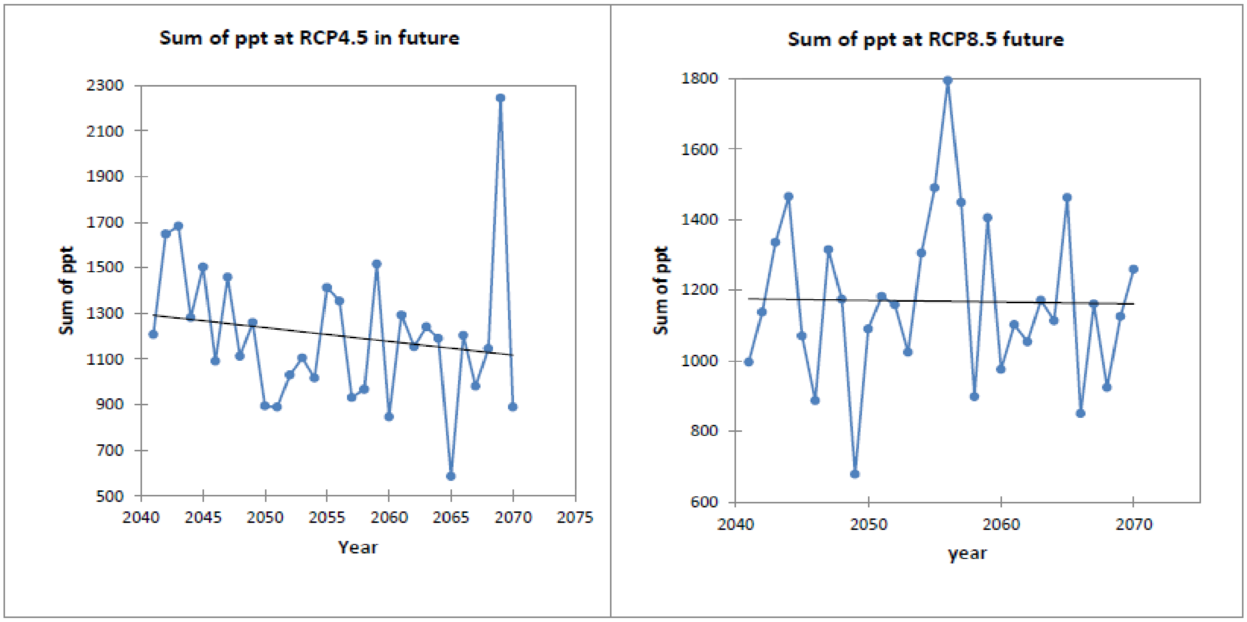

Figure 4.2: Trends of annual precipitation for the Borkena River basin in 2041-2070 period under RCP4.5 & RCP8.5.

4.1.2 Temperature trend

The Mann-Kendall test has simulated for to the trends of temperature for the representative station maximum and minimum temperature. This uses to estimate the temperature trend tests under two scenarios (RCP4.5 and RCP8.5). The general description of Mann-Kendall trend test result is provide in table 4.2 and figure 4.3.

Table 4.2: Results of Mann-Kendall test for maximum and minimum temperature of Borkena River catchment for historical and future period.

Sub-basin	Mann-Kendall test for historical											
Borkena river	Minimum temperature in future under RCP4.5			Maximum temperature under RCP4.5			Minimum temperature under RCP8.5			Maximum temperature under RCP8.5		
	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs
	103	0.016	0.237	239	0.025	0.549	131	0.023	0.301	207	0.02	0.476
Sub-basin	Mann-Kendall test for future											
Borkena river	Minimum temperature in future under RCP4.5			Maximum temperature under RCP4.5			Minimum temperature under RCP8.5			Maximum temperature under RCP8.5		
	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs	S	Sen's slope	Zs
	187	0.02	0.430^{ns}	183	0.031	0.421^{ns}	237	0.05	0.545^{ns}	297	0.044	0.683^{ns}

S is Mann-Kendall statistics, Zs Mann-Kendall trend test, slope (Sen's slope) tells the magnitude of the trend per annual, ns is non-significant the trend at 0.05 significant level the positive value of s indicates there is an increasing trend a negative value is decreasing trend.

The above Mann-Kendall test result is show that the basin has an increasing temperature trend in this catchment under both scenarios of high concentration and low-medium concentration (RCP8.5 and RCP4.5), the Sen's slope estimate indicates maximum and minimum temperature shows an increase trend by 0.025^{0}c/annual and 0.016^{0}c/annual under RCP4.5 scenarios respectively. Under high emission scenario the basin maximum and minimum temperature indicates increasing trends by 0.02^{0}c/annual and 0.023^{0}c/annual respectively in historical. In future, maximum and minimum temperature indicates increase trend by 0.031^{0}c/annual and 0.02^{0}c/annual under RCP4.5 scenarios respectively. Under high emission, scenario the basin maximum and minimum temperature will be increasing trends by 0.044^{0}c/annual and 0.05^{0}c/annual respectively. According to Mann-Kendal trend test result, the trends of temperature is non- significant the trends at 0.05 significant level.

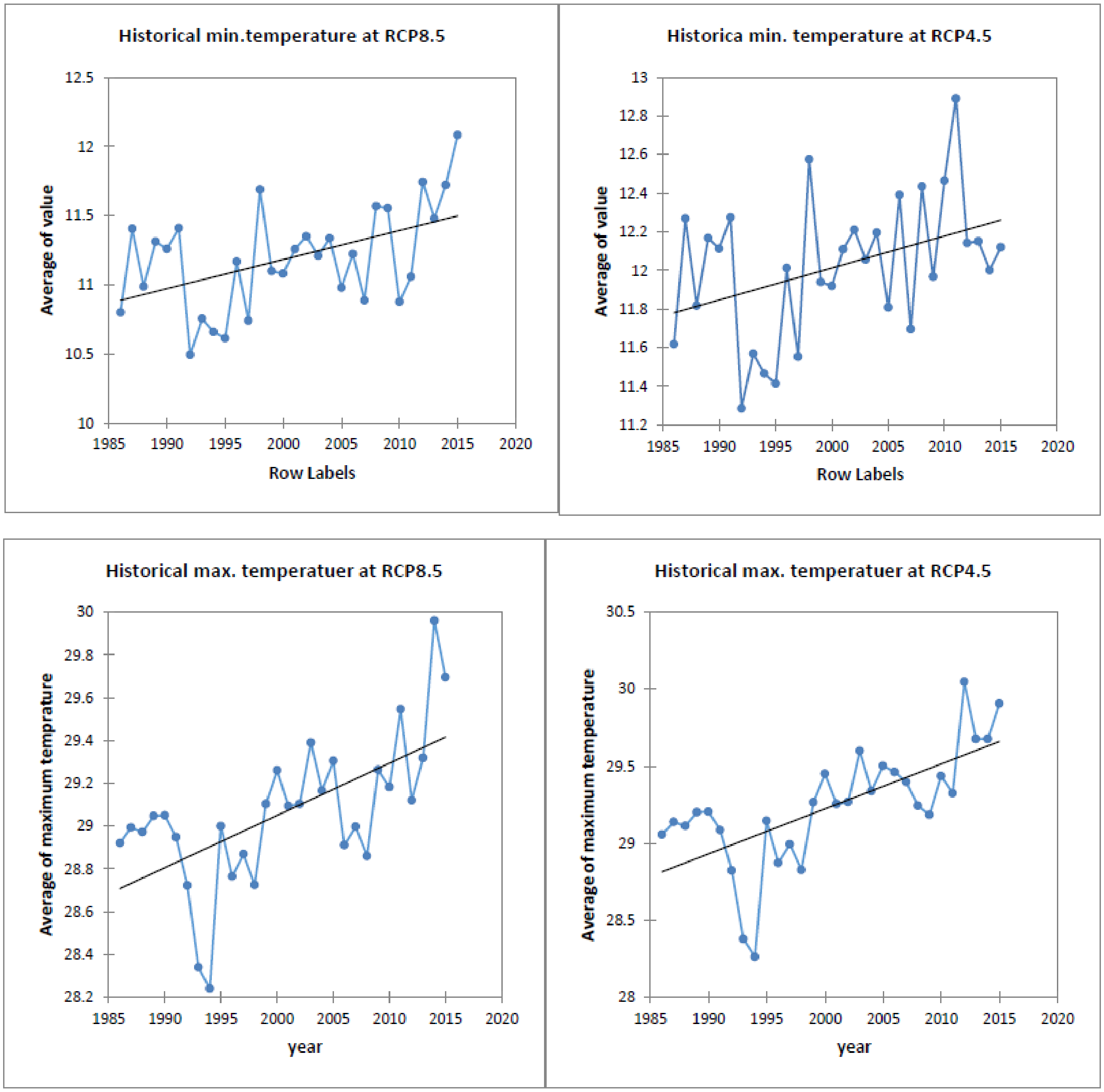

Figure 4.3: Trends of minimum and maximum temperature plot in Borkena River catchment for historical.

