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Addis Ababa University

Evaluation of Climate Change impacts on hydrology on selected catchments of Abbay Basin

MSc Thesis
By

Haileyesus Belay

June, 2011

Evaluation of Climate Change impacts on hydrology on selected catchments of Abbay Basin

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulics Engineering of Addis Ababa University.

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School of Post Graduate Studies

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Evaluation of Climate Change impacts on hydrology on selected catchments of Abbay Basin

Thesis submitted to Addis Ababa University, School of Graduate studies in partial fulfillment of the requirements for the degree of Master of Science in Hydraulics engineering.

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CERTIFICATION

The undersigned certify that he has read the Thesis entitled **Evaluation of Climate Change Impacts on hydrology on selected catchments of Abbay Basin** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science (Engineering).

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Abstract

The purpose of this study was to understand the climate change impacts on Abbay Basin located in Northwest of Ethiopia, using the RegCM3 Regional Climate Model. The RegCM3 model nested with the ECHAM5 General Circulation Model (GCM) were applied. Statistical Down Scaling Method (SDSM) is applied in order to downscale the climate variables at catchment level. A hydrological model, HBV-96 was utilized to simulate the water balance. In terms of hydrological modeling performance, R^2 criteria, the 10 catchments gave generally in the range between 0.60 and 0.81 in calibration and in validation between 0.54 and 0.75, which is good representation of the catchments. The projected future climate variables has two future time series, the first future time series (2031-2040) and the second future time series (2091-2100), for both future time series an increasing trend of potential evapotranspiration in all selected watersheds of Abbay basin is observed and the annual percentage change of PET with respect to the base period (1991-2000) has range between +2.78% and +18.98% at Anger and Beles catchments respectively. For the case of precipitation it doesn‘t manifest a systematic increasing or decreasing trend in the future time series. The annual rainfall change with respect to the base period has the range between -3.36% and +2.95% at Beles and Chacha watersheds respectively. The seasonal average runoff will reduce in most of the watersheds and it increase in some watersheds like Anger (+5.5%), Beles (+7.05%), Birr (+17.1%), Koga (+7.92%) and Teme (+2.94%) in the next future time series (2091-2100), the annual percentage change of runoff shows reduction in most of the watersheds between -0.59% (Koga) and -7.78%(Chacha) but only Anger (+7.25%), Neshi (+3.1%) and Teme (+3.86) watersheds show increment.

The sensitivity analysis has shown that Watersheds like Anger, Beles, Birr, Guder, Neshi, Muger are more sensitive to rainfall change relative to the other watersheds, and Chacha, Koga, Sechi, Teme, are more sensitive to potential evapotranspiration. Based on the checking of uncertainty almost in all watersheds the generated runoff for the future time series is placed out of the two bounds (5% and 95% probability flow), this implies that the change of percent of generated runoff is not because of hydrologic modeling (uncertainty because of hydrologic modeling is less significant).

Keywords: RegCM3, ECHAM5, GCM, SDSM, HBV-96, Watershed, uncertainty

ACKNOWLEDGEMENT

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List of Acronyms

Alfa Parameter defining the non linearity of the quick runoff reservoir in the HBV model

Bata Parameter in soil moisture routine in the HBV model

CCCM Climate and Carbon Cycle Model Group

CFCAS Canadian Foundation for Climatic and Atmospheric Sciences

DEM Digital elevation model

FAO Food and Agricultural Organizations

FC Parameter defining the maximum soil moisture storage in HBV model

GCM/s Global circulation Model/s

GIS – Geographic Information System

HadCM3 – Hadley Centre Coupled Model, version 3

HadCM3A2a – Hadley Centre Coupled Model, version 3, for the A2a emission scenario

HadCM3B2a – Hadley Centre Coupled Model, version 3, for the B2a emission scenarion

HBV Hydrologiska Byrans Vattenbalansavdelning (Hydrological Bureau Water balance Section)

Hq Parameter representing the high flow rate in the HBV model.

IHMS Integrated Hydrological Modeling System

IPCC Inter Governmental Panel on Climate Change

ITCZ Inter Tropical Convergent Zone

IVF Index Volume Fit

KHQ Parameter representing a recession coefficient at a corresponding reservoir volume in HBV model

LAM Limited-area models

MoWR Ministry of water resource

m.a.s.l – meters above sea level

NMSA Ethiopian National Metrological Service Agency

NCEP National Center for Environmental Prediction

PERC Percolation from upper to lower reservoir box [mm/day]

R^2 Nash and Sutcliffe coefficient

RCM Regional Climate Models

RVE Relative volume error.

SHMI Swedish Metrological and Hydrological Institute.

SRTM Shuttle Radar Topography Mission

SDSM Statistical Down Scaling Method

SRES Special Report on Emission Scenario

SWAT – The Soil and Water Assessment Tool

UNEP – United Nations Environment Programme

CHAPTER ONE

INTRODUCTION

1.1Background

The environment has been influenced by human beings for centuries. However, it is only since the beginning of the industrial revolution that the impact of human activities has begun to extend to a global scale. Today, environmental issue becomes the biggest concern of mankind as a consequence of scientific evidence about the increasing concentration of greenhouse gases in the atmosphere and the changing climate of the Earth. Globally, temperature is increasing and the amount and distribution of rainfall is being altered (Cubasch *et al.* 2001). According to the International Panel on Climate Change (IPCC) Scientific Assessment Report, global average temperature would rise between 1.4 and 5.8°C by 2100 with the doubling of the CO_2 concentration in the atmosphere. Sea level rise, change in precipitation pattern (up to ±20%), and change in other local climate conditions are expected to occur as a consequence of rising global temperature (Cubasch *et al.* 2001). This is expected to have a potential impact on different socio-economic sectors (IPCC 2001). Scientists have made estimates of the potential direct impacts on various socio-economic sectors, but in reality the full consequences would be more complicated as impacts on different sectors are indirectly interrelated to one another (UNEP 2005). The recent occurrences hurricanes and flooding in the World (Japan) and the very frequent drought in the African countries (including mainly Ethiopia) may be manifestation of these changes.

Being one of the very sensitive sectors, climate change can cause significant impacts on water resources by resulting changes in the hydrological cycle. The change on temperature and precipitation components of the cycle can have a direct consequence on the quantity of evapotranspiration component, and on both quality and quantity of the runoff component. Consequently, the spatial and temporal water resource availability, or in general the water balance, can be significantly affected, which clearly amplifies its impact on sectors like agriculture, industry and urban development (Hailemariam 1999).

Although climate change is expected to have adverse impacts on socio economic development globally, the degree of the impact will vary across nations. The IPCC findings indicate that developing countries, such as Ethiopia, will be more vulnerable to climate change. It may have far reaching implications to Ethiopia for various reasons, mainly as its economy largely depends on agriculture. A large part of the country is arid and semiarid, and is highly prone to desertification and drought. Climate change and its impacts are, therefore, a case for concern to Ethiopia. Hence, assessing vulnerability to climate change and preparing adaptation options as part of the entire program is very crucial for the country (NMSA 2001).

This research aims to generate climate change scenarios for precipitation and Evapotranspiration over Abbay basin catchments to assess their impacts on the flows of these catchments. The rainfall scenarios have been downscaled to the fine resolution required by the hydrological model from GCM using cascaded modeling approach of RCM and SDSM models. Potential (reference crop) Evapotranspiration (PET) scenarios have also been developed in the same way to be consistent with rainfall.

1.2 Statement of the problem

Climate change will have a profound impact on natural resources, of which water is one of the most important. With climate change the amount of rainfall in many parts of Africa is expected to decline while variability may increase dramatically (IPCC 2007).

With climate change and increases in climate variability, the need for managing water resources requires immediate action or attention. Due to climate change and variability there is an increase in severity of extreme events which results in fluctuation of storages. This may lead to an increase in floods and droughts.

Ethiopia has ample water resources, which can be appropriately utilized to enhance socioeconomic development of its people. Due to underdevelopment of this resource among others, the people of Ethiopia have been exposed to major problems such as impacts of drought and flood; shortage of clean water supply and inadequate energy supply (Hailemariam 1999).

Several studies have attempted to show the certainty of the rise of temperature over the Nile basin which started a century ago. Conway, (2005) indicates that with respect to future climate in Nile basin there is high confidence temperature will rise, leading to increase evaporation. However there is much less certainty about future rainfall because of low convergence in climate model projection in the key head water regions of the Nile. The same paper states that there is large inter-model difference in the rainfall changes over Ethiopia using the result from the seven recent climate model experiments. And Declan and Mike (1996) conclude that the effects of future climate change on Nile discharge would further increase uncertainties in Nile water planning and management.

The studies of (Abeyou, 2005) which illustrates the flow pattern of the tributary river of the lake Tana is not uniform and the major rivers in the recent year has shown decreasing trend and come to minimum at 2002. Especially in 2002-03 results the reduction of inflow by 10.54% and reduced lake level roughly by 1.4m and another study (Tarekegn. and. Tadege, 2006) climate change is projected at lake Tana indicates water resource of lake Tana is highly vulnerable to climate change and With climate change, the runoff may become much more seasonal and as a result small streams may completely dry up for the part of the year, this will become reason for a drying of wetlands, small springs and wells which are source of water supply to the rural community.

Studies done on Abbay river basin showed that the basin's water resource is very sensitive to incremental climate variability. However, these studies were only based on hypothetical precipitation and temperature change, which of course didn't take into consideration the Regional Climate Model (RCMs). Hence, studies that can narrow this gap are very important (Eman S.A. Soliman, 2009).

Having the above mentioned and other related problems, it is vital to understand the impact of future climate change on hydrology on Abbay basin based on Regional Climate Model (RCM).

1.3 Objective of the study and Research questions

1.3.1 Main Objective

The general objective of this study is to evaluate the spatial variability and behavior of impact of climate change on hydrology on selected catchments in Abbay river basin.

Specific Objective

In order to achieve the main objective of the study, the following specific objectives are set for major milestones of the study.

- Calibration and verification of impact assessment model (HBV-96 hydrological model).
- Generation of climate change scenarios for precipitation and temperature using statistical downscaling technique.
- Assessment of sensitivity and elasticity of Abbay basin catchments to climate change.
- Evaluation of impact of hydrological uncertainty on interpretation of climate change impacts.

1.3.2 Research Questions

The research questions addressed in this study are:

- What is the temporal climate change trend of temperature and precipitation using and its variation over the catchments of Abbay basin?
- Which climate variable dominates the future impact trajectory precipitation change or Evapotranspiration change?
- What is the impact trajectory and magnitude variation from catchment to catchment? Does it has similar patter or varies from catchment to catchment?
- How does the hydrological uncertainty affect climate change impact interpretation?

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1. Location

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

The Blue Nile (Abbay) River Basin, lies in the western part of Ethiopia, between 7^0 45‘ and 12^0 45‘N, and 34^0 05‘ and $39^0$45‘E as shown in Fig 2.1. It accounts for almost 17.1% of Ethiopia‘s land area and about 50% of its total average annual runoff. The climate of Abbay basin is dominated by an altitude ranging from 590 meters to more than 4000 meters. The influence of this factor determines the rich variety of local climates ranging from hot to desert-like climate along the Sudan boarder, to temperate on the high plateau, and cold on the mountain peaks. The annual rainfall varies between about 800 mm to 2,220 mm with a mean of about 1420 mm.

The Abbay originates in the highlands of Ethiopia. It drains towards Sudan on its western border and shares common boundaries with Tekeze basin to the north, Awash basin to the east and southeast, Omo-Ghibe basin to the south, and Baro-Akobo basin to the west (Master Plan of BNRB – Main Report, 1999).

The selected catchments are found mainly in central and southern of the Abbay basin. The catchments which are found in central of the Abbay basin are Birr, Koga, Gilgel Beles, and Teme. The others Anger,Chacha, Guder, Muger, Neshi, Sechi, are found at the periphery of the southern of the Abbay basin as shown below in figure 2.1 and 2.2.

The locations of the selected catchments are lie in the Abbay basin, between 7^0 45‘ and 12^0 45‘N, and 34^0 05‘ and $39^0$45‘E. Specifically catchments lie in this manner, Little Anger catchment which is found in Anger sub-basin and lies between (9^0 25‘ and10^0 05‘ N, 36^0 85‘ and 37^0 22‘ E), Gilgel Beles catchment which is found in Beles sub-basin and lies between (11^0 63‘ and11^0 55‘ N, 36^0 45‘ and 36^0 87‘ E), Birr catchment which is found in South Gojjam sub-basin and lies between (11^0 07‘ and 11^0 20‘ N, 37^0 37‘ and 38^0 08‘ E), Chacha catchment which is found in Jemma sub-basin and lies between (9^0 55‘ and 9^0 98‘ N, 39^0 67‘ and 39^0 98‘ E), Guder catchment which is found in Guder sub-basin and lies between (9^0 22‘ and 9^0 17‘ N, 38^0 02‘ and 38^0 42‘ E), Koga catchment which is found in Tana sub-basin and lies between (11^0 25‘ and 11^0 70‘ N, 37^0 05‘ and 37^0 57‘ E), Muger catchment which is found in Muger sub-basin and lies between (9^0 22‘ and 10^0 32‘ N, 38^0 72‘ and 39^0 20‘ E), Neshi catchment which is found in Fincha sub-basin and lies between (10^0 07‘ and 10^0 33‘ N, 37^0 10‘ and 37^0 48‘ E), Sechi catchment which is found in Dabus sub-basin and lies between (10^0 03‘ and 10^0 57‘ N, 35^0 10‘ and 35^0 62‘ E), Teme catchment which is found in North Gojjam sub-basin and lies between (11^0 03‘ and110 ^{0} 28‘ N, 37^0 82‘ and 38^0 20‘ E) as shown in the figure 2.1 and 2.2.

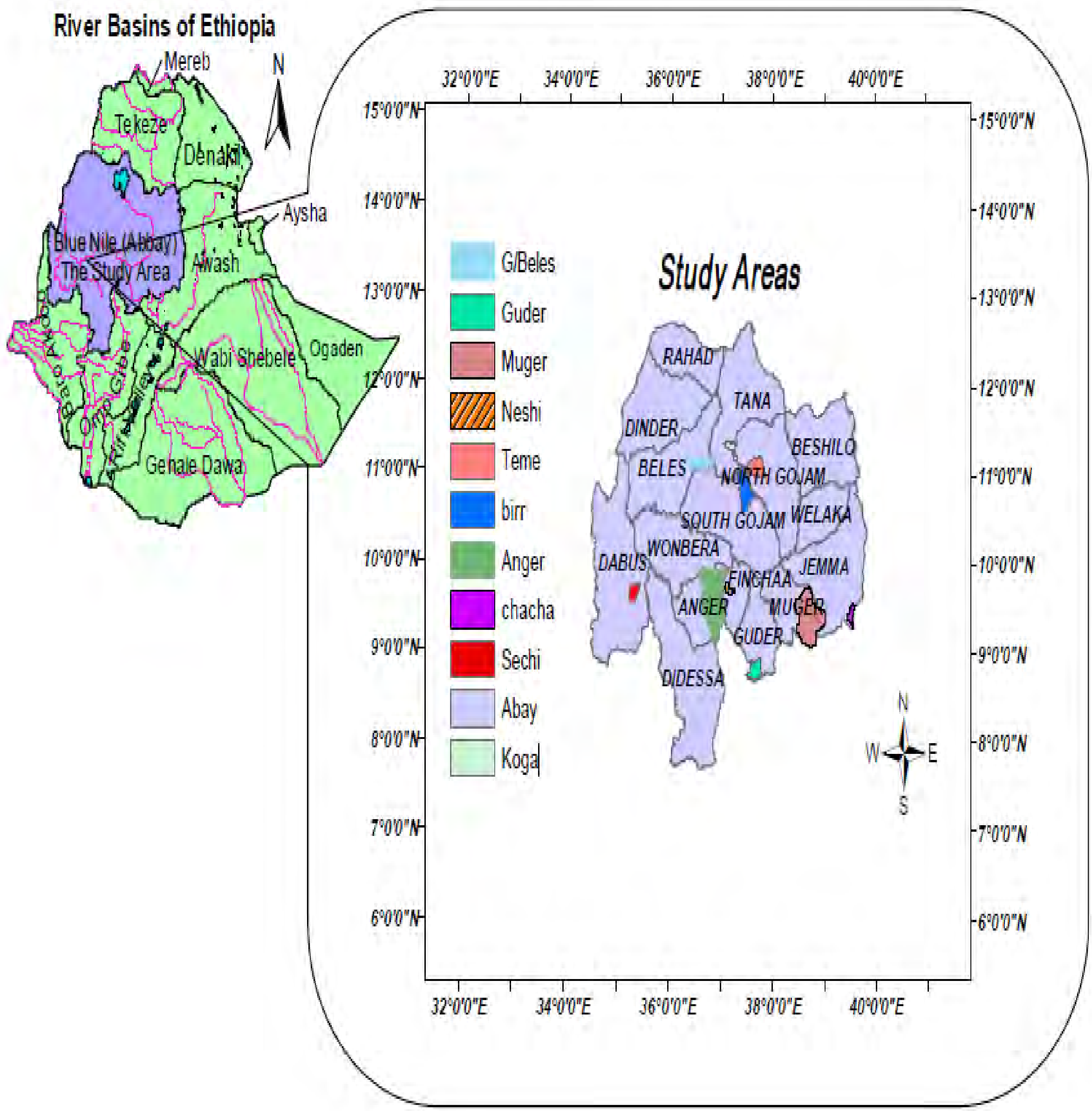


Figure.2.1. Location map of Abbay from Ethiopia

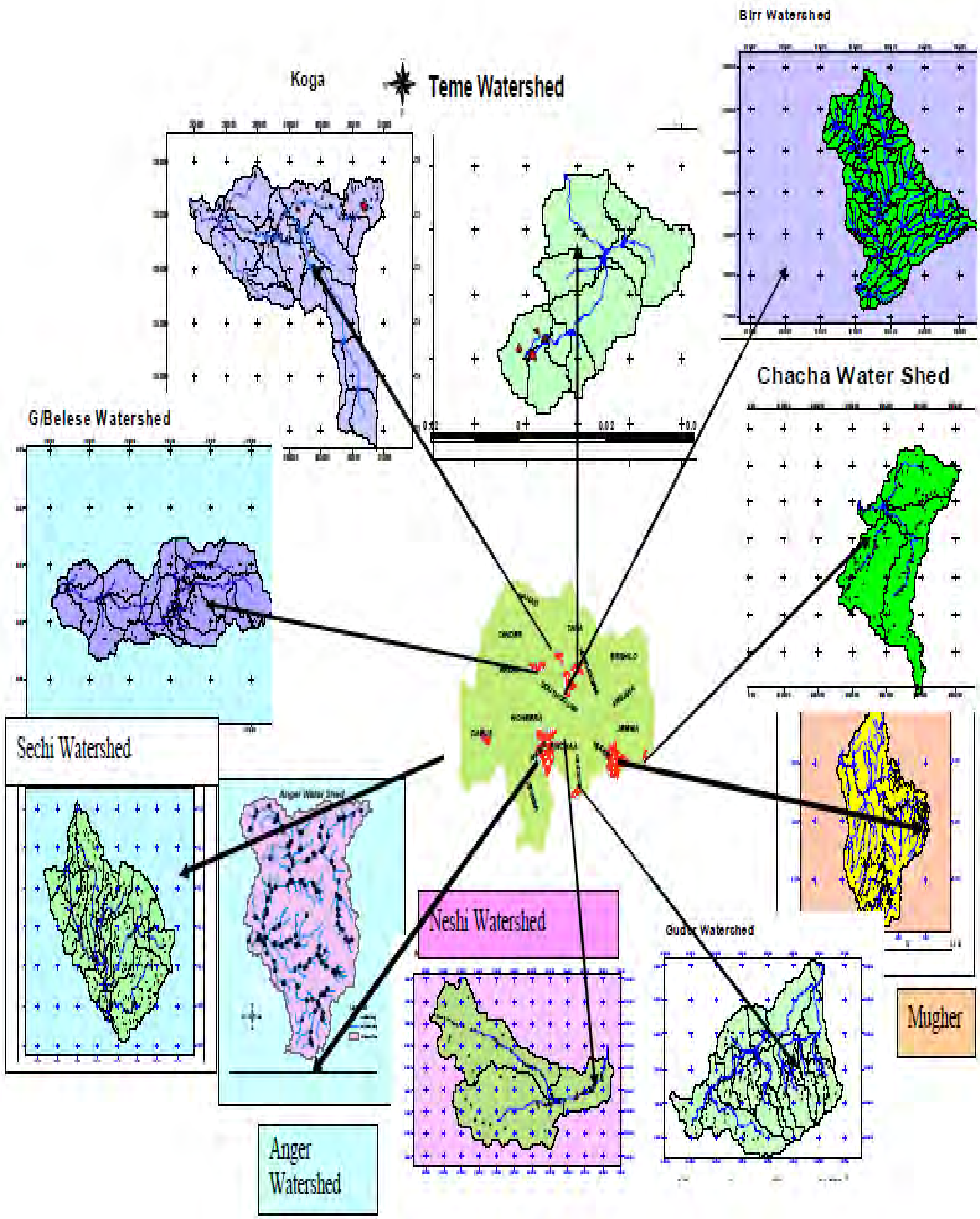


Figure.2.2. Map of the study area from Abbay Basin

2.2 Topography

Abbay basin is located northwest of Ethiopia. Rugged mountainous topography characterizes the Eastern and central part of the basin and along its periphery in the North and southeast. The remaining portion of the catchment is typically low laying plateau. The elevation ranges from 4239 m to 489 m a.m.s.l. The excessive slope area of the watershed lies in the East and decrease westwards.

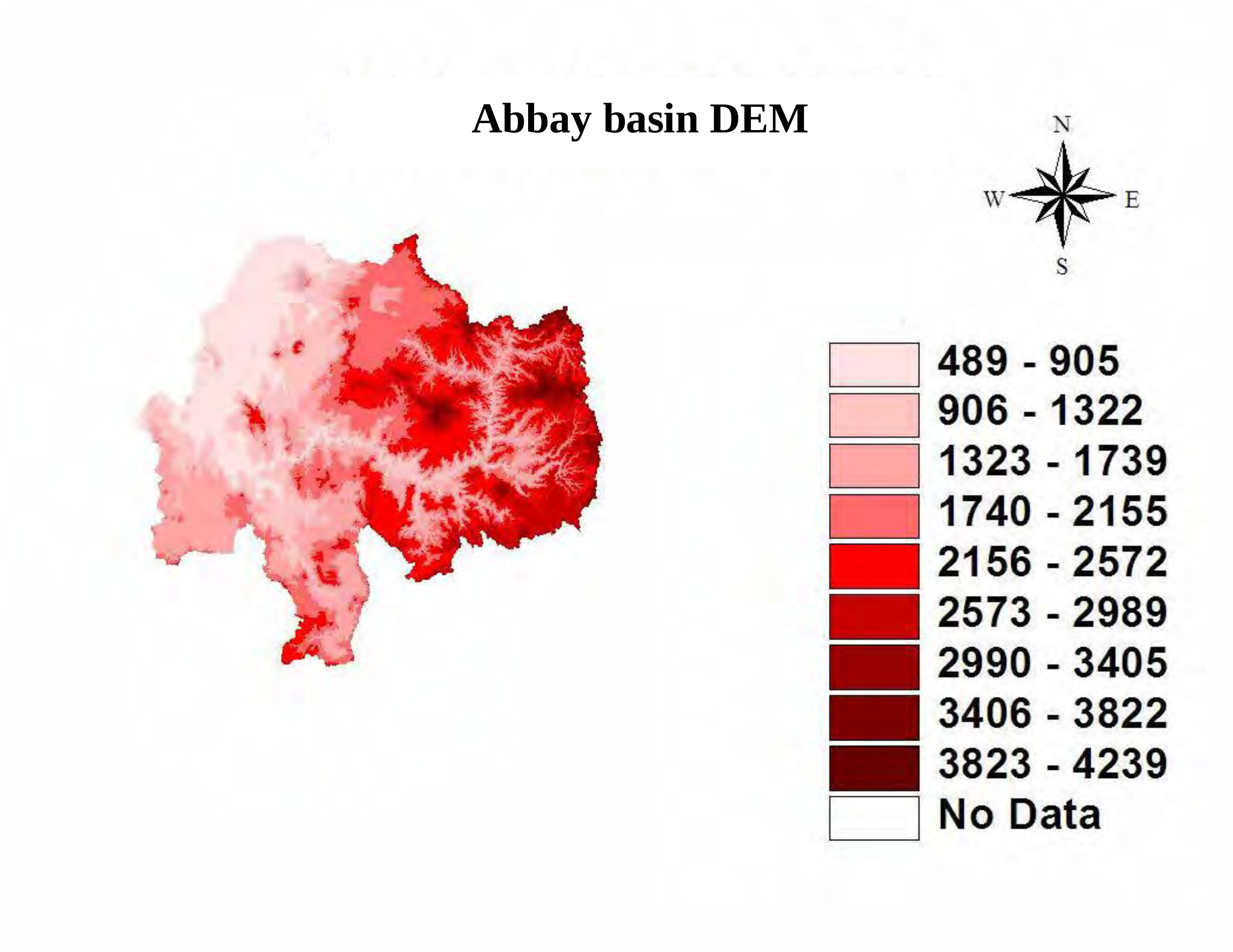


Figure 2.3 Digital elevation model (DEM) of Abbay Basin

2.3 Climate and Hydrology

The climate of the study area varies from humid to semiarid. Most precipitation occurs in the wet Kiremt season (June through September), and the remaining precipitation occurs in the dry Bega season (October through January or February) and in the mild Belg season (February or March through May). The annual precipitation increases from northeast to southwest over the basin. Annual precipitation has been found to range from 1200 to 1600 mm. The mean annual temperature from 1961 to 1990 was estimated to be 18.3 °C with a seasonal variation of less than 2 °C, and the annual potential Evapotranspiration was found to be about 1100 mm (Soliman, 2009).

Different studies conducted on Lake Tana Basin and Blue Nile Basin (Conway, 2000; Kebede et al., 2006; Tarekegn and Tadege, 2005) indicated that hydrological year of the study area is characterized by one main rainy season between June to September, in which 70% to 90 % of the annual total rainfall occurs.

According to Conway (1999) the climate of the high elevation areas can be considered as a temperate and that of the low elevation areas as tropical. The local climate classification in Ethiopia is based on elevation and temperature. In other words, depending on elevation for any area there is associated mean annual temperature range. This enables identifying traditional climate zone of a given area. The three traditional climate zones of Ethiopia are: Kola (elevation less than 1800 m a.m.s.l and mean annual temperature 20 – 28 ^{0}C), Woina Dega (elevation between 1800 m and 2400 m a.m.s.l and mean annual temperature 16 – 20^{0}C), and Dega (elevation between greater than 2400 m a.m.s.l and mean annual temperature 6 – 16^{0}C).
Figure 2.4 and 2.5 show that the monthly mean rainfall, monthly mean maximum and monthly mean minimum temperature of different stations in Abbay basin.

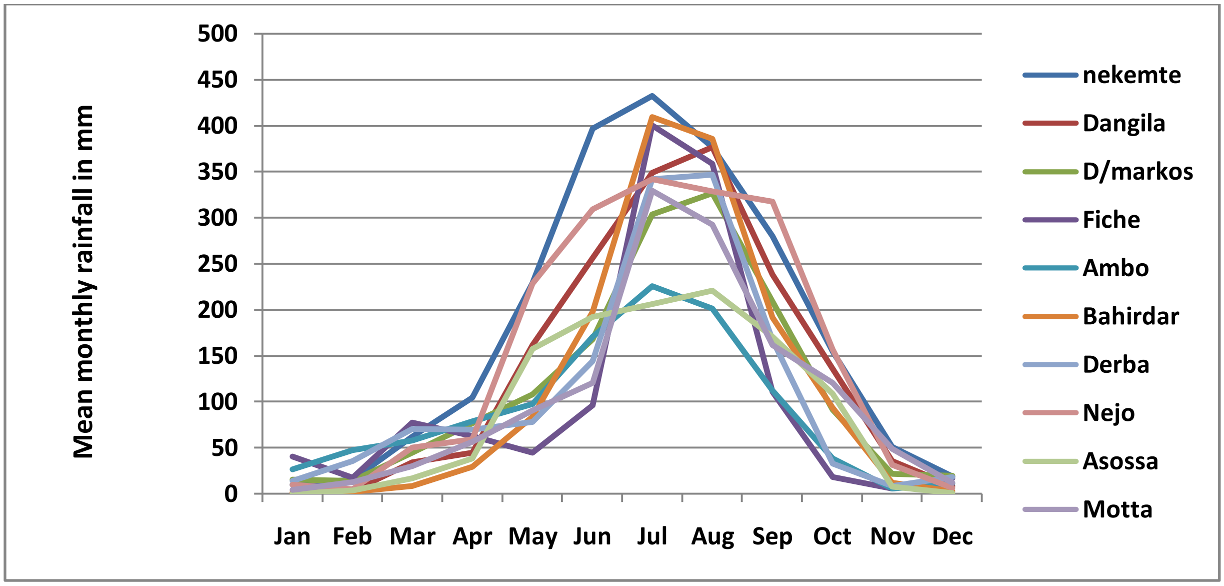


Figure 2.4 Average monthly rainfall of different stations in the study area

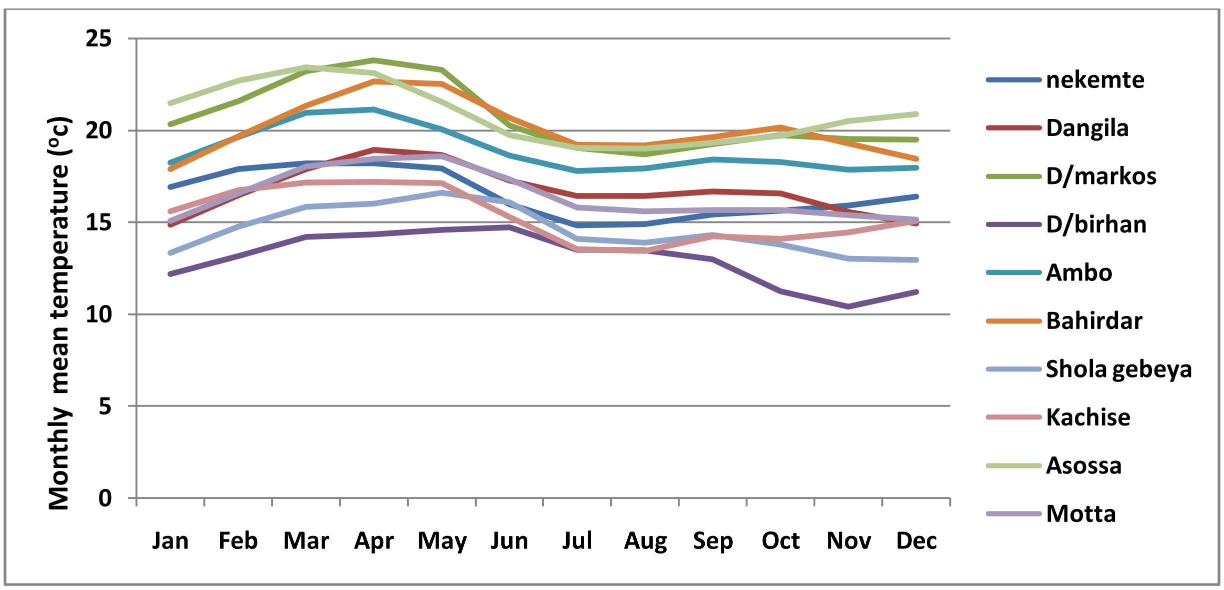


Figure 2.5 Monthly mean temperature of different stations in the study area

Blue Nile basin accounts for almost 17.1% of Ethiopia's land area, about 50% of its total average annual runoff and 25 % of its population. The Abbay river has an average annual runoff of about 50 BCM. This sub-basin is characterized by a highly seasonal rainfall pattern with most of the rainfall falling in four months (June to September – JJAS) with a peak in July or August. More than 80% of annual flow in the Blue Nile results from the summer monsoon and is concentrated between June and September (Elshamy, 2006).

Lake Tana outflows made up 8.1 per cent of the total Blue Nile flow at Roseires dam (near to the boarder of Ethiopia and Sudan) and were generated from 8.7 per cent of the total catchment area. The area drained between lake Tana and the gauge at Kese (near to Jema river) produces fairly low runoff owing to its lower rainfall, so that 36.9 per cent of the catchment area contributes only 29.1 per cent of the total runoff. Further downstream, river flows from the Didessa and the Angar rivers which drain the wetter south-west region amount to roughly twice that expected given their catchment areas. The Dabus, downstream of the swamp outlet, also contributes a high proportion of runoff, even after losses to evaporation in the swamp areas.

The seasonal distribution of runoff varies considerably owing to differences in the seasonality of rain-fall and catchment physiography. The smaller rivers have more rapid 'flashy' responses with less baseflow and many dry out after the wet season (e.g. Birr). The rivers in the south and south-west region tend to have longer flood periods and larger dry season flows (e.g. Angar, Didessa). Peak flows usually occur in August, one month after the rainfall maximum. These runoff patterns reflect the variation in rainfall distribution in the basin: longer wet seasons and flood periods and higher baseflow in the south-west; and Shorter wet seasons and flood periods and lower baseflow in the north and north-east (Conway, 2000).

