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DEPARTMENT OF CIVIL ENGINEERING



EVALUATION OF CLIMATE CHANGE IMPACT ON OMO GIBE BASIN
(CASE STUDY OF GILGEL GIBE III RESERVIOR)

By

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March, 2012

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A thesis submitted to the School of Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Hydropower Engineering

Addis Ababa Technology Institute

March, 2012

Certification

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa University a dissertation entitled "***Evaluation of Climate Impact on Omo Gibe Basin (Case Study of Gilgel Gibe III Reservoir)***" in partial fulfillment of the requirement for the degree of Master of Science in Hydropower Engineering.

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Evaluation of Climate Change Impact on Omo Gibe Basin

(Case Study of Gilgel Gibe III Reservoir)

Thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering under Hydro Power Engineering Stream.

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ABSTRACT

Global climate change is known to influence regional hydrology, through changes in patterns of precipitation, stream flow and other hydrologic variables. With several plausible climate change scenarios in place for future, it is important to assess the possible impact on water resources, arising out of such scenarios. Such an exercise involves projections of climatic variables (e.g., temperature, humidity, mean sea level pressure etc.) at global scales, downscaling of larger scale climatic variables to local scale hydrologic variables and computation of hydrologic risk for use in water resources planning and management. This research presents the results of a study on downscaling large scale atmospheric variables simulated with General Circulation Models (GCMs) to meteorological variables at local scale in order to investigate the hydrological impact of possible future climate change in Omo Gibe Basin (Ethiopia). Statistical Downscaling Model (SDSM) was employed to convert the GCM output into daily meteorological variables appropriate for hydrological impact studies. The meteorological variables (minimum temperature, maximum temperature and precipitation) downscaled from SDSM were used as input to the HBV hydrological model which was calibrated ($R^2=0.798$) and validated ($R^2=0.804$) with historical data to investigate the possible impact of climate change in the catchment. The results obtained from this investigation indicate that there is significant variation in the seasonal and monthly flow. The impact of climate change may cause a decrease in monthly flow volume up to 23.55% in the 2020s and increase up to 33.43% in the 2050s. In the main rainy season (June-September) the runoff will be reduced by 21.67% in the 2080s. Seasonal flow volume may show increase up to 18.72% in bega and 12.87% in Belg. However Kiremt season show decrease up to 17.59%. The result from different scenario also indicates that the catchment is sensitive to climate change.

Key words: Climate change, GCM, HBV, SDSM

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LIST OF ABBREVIATIONS

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
DEM	Digital elevation model
EEPCO	Ethiopian Electric Power Corporation
FAO	Food and Agricultural Organizations
FC	Parameter defining the maximum soil moisture storage in HBV model
GCM	Global circulation Model
HadCM3	Hadley Center for Climate Prediction
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
KHQ	Parameter representing a recession coefficient at a corresponding reservoir volume in HBV model
MoWR	Ministry of water resource
NMSA	Ethiopian National Metrological Service Agency
NCEP	National Center for Environmental Prediction
PERC	Percolation from upper to lower reservoir box [mm/day]
R²	Nash and Sutcliffe coefficient
RCM	regional climate model
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
WMO	World Metrological Organization

1. INTRODUCTION

1.1 Background

Global climatic changes caused by increases in the atmospheric concentration of carbon dioxide and other trace gases may begin to appear within the next few decades. It has been estimated by many authors (IPCC, 2007) that in 1990-level emissions of CO₂ to the atmosphere remain unabated, its concentration in the atmosphere could nearly double by the year 2100 or there about. Assessments of the consequences of a possible climate change for 'double CO₂' (2 x CO₂) conditions have become standard practice. Such hydrologic changes will affect nearly every aspect of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply, and fish and wildlife management. The tremendous importance of water in both society and nature underscores the necessity of understanding how a change in global climate could affect regional water supplies. (IPCC, 2007)

Global atmospheric general circulation models (GCMs) have been developed to simulate the present climate and have been used to predict future climatic change. While GCMs demonstrate significant skill at the continental and hemispheric spatial scales 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 (Wigley et al., 1990). When considering the impacts of global climate change the focus is primarily on societal responses to the local and regional consequences of large scale changes.