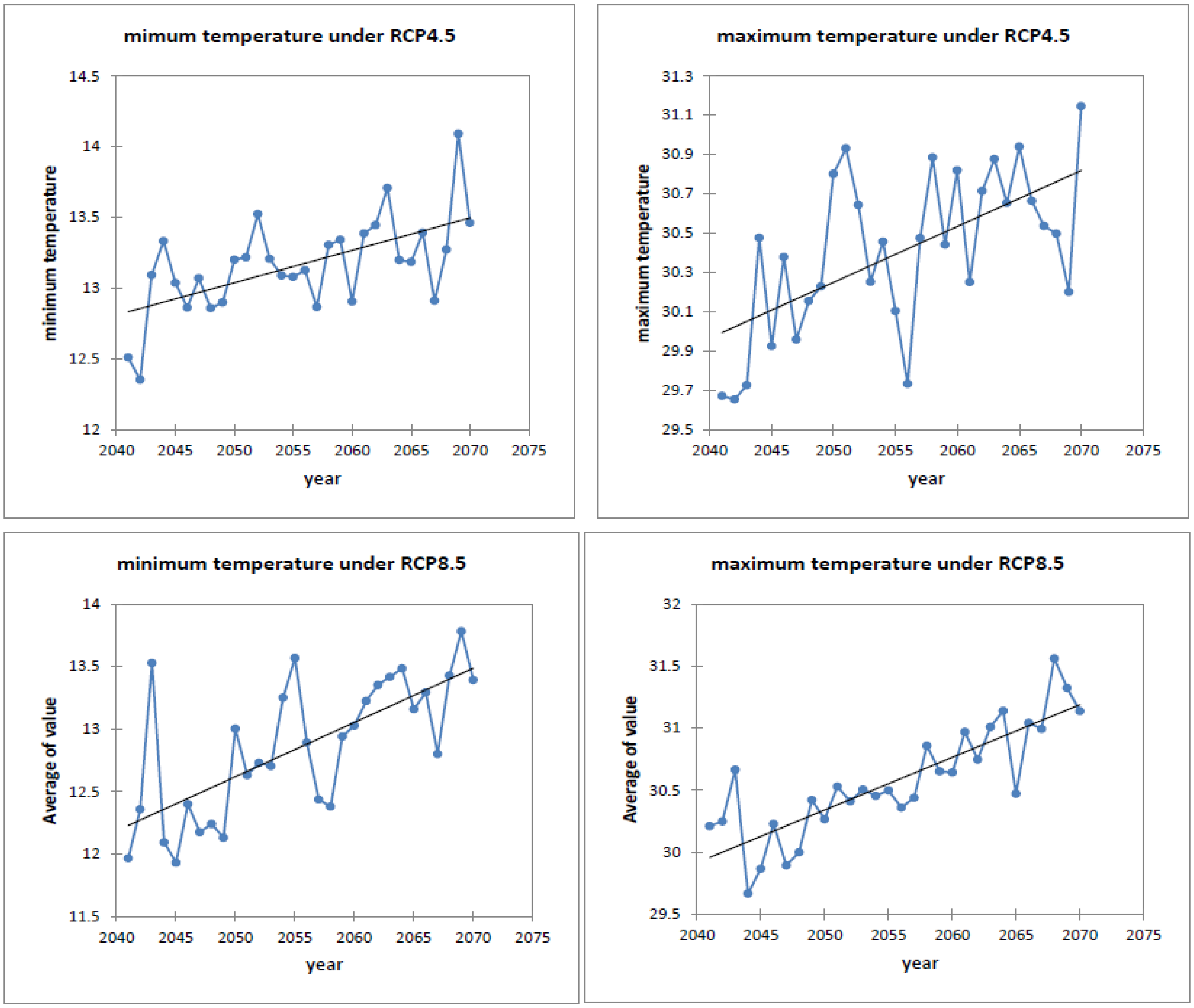

Figure 4.4: Trends of minimum and maximum temperature plot in Borkena River catchment for future.

4.1.3 Evapotranspiration trend

For this study, historical future evapotranspiration in the basin has computed by Mann-Kendall trend test. According to the MK test, potential evapotranspiration shows increasing trend for both scenarios due to increasing temperature. Sen's slope estimator express that areal evapotranspiration has increased by 1.6mm/annual and 1.09mm/annual over the historical period in the study area under the RCP4.5 and RCP8.5 scenarios respectively. For the future projection, the slope magnitude indicated that the areal evapotranspiration becomes increasing more than 1.8mm/annual and 1.9mm/annual in 2041-2070 under RCP4.5 and RCP8.5 respectively. On fitting linear trend line indicated in Figure4.5 that the future is an increasing evapotranspiration trend of Borkena catchment. The general results of Mann-Kendall trend test show in below table 4.3

Table 4.3: Mann-Kendall trend test results of evapotranspiration (ETo) for future period.

Sub-basin	Mann-Kendall test for historical						Mann-Kendall test for future					
Borkena river	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
	S	Sen’s slope	Zs	S	Sen’s slope	Zs	S	Sen’s slope	Zs	S	Sen’s slope	Zs
	149	1.633	0.343	133	1.093	0.306	147	1.829	0.338	203	1.9	0.467

S is Mann-Kendall statistics for strength of the trend. Sen’s slope is estimator for the determination of trend and slope magnitude. Zs is used a measure of significance of trend.

Figure 4.5: Trends of evapotranspiration for Future projection in Borkena river under RCP4.5 and RCP8.5.

4.2 Future climate variables change (rainfall, temperature and evapotranspiration)

Future climate change can be analyzed by comparing the future downscaled climate parameter with the baseline period (1986-2015). The climate scenarios was generated for the sub-basin for 30 years period from 2041-2070. The future periods used to see the climate change of the study area as middle term (2041-2070). Because of the short term (2011-2040) is more near to the historical period, the long term is far from the baseline period, since increasing of uncertainty, and the result is not effective in the long period (2071-2100).

4.2.1 Change in precipitation

The two scenarios RCP4.5 and RCP8.5 compared to baseline, the test statistics indicates that the rainfall may be increasing by 7.119% and 7.99% in the 2070s under the RCP4.5 and RCP8.5 scenarios respectively. Figure 4.6 Indicates the basin mean monthly rainfall will be increasing in the rainy season (July, August and September). Whereas the mean rainfall during the small rainy season (February-May) projection shows decreasing trend for RCP4.5 and RCP8.5 scenarios. The mean rainfall during the dry season Bega (October-January) projection shows increasing for the two emission scenarios except for December under RCP8.5 and February under RCP4.5. The rainy season may result probability of extreme rainfall in the basin. Generally, there will likely be more heavy rainfall over the East Africa with high certainty and more extremely wet days by the mid-20st century (IPCC, 2014).