Along with it also indicates there are sixteen sub-basins in the river basin as indicated in the figure 2.1 and table 5.1 with their corresponding aerial coverage, besides table 5.2 and table 5.3 shows the statistical summary data of rainfall and runoff.

Figure 2.6 below shows the monthly mean runoff of selected catchments of Abbay basin.

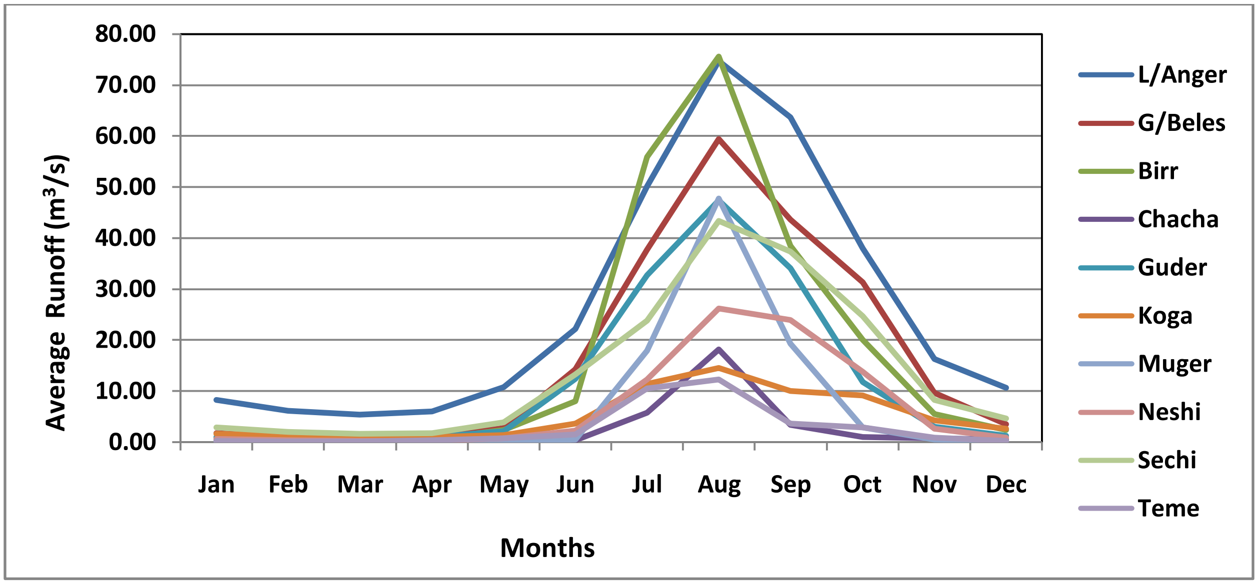


Figure 2.6 Monthly average runoff of selected catchments of Abbay basin

CHAPTER THERE

LITRATURE REVIEW

3.1 Over view of climate change

Climate change is considered as one of the biggest challenges of 21st century to the whole world will face. It is now widely accepted that climate change is already happening and further change is inevitable; over the last century (between 1906 and 2005), the average global temperature rose by about 0.74 ^{0}C. This has occurred in two phases, from 1910s to 1940s and more strongly from the 1970s to the present (IPCC, 2007a).

According to the International Panel on Climate Change (IPCC) Scientific Assessment Report, global average temperature would rise between 1.4 and 5.8°C by 2100 with the doubling of the CO2 concentration in the atmosphere. Sea level rise, change in precipitation pattern (up to ±20%), and change in other local climate conditions are expected to occur as a consequence of rising global temperature (Cubasch *et al.* 2001). This is expected to have a potential impact on different socio-economic sectors (IPCC 2001).

It is estimated that, for the 20th Century, the total global mean sea level has risen 12-22c m, this rise has been caused by the melting of snow cover and mountain glaciers (both of which have decline on average in both hemispheres) (IPCC, 2007a). The IPCC also notes that observations over the past century shows, changes are occurring in the amount, intensity, frequency and types of precipitation globally (IPCC, 2007a).

Among the different assessment that are carried out by the IPCC, the most recent which published in 2007, states the projected global surface warming lies within the range 0.6 to 4.0 ^{0}C, whilst the projected see level rise lies within the range 0.18 to 0.59 m at the end of next century (IPCC, 2007a).

3.2 Climate change in Ethiopia

According to the Ethiopian National Meteorological Services Agency (NMSA, 2001) study for 42 meteorological stations, the country has experienced both dry and wet years over the last 50 years. Trend analysis of the annual rainfall shows that there was a declining trend in the northern half of the country and southern Ethiopia while there is an increasing trend in the central part of the country. However, the overall trend in the entire country is more or less constant.

At the same year for 40 stations showed that there have been very warm and very cold years. However, the general trend showed there was an increase in temperature over the last 50 years. The study also noted that the minimum temperature is increasing at a higher rate than the maximum temperature.

Associated with rainfall and temperature change and variability, there was a recurrent draught and flood events in the country. There was also observation of water level rise and dry up of lakes in some parts of the country depending on the general trend of the temperature and rainfall pattern of the regions.

3.3 Climate scenario

Climate scenario refers to plausibly future climate that has been constructed for explicit use in investigating the potential consequence of anthropologic climate change (Houghton, 2001). It is important to emphasis that, unlike weather forecast, climate scenarios are not predictions. Weather forecasts make use of information to the observed state of atmosphere and calculate, using the law of physics, how this state will involve during the next few days, producing a prediction of future –a forecast. In contrast, a climate scenario is plausible indication of what the future could be like over the decades or centuries, giving a specific assumption. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumption about the behavior of climate system over long time scales. It is largely the uncertainty surrounding this assumption which determines the range of possible scenarios (carter, 2007).

Various types of climate scenarios are used in impact assessment. The most common scenarios types are applied based on the outputs from the climate models and the other types have been applied in reference to, or in conjunction, with model based scenarios.

I. **Scenarios based on outputs from climate models**: Climate models at different spatial scale and levels of complexity provide the major source of information for constructing scenarios. The most common method of developing climate scenarios for quantitative impact assessment is to use results from General Circulation Models (GCM).

II. **Hypothetical Scenarios:** The climate scenarios applied in reference to, or in conjunction, with model based scenarios, is hypothetical scenario.

This scenario describes techniques where a particular climate (or related) elements are changed by arbitrary amounts. For example, adjustment for baseline temperature by +1, +2, +3, +4 ^{o}C and baseline precipitation by ±5, 10, 15 and 20 percent could represent various magnitude of future change (Carter, 2007).

This scenario provides information in an ordered range of climate changes and can readily be applied in a consistent and replicable way in different studies and regions, allowing for direct Inter comparisons of results. However, such scenarios do not necessary present realistic set of changes that are physically plausible. They are usually adapted for exploring system sensitivity prior to the application of more credible, model based scenario (Hougton, 2001).

3.4 The special report on emission scenarios (SRES)

In 1996, the IPCC began the development of new set of emission scenarios, effectively to update and replace the well-known IS92 scenarios. The approved new set of scenarios is described in the IPCC special report on emission scenarios (SRES). Four different narrative storylines where developed to describe consistently the relationship between the forces driving emission and there evaluation and to add context for the scenario quantification. The resulting set of 40 scenarios cover the wide range of the main demographic, economic and technological driving forces of the future greenhouse gas and sulpher emission. Each scenario represents the specific quantification of one of the four storylines. All the scenarios based on the same storyline constitute a scenario _'family'' which briefly describe the main characteristics of the four SRES storylines and scenario family (IPCC-TGICA, 2007).

A1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis:

- Fossil intensive (A1FI)
- Non - fossil energy sources (A1T), or
- Balance across all sources (A1B)

(balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

B1. The B1 storyline and scenario family describe a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection.

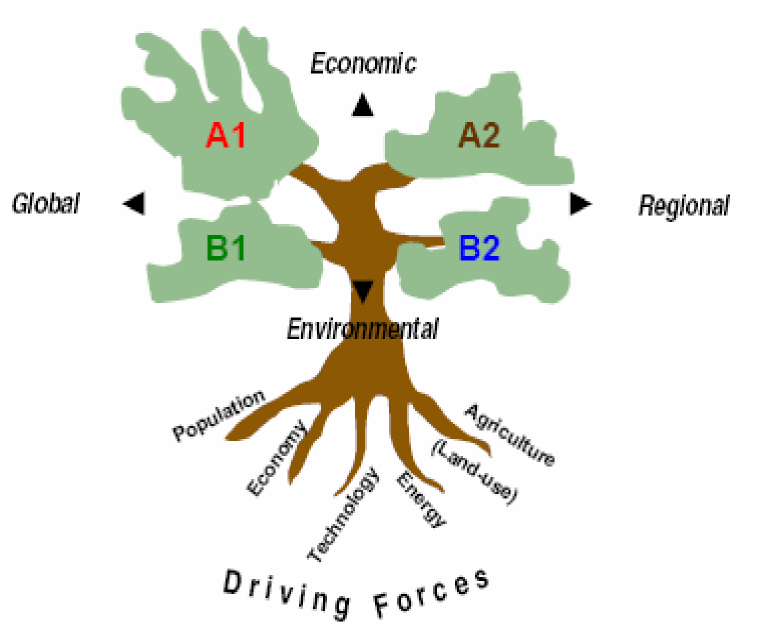


Figure.3. 1 the four IPCC SRES scenario storylines (IPCC-TGICA, 2007)

3.5 Downscaling methods and tools

The General Circulation Models (GCMs) used to simulate the present and project future climate with forcing by greenhouse gases and aerosols, typically divide the atmosphere and ocean into a horizontal grid with a resolution of 2 to 4º latitude and longitude, with 10 to 20 layers in the vertical. In general, most GCMs simulate global and continental scale processes in detail and provide a reasonably accurate representation of the average planetary climate. Over the past decade, the sophistication of such models has increased and their ability to simulate present and past global and continental scale climates has substantially improved. Nevertheless, while GCMs demonstrated significant skill at the continental and hemispherical scale and incorporate a large proportion of the complexity of the global system, they are inherently unable to represent local sub-grid scale features and dynamics, such as local topographical features and convective cloud process (Dibike & Coulibaly, 2005). Moreover, GCMs were not designed for climate change impact studies and do not provide a direct estimation of the hydrological responses to climate change. For example, assessment of future river flows may require (sub-) daily precipitation scenarios at catchment, or even station scales. Therefore, there is a need to convert GCM outputs into at least a reliable daily rainfall series at the scale of the watershed to which the hydrological impact is going to be investigated. The methods used to convert GCM outputs into local meteorological variables required for reliable hydrological modeling are usually referred to as ―downscaling" techniques. There are two categories of climatic downscaling, namely dynamic downscaling and statistical downscaling (Dibike & Coulibaly, 2005).

3.5.1 Dynamical downscaling

Dynamic downscaling approach is a method of extracting local-scale information by developing and using limited-area models (LAMs) or regional climate models (RCMs) with the coarse GCM data used as boundary condition. The basic steps are then to use the GCMs to simulate the response of the global circulation to large-scale forcing and the nested RCM to account for sub-GCM grid scale forcing such as complex topographical features and land cover heterogeneity in a physically-based way; and thus enhance the simulation of atmospheric circulations and climate variables at fine spatial scales.

RCMs have recently been developed that can attain horizontal resolution in the order of tens of kilometers or less over selected areas of interest. Compared with GCMs, the resolution of these RCMs is much closer to that of distributed-parameter hydrological models and that even makes coupling of such models possible.

3.5.2 Empirical (statistical) downscaling

Empirical downscaling starts with the premise that the regional climate is the result of interplay of the overall atmospheric, or oceanic, circulation as well as of regional topography, land-sea distribution and land use. As such, empirical statistical downscaling seeks to derive the local scale information from the larger scale through inference from the cross-scale relationship using some random or deterministic functions. In most cases, the regional climate is seen as a random process conditioned upon a driving large-scale climate regime. Therefore, the confidence that may be placed in downscaled climate change information is foremost dependent on the validity of the large-scale fields from GCM. For instance, derived variables (not fundamental to the GCM physics, but derived from the physics) such as precipitation are usually not as robust information at the regional and local scale (Cunderlik 2003). Conversely, tropospheric quantities like temperature or geo-potential height are intrinsic parameters of the GCM physics and are more skillfully represented by GCMs.

3.6 Hydrologic Modeling

Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. Without going into too much detail, deterministic hydrologic models can be classified into three main categories (Cunderlik 2003).

1. **Lumped models**. Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan et al., 1982). Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 2000).
2. **Semi-distributed models**. Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 2000). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin.
3. **Distributed models**. Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

3.6.1 Hydrologic Model Selection Criteria

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

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

One of the most frequently used conceptual model for climate change impact study is the HBV model. The HBV model is widely used in Nordic countries as a tool to assess the climate change effects. Climate change impact on runoff and hydropower in the Nordic countries has been studied by using the HBV models (Xu, 1999). (Booij, 2005) applied the HBV model to assess the impact of climate change on river flooding on Meuse River in the Netherlands. (Dibike and coulibaly, 2005) applied the HBV model to study the hydrological impact of climate change in the Saguenay watershed in Canada.

In Ethiopia it has been applied for different catchments to assess the climate change effects. Evaluation of climate change impact on Upper Blue Nile Basin Reservoir (Case Study on Gilgel Abbay Reservoir) (Habtom, 2009), Impact of climate change on hydrology and water resource availability of upper Blue Nile catchments (GCM) (Ashenafi, 2009), Evaluation of Impact of Climate Change on Water Resource Availability in the Catchments of Blue Nile Basin (hypothetical scenario) (Muluneh, 2008). In conclusion, the HBV model is selected for this study due to the following reason:

- The input data requirement is moderate;
- The model simulates the major hydrological process in the catchments;
- The model is tested for impact of climate change on hydrological study in different part of the world including Ethiopia and
- The availability of the model

3.7 Approach to Climate Change Impact Study on Water Resources

The water resources are one of the sectors to be severely affected by the changing climate. This is mainly because of the fact that even a minor long-term change in temperature and precipitation may have significant impacts on the hydrologic cycle especially at the basin scale. Consequently, it is quite essential to identify the level of impact on such resources.

Findings of the IPCC 2001, strongly suggests that water resource respond to global warming in ways that will negatively impacted the water availability and water supplies. The climate change has also the potential to deteriorate the surface water quality due to increased Evapotranspiration, lower flows and rivers becoming warmer, making the management of water treatment works (and subsequent compliance with the drinking water quality regulations) more challenging. The reduction in the runoff volume will lead to the decrease in the inflow to the reservoirs consequently; longer period might be required to fill the reservoir. As result of the increase in temperature the rate of evaporation from the reservoir open water surface may increase and this may create the reservoir to fail to supply at least the required amount of demand because of its depletion or decrease in the active storage volume and or water level.

3.8 Description of HBV-96 hydrological model

The HBV model is a conceptual hydrological model for continuous simulation of catchment runoff and out flow from reservoirs. It was originally developed at the Swedish meteorological and hydrological institute (SMHI) in the early 1970s. Since the model has found application in more than 40 countries. Originally the HBV model was developed for runoff simulation and hydrological forecasting. But the scope of the application has increased steadily. Today the HBV model can be used (Seibert, 2002):

- For water balance studies;
- For runoff forecasting (flood warning and reservoir operation);
- To compute design floods for dam safety;
- To investigate the effect of changes within the catchment;
- To simulate climate change effects

The general water balance can be described as:

$$P-E-Q = d/dt\,[SP + SM + UZ + LZ + lakes] \quad \text{--3.1}$$

Where,

P: Precipitation, E: Evapotranspiration Q: Runoff, SP: Snow pack, SM: Soil moisture, UZ: Upper groundwater zone, LZ: Lower groundwater zone, and Lake (reservoir volume)

The model consistence of subroutines for precipitation and snow accumulation, soil moisture accounting, actual evaporation and uses simple transformation functions routine procedures. Soil moisture accounting is governed by two simple relations that are parameterized by FC, which is the maximum soil moisture storage (mm) in the model, and LP that is the limit for potential Evapotranspiration and Beta control the contribution of the soil moisture storage, SM, to the response function $\Delta Q/\Delta P$.

$\Delta Q/\ \Delta P = [SM/_{FC}]^{Beta}$ --3.2

Q denotes the discharge and P denotes the precipitation while ΔQ/ ΔP is to be interpreted as runoff coefficient. Actual Evapotranspiration, Ea, which is controlled by the soil moisture routine, is linearly related to the potential Evapotranspiration, Ep, and reads;

$Ea=Ep*min\left\{\left(SM/_{(Lp*Fc)}\right), 1\right\}$---3.3

In HBV-IHMS the runoff routine comprises two reservoirs that distribute generated runoff over time to obtain quick and slow part of catchments runoff hydrograph. Runoff generated from the upper reservoir represents quick runoff discharges while runoff from the lower reservoir represents ground water discharges.

$Q_0=Khq*UZ^{(1+alfa)}$ ---3.4

Where Q_o is the direct runoff from upper reservoir the parameters UZ and Khq are the upper reservoir storage and the quick flow recession coefficient while Alfa is a measure for the nonlinearity of the flow. The lower reservoir is a simple linear reservoir that simulates base flow contributions by percolation from upper reservoir.

$Q_1=K_4 * LZ$ ---3.5

Q_1 denotes the outflow from lower reservoir; LZ is the lower reservoir storage while K_4 is the recession coefficient. Obviously, the combination of the parameters control runoff contribution over time that affects the shape of hydrograph.

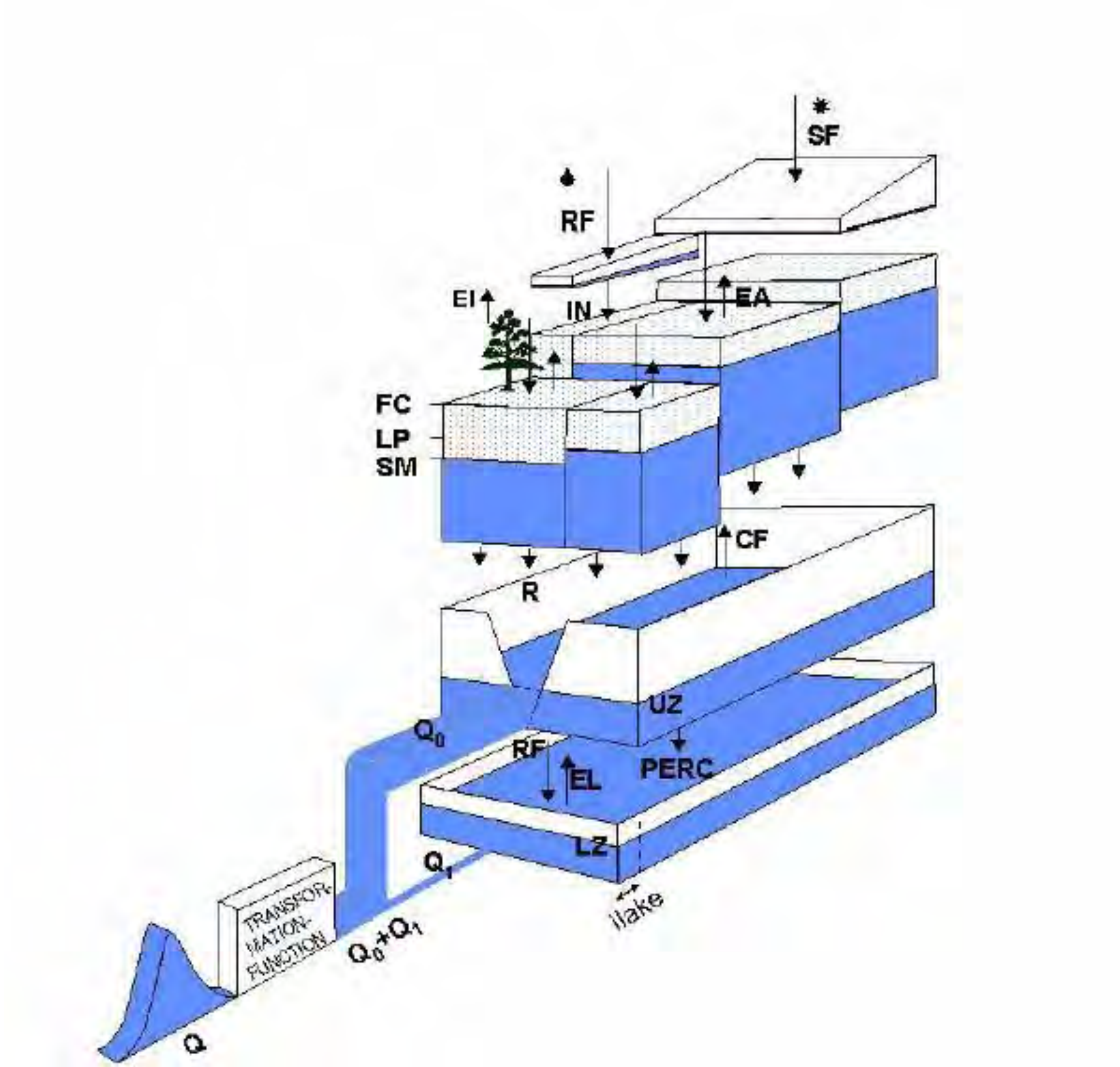


Figure.3. 2 Schematic representations of HBV model for one basin

Where,

SF: snowfall, RF: rainfall, EI: evapo-transpiration, IN: infiltration, EA: actual evaporation, FC: Maximum soil moisture storage, SM: compound soil moisture routine, CF: capillary rise, R: seepage, UZ; upper zone reservoir, Qo; direct runoff from upper reservoir, EL; lake evaporation, PERC; percolation capacity, LZ: lower zone reservoir and Q_1: base flow lower reservoir.

3.9 Related Studies in Ethiopia

3.9.1. Study on Lake Ziway Watershed

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

3.9.2. Blue Nile Basin

A) Study on Gilgel Abbay Catchment

Studies in the Gilgel Abbay river watershed reveals that the result of down scaled precipitation does not manifest a systematic increase or decrease in all future time horizons for both A2 and B2 scenarios unlike that of minimum and maximum temperature.

And the result from synthetic (hypothetical) scenario indicates that the Catchment is sensitive to climate change especially in rainfall. An increase of 2^{o}C without change in rainfall decreases the seasonal an annual runoff by 1.7 and 2%. However; if the change in temperature is changed by 20% rainfall reduction, seasonal and annual runoff will reduce by 33%. If the change in temperature is 4^{o}C, the seasonal and annual runoff decreased by 3.3 % and 4% respectively. If the 2^{o}C increase of temperature is occur simultaneously with rainfall reduction in 10% the seasonal and annual runoff will decreased by 17.7%. And it is concluded the Gilgel Abbay Catchments is more sensitive to change in rainfall than change temperature (Kedir, 2008).

B) Study on Tana Sub-Basin

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

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

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

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

CHAPTER FOUR

METHODOLOGY

4.1 General Methodology

Basically, the general methodology for the study can be described by the following flow chart;

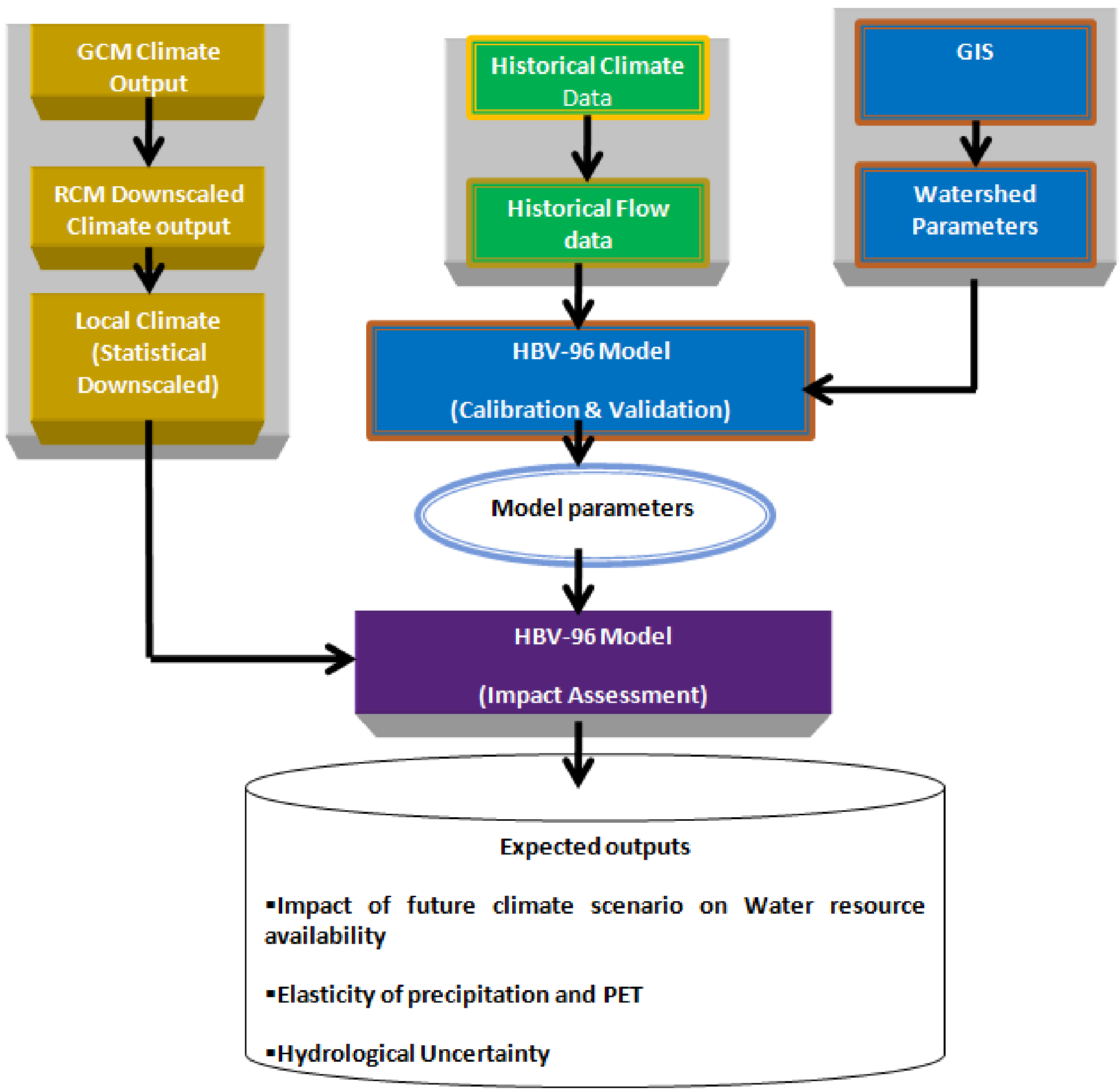


Figure.4. 1 General methodology flowchart used in the study

The above figure 4.1 or the flow chart shows the general methodology or the progress that have been taken for this study. The data that are the historical climate data and flow data have been collected from National metrological Agency and ministry of water resources that used to calibrate and validate HBV-96 model, but before the calibration has been taken for the given model, watershed parameters are needed, these watershed parameters are watershed area, mean elevation, land use and the shape of the watershed. These parameters are taken from the output of the digital elevation model (DEM) that has been processed by GIS. Taking these watershed parameters and the historical flow and climate data calibration has been taken to determine the model parameters. On the other hand the coarser climate data (GCM) are downscaled in to finer spatial resolution regional climate data (RCM) and these regional climate data are further downscaled in to station level by using statistical downscaling model (SDSM 4.2.2), these downscaled data have been taken directly as an input of the model to assess the future climate change impact on hydrology of the catchments. Elasticity and uncertainty have been also done to check the climate change is really because of climate change or because of the hydrologic model. This is the general description of the methodology besides the whole methodology is further discussed in this chapter.

4.2 Downscaling of Regional climate model outputs using statistical downscaling method

The outputs of the RCM data that are precipitation and the inputs used to calculate potential evapotranspiration (maximum and minimum temperature, wind speed, relative humidity, sunshine hour) that have grid resolution of 50 km (0.5^0 latitude by 0.5^0 longitude grid size) have been further downscaled in to station level by using statistical downscaling model (SDSM 4.2.2).

4.2.1 Grid Selection for Statistical Down Scaling Method

RCM grid outputs data have been classified based on their grid location (Latitude &Longitude). The grid data has been selected as a predictor for a given metrological station from the others grid data by identifying a grid location that can consist of the location (Latitude &Longitude) of a metrological station, and this grid data has been taken as a predictor of a given metrological station and the station data has been taken as pridictand, however if the metrological station is located near the border of two different neighbor grids, the values of the two grids outputs will be taken as the predictor of a given metrological station.

Quality control and data transformation: - The quality control in SDSM used to identify the gross data error, specification of missing data code and outliers prior to model calibration. In many instances it may be appropriate to transform predictors (grid data) and/or the predictand (measured station data) prior to model calibration. The transform facility takes chosen data files and applies selected transformations (e.g., logarithm, power, inverse, lag, binomial, etc).

Screening of downscaling predictor variables: - Identifying empirical relationships between gird predictors (such as mean sea level pressure) and single site predictands (such as station precipitation) is central to all statistical downscaling methods. The main purpose of the screen variables operation is to assist the user in the selection of appropriate downscaling predictor variables.

Model calibration: - The calibrate model operation takes the specified predictand along with a set of predictor variables, and computes the parameters of multiple regression equations via an optimization algorithm (either dual simplex of ordinary least squares). Then specification of the model structure: whether monthly, seasonal or annual sub–models are required; whether the process is unconditional or conditional. In unconditional models a direct link is assumed between the predictors and predictand but in conditional models, there is an intermediate process between regional forcing and local weather.

Weather generator: - The weather generator operation generates ensembles of synthetic daily weather series for a given observed atmospheric predictor variables. The procedure enables the verification of calibrated models (using independent data) and the synthesis of artificial time series for present climate conditions.

Graphical model out puts or graphical analysis:-the graphical model out puts are used to compare the generated daily climate data series with measured daily climate series data for calibration and the graphical model out puts are sum, mean, maximum, minimum and variance of the generated and measured data.

Scenario generation:-Finally, the scenario generator operation produces ensembles of synthetic daily weather series for the potential atmospheric predictor variables supplied by a climate model (either for present or future climate experiments), rather than observed predictors.

4.3 SDSM Model Calibration, validation and Scenario generation

The model calibration operation takes a selected predictand along with a set of predictor variables, and computes the parameters of multiple regression equations via an optimization algorithm (either dual simplex of ordinary least squares). There are options in SDSM model structure to perform calibration process either monthly, seasonally or annual time scale. Selecting one of these model type decide how the regression parameters are developed (for example if a model type monthly is selected, then the model develops one regression equation for the whole months and if annul model type is selected again one regression equation is develop for the whole one year and so on). For this particular study among the total period length of 1991-2000, 10 years of daily data is used for model calibration.

Generally, model calibration involves determination of model parameters that gives the best possible correspondence between station data and generated data from a given station. The parameters are variance inflation and bias correction.

Variance Inflation: Controls the magnitude of variance inflation in downscaled daily weather variables. This parameter changes the variance by adding/reducing the amount of ―white noise" applied to model estimates of the local process. The default value produces approximately normal variance inflation (prior to any transformation). Larger values increase the variance of downscaled properties. Variance inflation is de–activated by setting the parameter to zero.

Bias Correction: Compensates for any tendency to over or underestimate the mean of conditional processes by the downscaling model (e.g., mean daily rainfall totals). The default value is 1.0, indicating no bias correction.

The Weather Generator operation generates ensembles (up to a maximum of 100) of synthetic daily weather series given observed atmospheric predictor variables. The procedure enables the verification of calibrated models (using independent data) and the synthesis of artificial time series for present climate conditions.

The Scenario Generator operation produces ensembles of synthetic daily weather series from the starting of the baseline period (1991-2000) and two future time series (2031-2040) and (2091-2100). This function is identical to that of the Weather Generator operation in all respects except that it may be necessary to specify a different convention for model dates and source directory for predictor variables.

4.4 HBV-96 model Input data

The model input requirements for the HBV-96 model are daily rainfall, if there is calculated value of average monthly potential Evapotranspiration it can be used directly as an input of HBV-96 model, but if there is no calculated value, the inputs data that used to calculate potential Evapotranspiration are needed (maximum and minimum temperature, wind speed, sunshine hour and relative humidity) and catchments characteristics of the area. If snow exists in the watershed daily temperature data are compulsory. Temperature data are used for calculations of snow accumulation and melt, or to calculate potential evaporation. If none of these last options are used, temperature can be omitted in snow free areas.

I. Catchments data

Since the HBV-96 model works as semi-distributed model, the catchments area can be divided into different sub-basins and the sub-basins further be divided into different elevation and vegetation zones. Therefore a digital elevation map of the area was prepared using Shuttle Radar Topography Mission (SRTM) with a resolution of 90 m and the DEM was processed using AV-SWAT to extract drainage area, drainage network and to divide the area into different sub basins and elevation zones.

II. Aerial rainfall

The HBV model requires daily rainfall as input. Hence rainfall data for the period of twenty two years (1980-2002) was prepared for forty (40) meteorological stations for the all catchments area. Aerial rainfall in the model is computed by multiplying the rainfall by the weight of each station for the sub basin considered in the analysis. The weight of each meteorological station was computed by the Thiessen polygon and is adopted for further analysis.

III. Potential Evapotranspiration (PET)

Potential Evapotranspiration (is calculated using the penman montheth equation with temperature, wind speed, solar hour and humidity as input) fortunately the Average monthly values of daily PET of whole Abbay Basin is already done by (Tsegaye.E 2007), which used to be daily input for this Research.