The conflict between GCM performance at regional spatial scales and the needs of regional-scale impact assessment is largely related to model resolution in such a way that, while GCM accuracy decreases at increasingly finer spatial scales, the needs of impacts researchers conversely increase with higher resolution. (Chong-yu Xu, 1999)

Climate change profoundly affects the natural and social environment. For example, changes in seasonal to inter annual climate strongly affect agricultural production, the quantity and quality of water resources, and resources coming from land and marine ecosystems.

IPCC (2007b) indicates several key impacts on different sectors that are correlated with climate change such as freshwater resources and their management; ecosystems; food, fiber and forest products; coastal systems and low lying areas; industry ,settlement and society; and health.(Heru santoso,2008)

The Earth's climate is a highly complex and nonlinear system, and it is difficult to fully understand and simulate how climate is changing in space and time. With the advent of high speed computers and a better understanding of the climate system, numerical modeling of atmospheric and oceanic circulations has allowed climate forecasting and climate change projections to become increasingly skillful. The current state of climate modeling science is accomplished with general circulation models (GCMs), which integrate complex interactions of atmosphere-land-ocean-ice systems that simulate the Earth's climate and projections of its future change on timescales of seasonal forecasts to decades and centuries. GCMs run at climate centers throughout the world and reviews the current state of GCMs, including approaches, limitations, uncertainties, and skills. It also presents uncertainties associated with climate projections and downscaling techniques (Edward A.Parson.et al, 2007).

In addition to climate change variability, many developing countries, including Ethiopia will be confronted with energy crisis in the near future. Worldwide efforts and research are being carried out to exploit the existing conventional sources as well as newly developing clean energy sources. Having relatively high altitudes and huge unused water potential, Ethiopia has advantages in view of hydropower potential. Freely flowing surface waters of Ethiopia should therefore be utilized urgently for hydropower generation.

There is an unprecedented interest in Ethiopia to invest more in hydropower and build hydro-electric power stations of varying capacities. The next decades will therefore be devoted to assessment of clean energy sources with special emphasis to hydropower development to sustain the energy sector.

1.2 Statement of the Problems

Power production is one of several current and future critical issues facing Ethiopia. Since Ethiopia is on the way to transform to industrialization, investigating future climate change impact on power production is timely needed task. In the recent years there was shedding of light over the country, this crisis in the power supply has reached such a critical point that blackouts(shedding of light) occur every other day. The water level in the currently operating hydropower reservoirs was going down causing power failure. Hydro power reservoirs are not holding water in their full capacity to serve though out the season.

It is advisable to study the impact of climate change at sub-basin level. Hence, this study was targeted to address the impact of climate change on sub-basin level and understanding the general trends of the future climate variables such as Precipitation, Maximum Temperature and Minimum Temperature compared to the present condition and in what extent can this affect the reservoir inflow performance.

Therefore, this research evaluates climate variability and change on Gilgel Gibe III reservoir inflow, which have significant effect on socio economic activities carried out thought out the country.

1.3 Objective of the Study

- ✚ The general objective of this study is to evaluate the impact of climate change on the Gilgel Gibe III reservoir.
- ✚ The specific objectives are
 - ➡ To develop and evaluate climate scenario data for maximum temperature, minimum temperature and precipitation based on a General Circulation Model and a Statistical Downscaling Model.
 - ➡ To evaluate the Gilgel Gibe III reservoir inflow using different downscaled climate scenarios.
 - ➡ To evaluate the rate of change in open water evaporation from Gilgel Gibe III reservoir with the future climate change.

1.4 Thesis Outline

This thesis contains six chapters and organized as follows: Chapter one is an introduction to the study. Chapter two describes the study area. Chapter three reports on a literature review about the subject matter. Chapter four and five describes the methodology applied and data analysis in this research. In chapter six the results are shown and discussed. Chapter seven finalizes the thesis by conclusions and recommendations.

2. DESCRIPTION OF THE STUDY AREA

2.1 Location of Omo-Gibe Basin

Omo-Gibe Basin is situated in the southwest of Ethiopia between the latitudes of $4^{\circ} 30'$ and $9^{\circ} 30'N$; and longitudes of 35° and $38^{\circ} E$. The basin has an area of about 79,000 km², about 51% of the basin area falls in the lowlands. The Omo River flows into Lake Turkana with its tributaries; the Gibe and the Gojeb draining the north and the west of the basin respectively.