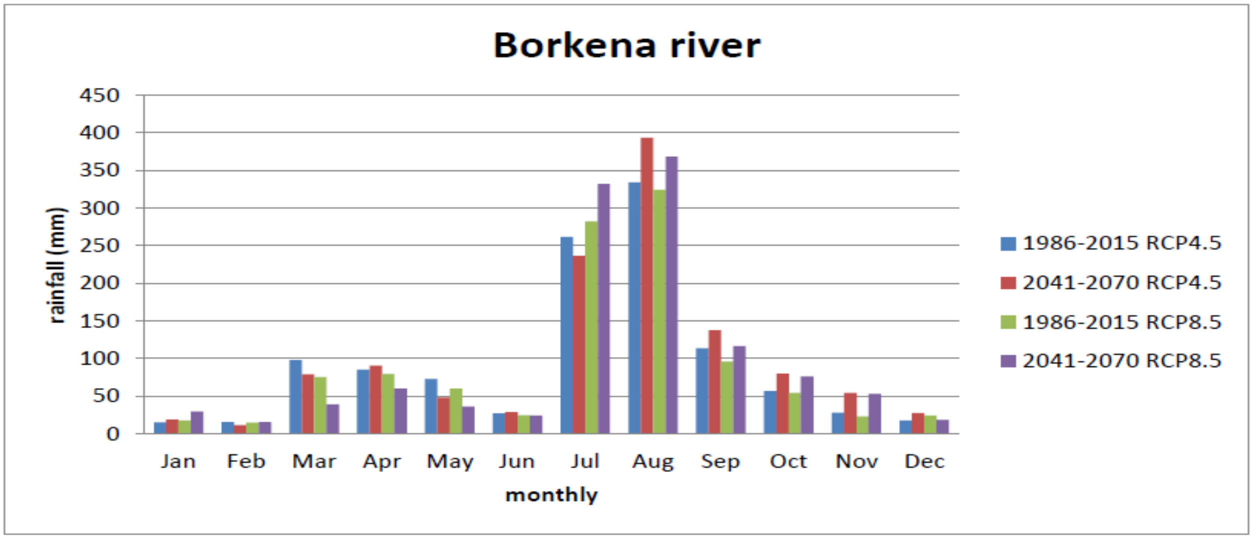

Figure 4.6: Comparison of areal means monthly precipitation of historical (1985-2015) and future (2040-2070) with two scenarios RCP4.5 and RCP8.5.

4.2.2 Change in temperature

The statistic show that, average maximum and minimum temperature significantly increases in the future period and both climate scenarios (RCPs). The test statistics indicates that the maximum and minimum temperature may warm 1.169^{0}c and 1.14^{0}c respectively in 2041-2070 under medium emission scenario RCP4.5. Under high emission scenario, RCP8.5 the maximum and minimum temperature will be increasing by 1.512^{0}c and 1.662^{0}c respectively in 2070s compared to baseline period. Figure 4.7 shows the comparison of arithmetic average monthly maximum temperature in the catchment for temperature comparison in the study area. The RCP4.5 and RCP8.5 scenarios generation result showed that the maximum temperature increase in all months in the basin. Figure 4.8 shows that the comparison of arithmetic average monthly minimum temperature at Borkena basin. It showed that the future minimum temperature increase in all months in the basin. Generally, the projected minimum and maximum temperature is within the range projected by IPCC, which reported average temperature rise by 1.4-5.8^{0}c towards the end of century (Adem et al, 2016). Maximum and Minimum temperature over equatorial east Africa will rise and that there will be warmer days compared to the baseline by the middle and end of century (IPCC, 2014).

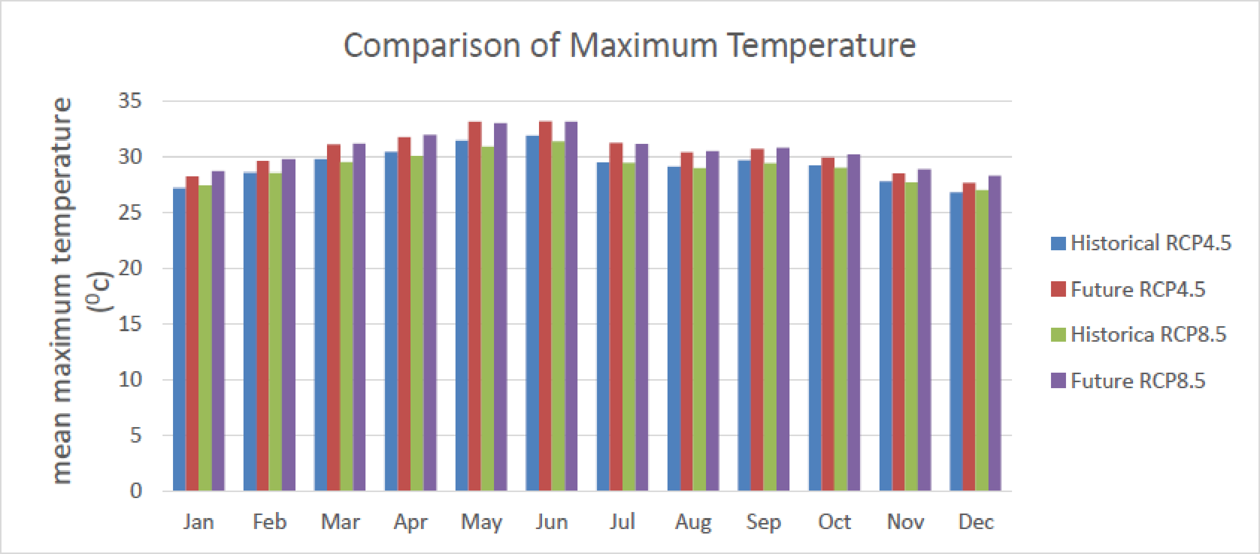

Figure 4.7: Comparison of mean maximum temperature of the historical period with future results of RCP4.5 and RCP8.5 scenarios.

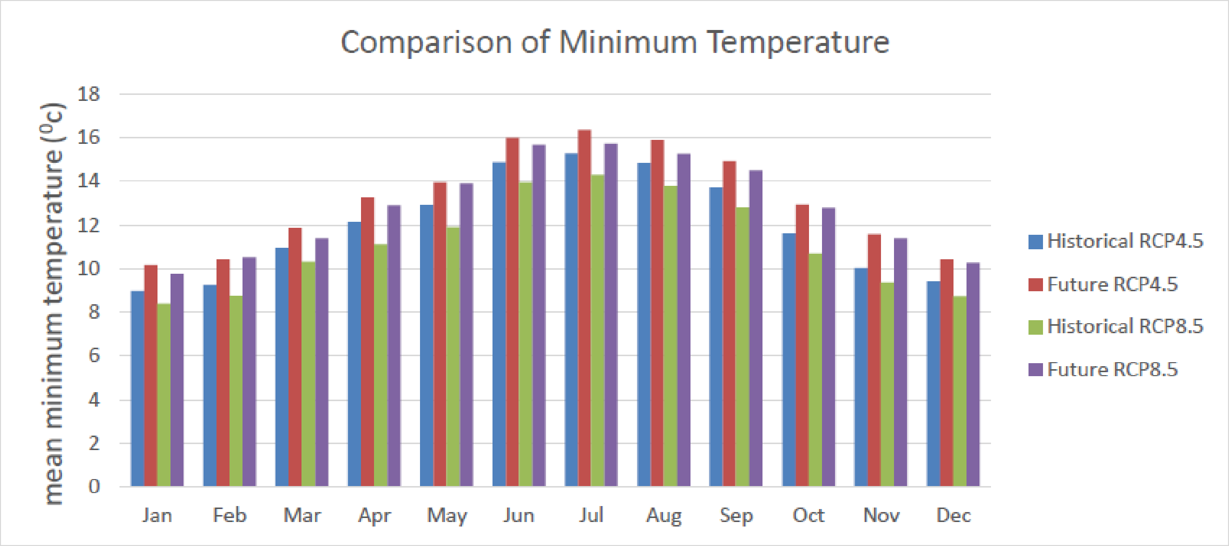

Figure 4.8: Comparison of mean minimum temperature of historical record with future results of RCP4.5 and RCP8.5 scenarios.

4.2.3 Change in evapotranspiration

Comparing with the historical data the average evapotranspiration increases significantly in both emission scenario. Evapotranspiration for the river flow will increase by 2.77% and 3.20% under RCP4.5 and RCP8.5 scenarios respectively. The increasing evapotranspiration of the stream flow is due to the increasing in the future climate scenarios temperature. Future evapotranspiration becomes highly during the month of March, April and May. In the month of January, February November and December the evapotranspiration is becomes low (Figure 4.9).