4.5 Model calibration, Validation

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated. Alike other similar conceptual models, HBV-96 model parameters has to be estimated through calibration. Generally, model calibration involves determination of model parameters that gives the best possible correspondence between observed and simulated runoff from a catchment. Among the different approaches for calibrating the model in order to identify the optimum parameter set; the manual calibration is functional for this model.

In HBV-96 model, it is recommended that calibration be done with not less than ten years of data. Calibration of model parameters is done from (1980-1992) following a procedure specified in the SMHI manual. Parameters are calibrated following a certain order. This order ought to be the following:

1. Volume parameters
2. Snow parameters
3. Soil parameters
4. Response parameters
5. Damping parameters

The catchments does not experience snow therefore snow parameters are not dealt with in this study. Calibration was done following the procedure stated above.

Table 4.1 Parameters used for the HBV model calibration process

PARAMETER	DESCRIPTION
Volume parameter **Rfcf**	This parameter is a rainfall correction factor. It was observed that as rfcf increased the volume of runoff increased but as the rfcf decreased the volume of runoff got reduced. **0.9-1.3**
Soil parameter **Fc (mm)**	Field capacity. As fc value increased, the volume of discharge decreased but as the field capacity decreased the volume of discharge produced increased.**100-1500**
Lp	Limit for potential evaporation. As lp increases, the base flow increase and quick runoff decreases. **<=1**
Beta	Beta is an exponent in formula for drainage in soil. As beta increases more water infiltrates into the soil and less runoff is created. **1-4**
Response parameter **K4**	=>K4 is a recession coefficient for the lower response box.K4 affected mainly the initial conditions. As K4 increased too much runoff was created. **0.001-0.1**
Perc (mm/day)	Perc represents percolation from the upper zone to the lower response box and it is given in mm per day. As perc increases quick runoff is reduced and the volume of base flow increases. **0.01-5**
Khq	This is the recession coefficient for the upper response box when the discharge is Hq. Hq is calculated for each basin Hq= $\left[\frac{(MQ*MHQ)^{\frac{1}{2}}*86.4}{A}\right]$ As the value of Khq decreases, the response of response of runoff was delayed hence a shift of the simulated hydrograph to the right Is a parameter used in the equation;
Alfa	=>$Q = k * UZ(Alfa+1)$ Where Q is discharge, k is a coefficient and UZ is content of upper box in response routine. As the value of alfa decreased, the accumulated difference of runoff increased. **0.5-1.1**
Damping parameter **Maxbaz (day)**	These are number of days in the transformation zone. Increase in number of days delayed the quick runoff **1-5**

4.6 Evaluation of the model result

While calibrating, it is important to have a good method of evaluating the results. Finally the model performance was evaluated for both calibration and validation in different ways including:

1. Visually inspecting and comparing the calculated and the observed hydrograph
2. By calculating Explained variance R^2

$$R^2 = \frac{\sum_{i=1}^{n}\left(Q_{obs\,(i)} - \bar{Q}_{obs\,(i)}\right)^2 - \sum_{i=1}^{n}\left(Q_{obs\,(i)} - Q_{sim\,(i)}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs\,(i)} - \bar{Q}_{obs\,(i)}\right)^2} \text{ --4.1}$$

Where,
Q_{obs} : Observed flow , Q_{sim} : Simulated flow , $\bar{Q}_{obs}$:Average of observed flow and $\bar{Q}_{sim}$:Average of simulated flow

R^2 can have values ranging from -∞ to 1. If the simulation is accurate, R^2 is equal to one. An efficiency of R^2 is equal to zero indicates that the model predictions are as accurate as the mean of the observed data. If the accuracy of the simulation results is smaller than the average value of the measured variables, then R^2 will have a negative value.

3. By calculating the index of Volumetric (IVF)

It is the ratio of the total volume of estimated to the total volume of observed flow.

$$IVF = \frac{\sum_{t}^{n}(Q_{sim})t}{\sum_{t}^{n}(Q_{obs})t} \text{ --4.2}$$

Where Q_{sim} and Q_{obs} are simulated and observed discharge and n is the total number of discharges Values.

CHAPTER FIVE

DATA AND DATA ANALYSIS

5.1 Hydro-Meteorological Data

The criterion for the selection of the Metrological data was based on the availability of data, the data quality and possibly whether the station is within the watershed or not? And if not it is within the Sub-basin or nearby. But the distribution of the river watershed (study Watershed) depends on the availability of concurrent long year daily data as that of climate data and to maintain the distribution as far as possible throughout the Sub-basins of Blue Nile. The locations of the climate stations and the details of the data collected are presented in table 5.1 and figure 5.1.

From the sixteen Sub basins in the Blue Nile Bain, only ten Watersheds are selected for the study, the other Watersheds in the rest of the Sub Basins are dropped for the reason of no availability of Metrological or hydrological data. The Sub Basins which have no hydro-Meteorological data are: Beshilo, Wonbera, Dinder, Rahid, Didessa and Woleka.

All hydro-metrological data screening and filling of missing data for the study area have been done by Muluneh (2008), and these data have been taken directly as the input of HBV-96 model for calibration and verification to assess the climate change impact.

Table 5.1 Sub catchments and Watershed Area from (MOWR) and the Selected Rainfall and PET stations

No	**Sub basin name /Area (Km^2)**	**Watershed /Area (Km^2)**	**Rainfall stations (1980-2002)**	**PET Stations (1992-2002)**
1	Anger/7941.48	Little Anger/374.2	Bako,Nekemite,Shambu	GidAyana, Nekemite
2	Belese/14200.13	Gilgel Belese/675	Chagni, Dangla	Bullen,Dangla,Pawe
3	Dabus/21029.95	Sechi/562	Asossa,Bambise,Jarso, Megen	Asossa
4	Fincha/4089.45	Neshi/322	Bako, ljaji, Nedjo, Shambu	GidAyana, Nedjo
5	Guder/7011.21	Guder/524	Ambo, Bussa, Gedo, ljaji, Jeldu, Nedjo, Teji, Kechise.	Nedjo,Kechisie
6	Jemma/15782.12	Chacha/418	Alemketema,Fiche ,Jarso,molale,sheno	DebreBirhan, Mehalmeda
7	Muger/8188.11	Muger/418	Derba, Jeldu, Fiche, Teji,	kechise ,SholaGebeya
8	North Gojjam/14389.47	Teme/156.3	Dejen,Debrework,Felgbirhan, Fresenbet,Gundewine, Motta,Tisabay, Yetmen	Adet, Motta
9	South Gojjam/16762.34	Birr/978	Chagni,Debremarkos, Engbara, Tilili, Gimgabet	LayBirr
10	Tana/15053	Koga/244	Aykel,Bahirdar,Chuahit, Dangla,Debretabor, Ebnat,Gonder,Hamusit,Zege	Bahirdar, Gonder

Table 5.2 Statistical summary of areal rainfall data (1980-2002)

Watershed		January	February	March	April	May	June	July	August	September	October	November	December	Annual
Anger	mean	17.2	24.0	68.90	100.75	156.29	237.76	297.36	285.45	196.31	92.45	33.05	14.93	1524.56
	Stdv	1.58	1.70	3.22	4.09	4.69	5.12	6.10	5.85	5.08	4.60	2.25	1.55	5.15
	Cv	2.96	2.08	1.52	1.27	0.97	0.68	0.66	0.66	0.81	1.61	2.13	3.35	1.29
Beles	mean	2.42	3.82	24.87	36.93	149.40	269.46	370.35	380.45	265.16	172.7	28.45	6.78	1710.87
	Stdv	0.43	0.91	2.35	2.36	5.29	6.29	8.06	7.10	6.12	6.08	2.07	0.83	6.41
	Cv	5.80	7.05	3.06	2.01	1.15	0.73	0.71	0.60	0.72	1.14	2.28	3.96	1.43
Birr	mean	10.8	9.38	39.36	66.59	160.67	292.63	419.00	400.93	287.76	144.1	49.43	19.62	1900.39
	Stdv	0.92	0.70	1.80	2.62	4.14	4.27	5.62	5.19	4.60	4.31	2.14	1.16	5.78
	Cv	2.74	2.20	1.48	1.24	0.84	0.46	0.43	0.42	0.50	0.97	1.36	1.92	1.16
Chacha	mean	13.3	21.9	53.32	64.66	88.21	118.21	323.82	331.06	159.56	47.30	13.16	8.59	1243.25
	Stdv	0.72	1.18	1.84	2.24	2.45	2.77	4.73	4.75	3.68	1.83	1.16	0.66	4.32
	Cv	1.75	1.59	1.12	1.09	0.90	0.74	0.47	0.46	0.72	1.25	2.76	2.51	1.33
Guder	mean	44.5	56.5	89.34	93.12	132.80	182.08	253.89	262.97	185.79	109.3	52.07	40.39	1502.84
	Stdv	1.04	1.57	2.28	2.11	2.50	2.55	3.10	3.19	2.98	2.47	1.05	0.84	3.26
	Cv	0.76	0.82	0.83	0.71	0.61	0.44	0.40	0.39	0.50	0.73	0.64	0.67	0.99
Koga	mean	2.07	2.48	19.48	36.96	103.75	209.67	378.83	351.22	180.55	96.77	17.73	5.66	1405.19
	Stdv	0.35	0.33	1.28	1.81	2.83	3.87	4.87	4.58	3.60	3.41	1.04	0.47	4.92
	Cv	5.53	3.88	2.12	1.53	0.89	0.58	0.42	0.42	0.63	1.14	1.84	2.70	1.34
Muger	mean	80.9	86.6	121.7	105.73	108.03	145.27	264.32	266.43	182.54	127.5	86.83	79.04	1655.00
	Stdv	1.33	1.91	2.32	1.80	1.70	2.89	3.40	3.84	3.44	2.45	1.64	1.67	3.12
	Cv	0.53	0.65	0.62	0.53	0.51	0.62	0.42	0.47	0.59	0.62	0.59	0.68	0.72
Neshi	mean	27.6	36.7	104.8	166.86	267.72	430.30	534.56	532.49	345.29	156.8	47.01	26.92	2677.22
	Stdv	1.51	1.44	2.97	4.18	4.87	5.06	6.00	5.92	5.10	4.29	1.89	1.55	5.13
	Cv	3.23	2.13	1.68	1.44	1.08	0.68	0.67	0.66	0.85	1.62	2.31	3.43	1.34
Sechi	mean	4.02	4.66	32.15	59.25	205.53	274.24	300.41	306.61	264.47	124.2	18.60	4.08	1598.26
	Stdv	0.89	0.54	2.10	2.60	4.57	4.88	4.81	4.81	4.79	3.55	1.19	0.48	5.10
	Cv	7.15	3.43	2.12	1.38	0.72	0.56	0.52	0.51	0.57	0.93	2.01	3.77	1.22
Teme	mean	9.31	12.0	42.10	58.73	92.12	156.98	360.51	336.86	161.66	99.38	26.70	12.86	1369.22
	Stdv	0.73	0.89	2.07	2.56	3.29	4.13	5.02	5.18	3.49	3.98	1.47	1.01	4.79
	Cv	2.54	2.19	1.60	1.37	1.16	0.83	0.45	0.50	0.68	1.30	1.73	2.55	1.33

The above table 5.2 shows the statistical summary of rainfall data from 1980 to 2002 considering monthly mean (mm), standard deviation and coefficient of variance of aerial rainfall data of the selected catchments. From this table we can identify the catchments which have high variation of rainfall data by comparing the values of coefficient of variance (Cv) which is calculated, dividing the standard deviation by the mean of the areal rainfall data. Beles, Neshi, Koga and Chacha catchments have maximum coefficient of variance on the other hand Muger and guder catchments have minimum coefficient variance. Those catchments which have maximum coefficient of variance show that the catchments have high variation of data on the hand catchments which have minimum coefficient of variance show that the data has no high variation of areal rainfall data.

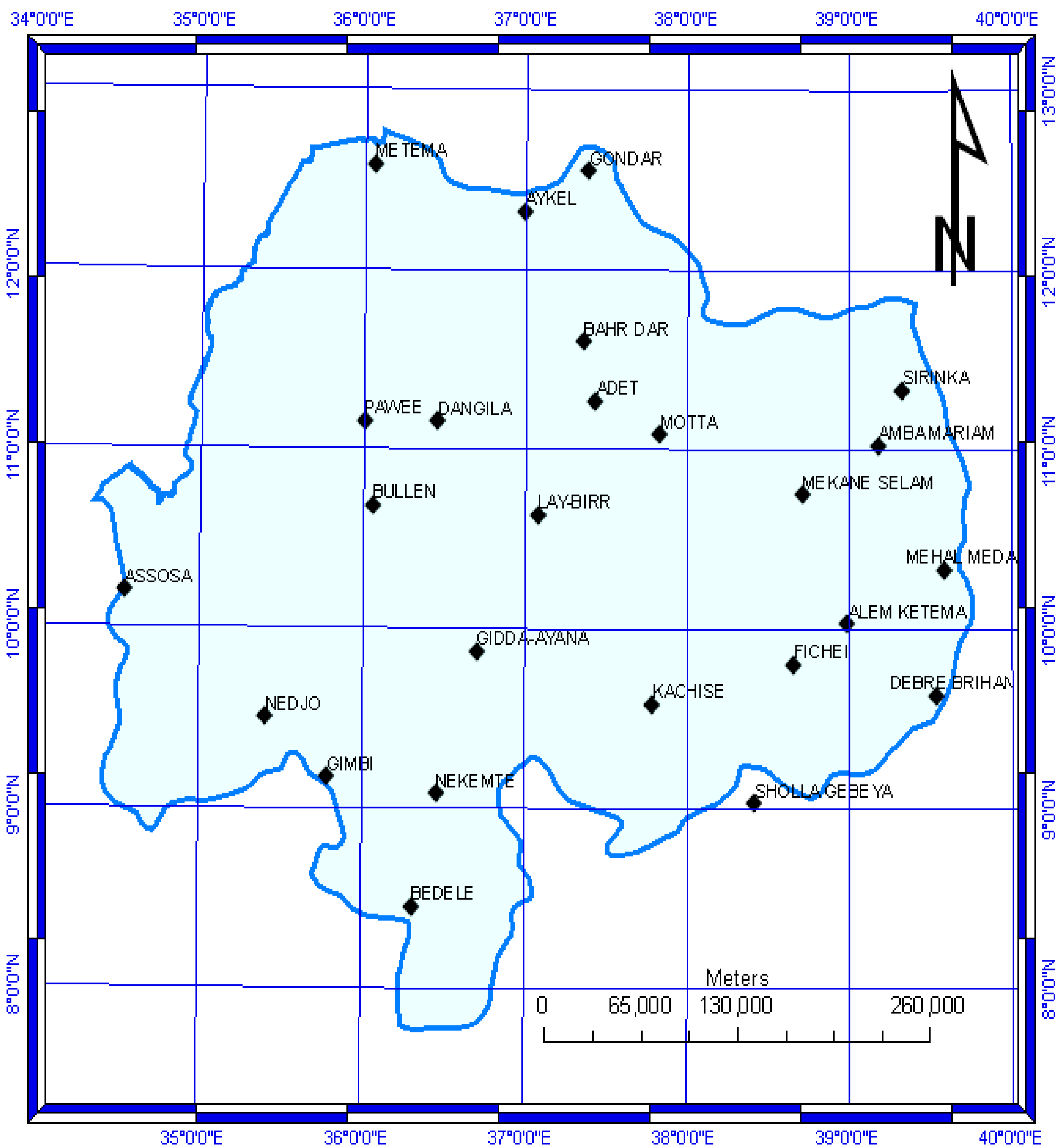


Figure.5.1 Location of rainfall and PET of Study areas

HBV model needs long years of climate data for the simulation of hydrological processes. For this study, the necessary climate data (1980-2002 Daily rainfall) from 40 (forty) stations were collected from the National Meteorological Services Agency (NMSA), Ethiopia.

5.2 Checking Precipitation data quality/Consistency

It is difficult to set out direct analysis to detect possible errors. However through checking consistency of individual stations, the data qualities with regard to possible temporal variations or errors have been investigated by double Mass curve using HBV-96 model. As a result the stations are found to be consistence. Typical graph is shown below in figure5.2 for Debemarkos station

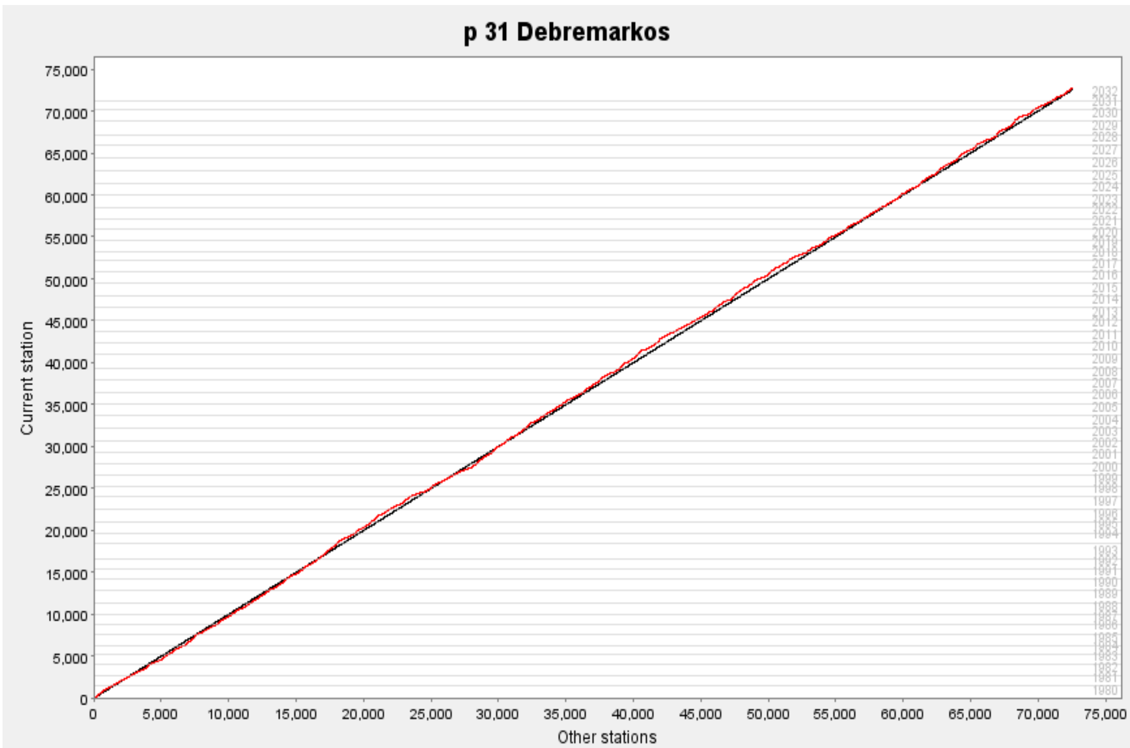


Figure 5.2 Consistency tests of rainfall data (double mass curve) for Debremarkos station

Table 5.3 Statistical summary of runoff data (1980-2002)

Watershed		January	February	March	April	May	June	July	August	September	October	November	December	Annual
Anger	mean	222	150	146.5	141.1	230.6	529.1	1403.8	2073.9	1796.6	1033.	404.9	281.1	8413.8
	Stdv	3.03	2.05	1.75	2.81	8.89	14.32	26.23	26.09	24.40	24.63	7.37	3.65	24.55
	Cv	0.44	0.40	0.39	0.62	1.25	0.85	0.61	0.41	0.43	0.77	0.57	0.42	1.11
Beles	mean	53.5	34.6	35.5	46.0	180.1	709.6	2147.2	2766.5	2676.9	911.2	301.2	93.6	9955.8
	Stdv	1.11	0.79	0.73	2.03	10.25	34.23	88.30	99.96	117.92	46.81	14.92	1.98	49.60
	Cv	0.67	0.68	0.67	1.39	1.85	1.51	1.33	1.17	1.38	1.66	1.55	0.68	1.90
Birr	mean	24.6	7.7	7.6	9.4	43.7	219.0	1541.7	2693.9	1289.3	465.1	134.2	60.8	6497.0
	Stdv	0.73	0.27	0.45	0.55	2.89	8.79	41.32	60.35	34.94	14.82	3.91	1.50	32.79
	Cv	0.96	1.03	1.91	1.83	2.14	1.26	0.87	0.73	0.85	1.03	0.91	0.80	1.93
Chacha	mean	13.3	10.8	15.2	17.4	17.0	11.2	206.3	561.4	175.2	28.1	16.0	15.3	1087.2
	Stdv	0.64	0.55	0.70	0.95	1.31	0.60	10.60	18.47	7.84	1.40	1.00	1.02	6.97
	Cv	1.56	1.51	1.50	1.72	2.49	1.69	1.67	1.07	1.40	1.61	1.95	2.16	2.45
Guder	mean	25.8	19.5	28.6	29.2	52.4	363.6	1097.0	1460.2	1072.0	368.0	74.5	36.0	4626.7
	Stdv	0.34	0.32	0.98	0.85	1.99	11.84	14.76	12.97	13.26	9.74	1.94	0.61	17.40
	Cv	0.42	0.48	1.11	0.92	1.23	1.02	0.44	0.29	0.39	0.86	0.81	0.55	1.44
Koga	mean	43.4	30.2	28.0	24.0	32.7	96.4	293.8	515.0	321.2	188.8	90.4	59.0	1722.9
	Stdv	0.72	0.54	0.37	0.22	0.15	0.29	0.82	3.31	2.78	1.79	1.22	0.92	5.15
	Cv	0.49	0.48	0.39	0.26	0.13	0.09	0.08	0.18	0.24	0.27	0.37	0.44	1.14
Muger	mean	6.3	5.0	5.7	7.9	8.6	26.9	659.6	1595.7	688.0	80.6	15.7	8.9	3108.9
	Stdv	0.06	0.02	0.02	0.03	0.03	0.05	0.19	6.26	1.40	0.13	0.13	0.11	18.00
	Cv	0.32	0.13	0.13	0.12	0.12	0.06	0.01	0.13	0.06	0.05	0.25	0.39	2.21
Neshi	mean	31.8	24.3	25.9	28.3	40.4	97.3	491.9	889.3	663.8	340.3	73.7	37.1	2744.4
	Stdv	1.34	1.37	1.44	1.52	1.93	4.87	11.97	13.26	9.82	9.69	1.95	1.16	10.15
	Cv	1.36	1.67	1.80	1.69	1.55	1.57	0.79	0.48	0.46	0.92	0.83	1.01	1.41
Sechi	mean	90.2	51.2	41.1	41.1	104.1	390.8	800.6	1302.2	1201.0	677.6	251.2	149.8	5100.9
	Stdv	0.79	0.52	0.70	1.36	3.37	9.55	15.31	21.89	17.76	13.85	3.27	1.81	16.79
	Cv	0.28	0.30	0.55	1.04	1.05	0.77	0.62	0.54	0.46	0.66	0.41	0.39	1.26
Teme	mean	5.7	3.3	4.6	7.5	16.8	46.1	320.1	403.7	104.9	62.6	18.8	8.4	1002.5
	Stdv	0.15	0.07	0.16	0.36	0.68	1.64	7.91	9.30	3.74	3.98	0.76	0.21	5.30
	Cv	0.84	0.66	1.12	1.52	1.32	1.11	0.80	0.75	1.12	2.06	1.26	0.80	2.02

From table 5.3 we can see that the statistical summary of runoff data from 1980 to 2002. The runoff data is summarized by monthly and annual mean, standard deviation and coefficient of variance. From this table we can see that Chacha, Muger, Teme, Birr and Beles catchments have high runoff data variation relative to the other catchments data, on the other hand Anger, Koga, Sechi, Neshi and Guder catchments have less runoff data variation compared to the other catchments runoff data.

CHAPTER SIX

RESULT AND DISCUSSIONS

6.1 Statistical Downscaling Results

The RCM output was downscaled using 50km by 50km gird resolution. The downscaled data consists of three time periods (windows) of base period 1991-2000 and two future climate scenario periods that are 2031-2040 and 2091-2100.

For the study period from 1980-2002 year records 1991-2000 baseline period has been selected to match with the downscaled grid data. The RCM output grid data are precipitation and the inputs used to calculate potential Evapotranspiration such as maximum and minimum temperature, wind speed, relative humidity, sunshine hour which are the inputs that used to drive the HBV model.

The outputs of the RCM model have been further downscaled into station data by statistical model (SDSM 4.2.2 version model). For this particular study among the total period length of 1991-2000, 10 years of daily data is used for model calibration.

Generally, model calibration involves determination of model parameters that gives the best possible correspondence between station data and generated data from a given station. The parameters are variance inflation and bias correction.

Calibration was done manually based on this; several runs were made to select the most optimum parameter by reducing or increasing the parameter values. The result of each run was evaluated by visually inspecting and comparing the variance, sum, mean, maximum, minimum of base period station data and generated grid data graphs of a given station. The graph of variance of Nekemte and the sum graph of Tilili are shown below in the figure 6.1 and figure 6.2.

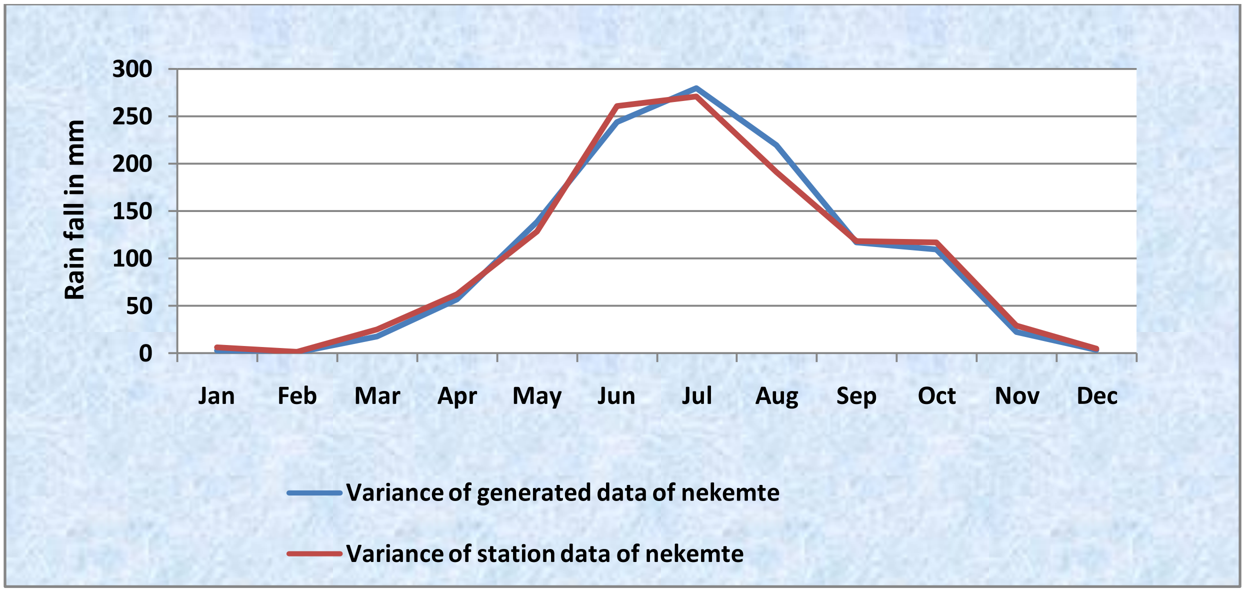


Figure 6.1 Variance of monthly rainfall station data and generated data of Nekemte using variance inflation 12 and bias correction 0.95 parameter value

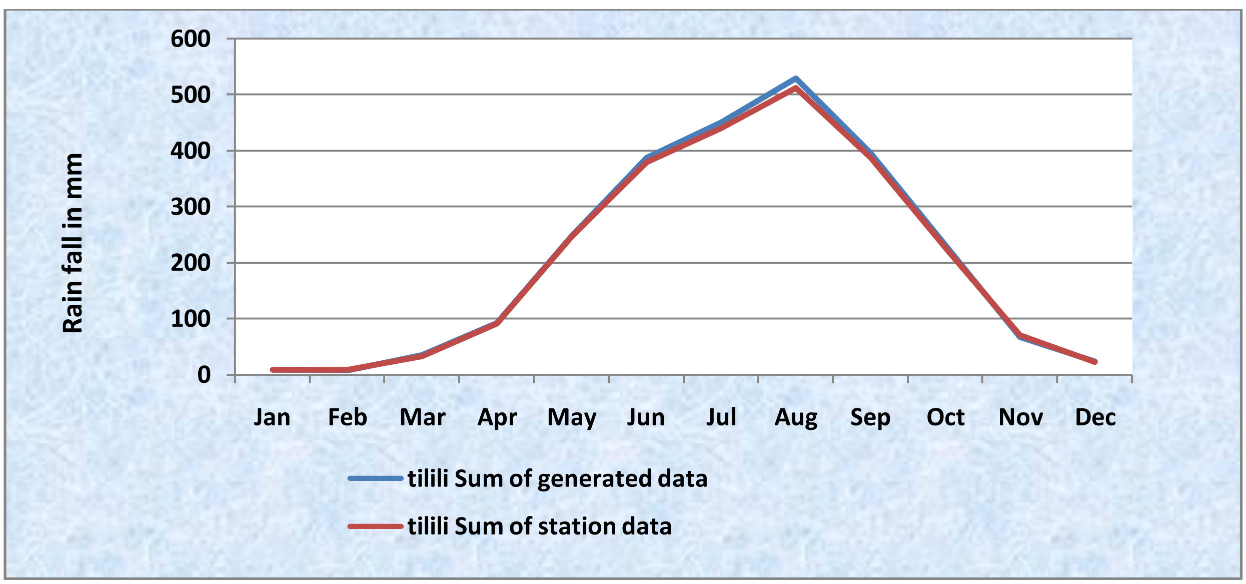


Figure 6.2 Sum of monthly rainfall of station data and grid data of Tilili using variance inflation 12 and bias correction 1.05 parameter values

6.1.1 Statistical Downscaling Results for base period

I. Potential Evapotranspiration

The result of long term monthly average potential Evapotranspiration of the observed data and the outputs of RCM within the base period shows good agreement.

The potential Evapotranspiration at base period have correlation coefficient of maximum 0.98 and minimum 0.90 with observed data and shown in the table 6.1.

Table 6.1 Correlation between observed and downscaled (baseline period) of long term monthly average potential Evapotranspiration

water shade	Anger	Beles	Guder	Neshi	Koga	Sechi	Teme	Muger	Birr	Chacha
correlation	0.98	0.98	0.98	0.98	0.96	0.96	0.94	0.92	0.90	0.90

The potential Evapotranspiration at base period for Neshi watershed has correlation coefficient of 0.98 with observed data, as we can observe from the sample figure below there is no under and over estimation between observed and downscaled data for the base period 1991-2000.

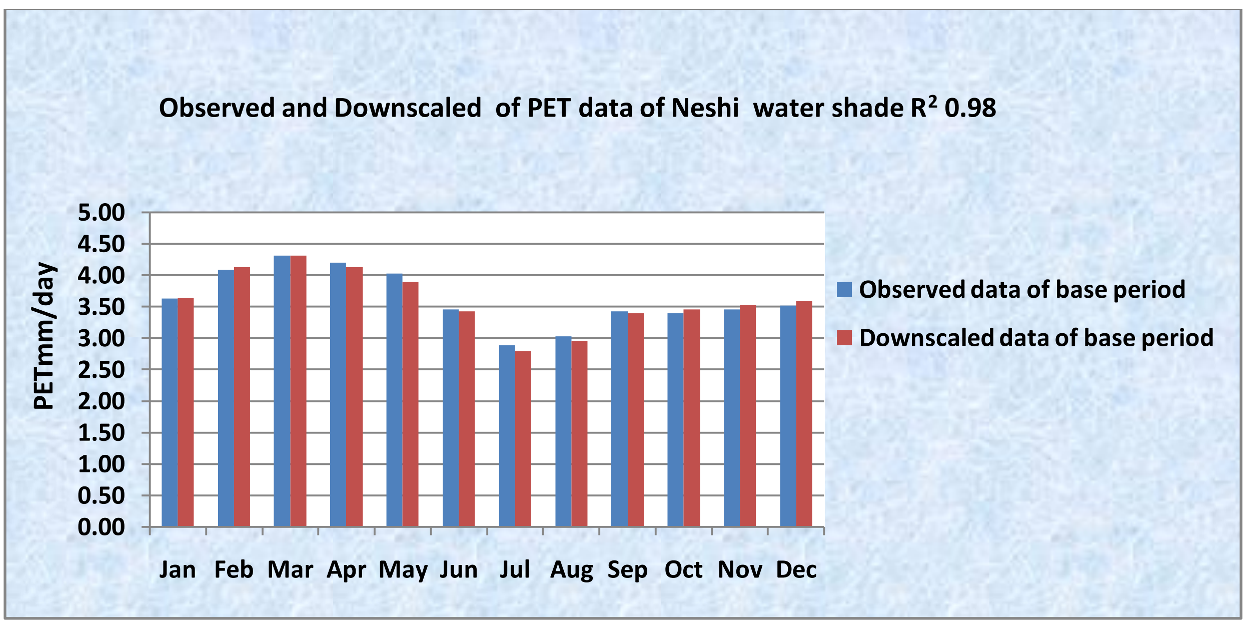


Figure 6.3 Daily average monthly observed and RCM potential Evapotranspiration at base period of Neshi watershed

II. Precipitation

Relative to the potential Evapotranspiration the precipitation could not able to replicate the historical (observed) data. This is due to complicated nature of precipitation processes and its distribution in space and time. But the monthly average downscaled precipitation and the frequency of events is almost similar behavior as the observed precipitation.