It is an enclosed river basin that flows in to the Lake Turkana in Kenya which forms its southern boundary. The western watershed is the range of hills and mountains that separate the Omo-Gibe Basin from the Bako-Akobo Basin. To the north and northwest the basin is bounded by the Blue-Nile Basin with small area in the northeast bordering the Awash Basin. The whole of the eastern side borders the Rift Valley Lakes Basin (Richard Woodroof and Associates, 1996].

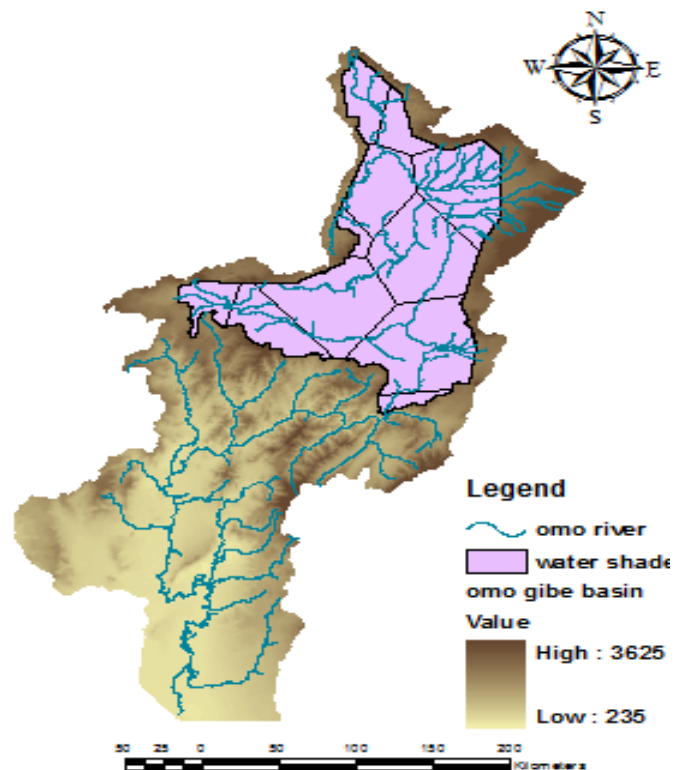


Figure 1.1 Map of location of study area

2.2 Location of Gilgel Gibe III Project

The Gibe III project area is some 400 km South West of Addis Ababa and 150 km South-west of Hawassa. The project is located within the jurisdiction of the Mareka Gana Wereda of the Dawro Zone and Kindo Koyisha Wereda of Sodo zone of the Southern Nations and Nationalities People Regional State . The Gibe III hydropower plant is the third plant of the Gibe cascade developing the hydroelectric potential of the Omo-Gibe river including: Gilgel Gibe or Gibe I operating since 2004 Gibe II currently completed Omo-Gibe IV and Gibe V projects, for hydropower and agricultural uses, currently being planned. The Gibe III project is located (coordinates 312,200 E, 757 200 N, dam axis) and of the other plants of the Cascade within the Omo river basin. [EEPCO, 2006]

2.3 Climate

The climate of the Omo-Gibe River Basin varies from a hot arid climate in the southern part of the floodplain to a tropical humid one in the highlands that include the extreme north and north-western part of the Basin. Intermediate between these extremes and for the greatest part of the basin the climate is tropical sub-humid. Rainfall in Omo-Gibe Basin varies from over 1900 mm per annum in the north central areas to less than 300mm per annum in the south. Moreover, the rainfall regime is unimodal for the northern and central parts of the basin and bimodal for south. The mean annual temperature in Omo-Gibe Basin varies from 16⁰c in the highlands of the north to over 29⁰c in the lowlands of the south. [Richard Woodroof and Associates, 1996]

2.4 Topography

The topography of the Omo-Gibe basin as a whole is characterized by its physical variation. The northern two-thirds of the basin has mountainous to hilly terrain cut by deeply incised gorges of the Omo, Gojeb, and Gilgel-Gibe Rivers, while the southern one-third of the basin is a flat alluvial plain punctuated by hilly areas.

The northern and central half of the basin lies at an altitude greater than 1500 m a.s.l with maximum elevation of 3360 m a.s.l (located between Gilgel-Gibe and Gojeb tributaries), and the plains of the lower Omo lies between 400-500 m a.s.l.