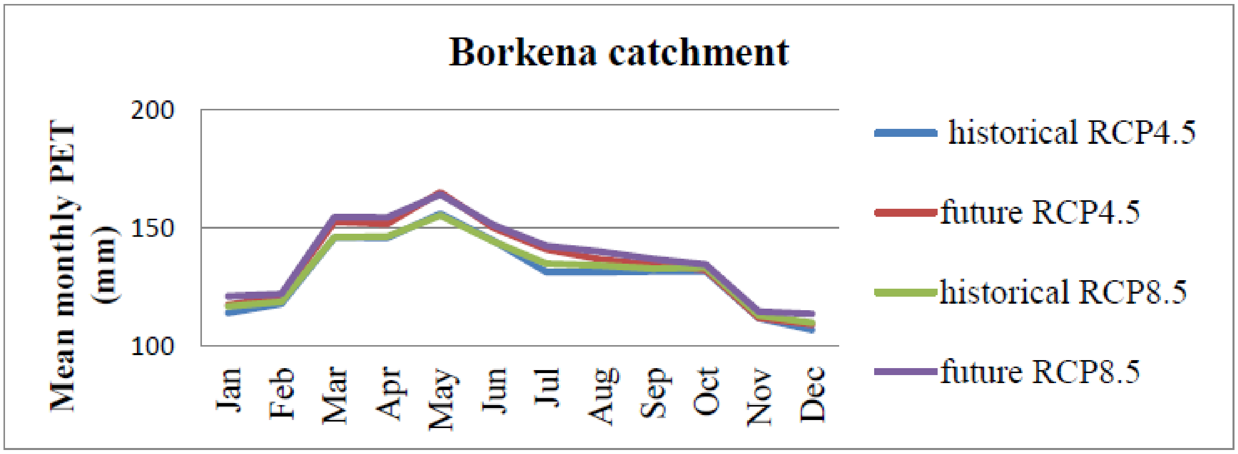

Figure 4.9: Mean monthly evapotranspiration of historical and future period under two scenarios (RCP4.5 and RCP8.5).

4.3 HEC-HMS result

4.3.1 Sensitivity analysis

Sensitivity of model result to the parameter can analysis by repeated the model runs by using the value of optimization parameter. The results show that how much the peak flow and volume of the flow are sensitive during optimization. From optimization process during parameterization of each parameter Time of concentration, Initial loss and Muskingum k values are highly sensitive and a slight change of these three parameters has a great on peak flow and volume of the flow. The final set of the parameters of the calibrated model taken for as normal parameter. The optimization parameter value has taken for future simulation of the outflow using climate scenarios RCP4.5 and RCP8.5. The rainfall runoff data in the catchment have used for model calibration and validation. The values of initial and optimized parameter are shows in table 4.4.

Table 4.4: Calculated Initial and optimized parameters for in the study area.

Element	Parameter	Initial value	Optimized value	Sensitivity
Sub-basin1	Initial loss (mm)	1.2	1.82	Sensitive
	Constant rate (mm)	1.0	1.18	Less sensitive
	Time of concentration	72	180	Sensitive
	Muskingum k (hr)	112	140.78	Sensitive
	Muskingum x	0.1	0.5	Less sensitive
Sub-basin2	Initial loss (mm)	1.2	1.82	Sensitive
	Constant rate (mm)	1.0	1.18	Less sensitive
	Time of concentration	76	200	Sensitive
	Muskingum k (hr)	120	150	Sensitive
	Muskingum x	0.1	0.12848	Less sensitive
Sub-basin3	Initial loss (mm)	1.2	1.82	Sensitive
	Constant rate (mm)	1.0	1.18	Less sensitive
	Time of concentration	120	240	Sensitive

4.3.2 Calibration and validation

In this study, the HEC-HMS model applied in the hydrologic simulation for Borkena River, which used the stream flow data of 2003 to 2010 for calibration and the data of 2011 to 2015 for validation. The model has been calibrated manually and automatically to optimize to obtain the best possible option fit parameters.

4.3.2.1 Flow calibration

HEC-HMS calibration important to the water balance and all agreement of the observed discharge using Nash and sutcliffe model efficiency (NSE), Pearson's coefficient of determination (R^2) and RVE daily calibration. Nash- sutcliffe model efficiency (NSE) is used to evaluated prediction overall performance of the model, and coefficient of determination (R^2) to check how the two values (simulated and observed) are correlated. In addition, RVE when the value of the objective function equals to zero, the computed hydrograph ordinates equal perfect with the observed values. The flow calibrated by using the observed areal precipitation, areal evapotranspiration and observed flow at Borkena gauging station. As represent in figure, the calibration result represents that there is a good agreement between the computed and observed daily flow. Nash-sutcliffe coefficient (NSE) found to be 0.714 and residual volume error (RVE) was found 4.0% that is good correlation.

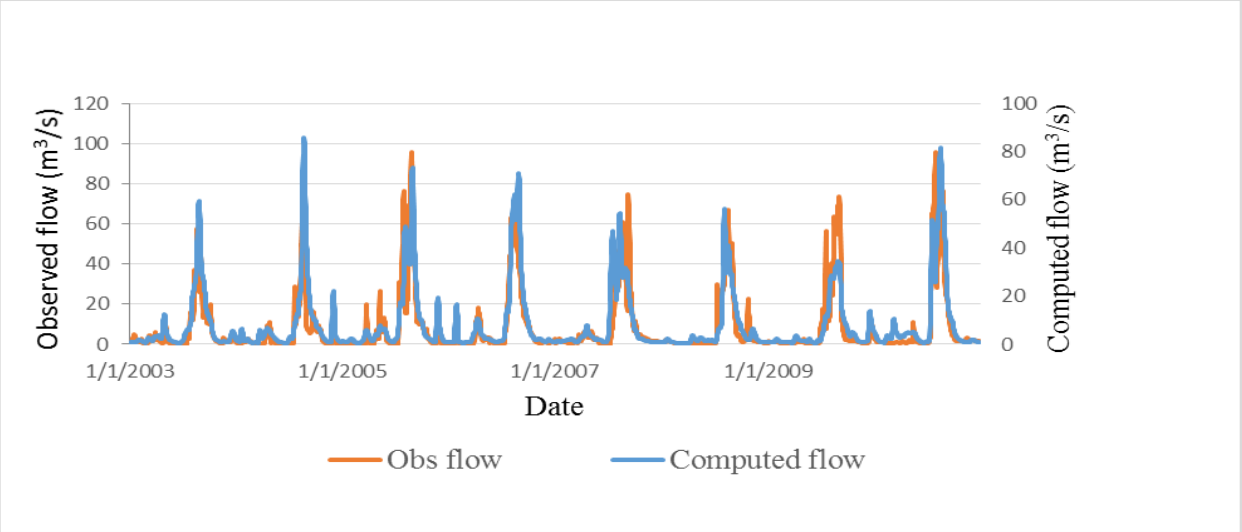

Figure 4.10: Daily computed and observed flow hydrograph calibration result.

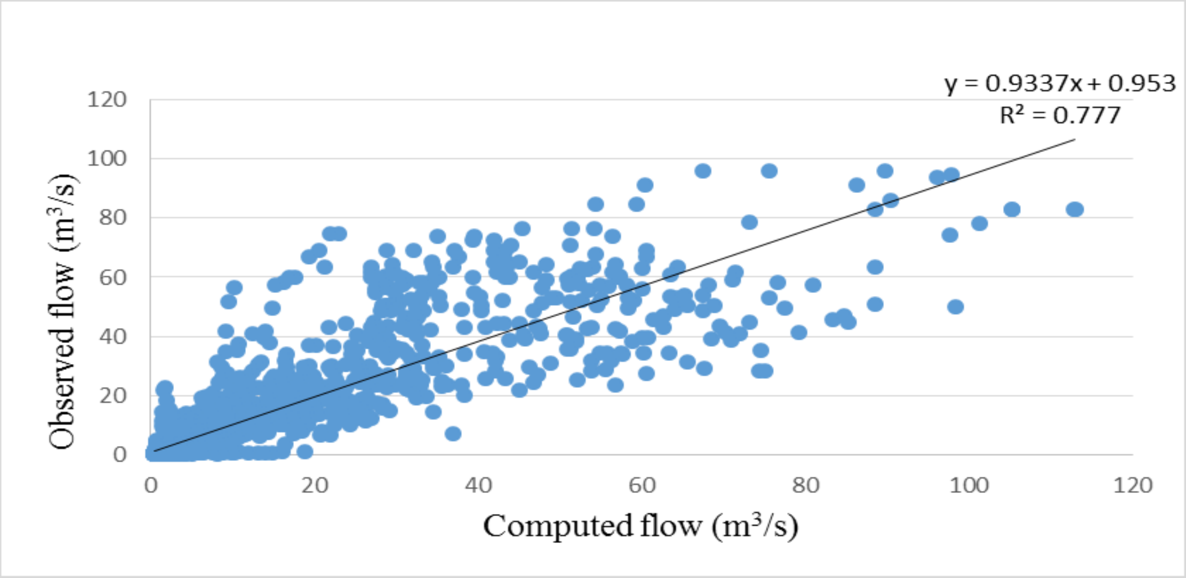

Figure 4.11: Scatter diagram of computed and observed flow during calibration.