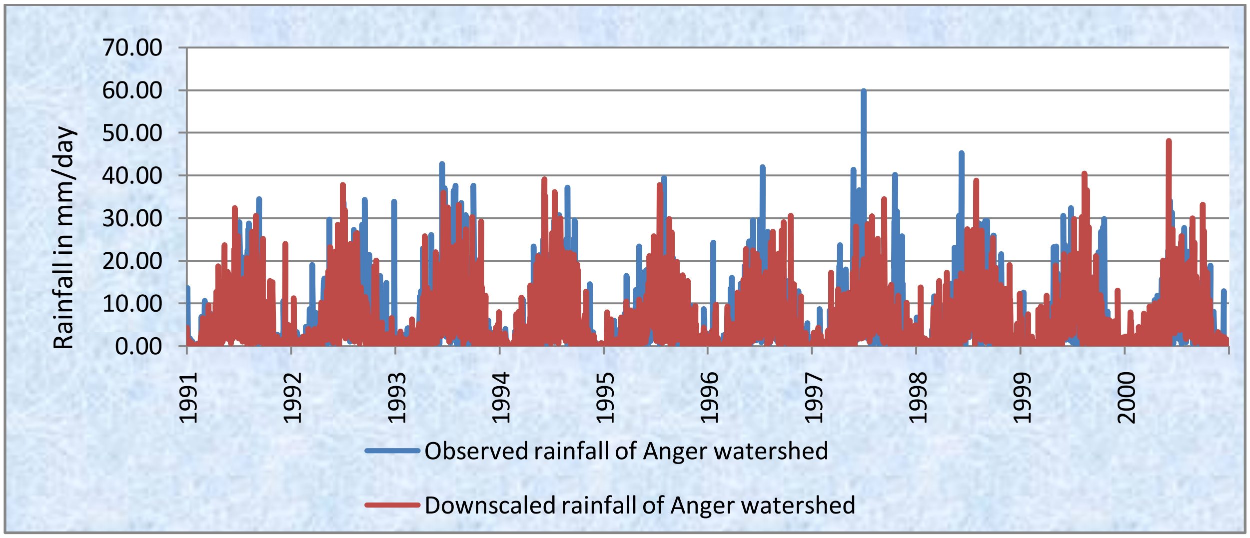


Figure 6.4 Daily rainfall of Observed and downscaled of Anger watershed for base period (1991-2000)

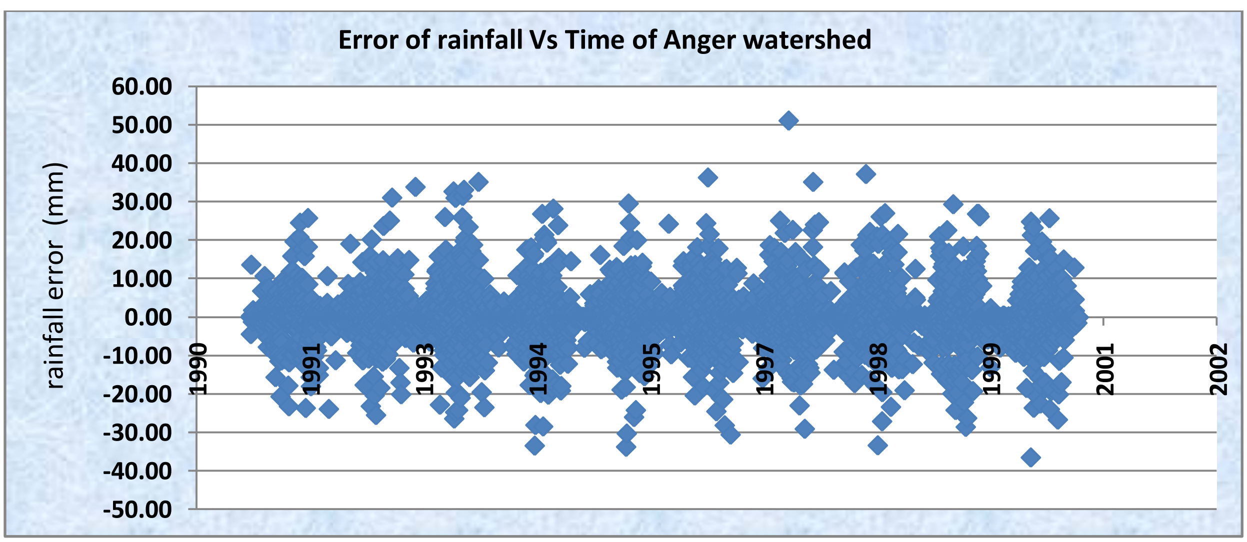


Figure 6.5 Error diagram of observed and downscaled rainfall for Anger watershed 1991-2000

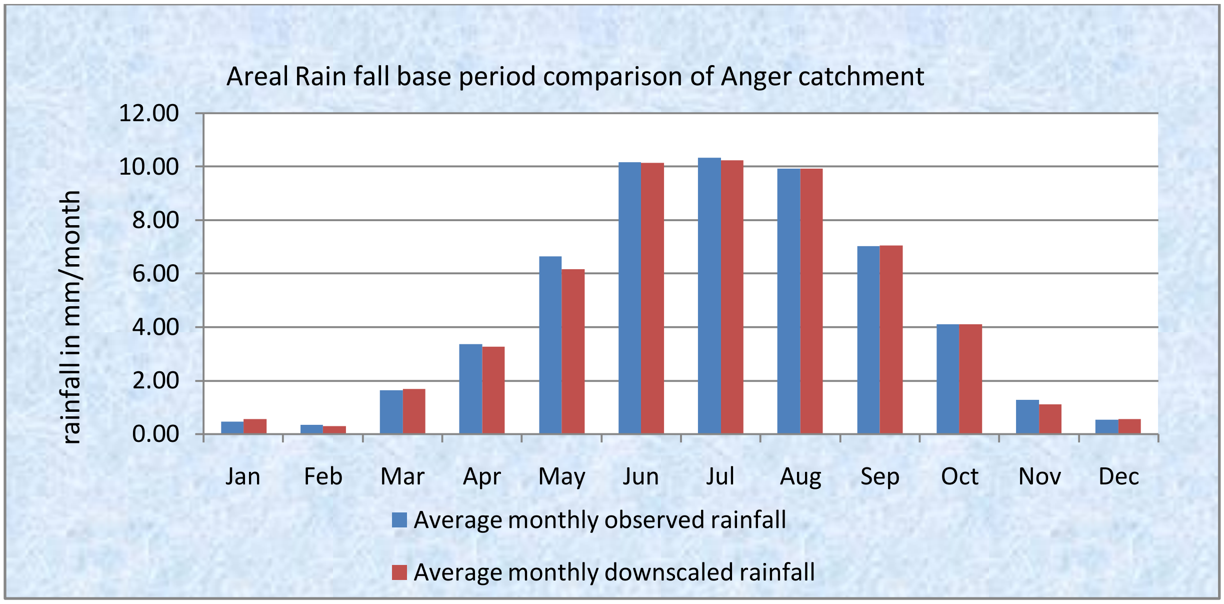


Figure 6.6 Downscaled and observed mean monthly rainfall of Anger watershed

The monthly average weighted rainfall at base period have correlation coefficient of maximum 0.99 and minimum 0.97 with observed data and shown in the table 6.2.

Table 6.2 Correlation between observed downscaled (baseline period) of monthly average weighted rainfall

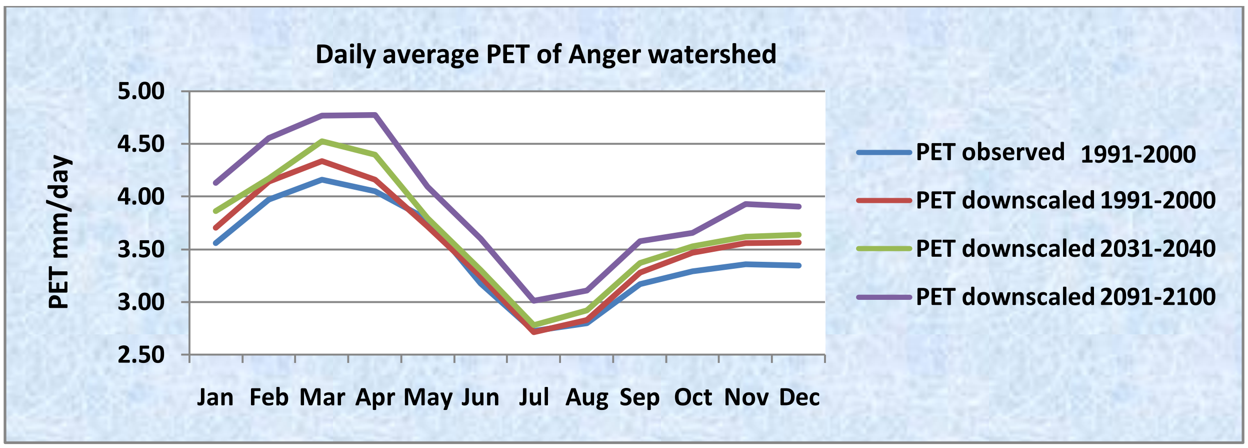
water shade	Anger	Chacha	Neshi	sechi	Guder	Muger	Birr	beles	Koga	Teme
correlation	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97	0.97

6.2. Projected future climate variables (Scenario generation)

The future scenarios were developed by dividing the future time series into two periods of 10 years: 2031-2040, 2091-2100. The period from 1991-2000 (or here called as "base period") was taken as a base period with which the comparison was made.

I. potential Evapotranspiration

The future scenario generated potential Evapotranspiration shows an increasing trend in the future time series for the two periods from 2031-2040 and 2091-2100 comparing with the base period: 1991-2000. From the figure shown below we can see that the potential Evapotranspiration that is generated for the second time series: 2091-2100 is higher than the first time series: 2031-2040, this strengthen the idea that has been mentioned above.



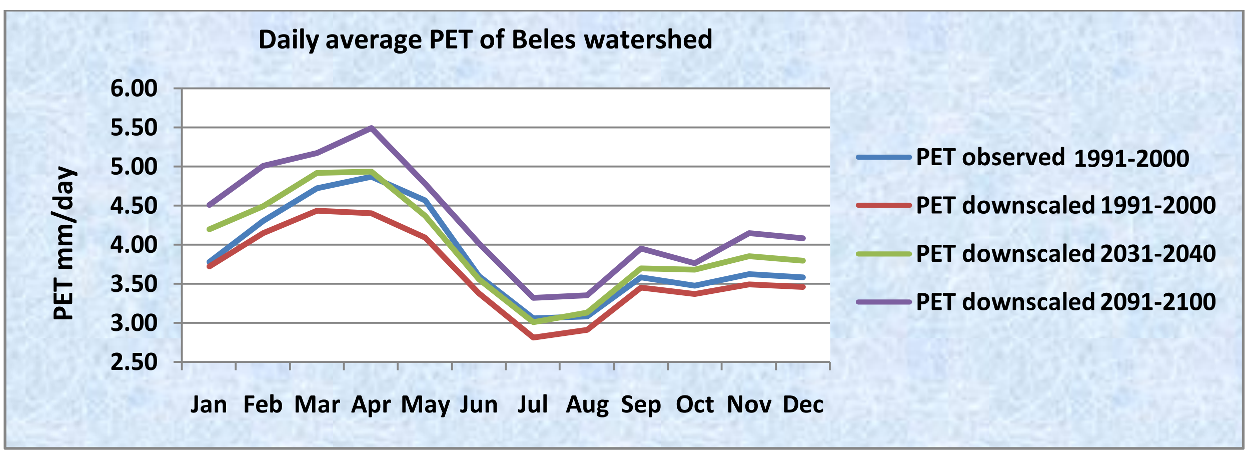


Figure 6.7 base periods and future time series of monthly average potential Evapotranspiration of Anger and Beles watersheds.

Table 6.3 Percentage of change of seasonal PET with respect to base period PET

			From 2031-2040	From 2091-2100
S.No	Water shade	Season	% change	% change
1	Anger	FMAM	3.56	11.51
		JJAS	2.54	10.22
		ONDJ	2.48	9.32
		Annual	2.78	7.32
2	Beles	FMAM	10.52	20.69
		JJAS	6.67	16.68
		ONDJ	10.66	17.50
		Annual	9.11	18.16
3	Birr	FMAM	3.21	15.30
		JJAS	2.95	12.27
		ONDJ	4.24	11.69
		Annual	3.37	12.92
4	Chacha	FMAM	4.69	18.98
		JJAS	3.71	14.05
		ONDJ	5.15	12.43
		Annual	4.52	15.03
5	Guder	FMAM	3.05	11.70
		JJAS	2.86	10.70
		ONDJ	3.40	10.05
		Annual	3.05	10.72
6	Koga	FMAM	3.16	13.59
		JJAS	2.76	12.39
		ONDJ	3.52	10.39
		Annual	3.00	12.06
7	Muger	FMAM	3.55	14.63
		JJAS	3.25	11.72
		ONDJ	4.49	11.09
		Annual	3.69	12.35
8	Neshi	FMAM	3.54	11.64
		JJAS	2.67	10.60
		ONDJ	2.59	9.63
		Annual	2.86	10.57
9	Sechi	FMAM	6.28	24.04
		JJAS	3.64	16.86
		ONDJ	6.86	17.32
		Annual	5.56	13.11
10	Teme	FMAM	3.07	13.92
		JJAS	2.85	11.79
		ONDJ	3.26	10.47
		Annual	2.97	11.90

Table 6.3 shows the change of potential Evapotranspiration in both future time series in percent of change with respect to the base period. As we see from the table all results show increment of potential Evapotranspiration in both future time series in all watersheds of upper Blue Nile. For the first time series: 2031-2040 in all watersheds higher increment is observed on ONDJ (Beles 10.66% and Sechi 6.86%) but for Anger (3.56%) and Neshi (3.54%) higher increments are observed on FMAM, for the next time series: 2091-2100 higher increments are observed on FMAM in all watersheds (specially Beles 20.69% and Sechi 24.04%) and lower increment is observed on JJAS in all water shades for both time series.

When we see the annual change in percent it has range from 2.78% at Anger and 9.11% at Beles for the first time series (2031-2040), for the second time series (2091-2100) the annual percent change has range between 7.32% (for Anger) and 18.16% (for Beles) watersheds.

II. Precipitation

According to the precipitation scenarios generated, change of precipitation in percent for the first future time series: 2031-2040 with respect to the base period shows, the seasonal change of precipitation increase in most of the water shades on ONDJ (7.41% at Sechi) and higher reduction(-6.51% at Muger) is also observed in the same season ONDJ, but higher increment value is observed for Chacha (7.71%) and Neshi (1.83%) watersheds on FMAM and higher reduction(-4.10%) is observed on FMAM for Beles watershed in the same future time series (2031-2040).

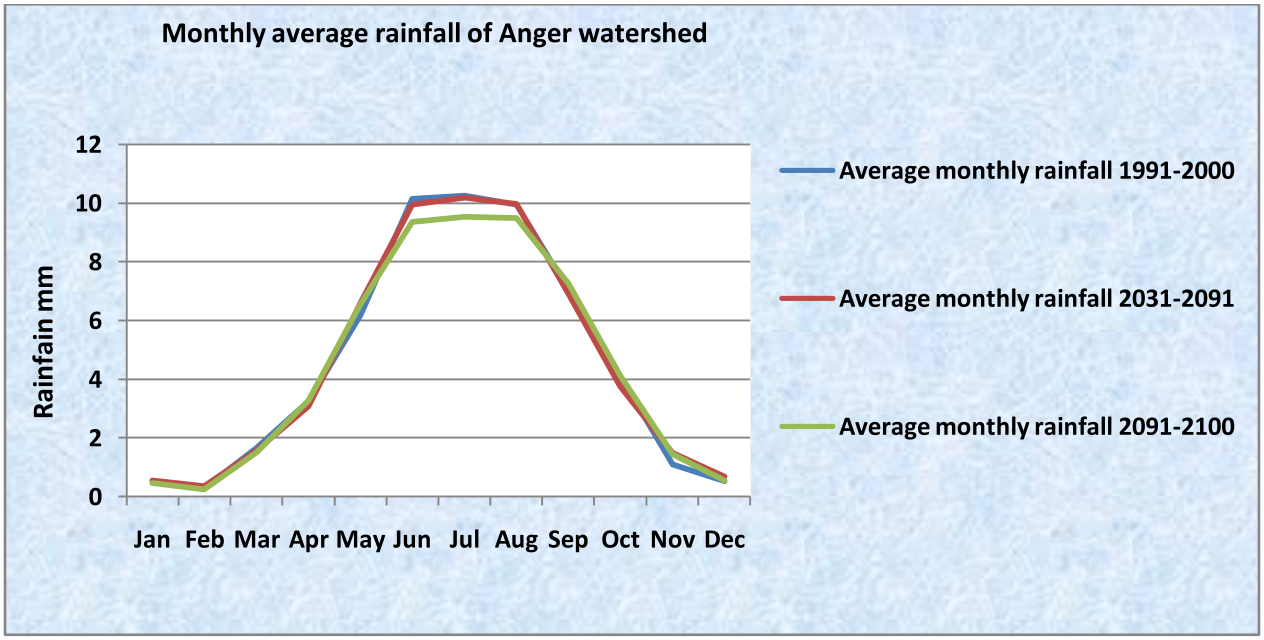
For the second future time series: 2091-2100 the change of percentage of precipitation with respect to the base period, in most of the watersheds higher increment (57.64% at Chacha and 22.47% at Seshi) are observed the same with the first future time series observed season (on ONDJ), and maximum reduction is observed in all catchments on JJAS season except Beles (-8.11%) and Koga (-3.20%) which have maximum reduction on FMAM.

The annual rain fall in most of the watersheds show some reduction in the range between 0 to -3.36% (Beles) and increment between 0 to +2.95% (Anger). Since ONDJ is dry season, even if the percent change increase in rainfall seems great, the seasonal increase in depth of rain fall is small compared to the reduction in depth on wet seasons.

Table 6.4 Percentage of change of seasonal precipitation with respect to base period precipitation

			From 2031-2040	From 2091-2100
S.No	Water shade	Season	% change	% change
1	Anger	FMAM	1.56	1.71
		JJAS	-0.93	-4.53
		ONDJ	2.35	4.15
		Annual	-0.04	-2.24
2	Beles	FMAM	-4.10	-8.11
		JJAS	-3.88	0.74
		ONDJ	-0.23	13.92
		Annual	-3.36	0.89
3	Birr	FMAM	1.26	0.17
		JJAS	-1.38	0.47
		ONDJ	2.48	12.40
		Annual	-0.47	2.02
4	Chacha	FMAM	7.71	5.11
		JJAS	-0.65	-1.63
		ONDJ	5.07	57.64
		Annual	1.10	2.95
5	Guder	FMAM	2.68	0.79
		JJAS	1.48	-1.06
		ONDJ	-3.18	1.74
		Annual	0.83	-0.06
6	Koga	FMAM	-0.96	-3.20
		JJAS	-1.06	2.50
		ONDJ	-3.36	8.57
		Annual	-1.29	2.44
7	Muger	FMAM	2.52	0.81
		JJAS	0.24	-3.86
		ONDJ	-6.51	2.42
		Annual	-0.86	-1.18
8	Neshi	FMAM	1.83	2.58
		JJAS	0.09	-2.68
		ONDJ	-0.08	4.01
		Annual	0.00	-0.01
9	Sechi	FMAM	3.93	4.94
		JJAS	-0.62	-0.24
		ONDJ	7.42	22.47
		Annual	1.04	2.87
10	Teme	FMAM	-0.24	-1.66
		JJAS	0.00	-1.94
		ONDJ	1.89	9.15
		Annual	0.20	-0.47

In most of the watersheds the monthly average rainfall in the two future time series:2031-2040 and:2091-2100 maximum variation of rainfall is observed on May, June, July, August months comparing with the base period:1991-2000 as shown below in the Figure 6.8



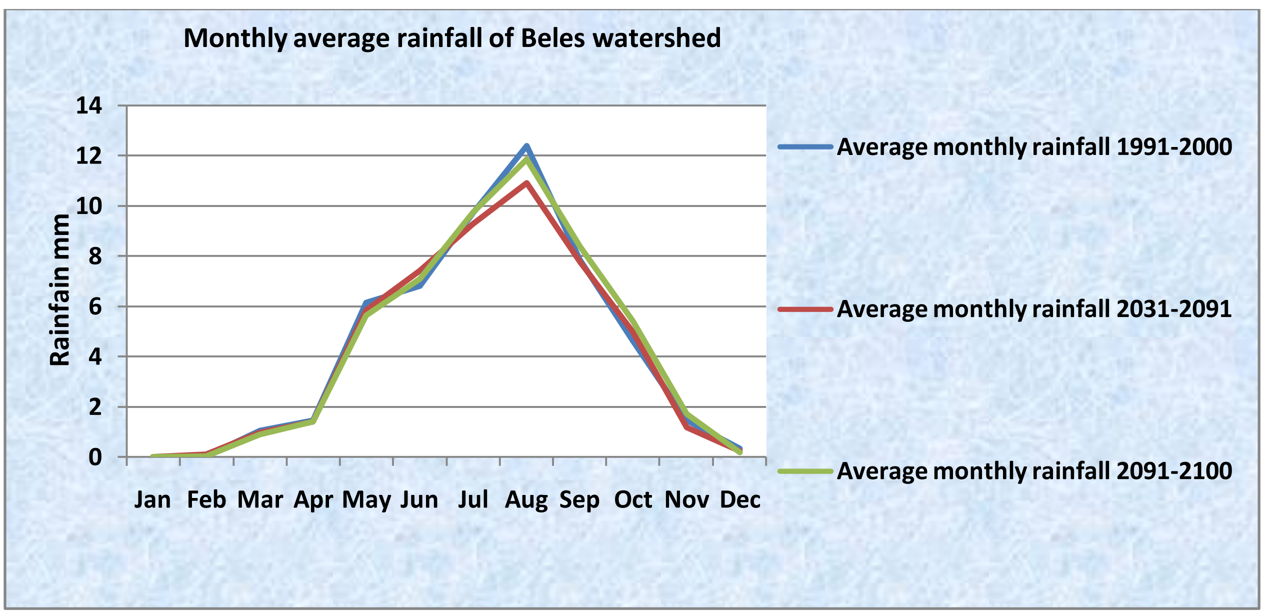


Figure 6.8 Monthly average rainfalls for base period and future time series for Anger and Beles watersheds

6.3 Calibration and Verification of the Hydrological model

HBV model parameters have to be estimated through calibration. Generally, model calibration involves determination of model parameters that gives the best possible correspondence between observed and simulated discharge from a catchment. Calibration was done manually by optimizing the model parameters in each subroutine that have significant effect on the performance of the model. Based on this, several runs were made to select the most optimum parameter set in order to match the observed discharge with simulate discharge. The result of each run was evaluated in different ways including:

1. Visually inspecting and comparing the calculated and observed hydrograph

2. Nash and Sutcliffe efficiency criteria

3. By calculating the index of Volumetric (IVF)

The following table shows recommended values of selected parameters for new sub-basin to be calibrated and the most optimum parameter set used in the calibration.

Table 6.5 Optimum parameter during calibration

S.No	Catchment	Parameter								
		Alfa	Beta	FC (mm)	K4	Khq	Lp	Maxbas (day)	Perc (mm/day)	Rfcf
1	Anger	2	2	500	0.012	0.01	0.8	2	0.5	1.5
2	Beles	0.5	1	550	0.21	0.09	0.3	1	0.9	1.07
3	Sechi	1.1	1	450	0.03	0.034	0.6	1	0.1	1
4	Neshi	1	3	220	0.013	0.032	0.9	2	0.5	1.01
5	Guder	0.5	4	250	0.01	0.1	0.04	1	0.2	1.29
6	Chacha	0.5	1	600	0.001	0.25	0.4	1	0.5	0.8
7	Muger	0.5	5	200	0.04	0.13	0.6	1	0.1	1.15
8	Teme	1.1	1	250	0.01	0.1	0.3	1	0.01	1
9	Birr	0.5	2	300	0.0001	0.15	0.75	2	2	0.8
10	Koga	0.5	1	650	0.008	0.08	0.5	1	1.1	0.9

Table 6.6 Summarized objective function during calibration, validation and simulation process

Catchment name	Area	Calibration		Verification	
		Explained variance (R^2)	IVF	**Explained variance** (R^2)	IVF
Anger	374.2	0.72	0.97	0.61	1.21
Beles	675	0.65	0.96	0.63	1.0
Sechi	562	0.65	1.05	0.56	0.99
Neshi	322	0.62	1.01	0.60	1.09
Guder	524	0.81	0.94	0.75	1.05
Chacha	418	0.61	0.85	0.61	0.80
Muger	489	0.63	0.91	0.61	0.80
Teme	156.3	0.63	0.89	0.57	0.93
Birr	978	0.60	0.88	0.54	1.19
Koga	244	0.70	0.90	0.60	1.17

Generally, the values of the performance criteria show that during the calibration period overall performance of HBV model (e.g. $0.60 < R^2 < 0.81$) is somewhat better compared to the validation period (e.g. $0.56 < R^2 < 0.75$). For the detail observation of the model performance (R^2 and IVF) value for each watersheds are presented in the table 6.6.

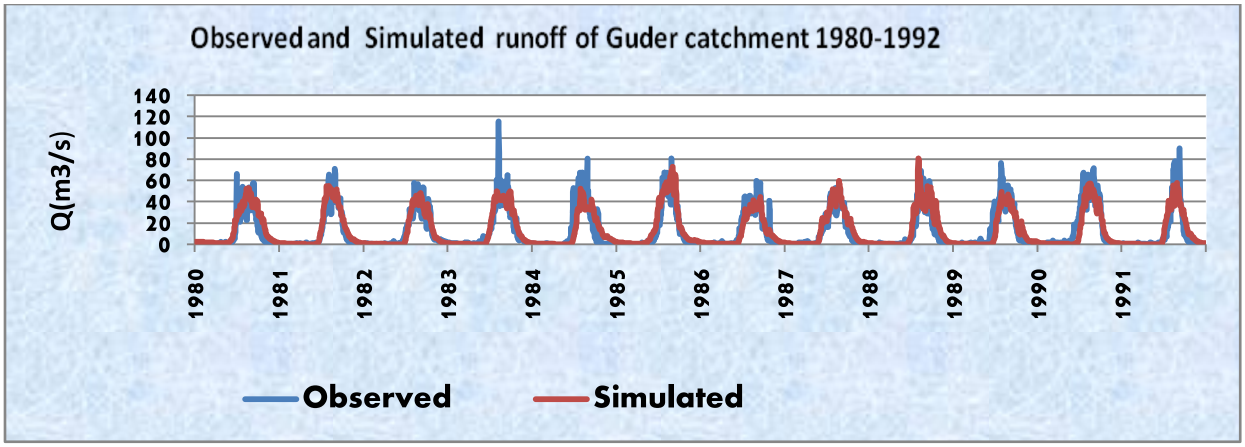


Figure 6.9 Observed and simulated runoff for Guder watershed 1980-1992

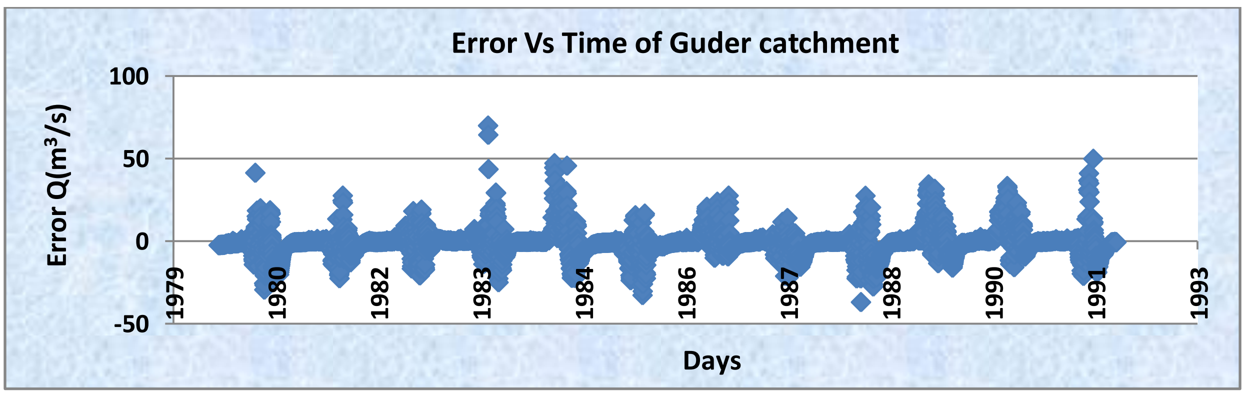


Figure 6.10 Error diagrams for Guder watershed 1980-1992

For illustration, the observed and simulated hydrograph of Guder watershed from 1980-1992 using the above optimum parameter is shown in Figure 6.9 Visually inspection of the observed and simulated hydrograph shows that the performance of the model in simulating the base flow, rising and recession limb of the hydrograph is good, but it overestimates the peaks. However, the overall flow trend is well simulated by the model.

6.4 Impact of Climate Change on water resource availability

After calibrating the hydrological models with the historical record, the next step is the simulation of river flows in the catchment by using precipitation and Evapotranspiration as input to hydrological models. Subsequently the hydrological model was used to identify possible trends in the simulated river flow. Based on this, hydrological impact of the upper Blue Nile is analyzed using HBV-96 hydrological model using the data that has two future time series from: 2031-2040 and: 2091-2100 for all RCM's.

The two inputs of HBV-96 model that are precipitation and potential Evapotranspiration was obtained from the RCM's grid data, but potential Evapotranspiration was calculated using FAO Penman-Monteith method taking the output RCM's data that are inputs used to calculate potential Evapotranspiration, such as maximum and minimum temperature, wind speed, sun shine hour, humidity and all data are changed from grid data in to station data to use directly as an input for the model. Out changing the parameters of the model and assuming that land uses are unchanging the model simulates the base period and future runoff.

The output obtained from the model is helpful to identify the possible trained of the simulated river flow. From Fig 6.11we can see the RCM (downscaled) output flow for base period tries to capture the daily observed flow except for some extreme flows, but the average monthly RCM (downscaled) output flow and the frequency of events is almost similar behavior as the observed flow as shown in Figure 6.12.

*(All **RCM output** or **down scaled** data mean that the data that are generated using statistical down scaling of the RCM output).