The head waters of the Great-Gibe River are at an elevation of about 2200 m a.s.l. Although there are some important tributaries from different directions, the general direction of flow of the Gibe River is southwards, towards the Omo River and then to Lake Turkana a fault feature, filled with alluvial and lacustrine sediments of recent origin associated with the Great Rift Valley. The Gibe river is known as the Omo River in its lower reaches, south-westwards from the confluence with the Gojeb River. This is the reason behind the name Omo-Gibe River Basin. [Richard Woodroof and Associates, 1996]

2.5 Land Use

In a very broad term, most of the northern catchments of the Omo-Gibe Basin is under extensive cultivation with increased land pressure, meaning the expansion of cultivated areas in to increasingly marginal lands at the expense of wood lands. Deforested areas are now confined to areas too steep and inaccessible to farm. The flatter poorer drained bottom lands of the northern catchments are usually not cultivated but are used for dry season grazing and eucalyptus tree plantations.

The main gorges of the basin are relatively unpopulated and support a cover of open wood-land and bush-land with grasses, the eastern part of the basin has some of the most densely populated and intensively farmed areas in the country, let alone the basin. The south of the basin is more sparsely populated with a greater population of natural vegetation, through even here the forest is decimated at an alarmingly rate. [Richard Woodroof and Associates, 1996]

2.6 Relief

Many of the rivers rise in plateau areas at an elevation above 2000 m and parts of the basin are higher than 3000 m. Lake Turkana is at an elevation of around 470 m. The Gibe itself rises at an elevation of 2000 m and crosses the 1000 m contour between the Megecha and Gojeb tributaries.

To the west of the river basin the watershed reaches an elevation of 3000 m between the Gojeb and Gilgel-Gibe. To the south-east, parts of the Meki sub catchment area are above 2000 m. [Richard Woodroof and Associates, 1996]

3. LITERATURE REVIEW

3.1 Climate Change

On a global scale, mean annual surface temperature has increased over the past century by 0.6°C (IPCC, 2001). In the scientific community, there is a general consensus that this increase during the past 50 years can be attributed partly to Greenhouse Gas (GHG) emissions from human activity. Global Climate Models (GCMs), which are capable of providing credible projections of climate changes into the next 100 years, use a coarse global grid scale (IPCC, 2001). Temperature and precipitation trends, however, differ on a regional scale due to different feedbacks appearing from synoptic to local scales. This results in differing impacts at different regional scales. To date, impacts researchers have only had GCM scale output to help determine the impacts of climate change to species and ecosystems on a 50-100 year time scale.

In order to best assess the expected climate change impacts on a species, ecosystem or natural resource in a region, climate variables and climate change scenarios must be developed on regional or even site-specific scale (Wilby et al, 2001). To provide these values, projections of climate variables must be 'downscaled' from the GCM results, utilizing either dynamical or statistical methods (IPCC, 2001)

Downscaling can be accomplished by using either a Regional Climate Model (RCM), or a statistical technique. Since RCM model output is not readily available for Atlantic Canada, a statistical technique was chosen for this study. Statistical models are not only readily available, but have the added advantage of being extremely parsimonious. Thus most downscaling experiments can be run in minutes on a Personal Computer (PC) with a moderate processor speed(400-600 MHz), allowing for multiple computations to be run in real time, if required. Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2007).

3.2 Climate Change and Water/Reservoir

Water is involved in all components of the climate system. Therefore, climate change affects water through a number of mechanisms. Although climate change is expected to affect many sectors of the natural and man-made sectors of the environment, water is considered to be the most critical factor associated with climate change impacts. Therefore, it is very important to make evaluations of the expected impact on the hydrology and water resources due to expected climate changes regardless of the direction of the change (Ringius et al. 1996).

3.3 Climate Change Scenarios

A scenario is a description of potential future conditions produced to inform decision-making under uncertainty. Scenarios use to make decisions that involve high stakes and poorly characterized uncertainty, which may thwart other, conventional forms of analysis or decision support. Originally developed to study military and security problems, scenarios are now widely used for strategic planning and assessment in businesses and other organizations, and increasingly to inform planning, analysis, and decision-making for environmental issues, including climate change.