Table 4.5: Daily calibration model parameter result.

Validation parameter	Daily validation
Nash-sutcliffe efficiency	0.714
Pearson's coefficient of determination R^2	0.777
RVE	4.0%

Table 4.6: comparison of simulated and observed runoff depth for calibration period (2003-2010).

Borkena river	Stream volume (MM)	Peak discharge (m^3/s)
Observed flow	1250.68	96.0
Computed flow	1255.85	85.8

4.3.2.2 Flow validation

HEC-HMS model validation is used to determination the effectiveness of the parameterization and calibration methodologies. The validation applied out over the period of five years from 2011 to 2015. The Nash-sutcliffe efficiency was found 0.615 that represents good correlation with the observed.

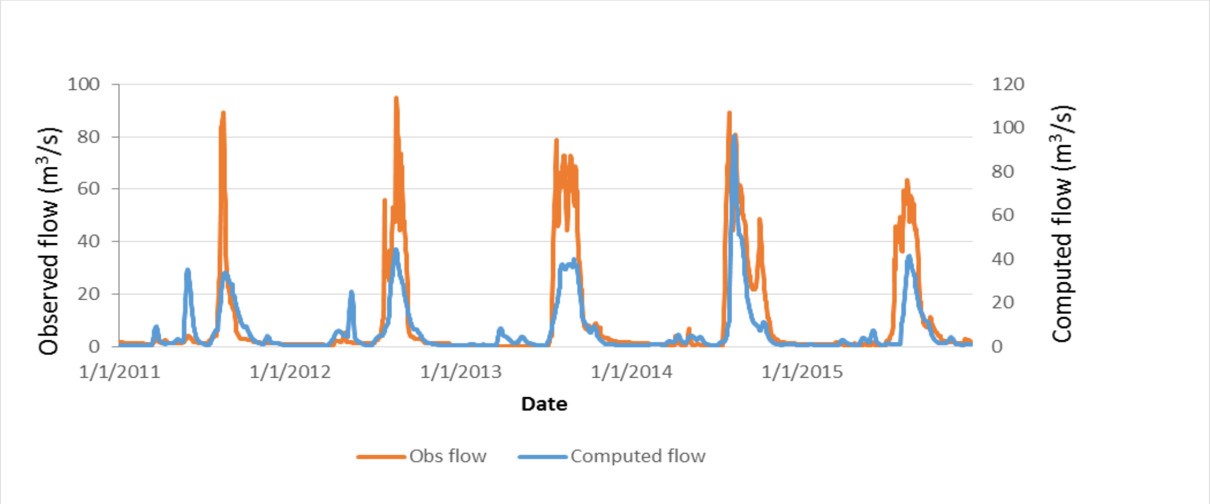

Figure 4.12: Simulated and observed hydrograph validation result.

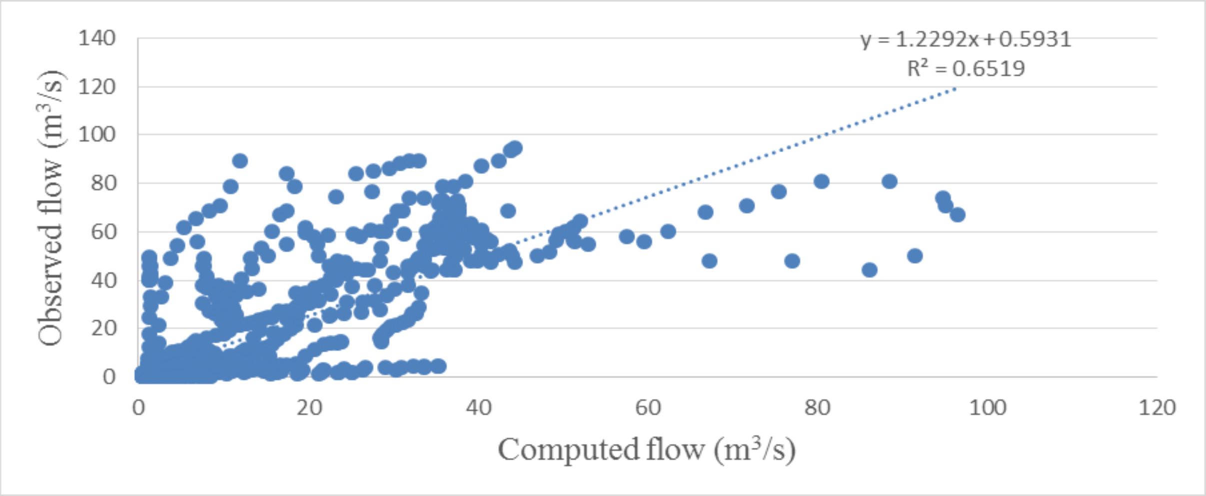

Figure 4.13: Scatter diagram of computed and observed flow during validation

Table 4.7: Daily validation model parameter result.

Validation parameter	Daily validation
Nash-sutcliffe efficiency	0.615
Pearson’s coefficient of determination R^2	0.652
RVE	-13%

Table 4.8: Comparison of simulated and observed stream flow for validation.

Borkena river	Stream volume (MM)	Peak discharge (m^3/s
Observed flow	871.70	94.8
Computed flow	664.01	96.5

4.4 Comparison of future impact of climate change on average runoff on Borkena River

In this study, future climate projections have been used in hydrological modeling to examine effect of climate change on the catchment yield. So to examine the impacts of climate change on surface water potential on the river, a hydrological model HEC-HMS was produced based on CMIP5 climate model simulation of precipitation, temperature and evapotranspiration on the targeted catchment in the basin. The flow simulation has been used RCP4.5 and RCP8.5 scenarios climate input to the HEC-HMS model and the simulation period 2041-2070 according to World Meteorology Organization recommendation of 30 years climatology.

The simulation in the river result increases that the stream flow in Borkena River in the future periods (2041-2070) under a low-medium concentration RCP4.5 and high concentration RCP8.5 scenarios. Moreover, the peak discharge becomes increased the river in both scenarios of future periods as compared to historical period. As simulated result of runoff volume showed in table 4.5. The future surface water content has increased which is estimated for medium term where annual stream flow is increase relative to the baseline period for both scenarios.

Table 4.9: Stream volume and peak discharge comparison for future period relative to historical.

Volume of the stream (MM)				Peak discharge (m^3/s)			
Historical	RCP4.5	Difference	%	Historical	RCP4.5	Difference	%
5535.9	6372.37	836.47	13.13	290	370.1	80.1	21
Historical	RCP8.5	Difference	%	Historical	RCP8.5	Difference	%
5180.53	6127.27	946.74	15.45	196.6	372.6	176	47.23

Comparison to the historical period and the future period annual stream inflow volume for the catchment shows an increasing 13.13% and 15.44% in 2041-2070 under both scenarios RCP4.5 and RCP8.5 respectively. Generally, the inflow of the future period shows that increasing trend in the medium-term compared to the historical period. The stream flow variation for both scenarios RCP4.5 and RCP8.5 are shows in figure 4.14. According to all simulated results, the future available water content for the study area is increasing in steam flow volume is in 2041-2070 under both a low medium and high concentration scenarios (RCP4.5 and RCP8.5). Future projection change of 2041-2070 of RCP4.5 is more than of RCP8.5 scenarios, due to high increase in precipitation and evapotranspiration in the basin.