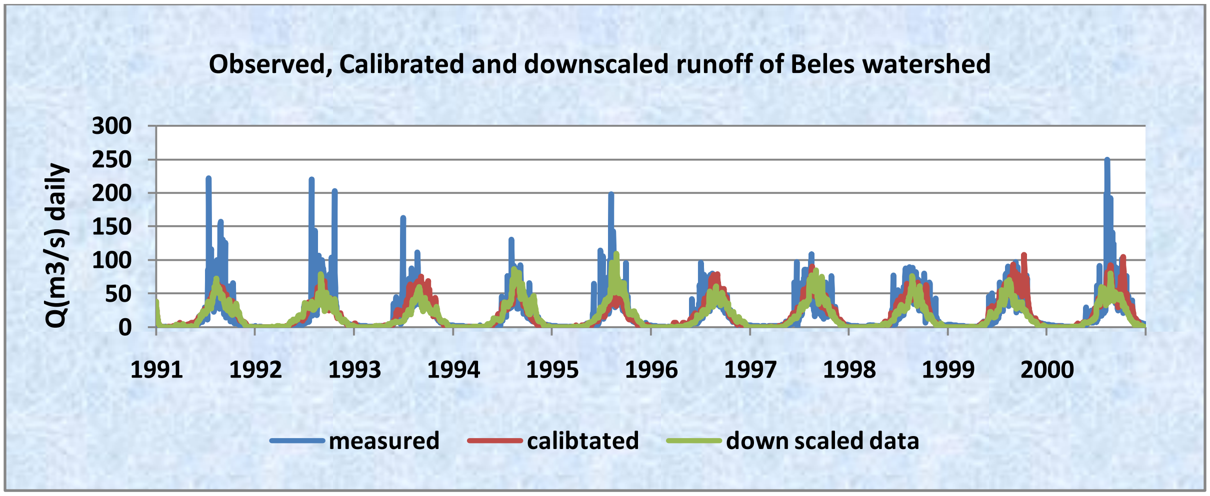


Figure 6.11 Observed runoff, Calibrated runoff and Runoff from downscaled areal rain fall

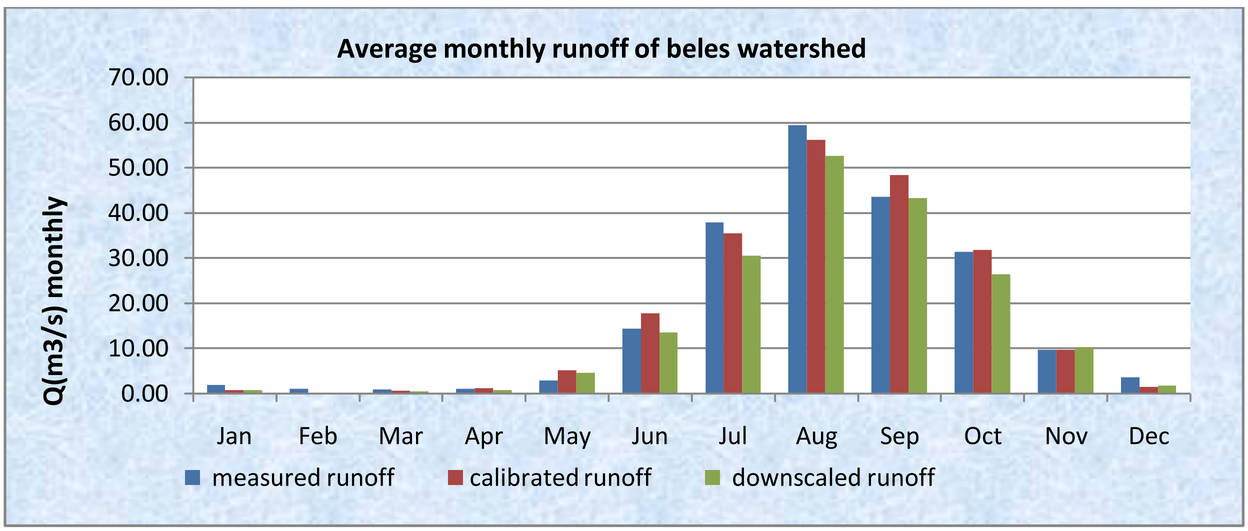
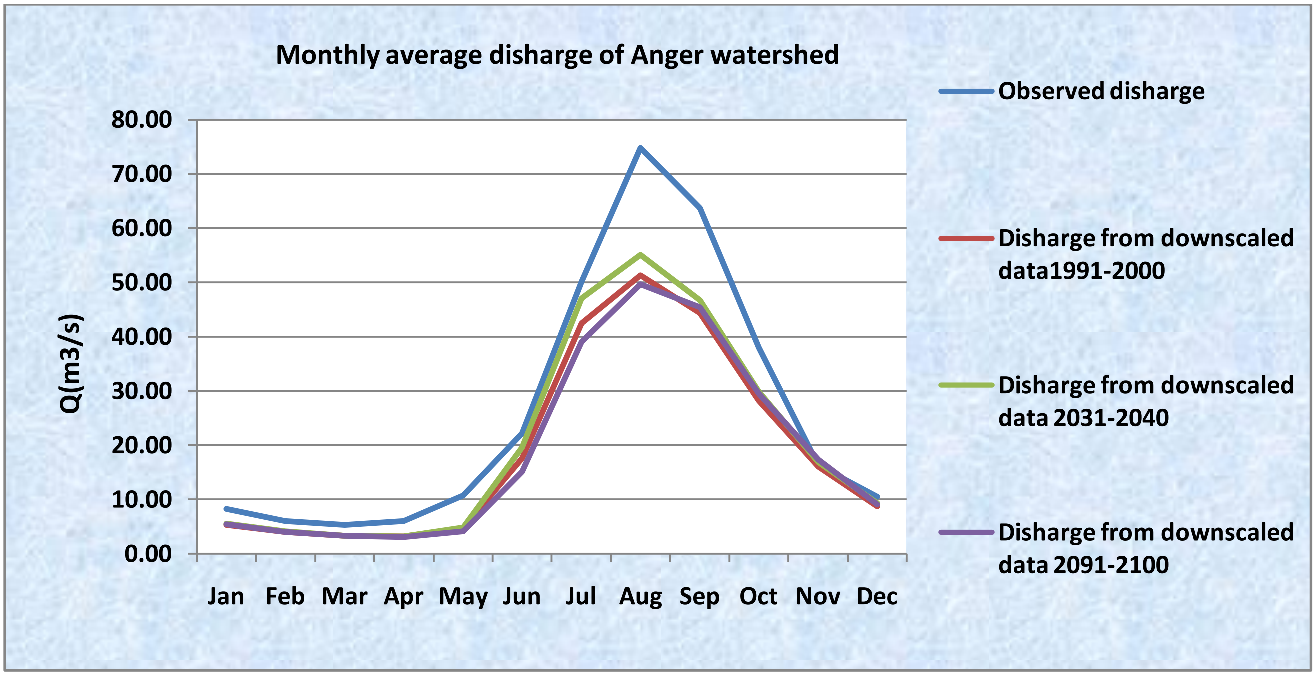


Figure 6.12 Average monthly observed runoff, Calibrated runoff and Runoff from downscaled rain fall

The future scenario generated runoff for most of the watersheds shows a decreasing trend in the future time series for the two periods from 2031-2040 and 2091-2100 comparing with the base period: 1991-2000, but some of the catchments show in wet season the future time series: 2031-2040 has an increasing trend comparing with the base period. From the figure 6.13 shown below we can see that the average monthly runoff that is generated for both time series has no significant change in dry season rather than wet season.



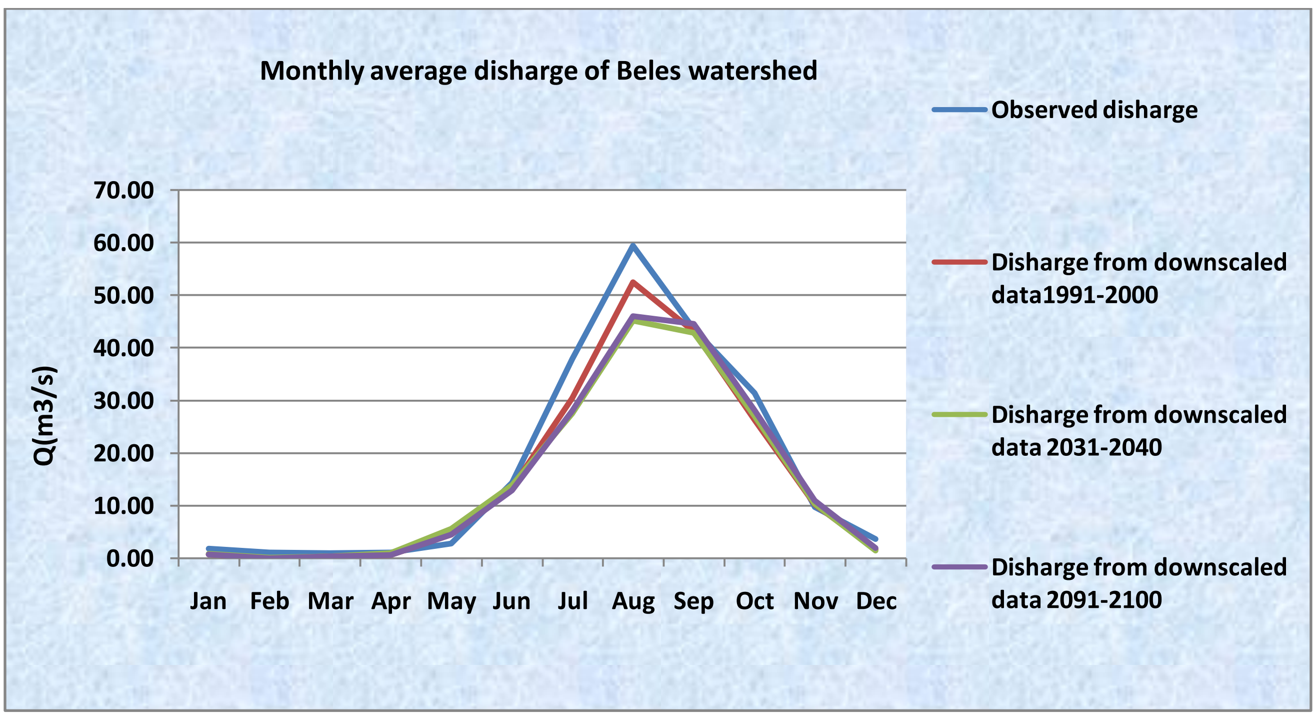


Figure 6.13 Average monthly observed discharge, average monthly discharge: 1991-2000, average monthly Discharge: 2031-2040 and average monthly discharge: 2091-2100 of Anger and Beles watersheds

6.4.1Seasonal and annual impacts on future flow

As we see from Table 6.7 below which shows the change of runoff in percent for the two future time series: 2031-2040 and: 2091-2100 with respect to the base period. The simulated flow at: 2031-2040 with scenario from RCM shows reduction and increment of runoff in the water shades and it is directly related to the reduction and increment in precipitation, but in some water shades there is reduction of rainfall and increment in potential Evapotranspiration in a season, these factors are anticipated to decrease the runoff on that season, however there is increment of runoff.

For the next future time series: 2091-2100 even if the percentage change of precipitation with respect to the base period for this future time series has the same value with the first future time series: 2031-2040, high reduction flow is anticipated for the time period of: 2091-2100, because there is high increment of potential Evapotranspiration in this future period rather than the first future time series (2031-2040), which has a great factor for the simulated flow. Maximum percent of increment of runoff (22.45% at Beles) and maximum reduction (-25.54% at Muger) is observed on the same season FMAM for the first future time series.

From Table 6.6 we can see that all watersheds have reduced value of runoff in percentage in the second future time series (2091-2100) in all season except Teme (2.94%), Beles (7.05%), Koga (7.92%), Birr (17.10%) and Anger (5.55%) watersheds which show increment only on ONDJ season. Even if the increase in percent change of precipitation on ONDJ seems high, the depth of rainfall is much smaller than the depth of potential Evapotranspiration and it is incapable of creating runoff.

The seasons like JJAS, FMAM show high reduction in runoff in both future time series (2031-2040 and2091-2100) in most of the watersheds. The annual flow shows maximum reduction of -18.16% at Muger watershed and maximum increment +7.25% at Anger watershed.

Table 6.7 Percentage of change of seasonal Runoff with respect to base period Runoff

			From 2031-2040	From 2091-2100
S.No	Watershed	Season	% change	% change
1	Anger	FMAM	2.26	-4.84
		JJAS	8.22	-4.10
		ONDJ	5.97	5.55
		Annual	7.25	-1.68
2	Beles	FMAM	22.45	-3.87
		JJAS	-7.37	-5.95
		ONDJ	1.98	7.05
		Annual	-1.68	-3.12
3	Birr	FMAM	0.90	-0.29
		JJAS	-3.92	-11.59
		ONDJ	6.19	17.10
		Annual	-2.33	-7.22
4	Chacha	FMAM	-2.11	-5.46
		JJAS	-2.07	-8.16
		ONDJ	-0.07	-7.00
		Annual	-1.83	-7.78
5	Guder	FMAM	-13.47	-16.37
		JJAS	-0.62	-13.77
		ONDJ	0.01	-10.71
		Annual	-0.73	-13.11
6	Koga	FMAM	2.63	1.20
		JJAS	-2.38	-1.10
		ONDJ	3.14	7.92
		Annual	-0.59	1.34
7	Muger	FMAM	-25.54	-44.16
		JJAS	-1.43	-16.66
		ONDJ	-7.52	-17.14
		Annual	-3.92	-18.16
8	Neshi	FMAM	1.13	-2.47
		JJAS	2.69	-7.89
		ONDJ	4.77	-5.03
		Annual	3.10	-6.98
9	Sechi	FMAM	-10.37	-12.88
		JJAS	0.98	-1.70
		ONDJ	-0.03	-5.42
		Annual	0.18	-3.11
10	Teme	FMAM	-2.27	-13.28
		JJAS	3.29	-7.33
		ONDJ	8.89	2.94
		Annual	3.86	-6.15

Table 6.8 Percentage of change of rainy month's runoff with respect to base period runoff

			From 2031-2040	From 2091-2100
S.No	Watershed	Month	% change	% change
1	Anger	June July August September	11.95 10.89 7.28 5.23	-13.69 -7.90 -3.19 2.37
2	Beles	June July August September	2.60 -9.43 -13.90 -0.77	-3.89 -8.05 -12.48 3.14
3	Birr	June July August September	-12.00 5.43 -4.87 -9.25	-23.60 -10.16 -12.93 -9.20
4	Chacha	June July August September	-6.08 -2.55 -2.56 0.00	-14.73 -11.68 -7.23 -5.36
5	Guder	June July August September	-28.37 -7.23 4.31 1.01	-53.42 -27.38 -7.75 -6.86
6	Koga	June July August September	-7.60 -3.14 -2.70 -0.39	-16.42 -9.53 2.28 3.72
7	Muger	June July August September	-23.85 -10.85 0.20 8.88	-55.14 -30.20 -11.34 -5.67
8	Neshi	June July August September	8.25 -3.87 2.72 7.49	-5.86 -9.37 -11.10 -3.16
9	Sechi	June July August September	-8.74 0.36 3.15 4.55	-2.58 -2.34 -4.16 2.10
10	Teme	June July August September	17.94 3.80 3.06 -0.62	-8.11 -7.58 -7.44 -6.64

Table 6.9 Percentage change of maximum flow in daily time scale

watershed	Daily maximum value			Percentage change	
	From 1991-2000	From 2031-2040	From 2091-2100	From 2031-2040	From 2091-2100
Anger	76.11	83.06	68.48	9.13	-10.02
Beles	109.24	87.55	105.42	-19.86	-3.50
Birr	72.86	71.91	68.85	-1.30	-5.50
Chacha	26.34	23.61	23.51	-10.36	-10.74
Guder	56.64	58.73	53.47	3.69	-5.60
Koga	18.54	18.12	19.18	-2.27	3.45
Muger	59.92	58.29	60.00	-2.72	0.13
Neshi	30.47	35.43	28.35	16.28	-6.96
Sechi	56.58	64.57	70.68	14.12	24.92
Teme	21.83	24.6	18.6	12.69	-14.80

The percentage change of maximum daily flow in table 6.9 shows that for the first future time series (2031-2040) the maximum daily flow increases in some catchments expressly in Neshi, Sechi and Teme catchments which have more than 10% change with respect to the base period flow (1991-2000), and some catchments show decrement mainly at Beles and Chacha catchments which have reduction more than 10%. Neshi catchment shows the highest increment (16.28%) and Beles catchment shows the highest reduction (-19.86%) for the first future time series with respect to the base period maximum daily flow.

For the second future time series (2091-2100) the percentage change of maximum daily flow shows that in most of the catchments there is reduction except Koga (3.45%), Muger (0.13%) and Sechi (24.92%) catchments which show increment in percentage with respect to the base period. Sechi (24.29%) and Teme (-14.80%) catchments show maximum increment and reduction respectively for the second time series. Sechi catchment shows increment whereas Beles, Birr and Chacha catchments show decrement for both future time series.

6.5 Simple estimates of climate change impact on mean annual runoff

Hydrologic sensitivity to climate

The sensitivity is either negatively or positively change rate of water resource (water resource availability) to a change of climate variable. Most climate change impact studies involve the use of a hydrological model, the modeling approach generally provides a reliable estimate of the hydrologic sensitivity to climate when a suitable model is used and calibrated properly.

The change in mean annual runoff for a given change in mean annual rainfall and PET can be expressed as

$\delta Q = \varepsilon P * \delta P - \varepsilon PET * \delta PET$--- 6.1

Where

δQ is change in mean annual discharge

δP is change in mean annual rainfall

δPET is change in mean annual Potential Evapotranspiration

εPET is Potential Evapotranspiration elasticity of stream flow

εP is rainfall elasticity of stream flow

εP is calculated using the following equation 6.2

$\varepsilon P = \text{median}\left(\frac{Q_t - Q_{avg}P_{avg}}{P_t - P_{avg}Q_{avg}}\right)$--6.2

Where

εP is rainfall elasticity of discharge

Q_t is annual time series of discharge

P_t is annual time series of rainfall

Q_{avg} is mean annual discharge

P_{avg} is mean annual rainfall

εPET is calculated using the same with equation 6.2 only changing the precipitation with Potential Evapotranspiration

$$\varepsilon PET = \text{median}\left(\frac{Q_t - Q_{avg}\, PET_{avg}}{PET_t - PET_{avg}\, Q_{avg}}\right) \text{---6.3}$$

Where

εPET is Potential Evapotranspiration elasticity

PET_{avg} is mean annual Potential Evapotranspiration

PET_t is annual time series of Potential Evapotranspiration

The following relations are developed and shown in Table 6.10 for the water shades using equation 6.1, 6.2 and equation 6.3.

Table 6.10 Developed equation for water shades

S.No	Watershed	Developed equations
1	Anger	δQ = 0.812* δP – 0.727 * δPET
2	Beles	δQ = 0.821 * δP – 0.780 * δPET
3	Birr	δQ = 0.861 * δP – 0.811 * δPET
4	Chacha	δQ = 1.142* δP – 1.204 * δPET
5	Guder	δQ = 0.816 * δP – 0.780 * δPET
6	Koga	δQ = 0.878 * δP – 0.895 * δPET
7	Muger	δQ = 0.901 * δP – 0.857 * δPET
8	Neshi	δQ = 0.919* δP – 0.890 * δPET
9	Sechi	δQ = 0.678* δP – 0.846* δPET
10	Teme	δQ = 1.157 * δP – 1.192 * δPET

The relations developed above may be used to estimate the change in mean annual runoff for a given change in mean annual rainfall and PET for each water shades of Blue Nile at any time in the future without using hydrological model. The elasticity‘s εP and εPET shows how much sensitive the runoff is for a 1% change in annual precipitation for constant PET or potential Evapotranspiration for constant precipitation.

The equation that is developed for different water shades are checked by applying the two future time series: 2031-2040 and: 2091-2100, comparing the change of runoff that are from developed equation (without model) and with model, shows a satisfactory agreement with annual percent of change of runoff in both future time series presented in Table(6.11).

Water shades like Anger, Beles, Birr, Guder, Neshi, Muger are more sensitive to rainfall change relative to the other water shades, and Chacha, Koga, Sechi, Teme, are more sensitive to potential Evapotranspiration.

Table 6.11 comparison of percentage change of annual runoff with model and without model for the two future time series

Watershed		Change of runoff % (2031-2040)	Change of runoff % (2091-2100)
Anger	With model	7.25	-1.68
	Without model	-2.5	-7.17
	error	9.3	5.49
Beles	With model	-1.68	-3.12
	Without model	-9.86	-13.43
	error	8.18	10.31
Birr	With model	-2.33	-7.22
	Without model	-3.14	-8.75
	error	0.81	1.53
Chacha	With model	-1,83	-7.78
	Without model	-4.18	-14.72
	error	2.35	6.94
Guder	With model	-0.07	-13.11
	Without model	-1.7	-8.41
	error	1.63	-4.70
Koga	With model	-0.59	1.34
	Without model	-3.82	-8.65
	error	3.23	9.99
Muger	With model	-3.92	-18.16
	Without model	-3.94	-11.65
	error	0.02	-6.51
Neshi	With model	3.1	-6.98
	Without model	-2.54	-9.41
	error	5.64	2.43
Sechi	With model	0.18	-3.11
	Without model	-4.0	-9.15
	error	4.18	6.04
Teme	With model	3.86	-6.15
	Without model	-3.31	-14.73
	error	7.17	8.58

6.6 Uncertainties in impact analysis

This study on the impact of climate change on water availability in Abbay river basin, involved a series of models and model outputs, which are based on simplified assumptions. Hence, it is anticipated that the uncertainties presented in each of the models and model outputs kept on cumulating while progressing towards the final output.

The types of uncertainties existing throughout the whole process can be associated with the data quality, the GCMs and SRES scenarios selected, the downscaling method used, the conversion of grid data to station data and the hydrologic modeling applied (the parameters that we have used for calibration may not represent the catchment).

The last type of uncertainty (hydrologic modeling applied) can be checked using bounded uncertainty checks - upper bound (5% probability flow) and lower bound (95% probability flow). It is a well established concept that if the future generated runoff placed between the two bounds, it is anticipated the hydrological uncertainty is less significant, otherwise, it is considered as significant. Almost in all watersheds the generated runoff of the two future time series are placed out of the two bounds this implies that the change of generated runoff is not because of hydrologic modeling (there hydrologic uncertainty is less significant). Sample Figure (6.14) shows the upper and lower bounds with future generated runoff at Guder catchment. The rest graphs are presented on Appendix G.

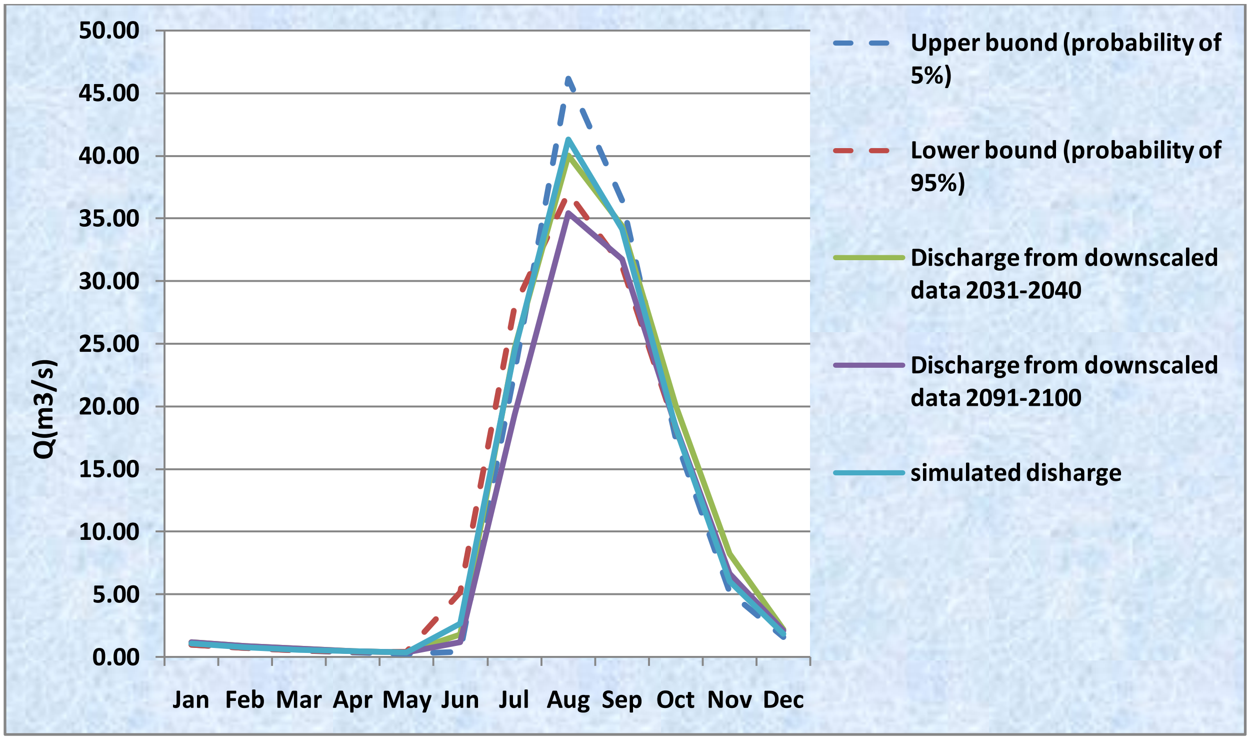


Figure 6.14 the upper and lower bounds with future generated discharge of Guder watershed

From figure 6.14 we can see that whether hydrologic uncertainty is significant or not for the future generated runoff at the Guder watershed. The discharge that is generated for 2031-2040 placed between the bounds from May to September, this shows that hydrologic uncertainty is significant during this period (the change of discharge is because of hydrology modeling) however the simulated flow is between the bounds this indicates that the hydrology model has less significant uncertainty. But for discharge generated for 2091-2100 hydrologic uncertainty is not anticipated, because the discharge generated is out of bounds that shows that the change of discharge is because of climate change.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

1. HBV-96 hydrological model used for calibration and validation on 10 sub-catchments of the Upper Blue Nile in view of using for evaluation of impact of climate change on these sub-catchments using daily data of precipitation and potential Evapotranspiration. The result of hydrological model calibration and validation indicates that the HBV model simulates the runoff considerably good for the study area. The model performance criterion which is used to evaluate the model result indicates that the daily Nash and Sutcliffe efficiency criteria (R^2) in between 0.81 and 0.60 during calibration and 0.75 to 0.54 during validation period.

2. The result of long term monthly average potential Evapotranspiration of the observed data and the outputs of RCM within the base period shows good agreement. The potential Evapotranspiration at base period have correlation coefficient of maximum 0.98 and minimum 0.90 with observed data. The future scenario generated potential Evapotranspiration shows an increasing trend in the future time series for the two periods from 2031-2040 and 2091-2100 comparing with the base period: 1991-2000 in all ten catchments of the Upper Blue Nile.

For the first time series: 2031-2040 in all watersheds higher increment is observed on ONDJ (Beles 10.66% and Sechi 6.86%) but for Anger (3.56%) and Neshi (3.54%) higher increments are observed on FMAM, for the next time series: 2091-2100 higher increment is observed on FMAM in all watersheds (specially Beles 20.69% and Sechi 24.04%) and lower increment is observed on JJAS in all watersheds for both time series.

When we see the annual change in percent it has range from 2.78% at Anger and 9.11% at Beles for the first time series (2031-2040), for the second time series (2091-2100) the annual percent change has range between 7.32% (for Anger) and 18.16% (for Beles)watershed

3. The annual rainfall change in the future climate scenario is not consistently increasing as in Evapotranspiration scenario. Rainfall change shows mixed signals of increasing in some catchments and decreasing in the other catchments. Over all a reduction in the range between 0 to -3.36% (Beles) and increment in the range between 0 to +2.95% (Chacha) was observed. change of precipitation in percent for the first future time series: 2031-2040 with respect to the base period shows, the seasonal change of precipitation increase in most of the watersheds on ONDJ (7.41% at Sechi) and higher reduction(-6.51% at Muger) is also observed in the same season ONDJ, but higher increment value is observed for Chacha (7.71%) and Neshi (1.83%) water shades on FMAM and higher reduction(-4.10%) is observed on FMAM for Beles watershed in the same future time series (2031-2040).
For the second future time series: 2091-2100 the change of percentage of precipitation with respect to the base period, in most of the watersheds higher increment (57.64% at Chacha and 22.47% at Seshi) are observed the same with the first future time series observed season (on ONDJ), and maximum reduction is observed in all catchments on JJAS season except Beles (-8.11%) and Koga (-3.20%) which have maximum reduction on FMAM.

4. The simulated flow at: 2031-2040 with scenario from RCM shows reduction and increment of runoff in the watersheds and it is directly related to the reduction and increment in precipitation, but in some watersheds there is reduction of rainfall and increment in potential Evapotranspiration in a season, these factors are anticipated to decrease the runoff on that season, however there is increment of runoff.

Maximum percent of increment of runoff (22.45% at Beles) and maximum reduction (-25.54% at Muger) is observed on the same season FMAM for the first future time series. All watersheds have reduced value of runoff in percentage in the second future time series (2091-2100) in all season except Teme (2.94%), Beles (7.05%), Koga (7.92%), Birr (17.10%) and Anger (5.55%) watersheds which show increment only on ONDJ season.

The seasons like JJAS, FMAM show high reduction in runoff in both future time series (2031-2040 and2091-2100) in most of the watersheds. The annual flow shows maximum reduction of -13.11% at Guder watershed and maximum increment +7.25% at Anger watershed

5. Watersheds like Anger, Beles, Birr, Guder, Neshi, Muger are more sensitive to rainfall change relative to the other watersheds, and Chacha, Koga, Sechi, Teme, are more sensitive to potential Evapotranspiration.

6. In terms of spatial variability of changes, the 10 catchments can be ordered from the most sensitive to least sensitive as Chacha, Teme, Neshi, Muger, Koga, Birr, Gilgel, Belese, Guder, Little Anger and Sechi. Particularly catchment Chacha showed extreme sensitivity for both rainfall and PET changes far beyond other catchments. From this we can conclude that the Southeast catchment (Chacha) is more sensitive where as the Western catchment (Sechi) is less sensitive. In view of that we can say that as we go from east to west the sensitivity will decrease.

7. Almost in all watersheds the generated runoff for the two future time series (2031-2040 and 2091-2100) are placed out of the two bounds (5% and 95% probability flow) this implies that the change of percent of generated runoff is not because of hydrologic modeling (uncertainty because of hydrologic modeling is less significant).

7.2 Recommendation

This study involved various models and model outputs where each possessed a certain level of uncertainty. Hence, the results of this study should be taken with care and be considered as indicative of the likely future rather than accurate predictions. Meanwhile, this study should be extended by considering changes in land use, soil and other climate variables in addition to the changes in precipitation and temperature. The impacts of climate change on the water utilizing socio-economic sectors should also be considered.

This study was based on The RegCM3 output downscaled using 50km by 50km gird resolution and future work should focus on RCM outputs that have downscaled using high gird resolution to evaluate the likely impacts anticipated in the Blue Nile Basin as a consequence the future climate change scenario.

Continuing studies should consider the wide range of uncertainties associated with models and try to reduce these uncertainties by the use of different RCM outputs, downscaling techniques, and emission scenarios. For the sake of this paper, the changes that would result from the emissions trajectory of the A1B Scenario was selected to be analyzed, but all SRES scenarios have equal probability of occurrence, future studies should also consider the entire emissions Scenario, using this application a number of RCMs can help to generate a more ―reliable" ensemble mean.

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Annex

APPENDIX A: Definitions of some important words

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

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

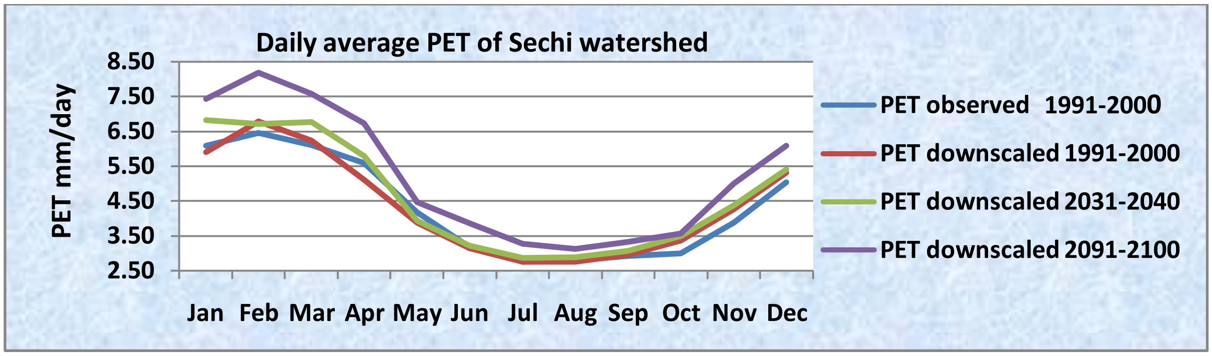
Scenario A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario but scenarios often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

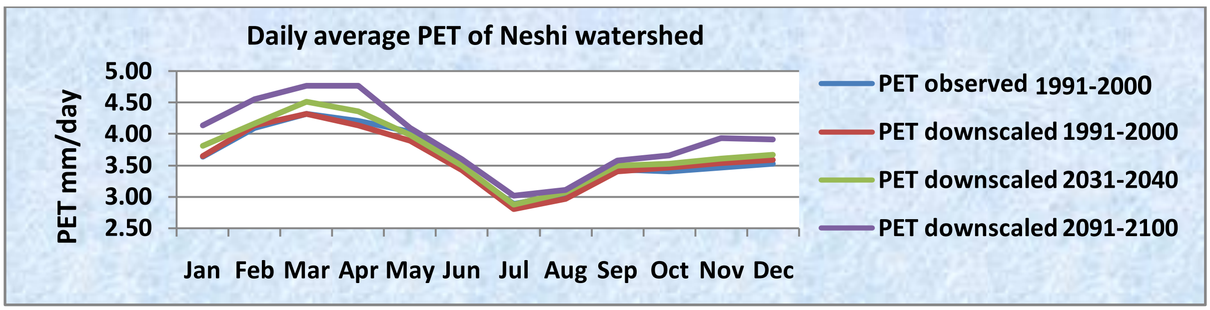
Emission Scenario: projections of a potential future, based on a clear logic and a quantified storyline.