Scenarios can serve many purposes. They can inform specific decisions, or can provide inputs to assessments, models, or other decision-support activities when these activities need specification of potential future conditions. They can also provide various forms of indirect decision support, such as clarifying an issue's importance, framing a decision agenda, shaking up habitual thinking, stimulating creativity, clarifying points of agreement and disagreement, identifying and engaging needed participants, or providing a structure for analysis of potential future decisions.(U.S.CCSP,2007)

3.3.1 Climate Change Scenario Causal Relationship

Developing a scenario exercise involves many design choices, of which the most important involve choosing the few key un-certainties to represent in alternative scenarios. Five types of scenarios have been developed to address different aspects of the climate-change issue; these are distinguished by where they fall along a simple linear causal chain extending from the socio-economic determinants of greenhouse-gas emissions through the impacts of climate change as shown in Figure 3.1. (This figure does not represent the complete causal structure of the climate issue, which has many linkages and feedbacks. Rather, this simple structure only illustrates how scenarios have been used to fit within the simplest and most prominent causal pathway of the issue.)(Edward A Parson et al, 2007)

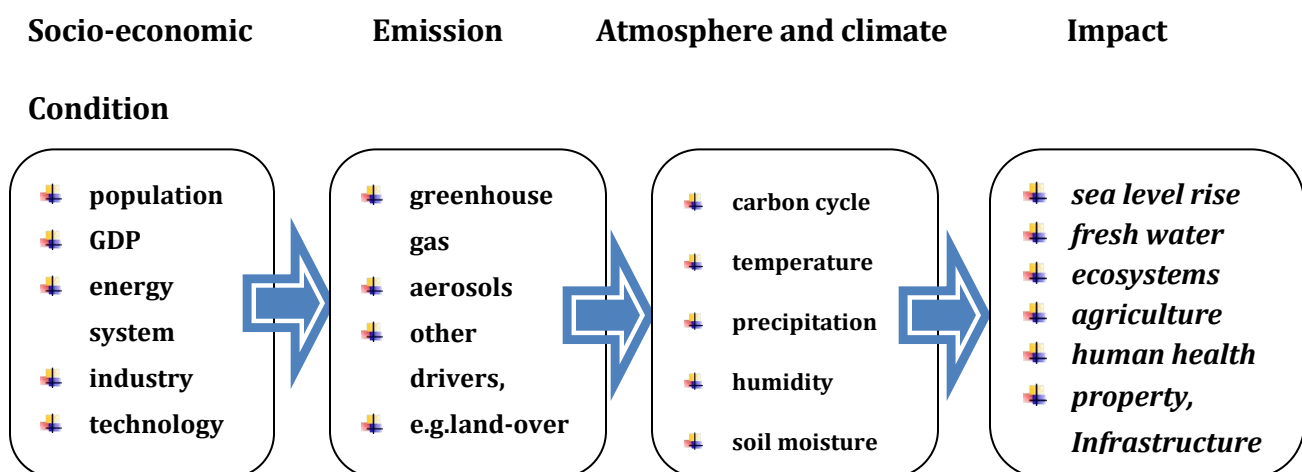


Figure 3.1 Scenarios of anthropogenic climate change: simple linear causal chain

3.3.2 Use of Scenarios in Climate-Change Decisions

Climate change profoundly affects the natural and social environment. For example, changes in seasonal to inter annual climate strongly affect agricultural production, the quantity and quality of water resources, and resources coming from land and marine ecosystems. IPCC (2007b) indicates several key impacts on different sectors that are correlated with climate change such as freshwater resources and their management; ecosystems; food, fiber and forest products; low lying areas; industry, settlement and society; and health.

Decision-makers and resource managers require information regarding future changes in climate average and variability to better anticipate potential impacts of climate change. However, future climate patterns are difficult to predict (Goodess 2000).

In particular, the future radiative forcing from greenhouse gases is difficult to quantify because the emissions of these gases depend on many assumptions and uncertain factors such as population growth, the use of carbon fuel as an energy source, technological development, economic development, policy and attitudes towards environment, etc.

To improve understanding of the complex interactions of the climate system, ecosystems, and human activities and conditions, the research community develops and uses scenarios. These scenarios provide plausible descriptions of how the future might unfold in several key areas -socioeconomic, technological and environmental conditions, emissions of greenhouse gases and aerosols, and climate. When applied in climate change research ,scenarios help to evaluate uncertainty about human contributions to climate change, the response of the Earth system to human activities, the impacts of a range of future climates, and the implications of different approaches to mitigation (measures to reduce net emissions) and adaptation (actions that facilitate response to new climate conditions).

Scenarios can make valuable contributions to climate-change decision-making. There is a big gap between the use of scenarios in current practice and their potential contributions, but interest in using scenarios is increasing.