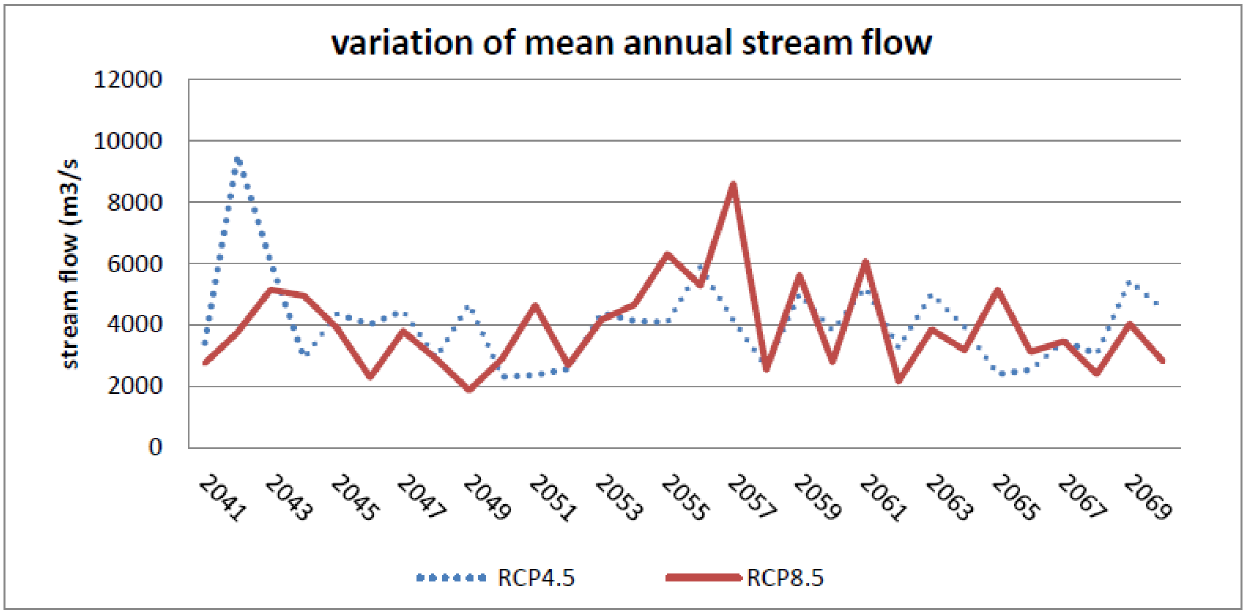

Figure 4.14: Variation of projected annual stream flow (m3/s) in Borkena catchment.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, assess the impact of climate change on surface water potential in Borkena River by using HEC-HMS hydrological model. A trend of precipitation, temperature and evapotranspiration has been analyzed for future time horizons (2041-2070) in the basin. The projection of precipitation changes for the catchment showed in the two scenarios (RCP4.5 and RCP8.5) in the future period.

The MK result show that the study area mean annual precipitation will decrease more than 12.12mm/annual and 0.46mm/annual in 2041-2070 under both a low-medium and high concentration scenarios (RCP4.5 and RCP8.5) respectively. The CMIP5 ensemble model output (RCP4.5 and RCP8.5) projection temperature increasing trend in 2041-2070 periods in the basin. According to the MK trend test indicates maximum temperature will be increase trend by 0.031^{0}c/annual and 0.044^{0}c/annual for RCP4.5 and RCP8.5scenario respectively. Average evapotranspiration increase to more than 1.7mm/annual and 1.4mm/annual in 2070s under RCP4.5 and RCP8.5 concentration scenarios respectively. According to the MK test and the Sen's slope projection of temperature, precipitation and evapotranspiration are non-significant at 5% significant level in the basin.

For general comparison basin rainfall, temperature and evapotranspiration was calculated as arithmetic average value all station. The statistical indicated that the rainfall may increasing by 7.12% and 6.56%mm in 2070s under RCP4.5 and RCP8.5 respectively. Average maximum temperature may warm 1.14^{0}c and 1.13^{0}c and the minimum temperature will be increasing by 1.15^{0}c and 1.17^{0}c under RCP4.5 and RCP8.5 respectively. Evapotranspiration for the catchment will be increasing by 3.5% and 3.6% under RCP4.5 and RCP8.5 scenarios respectively.

The HEC-HMS hydrological model calibration and validation for the catchment indicates that the model rainfall-runoff simulation was considerably good performance. The Nash-Sutcliff performance efficiency measured values showed 0.714 and 0.615 for calibration (2003-2010) and for validation (2011-2015) periods respectively.

The climate variables changes are likely to have a significant impact on stream flow volume. Comparing with the baseline period, the future average annual inflow volume shows increasing up to 13% and 15% during 2041-2070 under RCP4.5 and RCP8.5 scenarios respectively.

According to this research, model output mean monthly stream flow will increase in the wet season (July-September). This research result indicates that in the future summer runoff highly increasing due to climate change. Climate change may contribute positive aspect for crop water availability in the short period if only farmer will alter to himself or herself to what type of harvest and work schedule. However, precautionary opinion should be taken for flood controlling in flood plain areas.

5.2 Recommendation

Generally, from this specific study the following some main point are strongly recommended.

- The bias correction method temperature based for future ETo estimation method uncertainty should be further examined. Hence, the results of this study should be taken with care and be considered as indicative of the likely future rather than accurate predictions.
- The model simulation not considered land use land cover change but change in land use and soil management activities can influence rainfall runoff process. Therefore, it is recommended for future studies to consider land use land cover change and effective of soil type.
- This study uses emission concentration scenarios of RCP4.5 & RCP8.5 for the analysis of climate change in the future, but all RCPs of CMIP5 output have equal probability of happening. Therefore, the further study becomes more advance considering the entire concentration scenarios of CMIP5 output RCP2.6 and RCP6.

REFFERANCE

Adem et al. (2016). climate change impact impact on stream flow in upper Gilgel Abay catchment, Blue lile Basin, Ethiopia. *spring international publishing Switzerland*, pp645-673. DOI 10.1007/978-3-319-1887-7_29.

ADSWE.A.D. (2012). *Afar National Regional State, lower awash sub-basin Integrated land use planning and Eviromental Impact study Projected*,. Bahir Dar: Technical report: Hydrology and Water resource study (Afar LUPESP) LASB: V/2012.

Alemu. (2011). Evaluation of climate change impact on extreme hydrological. cause study: Addis Ababa and surroundin catchment. MSc thesis. *Addis ababa institue of Technology* .

Arnell, N. (1999). *Climate change and Global water resource.* southampton: university of southampton.

Conway. (2011). Addaptation to climate change in africa: challengesand opportunities identified from ethiopia. *Global Enviromental Change*, 21(1), 227-237.

Detlef. (2013). A new scenario framework for climate change research. *springer scince+business media*, 5.

Filippo et al. (2009). addressing climate information needs. *at WMO Bulletin 58(3)*, 175-183.

Ford, D. (2008). *hydrological modeling system HEc-HMS, Applications Guid.* Davis,CA.

Hibbard. (2007). A strategy for climate change stabilization experiments. *EOS 88*, 217-221.

Hudson, R. J. (2002). Regional Climate Model simulation of present-day and future climates of south africa. *Met office, Handley center for climate prediction and research londonrod rg12 25y UK*.

IPCC. (1996). *climate change.* cambridge: cambridge university press.

IPCC. (2007A). *Intergevernmental paanel on climate change* . Geneva: IPCC Secretariat.

IPCC. (2008). *Towards New scenarios for analysis of emissions, climate change, impact and response.* Geneva: IPCC.

IPCC. (2013). *Climate change.* Cambridge and nework: The physical science bais. Cambridge university press .

IPCC. (2014). *The sciences of climate change.* cambridge: cambridge university press.

Juraj, M. (2003). *Hydrologic model selection for the CFCAS peroject: Assessment of water resources risk vulnerability to changing climatic conditions.* Canada: University of western ontario.

Karamouz, N. a. (2013). *Hydrology and hydroclimatology priniciple and application.* Nework: CRC press.

Khublaryan. (1994). Types and properties of water-surface water: river, streams, lakes and wetland. *Water problems, Institute, Russian Accademy of sciences, Moscow, Russia*.

Kinfe.H. (1999). Impact of climate change on the water resource of awash river basin, Ethiopia.

Laijenogo, and Rolald. (2013). *Assessment of water governance capacity in the awash river basin.* Addis Ababa: water governance city center Ethiopia.

Lam, N. (1983). spatial interpolation methods review. *The American cartographer,*, 129-149.

Leander, B. (2007). climate model output for the simulation of extreme river flow. *hydrol*, 487-496.

Marius. (2009). *climate risk and development.* Oromiya Ethiopia: Assessment-Level-Project in Gudru.

Mearns, F. (2003). *Guide lines for use of climate model experment.* DDC of IPCC TGCIA.

NOAA. (2007). *climate change.* National weather servies .

Pohlert, T. (2018). Non-parametric trend tests and change point detection. 1-2.

Ragunath, M. (2006). Estimates of missing data and adjustment of records. by New Age International (p) Ltd.

Sahele, M. (2001). *Hydrogeological investigation of the upper and middle borkena river catchment thesis.* Addis Ababa: Addis Ababa university.

Santaso, M. (2008). *Climate scenario: what we need to know and how to generate them.* center for international forestly research.

Scharffenber, W. (2010). *hydrological modeling system (HEC-HMS): physically based simulated component.* Las Vegas: NV:2nd joint federal interagency.