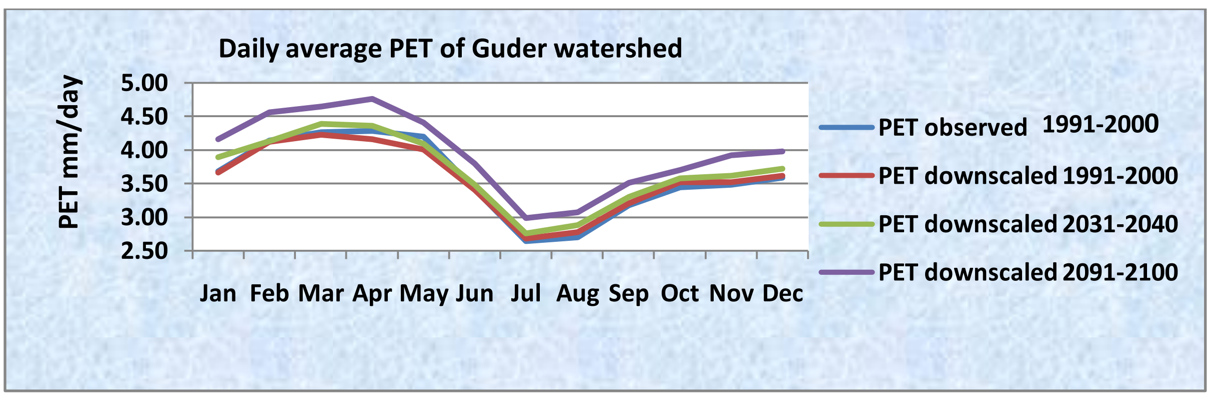
Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

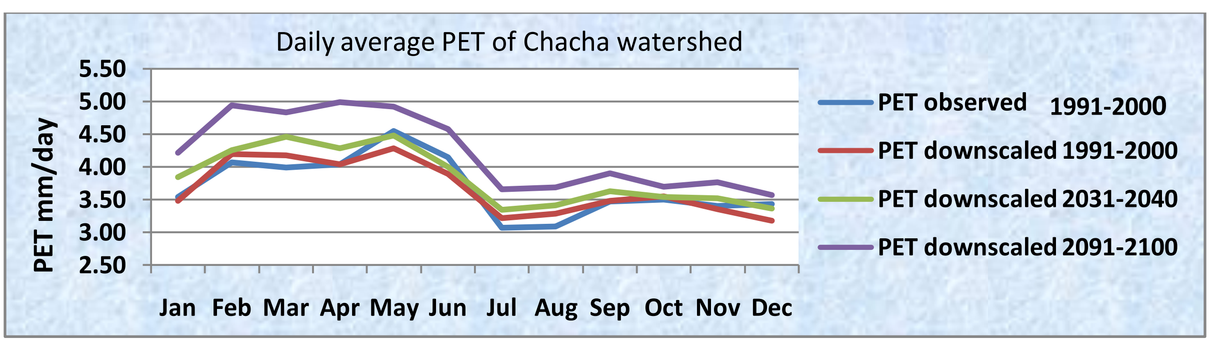
APPENDIX B

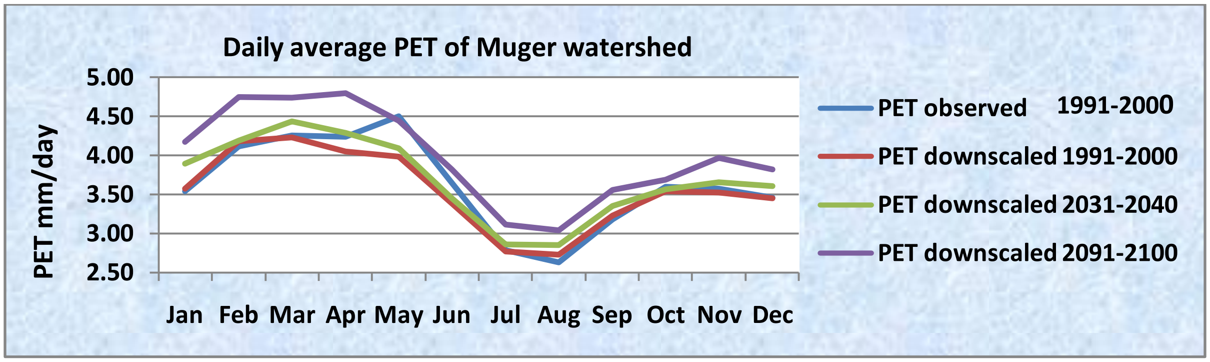
FIGURE B.1 base periods and future time series of monthly average potential Evapotranspiration of different watershed

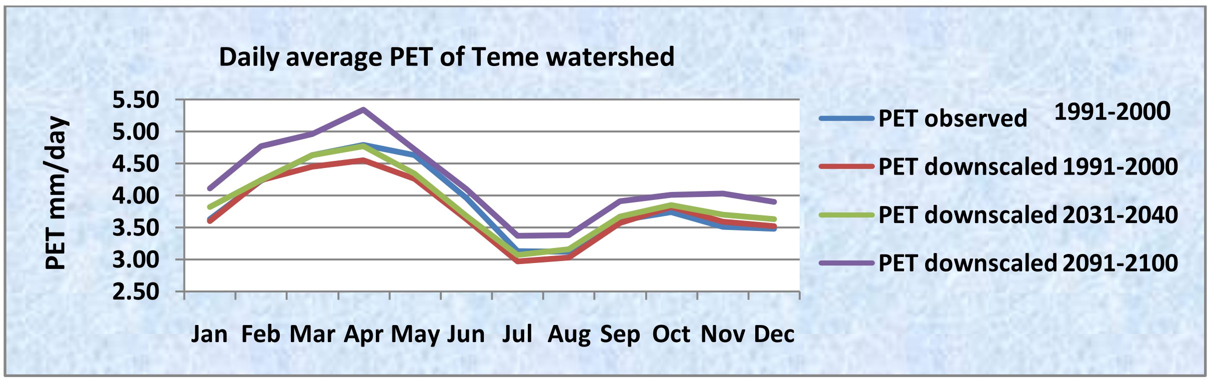


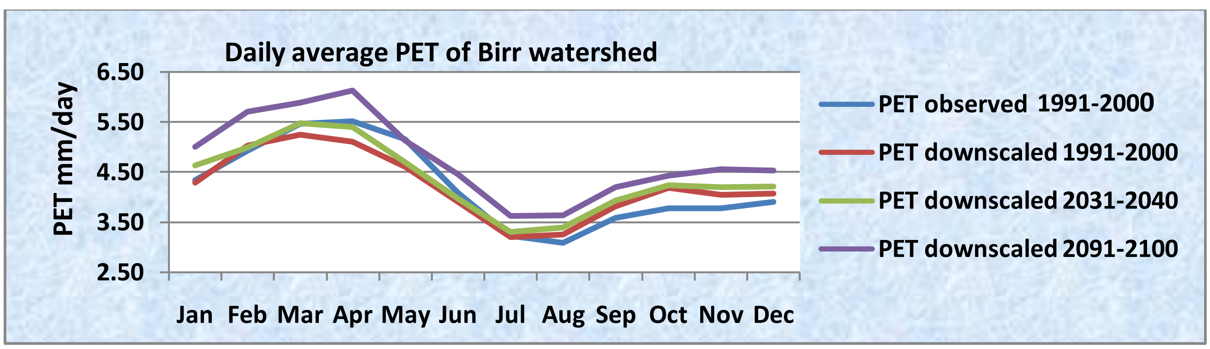


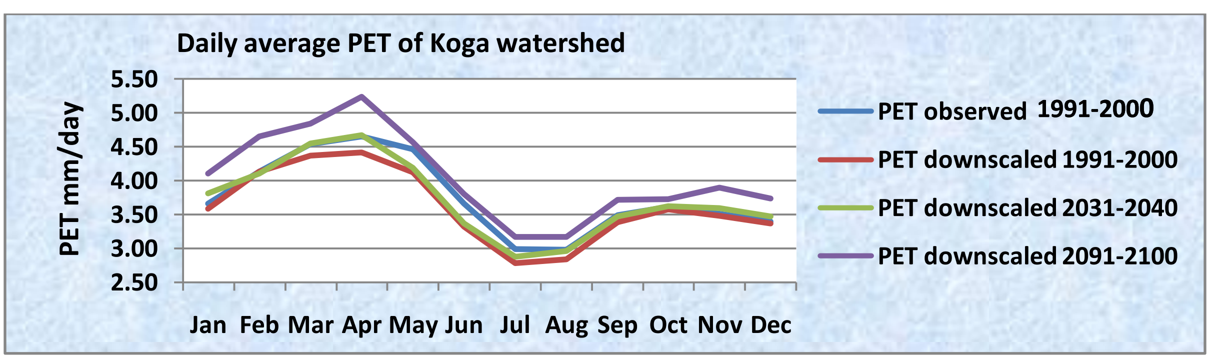





Daily average PET of Muger watershed
PET mm/day
5.00
4.50
4.00
3.50
3.00
2.50
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
PET observed 1991-2000
PET downscaled 1991-2000
PET downscaled 2031-2040
PET downscaled 2091-2100

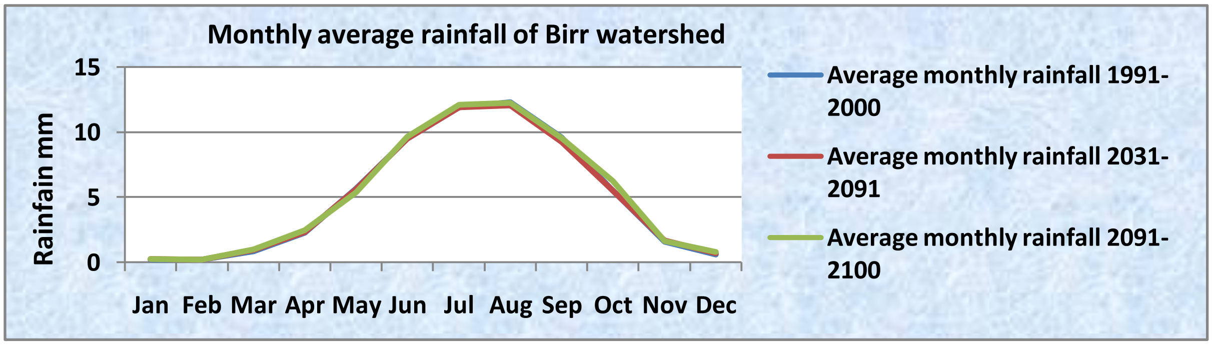

Daily average PET of Teme watershed
PET mm/day
5.50
5.00
4.50
4.00
3.50
3.00
2.50
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
PET observed 1991-2000
PET downscaled 1991-2000
PET downscaled 2031-2040
PET downscaled 2091-2100

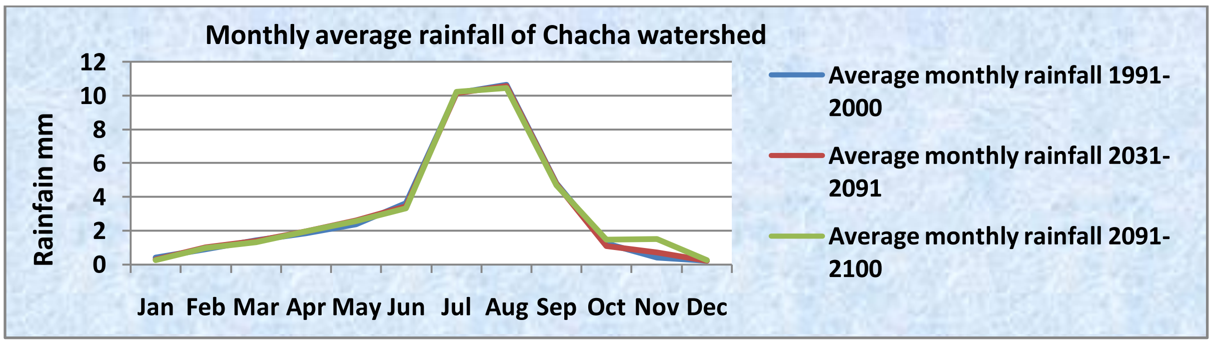

Daily average PET of Birr watershed
PET mm/day
6.50
5.50
4.50
3.50
2.50
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
PET observed 1991-2000
PET downscaled 1991-2000
PET downscaled 2031-2040
PET downscaled 2091-2100

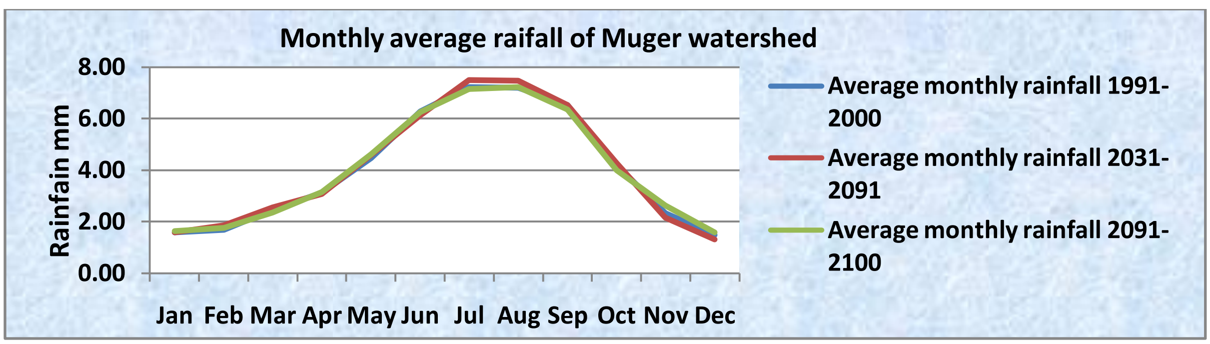

Daily average PET of Koga watershed
PET mm/day
5.50
5.00
4.50
4.00
3.50
3.00
2.50
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
PET observed 1991-2000
PET downscaled 1991-2000
PET downscaled 2031-2040
PET downscaled 2091-2100

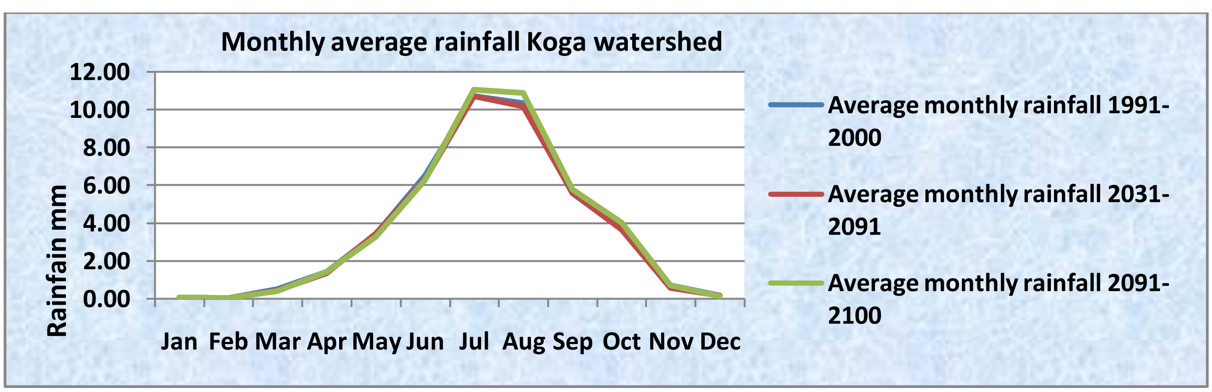
APPENDIX C

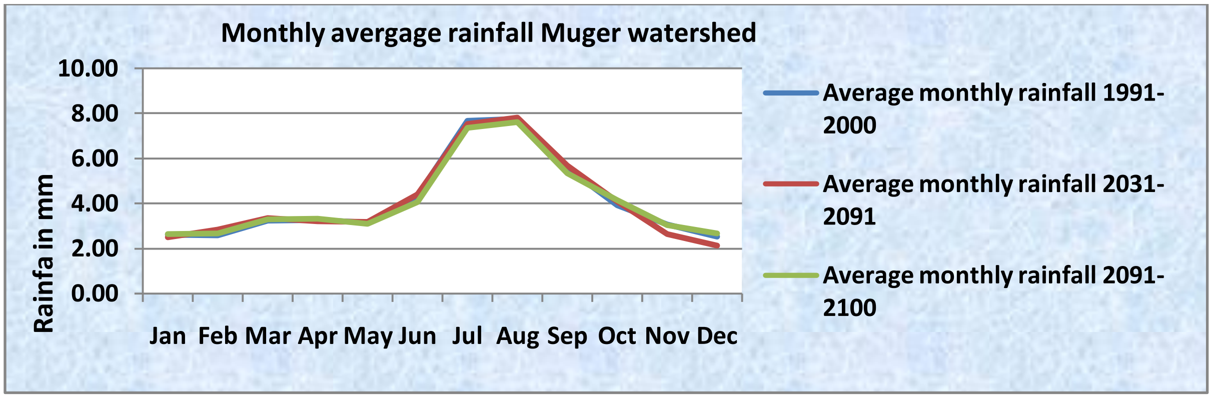
FIGURE C.1Monthly average rainfalls for base period and future time series of different watershed

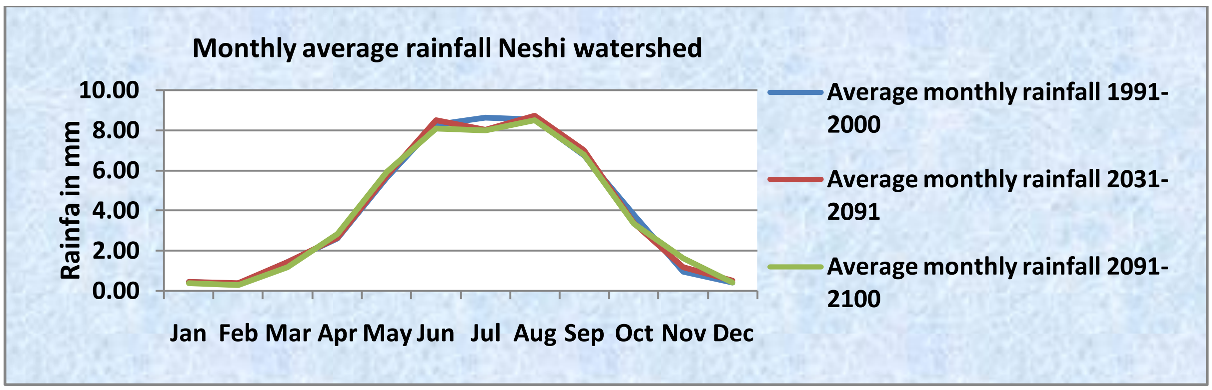


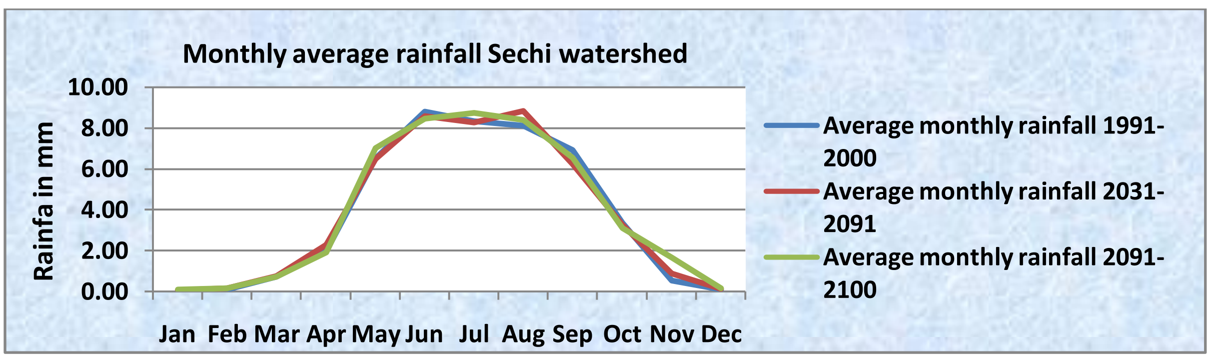


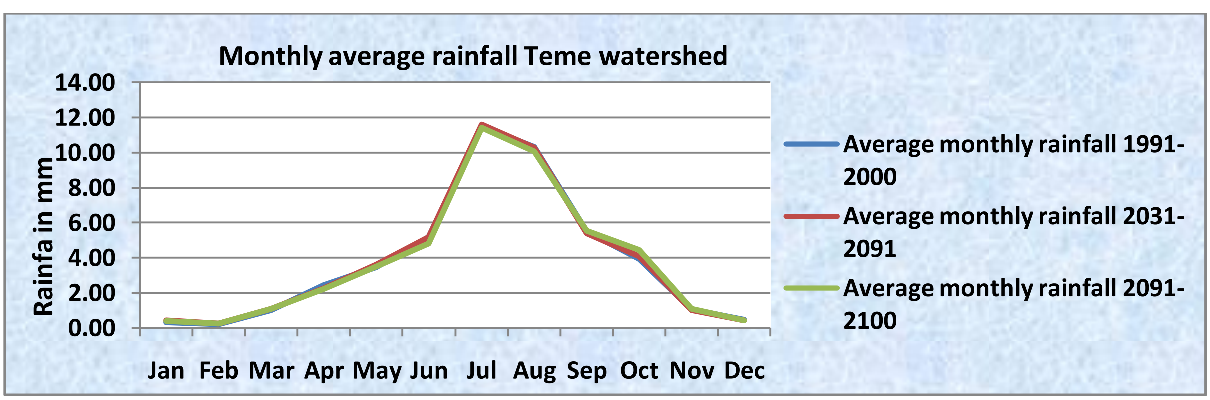





Monthly avergage rainfall Muger watershed
10.00
8.00
6.00
4.00
2.00
0.00
Rainfa in mm
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average monthly rainfall 1991-2000
Average monthly rainfall 2031-2091
Average monthly rainfall 2091-2100

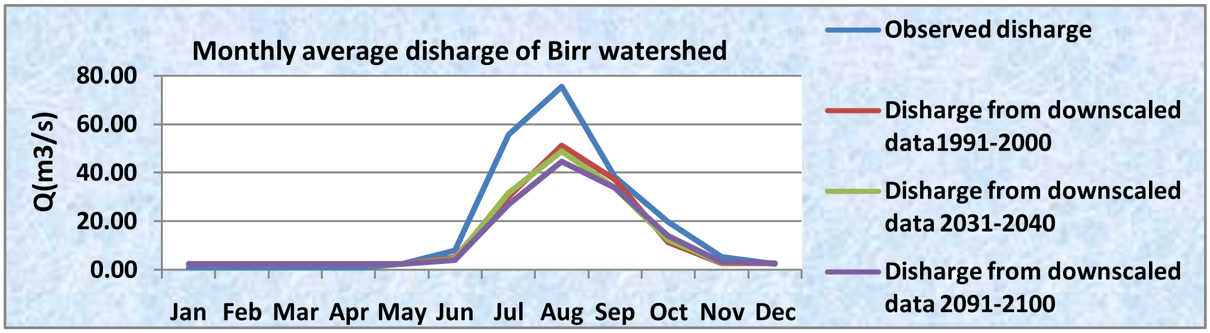

Monthly average rainfall Neshi watershed
10.00
8.00
6.00
4.00
2.00
0.00
Rainfa in mm
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average monthly rainfall 1991-2000
Average monthly rainfall 2031-2091
Average monthly rainfall 2091-2100

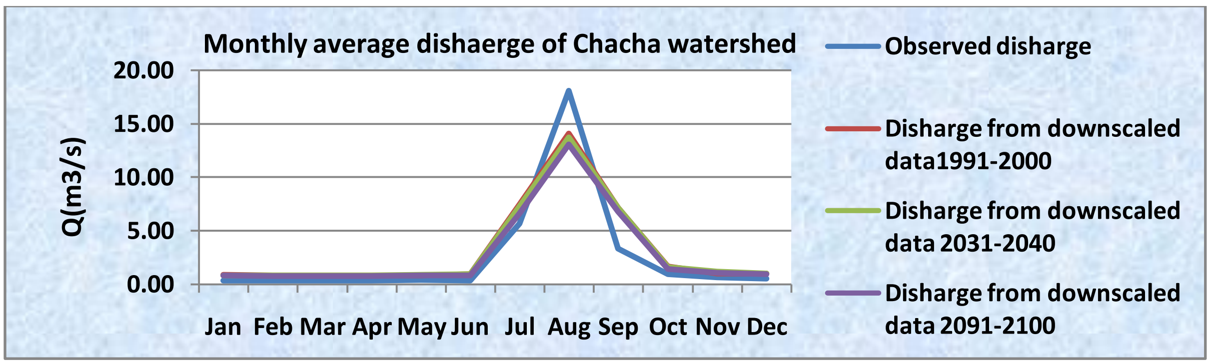

Monthly average rainfall Sechi watershed
10.00
8.00
6.00
4.00
2.00
0.00
Rainfa in mm
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average monthly rainfall 1991-2000
Average monthly rainfall 2031-2091
Average monthly rainfall 2091-2100

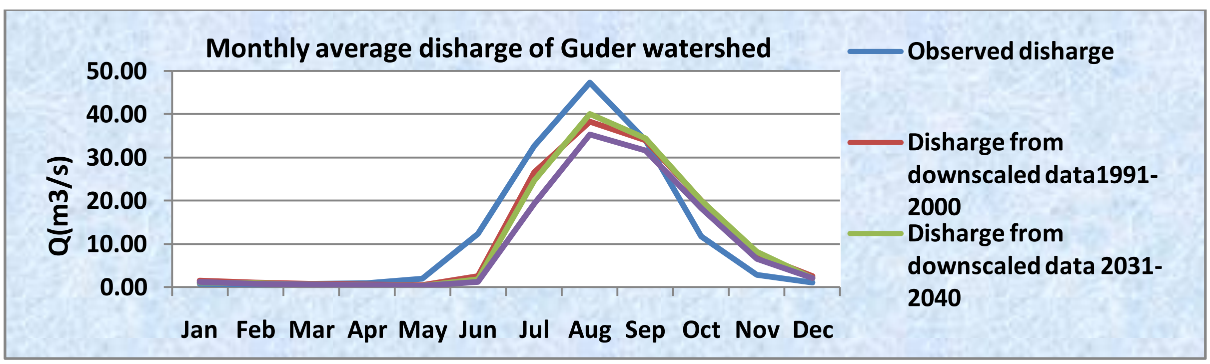

Monthly average rainfall Teme watershed
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Rainfa in mm
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average monthly rainfall 1991-2000
Average monthly rainfall 2031-2091
Average monthly rainfall 2091-2100

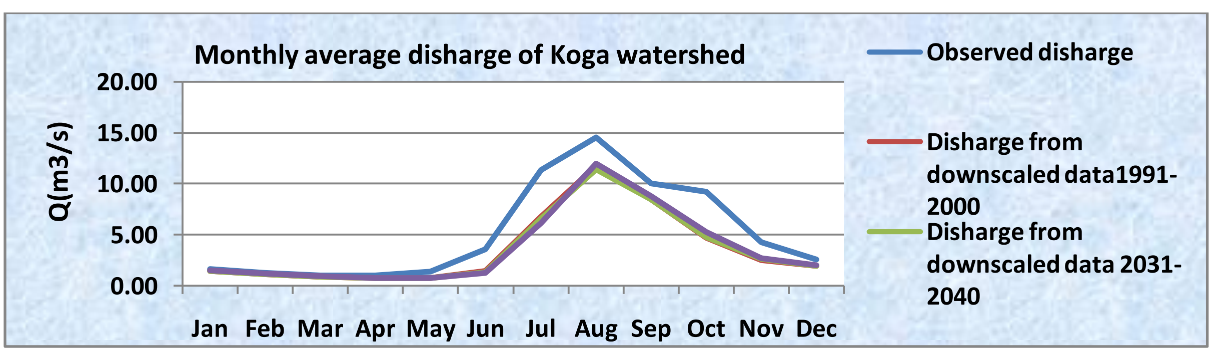
APPENDIX D

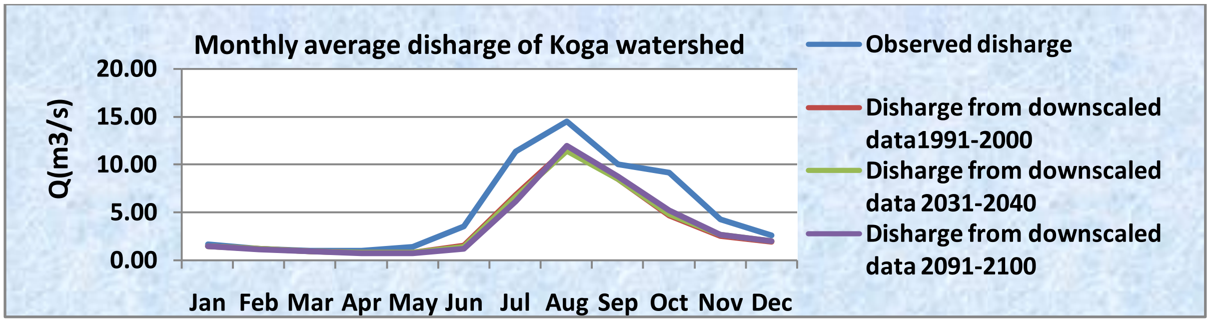
FIGURE D.1 Average monthly observed discharge, average monthly discharge: 1991-2000, average monthly Discharge: 2031-2040 and average monthly discharge: 2091-2100 of different watersheds

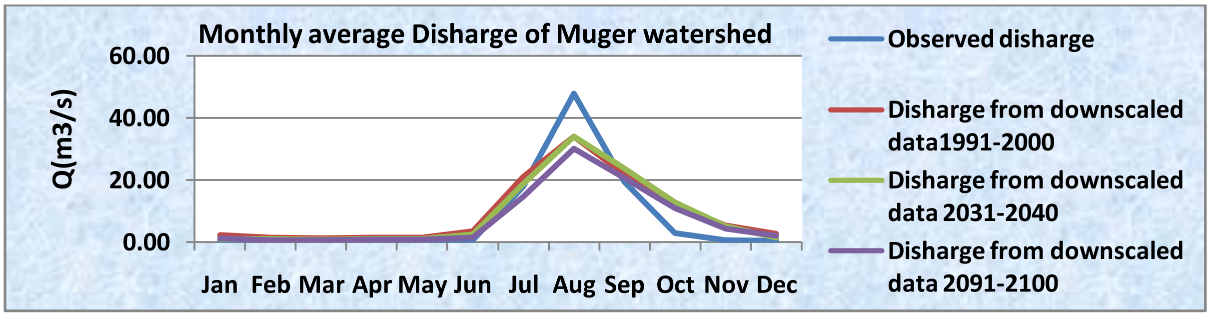


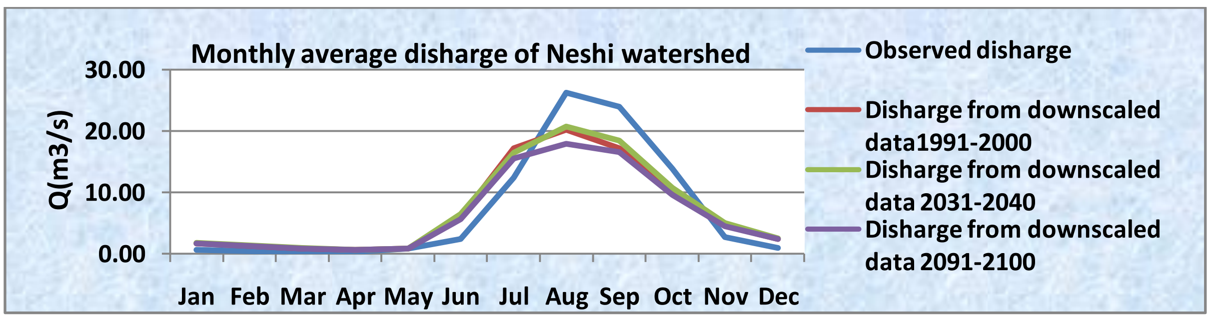


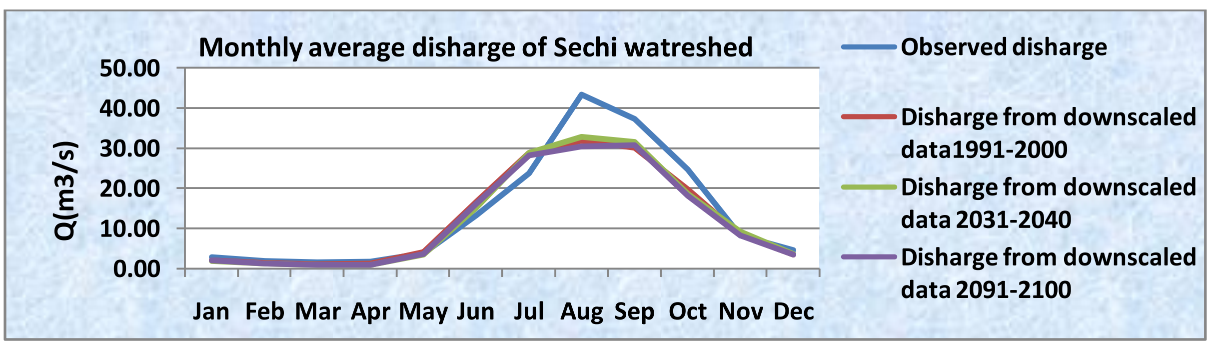


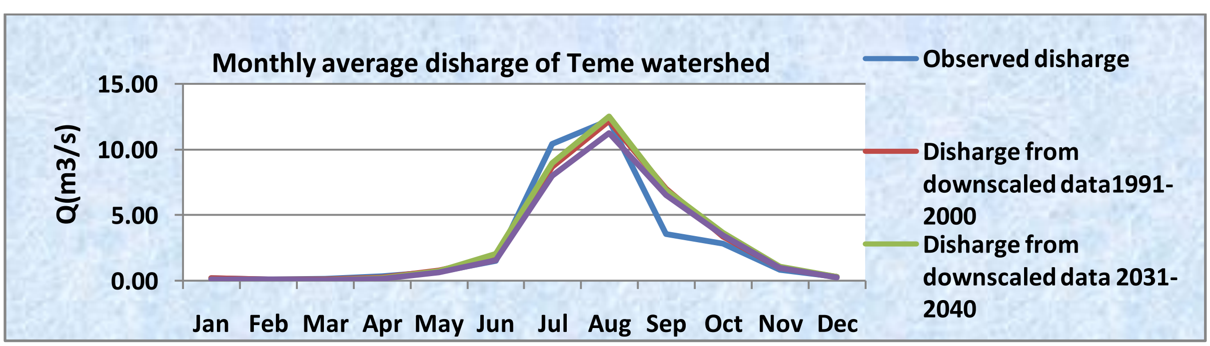



Monthly average disharge of Koga watershed
Q(m3/s)
20.00
15.00
10.00
5.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed disharge
Disharge from downscaled data1991-2000
Disharge from downscaled data 2031-2040
Disharge from downscaled data 2091-2100