Taylor et al. (2012). An over view of CMIP5 and the Experimental Design. *doi:10:1175/BAMS-D-11-0094.1, Bulletin of America meteorological society*, 485-498.

UNESCO. (2006). *Watershed responsibility.* The united nation world water development report .

USAC. (2009). *HEC-GeoHMS: Geospatial Hydrologic Modeling Extension user's mannual.*

USACE. (2000). *Hydrological modeling system HEC-HMS. Technical referance manual.* US Army Crops of Engineers Hydrologic engineering center.

Van Vuuren, D. (2011). The representative concentration pathway: an over view climate change . 109,5.

Wilby, R. (2002). A decision support tool for the assesment of reginal climate change . *SDSM Environ.Modell. Softw, 17,*, 145-157.

Yilma. (2005). ethiopian rainfall climate . In *Engineering Hydrology* (pp. 16-20). Addis Ababa.

APPENNDIX

Appendix A, List of table

Table A. 1: Summary information of climatological data for selected station of study area

No.	Name of station	Longitude (^{0})	Latitude (^{0})	Period include	Types of data	Missing (%)
1	Kombolcha	39.82	11.08	2003-2015	Temperature	5
					Rainfall	5
					Relative Humidity	7
					Sunshine hour	7
					Wind speed	7
2	Cheffa	39.81	10.84	2003-2015	Temperature	4
					Rainfall	4
					Relative Humidity	4
					Sunshine hour	4
					Wind speed	4
3	Majete	39.85	10.5	2003-2015	Temperature	8
					Rainfall	8
					Relative Humidity	8
					Sunshine hour	8
					Wind speed	8
4	Kemisie	39.87	10.72	2003-2015	Temperature	5
					Rainfall	7
5	Harbu	39.78	10.93	2003-2015	Temperature	6
					Rainfall	12
6	Tita	39.66	11.17	2003-2015	Temperature	11
					Rainfall	11
7	Guguftu			2003-2015	Temperature	5
					Rainfall	7
8	Haik	30.7	11.3	2003-2015	Temperature	5
					Rainfall	13

Table A. 2: Descriptive statistics of total annual rainfall (mm) for some meteorological stations.

Year	Haik RF	Kemisie RF	Tita RF	Cheffa RF	Kocha RF	Majete RF	Harbu RF	Guguftu RF
2003	1254.8	917.2	1044	1044.973	1041.14	1058.7	1139.2	1297.4
2004	1095	1105.7	987.8	941.67	957.77	1077.73	818.9	1388.7
2005	1259.5	870	1237.795	1053.76	1025.6	1171.65	1052.2	1436.6
2006	1177.6	1191.06	1272.45	1024.8	1172.6	1348.6	1026.5	1287.4
2007	1071.925	1020.5	1112.63	1285.2	908.5	1243.8	935.1	897.9
2008	930.7	807.8	859.5	744	804.2	916	814.3	1030.4
2009	1048.4	781.5	1006.2	697.94	959.3	924.6	981.9	1022.33
2010	1825.3	1390.5	1491.7	1162.9	1313.6	1459.4	1210.7	1690.2
2011	1063.6	789.8	1045.4	862.5	1007.3	876.6	795.1	1190.5
2012	1140.9	763.7	1010.9	949	971.84	1095.3	1200	1385.9
2013	1016.5	1111	1024.4	1174.2	1010	1154.35	906.8	1711.7
2014	1194.98	1174.8	1297.4	1194.18	1041.3	1310.3	680.1	1495.6
2015	832.7	675.9	862.275	674.1	725.1	851.8	502.9	919.8
Average	1147.07	969.189231	1096.342	985.3249	995.25	1114.525	927.9769	1288.802
Stdev	237.2168	213.038236	181.8011	197.1784	146.7884	191.393	206.4984	267.7787
CV	0.206802	0.21981077	0.165825	0.200115	0.147489	0.171726	0.222525	0.207773

Table A. 3: Monthly observed rainfall of all selected station in the study area.

Month	Chefe RF	Kombolcha RF	Magete RF	Haik RF	Harbu RF	Kemise RF	Titar RF	Guguftu RF
JAN	176.6	264.0	371.0	245.1	128.2	191.3	271.5	211.3
FEB	267.7	150.6	253.6	375.4	172.2	152.5	348.5	323.8
MAR	917.2	792.8	961.0	1295.6	1079.7	646.8	910.9	827.7
APR	1129.8	942.3	1162.8	1123.5	1124.6	877.2	1076.5	909.7
MAY	775.5	722.9	935.1	959.7	596.3	767.7	998.9	980.8
JUN	268.7	344.1	378.2	467.9	271.6	283.3	473.2	912.7
JUL	3365.5	3700.4	3151.7	4061.8	3125.3	3208.7	3870.9	5273.3
AUG	3834.6	3890.5	4415.7	3953.8	3497.5	4329.1	4015.0	5200.4
SEP	1075.0	1218.8	1582.1	1249.4	1166.5	1225.7	1170.1	1246.9
OCT	443.2	557.2	589.7	528.7	251.0	468.9	611.0	476.2
NOV	313.4	216.9	446.3	439.7	282.0	299.5	300.4	218.7
DEC	242.1	137.8	241.7	211.3	368.8	148.8	205.6	172.9

Table A. 4: Precipitation bias correction the value of a and b for each sub-basin.

RCP8.5					
Sub-basin 1		Sub-basin 2		Sub-basin 3	
Parameter a	Parameter b	Parameter a	Parameter b	Parameter a	Parameter b
1.542593	0.907694	0.824459207	1.004519	0.657426	1.543907
0.942743	0.879076	0.363876598	1.215664	0.193497	1.725471
2.193098	0.605387	0.45955185	1.066169	0.600206	1.182773
1.927701	0.540517	0.842410287	0.770762	0.801173	0.949132
0.261281	1.214438	0.104669786	1.410125	0.698313	1.070965
0.030099	1.732698	0.016833911	1.780763	0.006655	2.471846
0.410796	1.269072	0.093906949	1.607293	0.12342	1.816004
0.260432	1.308668	0.060553165	1.661587	0.070374	2.009481
0.049934	1.563462	0.017428282	1.737094	0.038735	1.920805
0.731187	0.943153	0.629527828	0.869367	1.480435	0.830214
0.09823	1.471538	0.001333173	2.551564	0.013726	2.182842
0.205299	1.451343	0.017244663	2.253798	0.149524	1.687927

Table A. 5: Future annual stream flow of two scenarios RCP4.5 and RCP8.5.

Year	Future annual flow data for RCP4.5	Future annual flow data for RCP8.5
2041	3420.2	2762
2042	9536	3768.9
2043	6050.6	5156.9
2044	2929.4	4954.7
2045	4359	3902.1
2046	4030.9	2296.8
2047	4456	3801.1
2048	2943.7	2901.2
2049	4689.5	1873.3
2050	2312.8	2907.4
2051	2365.3	4642.9
2052	2572	2693.3
2053	4399	4164.8
2054	4139.1	4665
2055	4096.3	6307.7
2056	5887.2	5287.4
2057	4150.4	8611.4
2058	2632.9	2538.4
2059	5023.7	5628.8
2060	3823.2	2786.3
2061	5223.3	6082.5
2062	3263.9	2160.7
2063	5016.6	3854.9
2064	3929.4	3186.7
2065	2406.6	5154.2
2066	2541.4	3126.5
2067	3475.5	3475
2068	3056.1	2410.9
2069	5447.1	4038
2070	4524.5	2826

Table A. 6: Monthly areal precipitation historical and future period under RCP4.5 and RCP8.5.