Monthly average Disharge of Muger watershed
Q(m3/s)
60.00
40.00
20.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed disharge
Disharge from downscaled data1991-2000
Disharge from downscaled data 2031-2040
Disharge from downscaled data 2091-2100

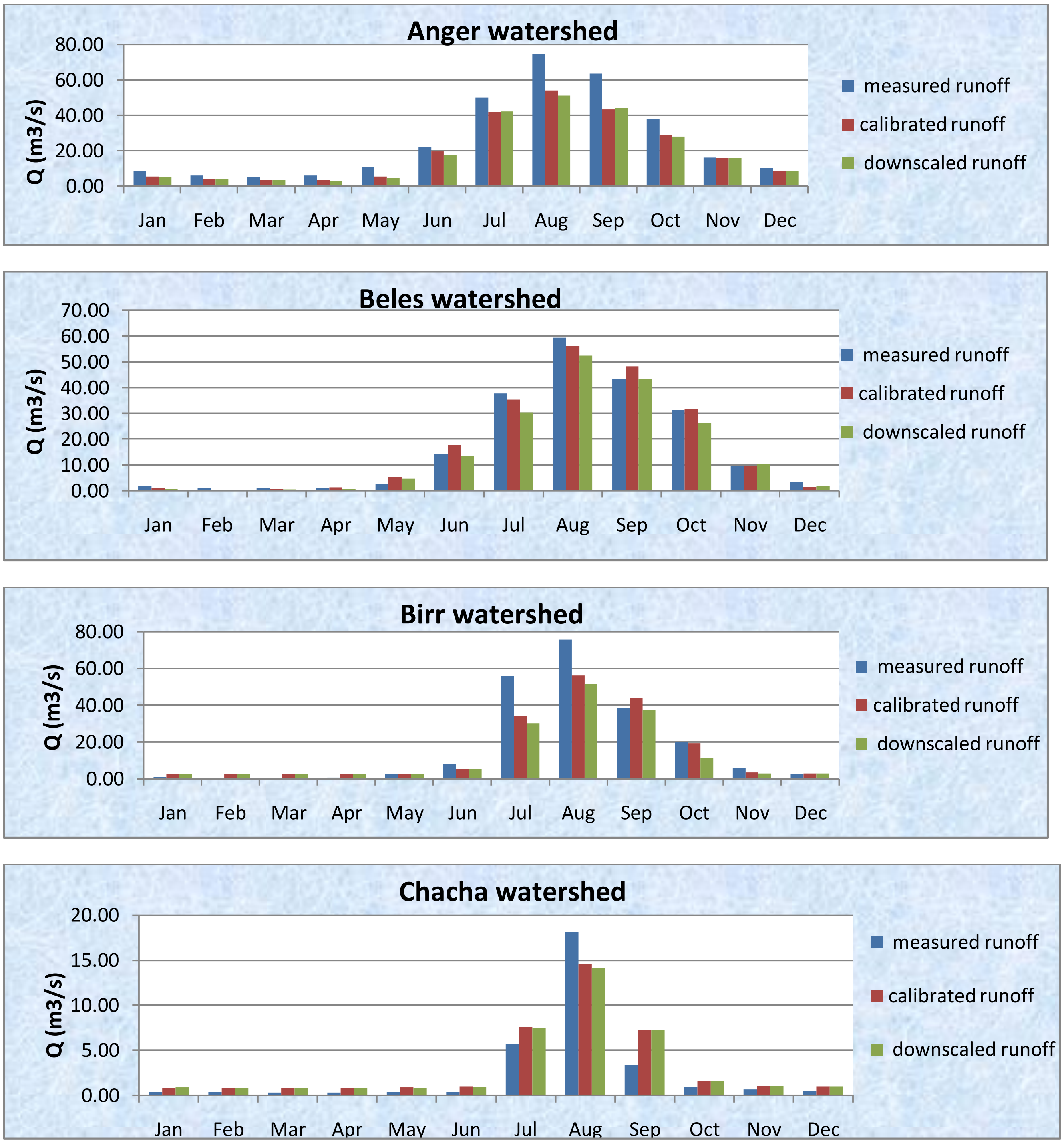

Monthly average disharge of Neshi watershed
Q(m3/s)
30.00
20.00
10.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed disharge
Disharge from downscaled data1991-2000
Disharge from downscaled data 2031-2040
Disharge from downscaled data 2091-2100

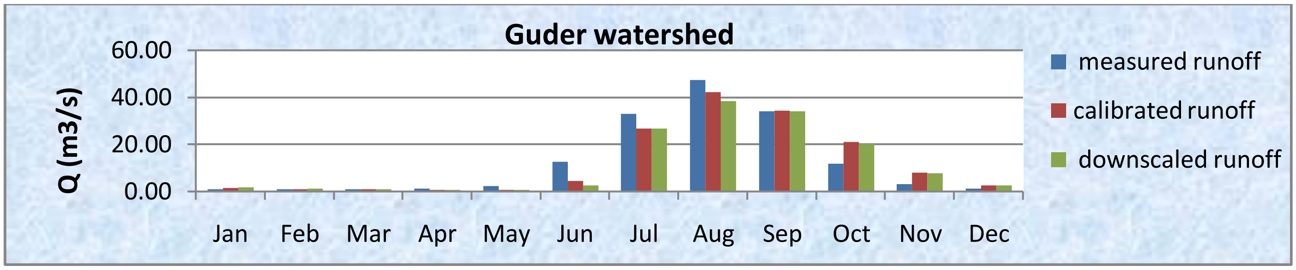

Monthly average disharge of Sechi watreshed
Q(m3/s)
50.00
40.00
30.00
20.00
10.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed disharge
Disharge from downscaled data1991-2000
Disharge from downscaled data 2031-2040
Disharge from downscaled data 2091-2100

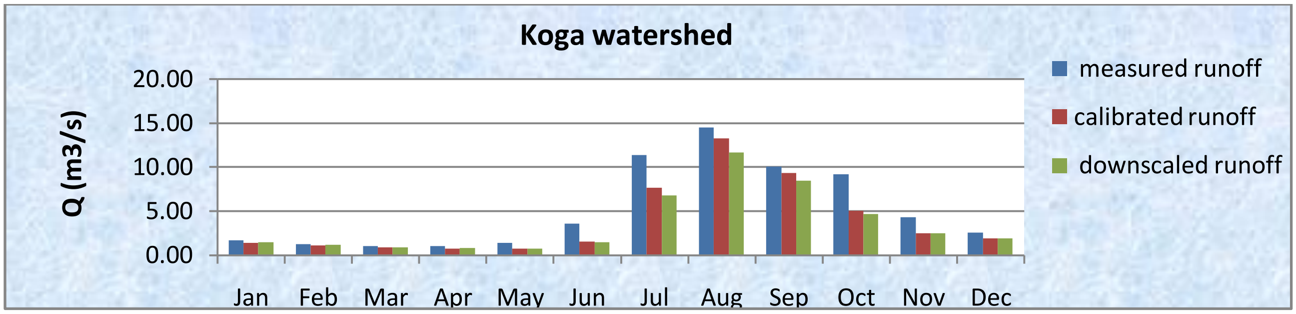

Monthly average disharge of Teme watershed
Q(m3/s)
15.00
10.00
5.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed disharge
Disharge from downscaled data1991-2000
Disharge from downscaled data 2031-2040

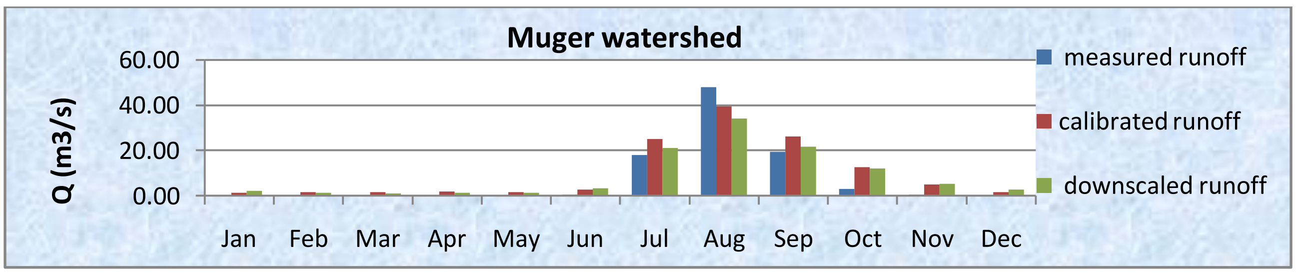
APPENDIX E

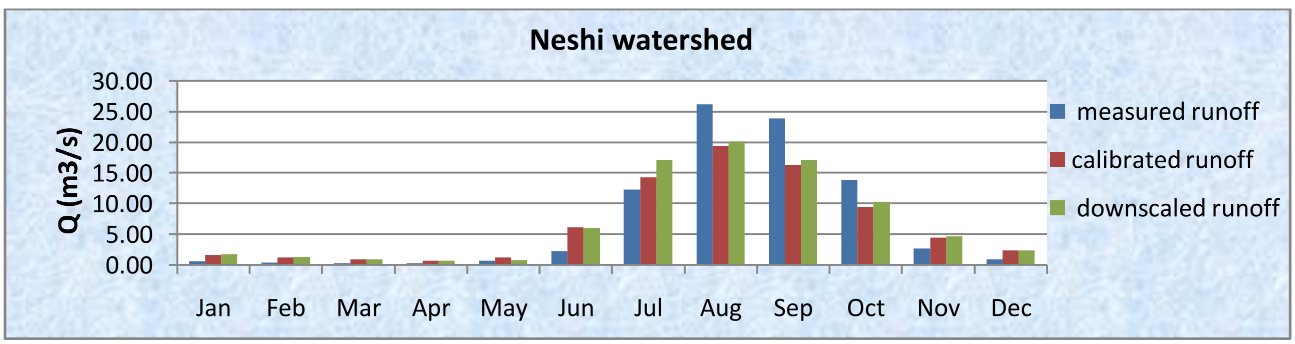
FIGURE E.1 Observed runoff, Calibrated runoff and Runoff from downscaled data at base period.

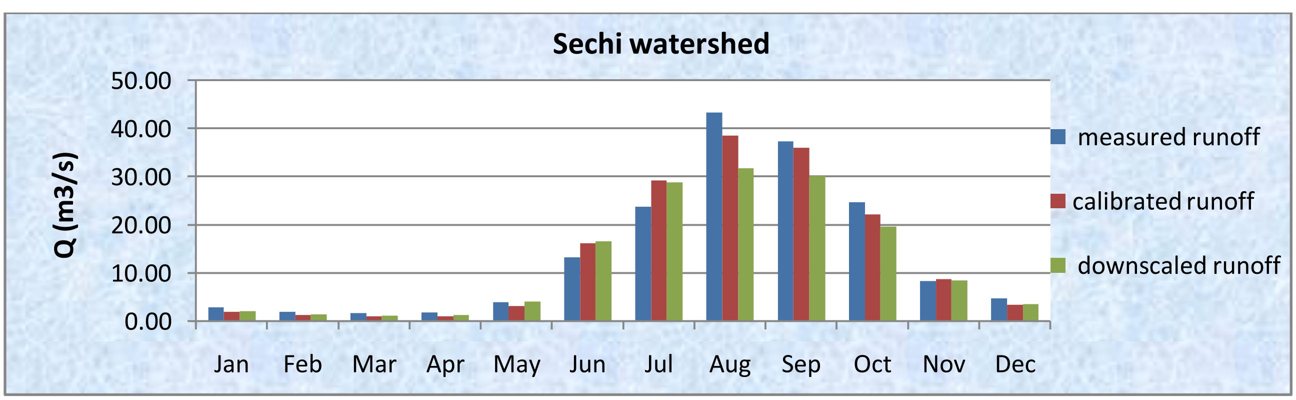



Guder watershed
Q (m3/s)
60.00
40.00
20.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
measured runoff
calibrated runoff
downscaled runoff


Koga watershed
Q (m3/s)
20.00
15.00
10.00
5.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
measured runoff
calibrated runoff
downscaled runoff

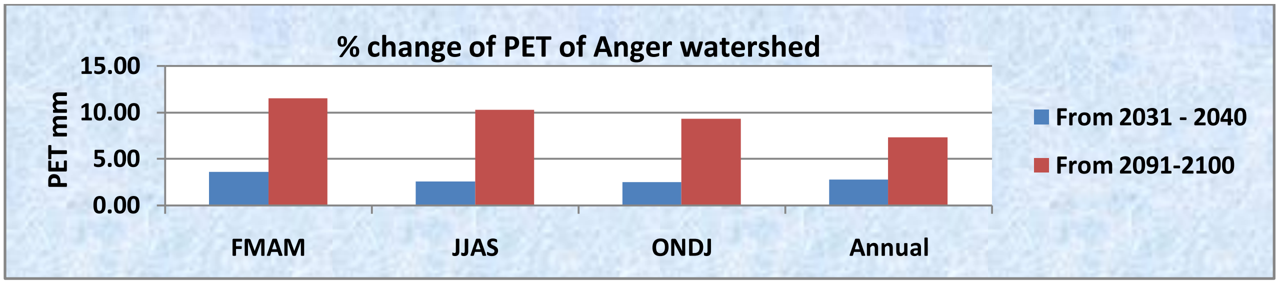

Muger watershed
Q (m3/s)
60.00
40.00
20.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
measured runoff
calibrated runoff
downscaled runoff

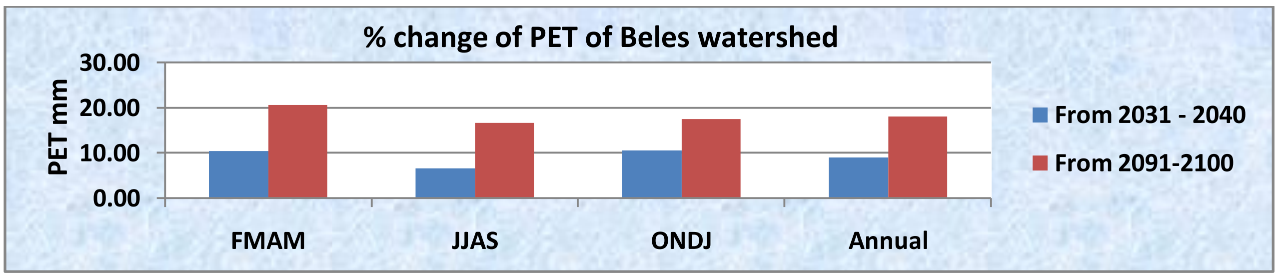

Neshi watershed
Q (m3/s)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
measured runoff
calibrated runoff
downscaled runoff

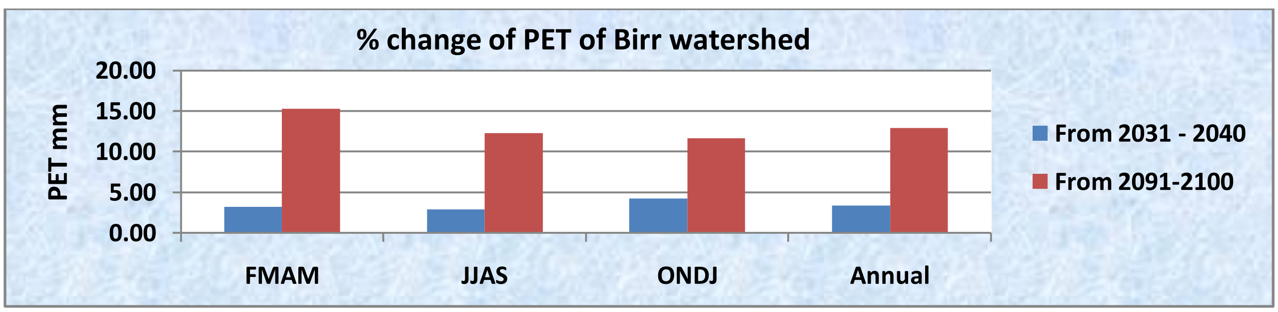

Sechi watershed
Q (m3/s)
50.00
40.00
30.00
20.00
10.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
measured runoff
calibrated runoff
downscaled runoff

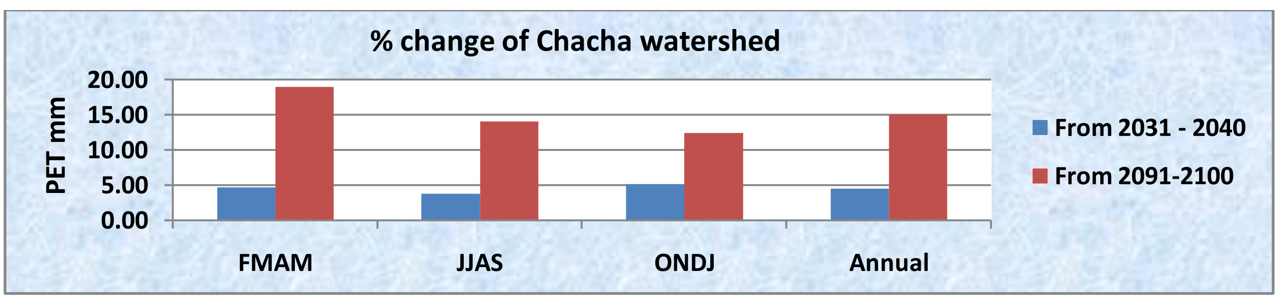
APPENDIX F

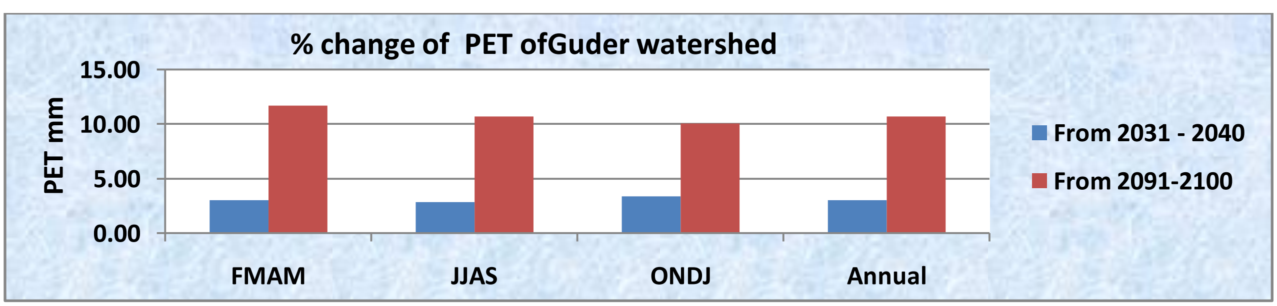
FIGURE F.1 Percent of change of PET for the two future time series (2031-2040) and (2091-2100) with respect to base period (1991-2000).

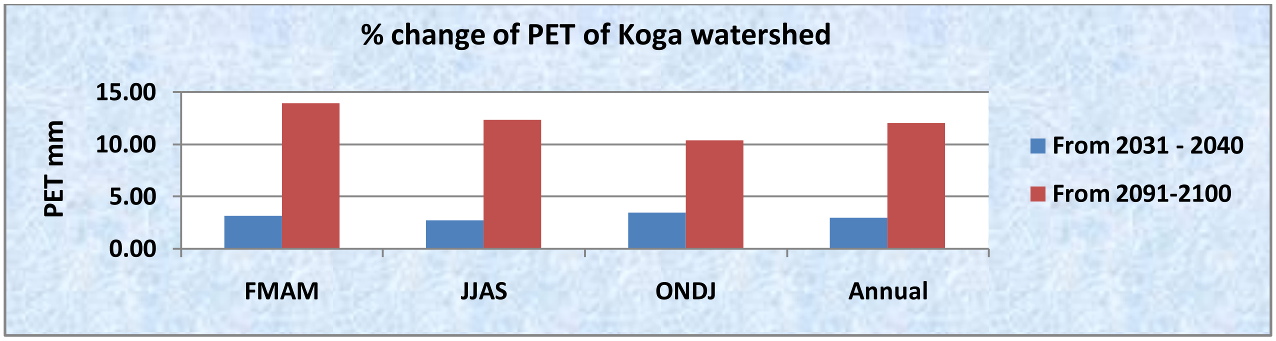


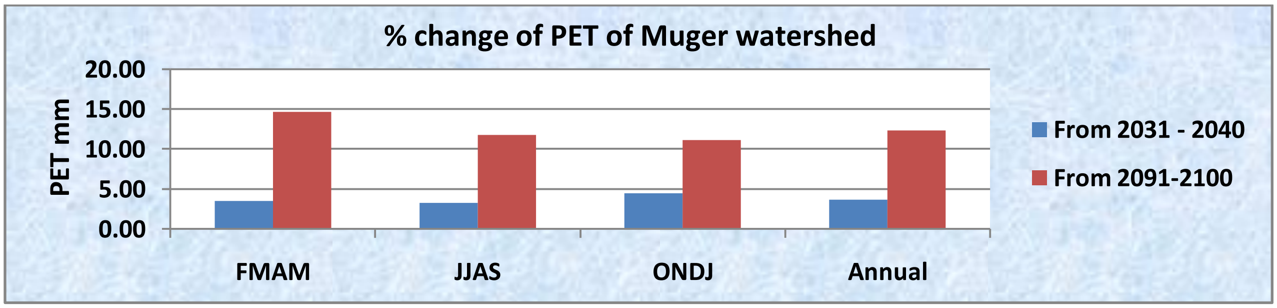


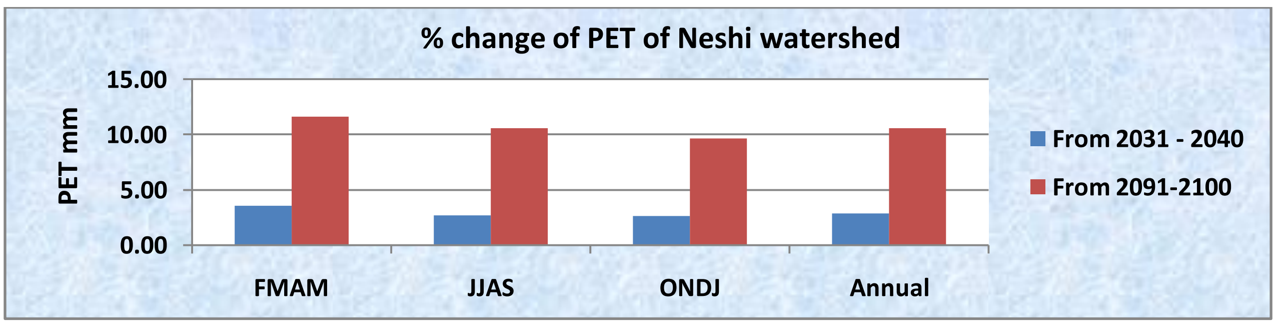


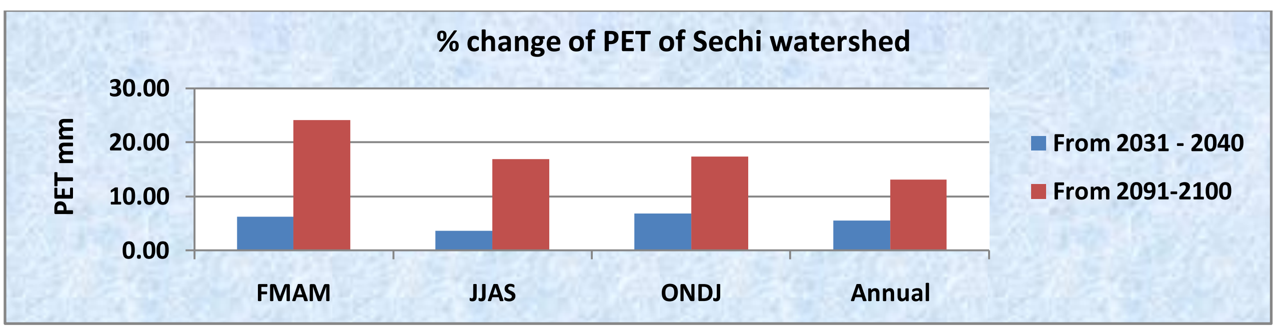


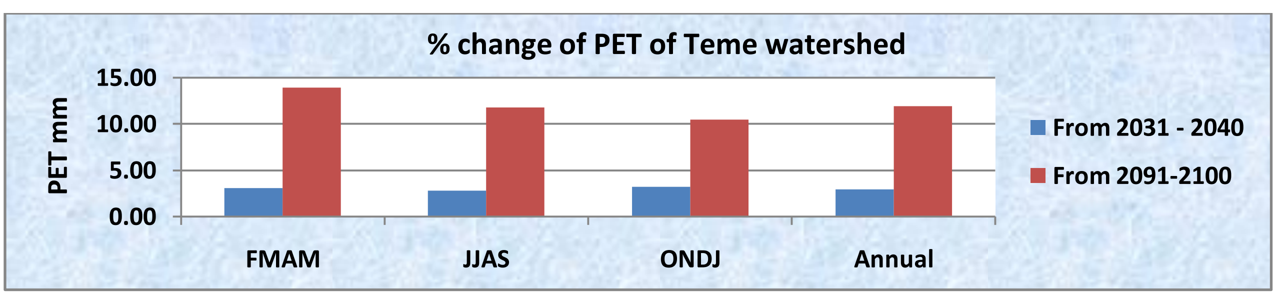



% change of PET of Koga watershed
PET mm
15.00
10.00
5.00
0.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091-2100


% change of PET of Muger watershed
PET mm
20.00
15.00
10.00
5.00
0.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091-2100

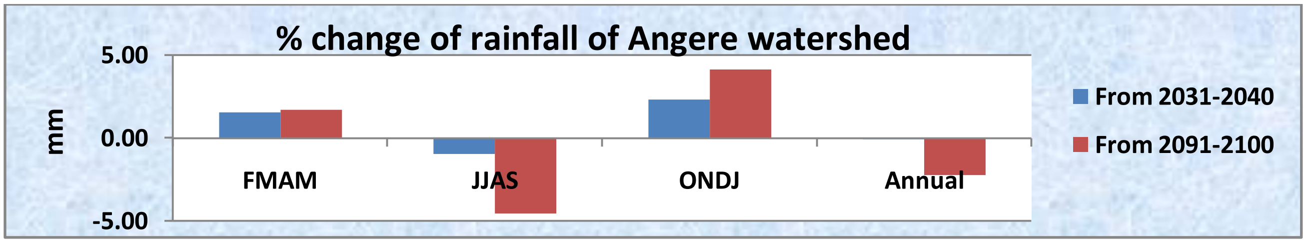

% change of PET of Neshi watershed
PET mm
15.00
10.00
5.00
0.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091-2100

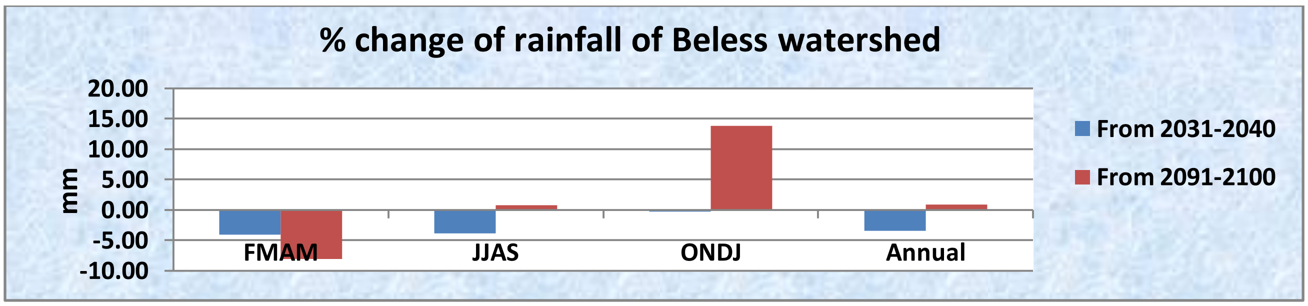

% change of PET of Sechi watershed
PET mm
30.00
20.00
10.00
0.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091-2100

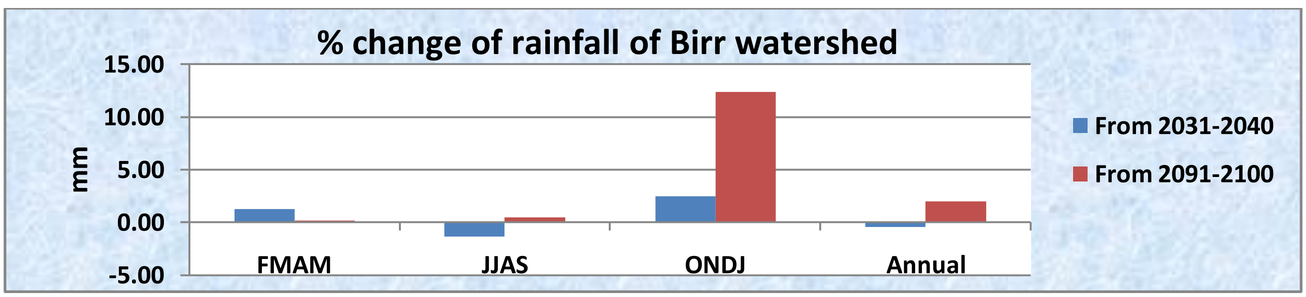

% change of PET of Teme watershed
PET mm
15.00
10.00
5.00
0.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091-2100

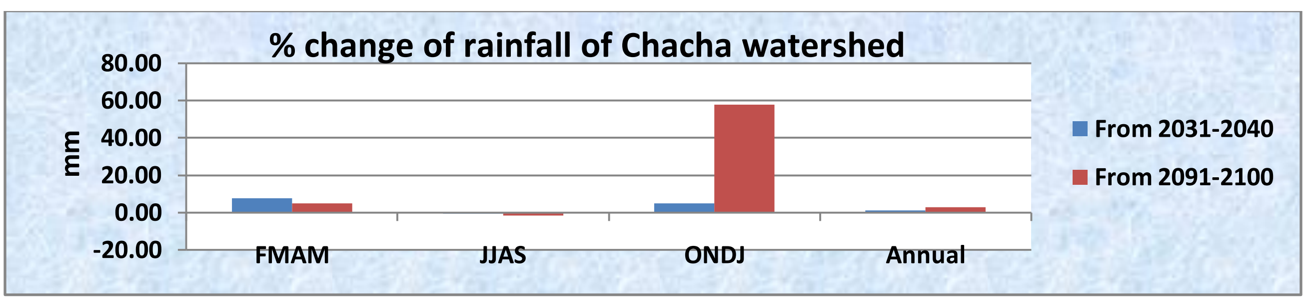
APPENDIX G

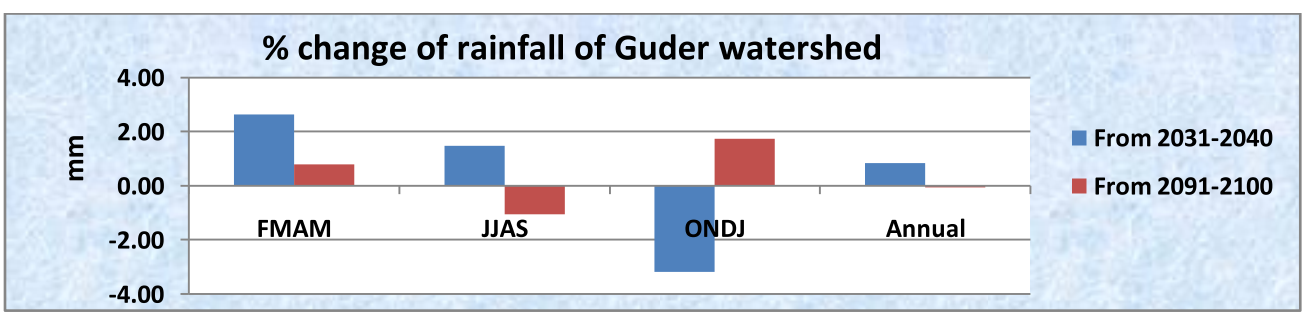
FIGURE G.1 Percent of change of rainfall for the two future time series (2031-2040) and (2091-2100) with respect to base period (1991-2000).

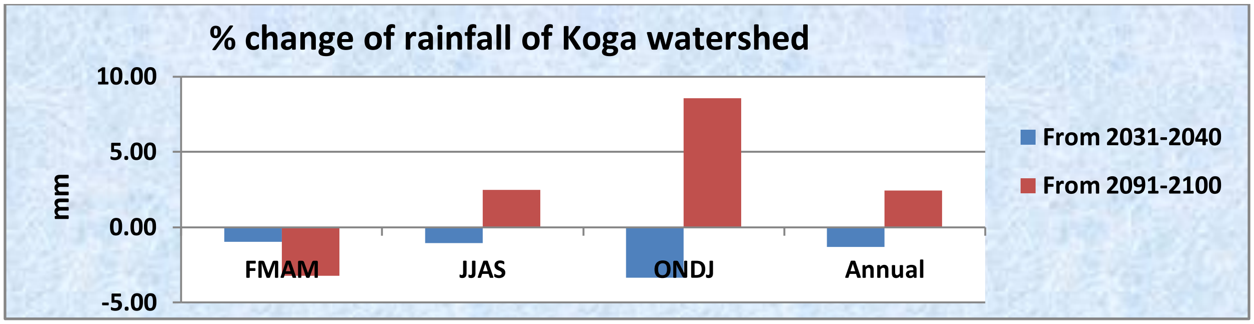


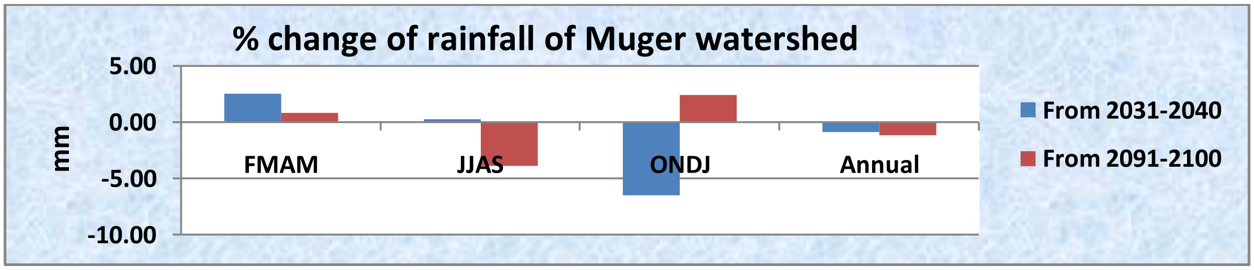


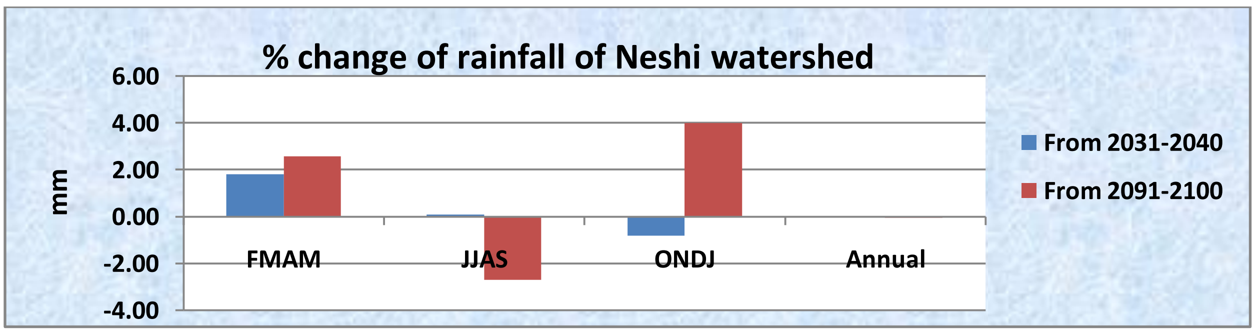


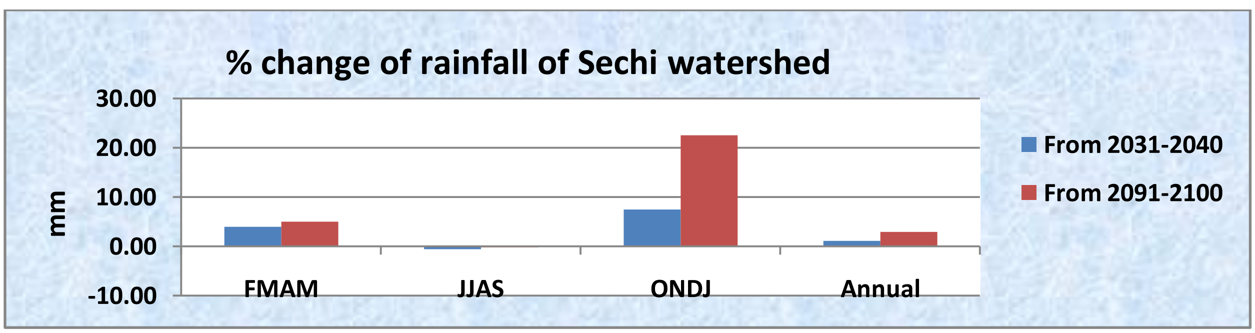


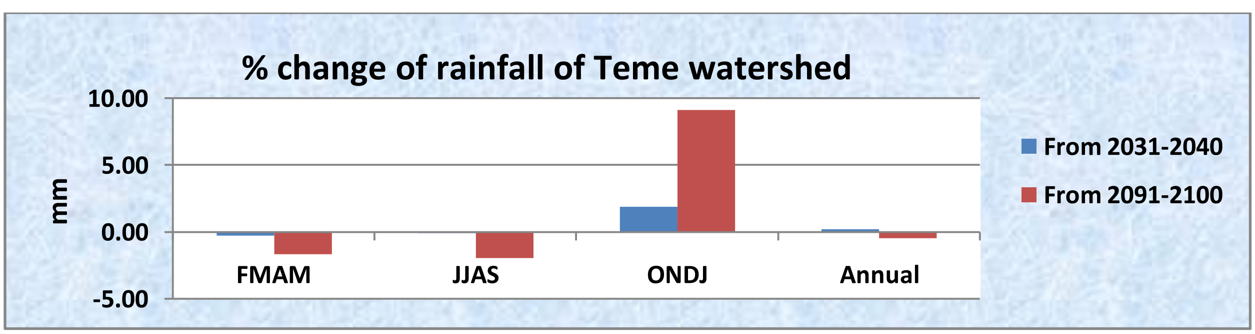



% change of rainfall of Koga watershed
10.00
5.00
0.00
-5.00
mm
FMAM
JJAS
ONDJ
Annual
From 2031-2040
From 2091-2100


% change of rainfall of Muger watershed
5.00
0.00
-5.00
-10.00
mm
FMAM
JJAS
ONDJ
Annual
From 2031-2040
From 2091-2100

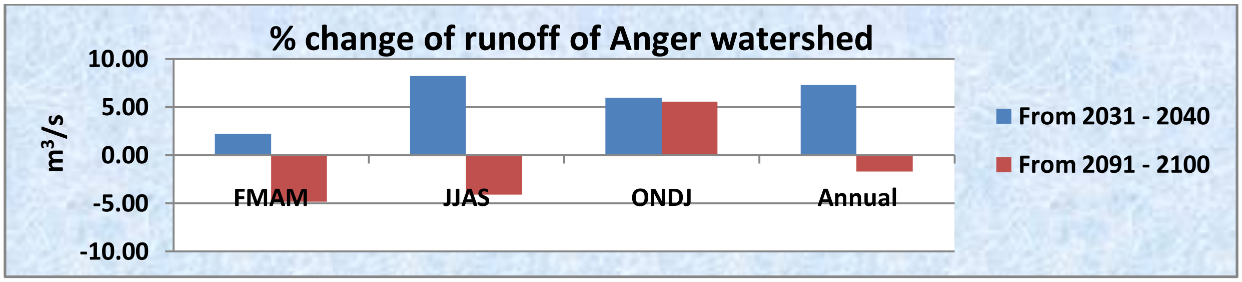

% change of rainfall of Neshi watershed
6.00
4.00
2.00
0.00
-2.00
-4.00
mm
FMAM
JJAS
ONDJ
Annual
From 2031-2040
From 2091-2100

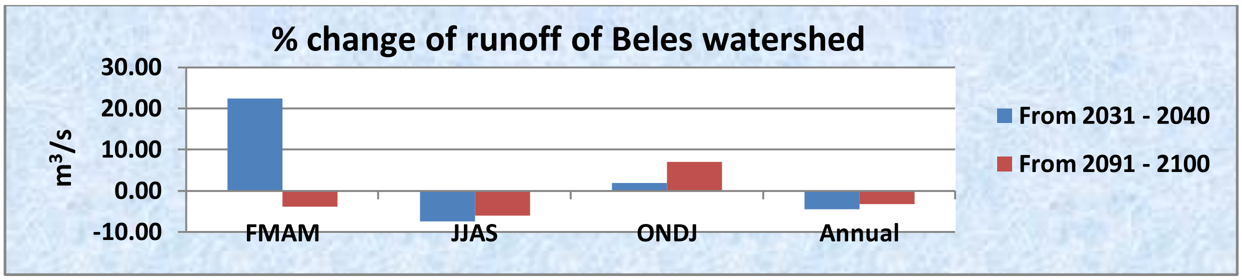

% change of rainfall of Sechi watershed
30.00
20.00
10.00
0.00
-10.00
mm
FMAM
JJAS
ONDJ
Annual
From 2031-2040
From 2091-2100

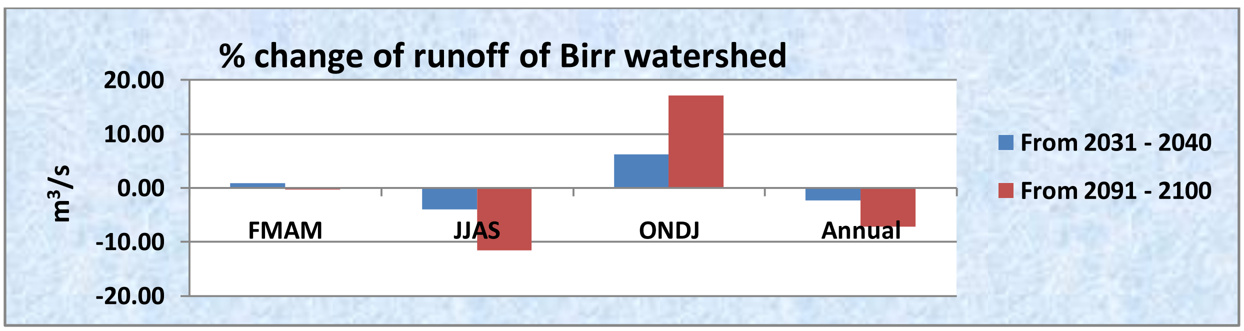

% change of rainfall of Teme watershed
10.00
5.00
0.00
-5.00
mm
FMAM
JJAS
ONDJ
Annual
From 2031-2040
From 2091-2100

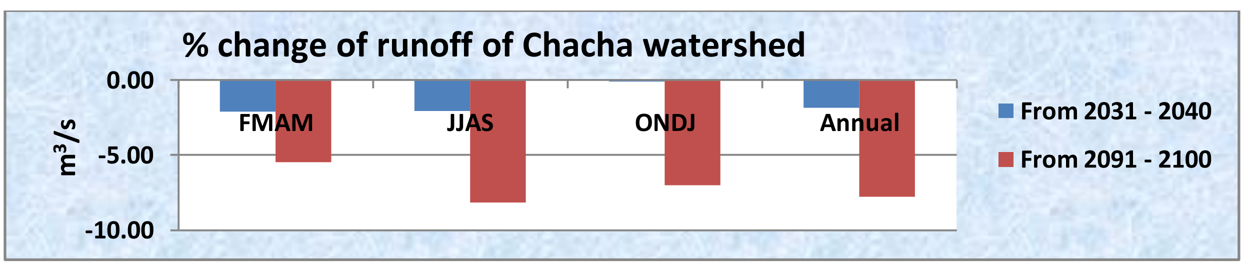
APPENDIX H

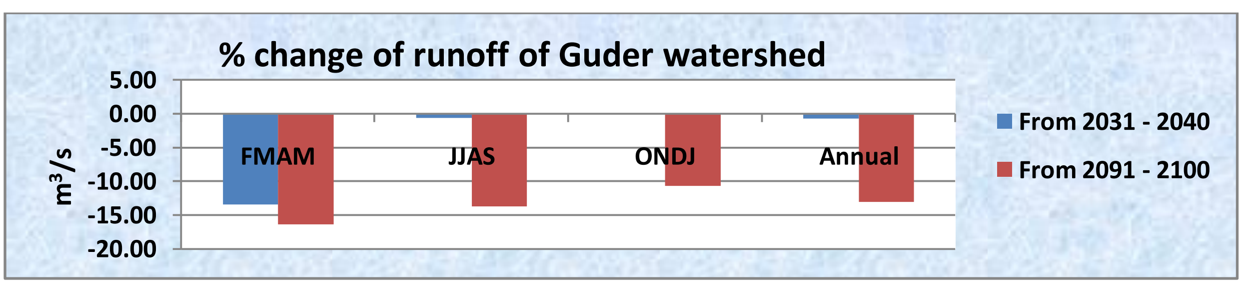
FIGURE H.1 Percent of change of runoff for the two future time series (2031-2040) and (2091-2100) with respect to base period (1991-2000).

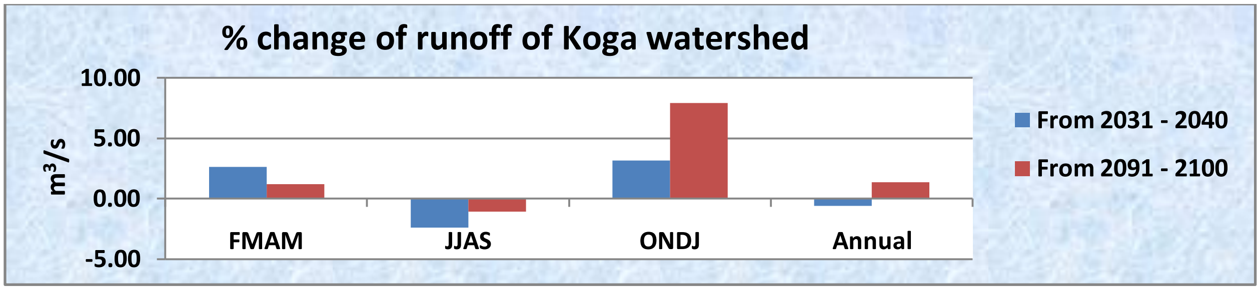


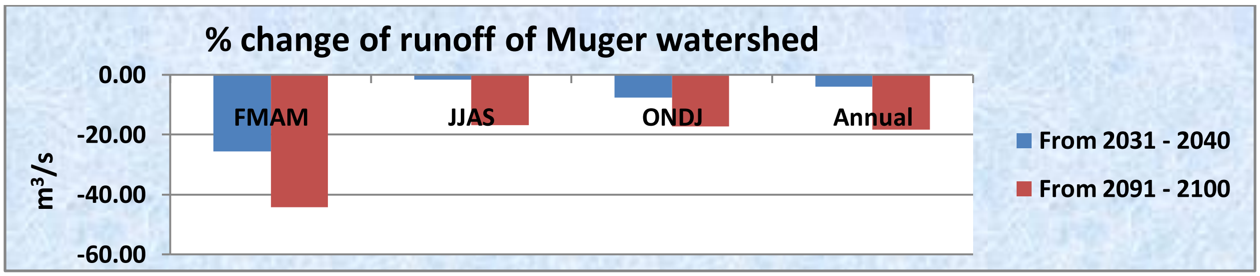


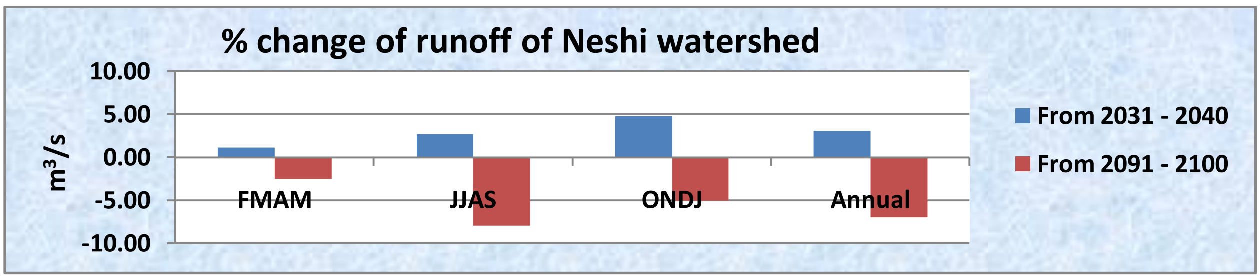


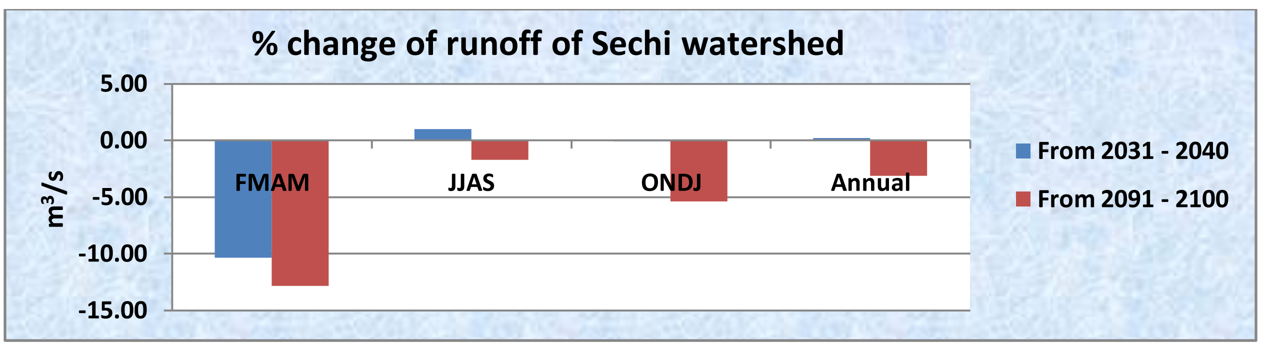


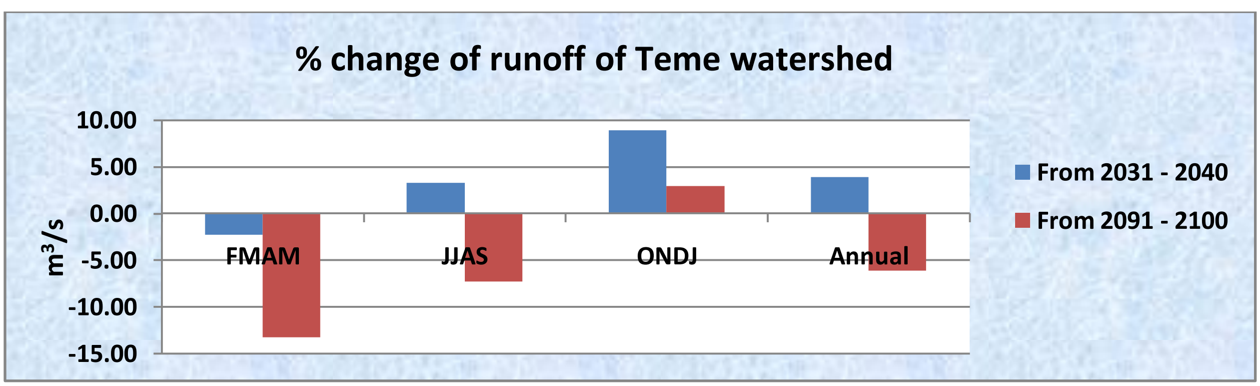



% change of runoff of Koga watershed
m³/s
10.00
5.00
0.00
-5.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091 - 2100


% change of runoff of Muger watershed
m³/s
0.00
-20.00
-40.00
-60.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091 - 2100

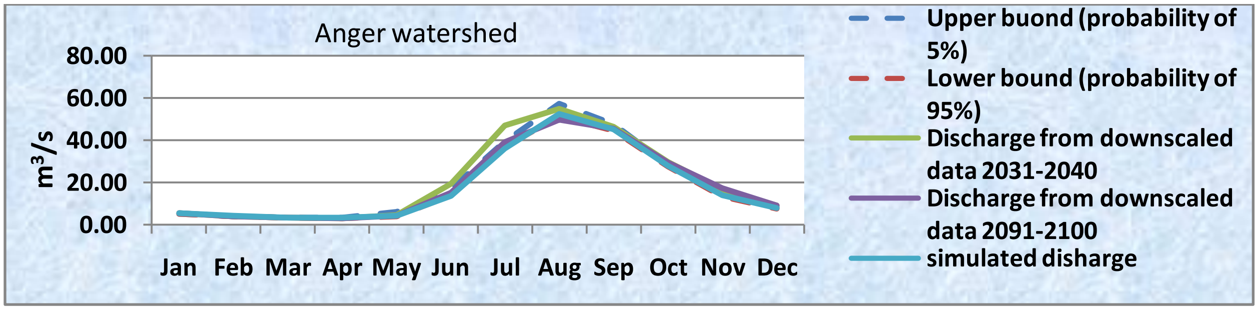

% change of runoff of Neshi watershed
m³/s
10.00
5.00
0.00
-5.00
-10.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091 - 2100

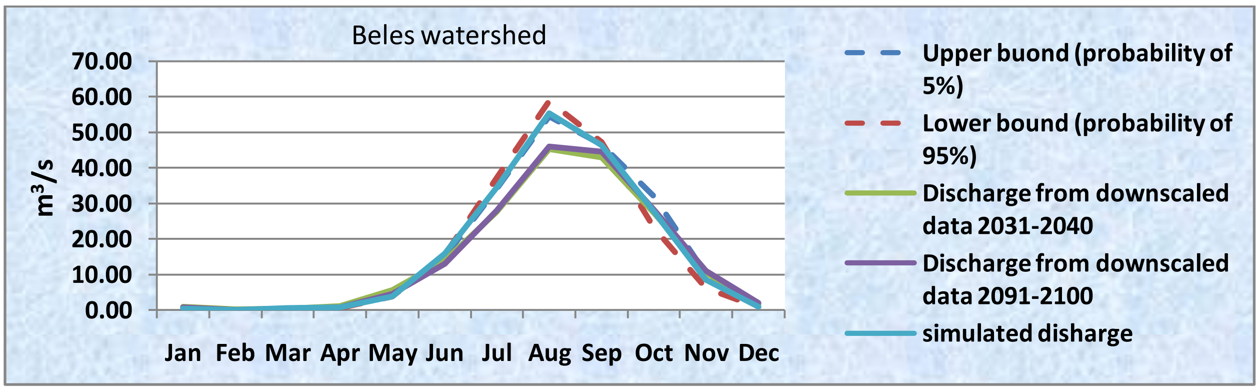

% change of runoff of Sechi watershed
m³/s
5.00
0.00
-5.00
-10.00
-15.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091 - 2100

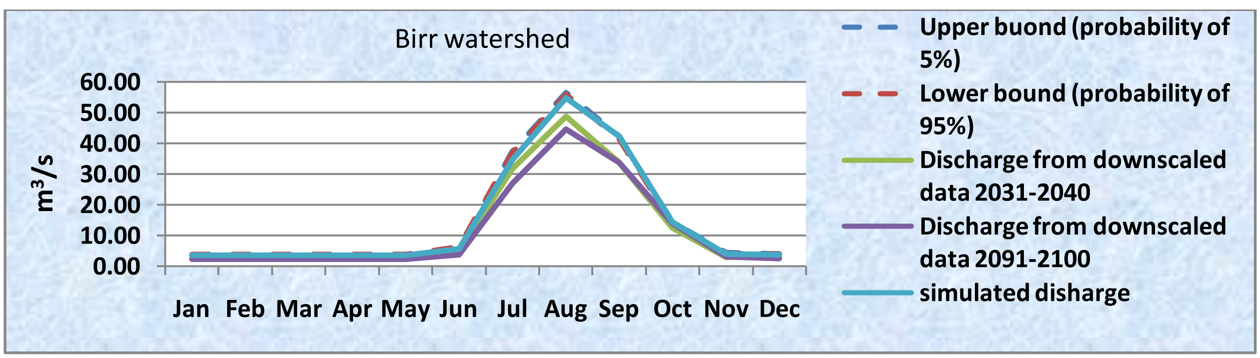

% change of runoff of Teme watershed
m³/s
10.00
5.00
0.00
-5.00
-10.00
-15.00
FMAM
JJAS
ONDJ
Annual
From 2031 - 2040
From 2091 - 2100

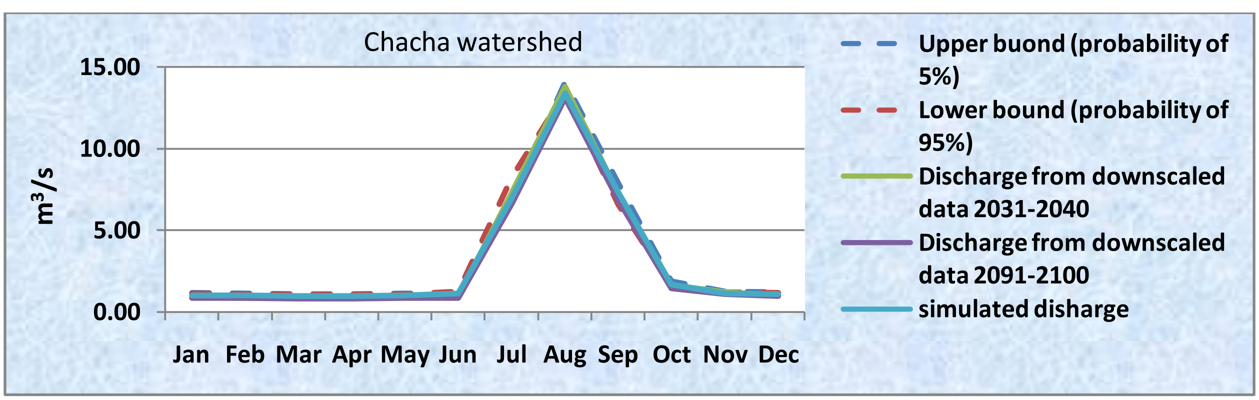
APPENDIX I

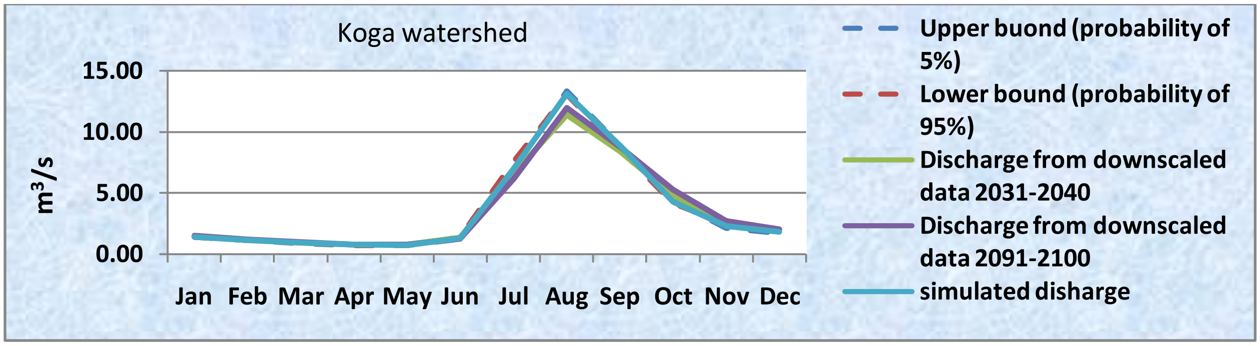
FIGURE I.1 the upper and lower bounds with future generated runoff (checking hydrologic uncertainty)

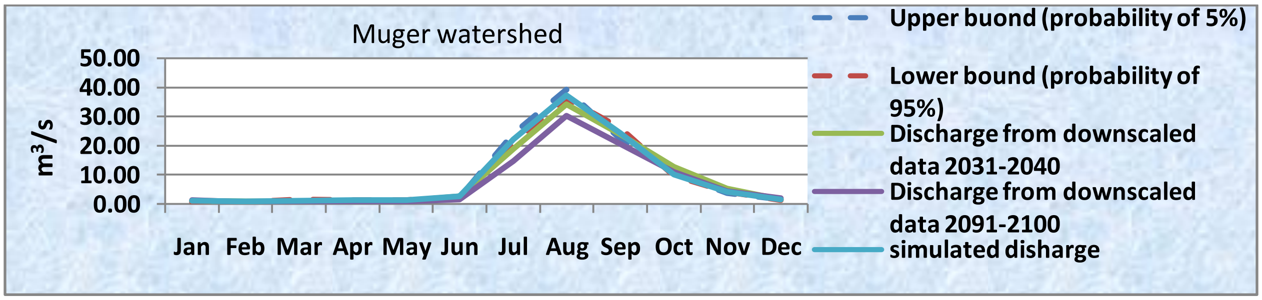


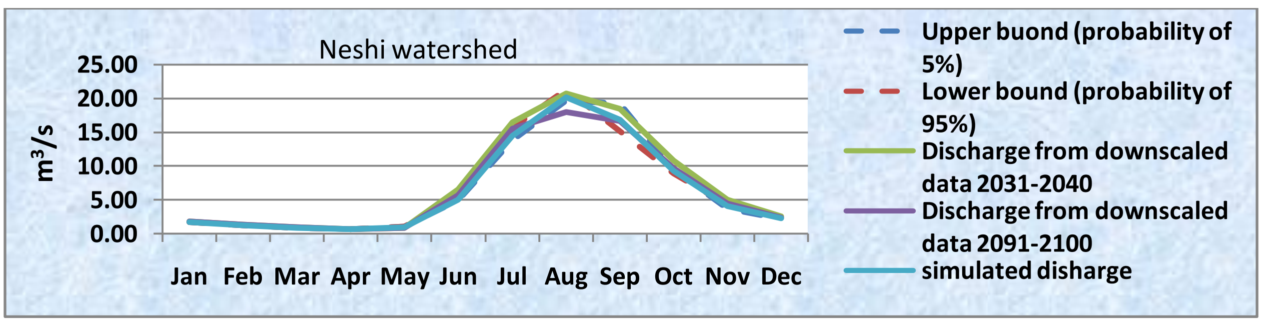


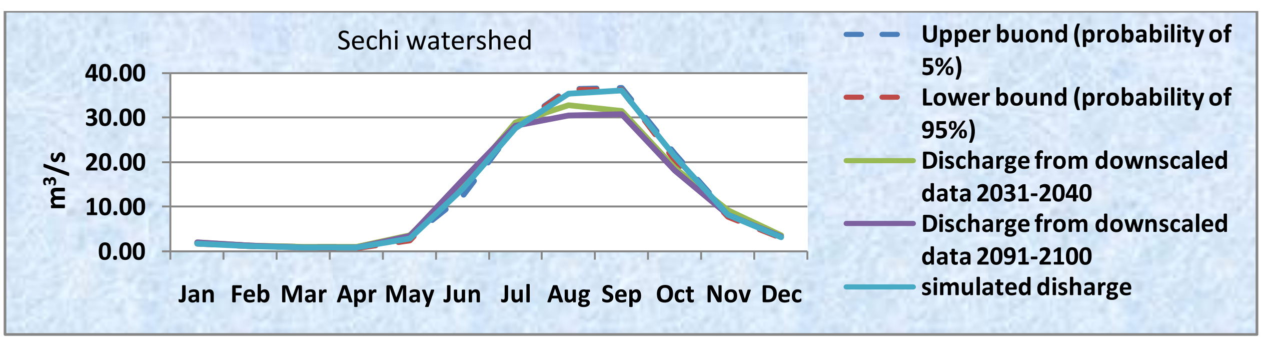


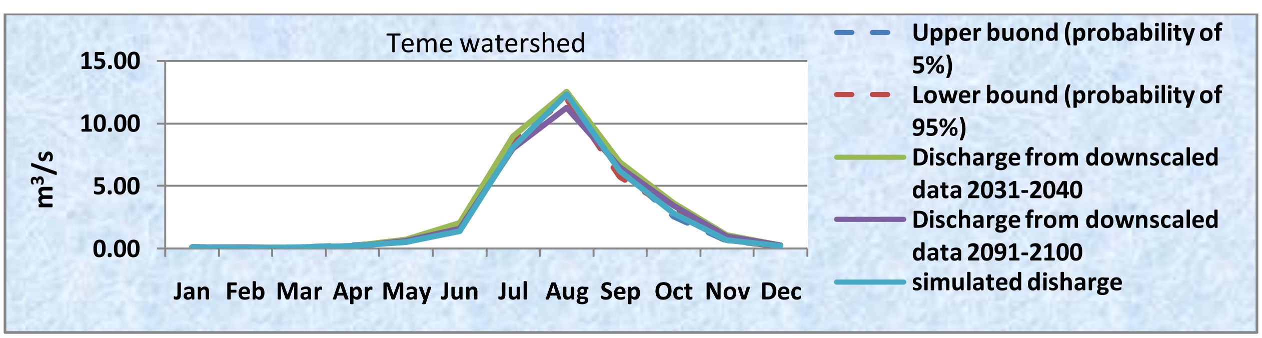



Koga watershed
15.00
10.00
5.00
0.00
m³/s
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Upper buond (probability of 5%)
Lower bound (probability of 95%)
Discharge from downscaled data 2031-2040
Discharge from downscaled data 2091-2100
simulated disharge


Muger watershed
50.00
40.00
30.00
20.00
10.00
0.00
m³/s
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Upper buond (probability of 5%)
Lower bound (probability of 95%)
Discharge from downscaled data 2031-2040
Discharge from downscaled data 2091-2100
simulated disharge


Neshi watershed
25.00
20.00
15.00
10.00
5.00
0.00
m³/s
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Upper buond (probability of 5%)
Lower bound (probability of 95%)
Discharge from downscaled data 2031-2040
Discharge from downscaled data 2091-2100
simulated disharge


Sechi watershed
40.00
30.00
20.00
10.00
0.00
m³/s
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Upper buond (probability of 5%)
Lower bound (probability of 95%)
Discharge from downscaled data 2031-2040
Discharge from downscaled data 2091-2100
simulated disharge


Teme watershed
15.00
10.00
5.00
0.00
m³/s
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Upper buond (probability of 5%)
Lower bound (probability of 95%)
Discharge from downscaled data 2031-2040
Discharge from downscaled data 2091-2100
simulated disharge