	1986-2015 RCP4.5	2041-2070 RCP4.5	1986-2015 RCP8.5	2041-2070 RCP8.5
Jan	15.01665767	18.7035497	17.77425937	29.5476135
Feb	15.47523469	11.44267251	14.49697669	15.33761382
Mar	98.00036233	78.73757277	75.3255071	39.18688224
Apr	85.11202403	90.66065124	79.41397723	59.71904494
May	72.63795737	47.9457289	59.78661816	36.07834864
Jun	27.11306972	28.65358893	24.62518904	23.94406537
Jul	261.6810302	236.4879726	282.0672649	332.0056652
Aug	334.1821436	393.4769298	324.5196328	368.6789607
Sep	113.4807691	137.3632493	95.75065358	116.5723924
Oct	56.67479924	79.81083713	54.49665484	76.07902304
Nov	27.71571849	54.49296684	22.77278518	53.00489099
Dec	17.80898157	27.20514944	24.2578611	18.50067921

Table A. 7: Monthly calculated evapotranspiration of historical and future period under two scenarios RCP4.5 and RCP8.5.

	historical RCP4.5	future RCP4.5	historical RCP8.5	future RCP8.5
Jan	114.0170007	117.293733	116.7338648	121.112991
Feb	117.7653396	121.194757	118.75398	121.99832
Mar	145.9167175	152.611314	145.9751579	154.61879
Apr	145.7886574	151.728639	146.3877737	154.411825
May	156.0197054	165.112181	155.2451899	164.155616
Jun	144.6356978	150.068875	144.2368194	151.258173
Jul	131.2979324	140.904315	134.8166851	142.333665
Aug	131.2144308	136.76347	134.1228918	139.954637
Sep	131.627531	134.495863	132.7724778	136.898119
Oct	131.7584133	132.366356	133.1977804	134.537011
Nov	111.6731603	111.855429	112.9527906	114.566454
Dec	106.8097075	109.102588	109.8585626	113.552213

Appendix B list of figure

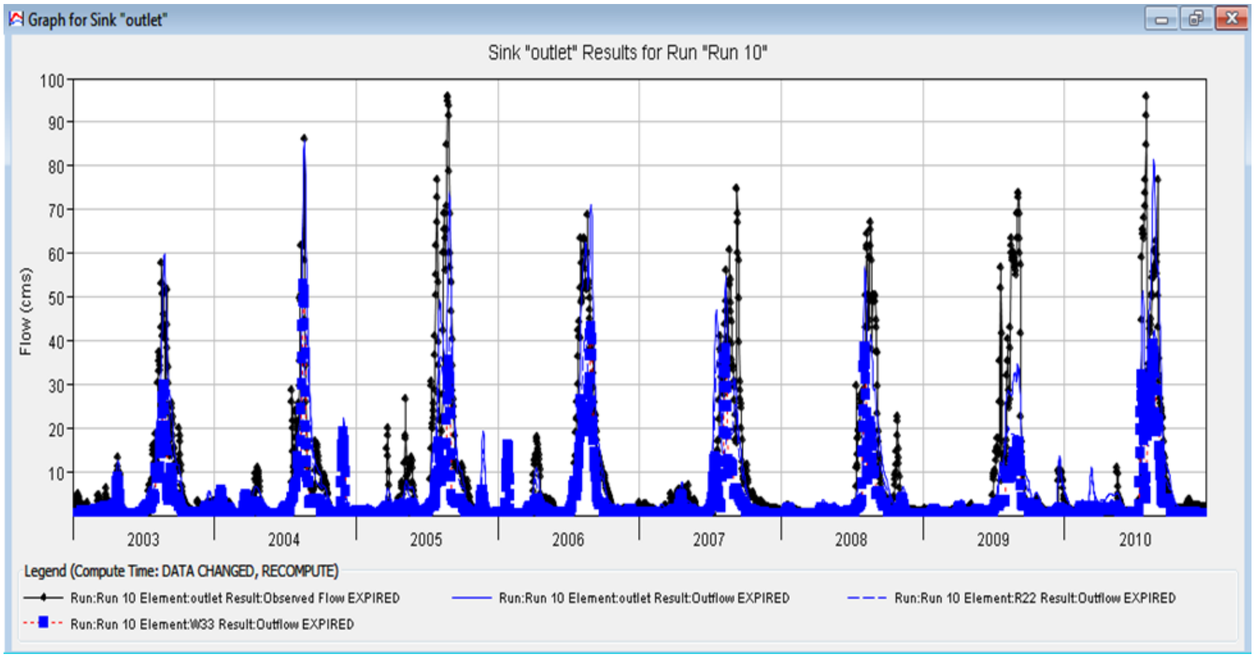

Figure B- 1 Simulated and observed hydrograph calibration (2003-2010) HEC-HMS result.

Project: borkena Simulation Run: Run 10

Sink: outlet

Start of Run: 01Jan2003, 00:00
End of Run: 31Dec2010, 00:00
Compute Time:DATA CHANGED, RECOMPUTE

Basin Model: Basin 1
Meteorologic Model: Met 1
Control Specifications:Control 1

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge:85.8 (M3/S)
Volume: 1255.85 (MM)
Date/Time of Peak Discharge21Aug2004, 00:00

Observed Hydrograph at Gage Gage 1

Peak Discharge:96.0 (M3/S)
Mean Abs Error:3.9 (M3/S)
Volume: 1250.68 (MM)
Nash-Sutcliffe: 0.714
Date/Time of Peak Discharge:24Aug2005, 00:00
RMS Error: 8.4 (M3/S)
Volume Residual: 5.15 (MM)

Figure B- 2 Comparison of simulated and observed runoff depth for calibration.

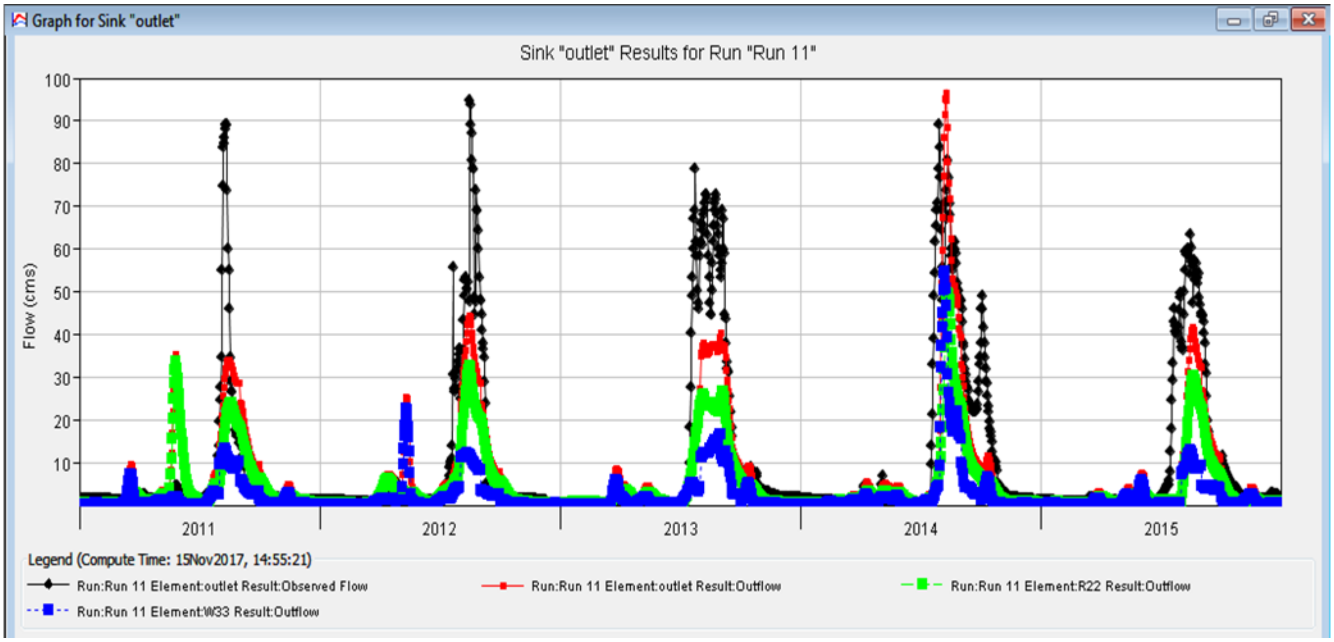

Figure B. 3: Simulated and observed hydrograph validation (2011-2015) HEC-HMS result.

Summary Results for Sink "outlet"

Project: borkena Simulation Run: Run 11

Sink: outlet

Start of Run: 01Jan2011, 00:00 Basin Model: Basin 1
End of Run: 31Dec2015, 00:00 Meteorologic Model: Met 2
Compute Time: 15Nov2017, 14:55:21 Control Specifications: Control 2

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 96.5 (M3/S) Date/Time of Peak Discharge 10Aug2014, 00:00
Volume: 664.01 (MM)

Observed Hydrograph at Gage Gage 1

Peak Discharge: 94.8 (M3/S) Date/Time of Peak Discharge: 16Aug2012, 00:00
Mean Abs Error: 5.2 (M3/S) RMS Error: 11.4 (M3/S)
Volume: 871.70 (MM) Volume Residual: -207.71 (MM)
Nash-Sutcliffe: 0.615

Figure B. 4: Comparison of simulated and observed runoff for validation.