Scenarios of global emissions and resultant climate change are required by many diverse climate-related decision-makers, but beyond these common requirements decision-makers' needs from climate-change scenarios are highly diverse.

Mitigation policy-makers, who are mainly but not exclusively national officials, need scenarios of global and national emissions trends, resultant climate change, and aggregate impacts.

In addition, they need scenario information about the potential policy environment for their choices, including alternative scenarios of other nations' mitigation strategies, international mitigation decisions, and implementation and compliance. Income cases, they can usefully employ target-driven scenarios for back casting analysis. Mitigation decisions require scenario development capacity at the national level.

Energy resource and technology managers, who are mainly private-sector actors, primarily need scenarios that represent alternative policy regimes over the 30- to 50-year time horizons relevant for investment and technology-development decisions. Scenarios of emissions and climate change may provide background, but do not capture the most important uncertainties for these decision-makers.

Large-scale, official assessments are currently the main users of scenarios and will likely remain major users. Scenarios in assessments mostly support further analysis, modeling, and assessment. They can also help frame the climate issue for the public and policy-makers. Presentation of scenarios in assessments leads to additional un-foreseen uses.

Scenarios contain unavoidable elements of judgment in their production and use. This makes them vulnerable both to attempts at bias and to partisan attack. The most productive response lies in transparency about the process, reasoning, and assumptions used to produce scenarios, which can both help limit bias in scenario production and focus subsequent argument on underlying uncertainties. For this reason, climate scenarios have been developed to investigate the potential consequences of anthropogenic climate change (Heru, 2008)

3.3.3 Developing Climate Change Scenarios

Of particular interest for projections of water resources, with or without climate change, are possible changes in dam construction and decommissioning, water supply infrastructure, waste water treatment and reuse, desalination, pollutant emissions and land use, particularly with regard to water resource development projects.

Irrespective of climate change, new dams are expected to be built in developing countries for hydropower generation as well as water supply, even though their number is likely to be small compared to the existing large dams. However, the impacts of a possible future increase in hydropower demand have not been taken into account (World Commission on Dams, Climate scenario data is likely to increase. Several of these pollutants are not removed by current wastewater treatment technology. Modifications of water quality may be caused by the impact of sea-level rise on storm-water drainage operations and sewage disposal in coastal areas. [IPCC, 2007]

Climate scenarios specify potential future climate conditions to inform assessments of impacts, vulnerabilities, and adaptation options, and inform decision-making for adaptation or mitigation. They can be produced by arbitrary perturbation of present conditions, by using climates from elsewhere or the past as a proxy for potential future climate in a given location, or by climate-model simulations driven by some specified scenario of future emissions.

Emissions scenarios present future paths of greenhouse-gas emissions or other climate perturbations. A major use of these is to provide needed inputs to climate models. Such scenarios may specify simple arbitrary perturbations of emissions or concentrations

(e.g., doubling atmospheric CO₂), or time paths reflecting specified assumptions for evolution of socio-economic drivers such as population, economic growth, and technological change. (Edward A Parson et al, 2007)

Climate change scenarios for impact assessment can be developed in three major techniques; analogue, synthetic and GCM-based climate change scenarios. These scenario construction techniques were dealt as below.

1. Analogue Scenarios:

Analogue scenarios are constructed by identifying a recorded climate regime which may resemble the future climate anticipated for a particular site or region. These recorded climates may be identified in the long observational record at a site (temporal analogues) or from other geographical locations (spatial analogues). Temporal analogues can be either palaeoclimatic analogues or instrumental analogues. In palaeoclimatic analogues the past climate may be reconstructed by using information from the geological record and used to construct scenarios used to represent future climate conditions. While the instrumental analogues uses the past periods of instrumental records to provide analogue for the future climate. Spatial analogues are regions which today have a climate analogous to that anticipated for the study region in the future. In essence, the climate record from one location is assumed to represent the future climate at a different location. Such scenarios have the advantage of representing conditions that have actually been observed and experienced. However, since the causes of the analogue climate are most likely due to changes in atmospheric circulation, rather than due to greenhouse gas-induced climate change, these types of scenarios are not recommended to represent the future climate in quantitative impact assessments (Smith and Hulme, 1998).

2. Synthetic Climate Change Scenario:

It is also called arbitrary scenario, which is the simplest scenario available. In this scenario type, a historical record for a particular climate variable is simply perturbed by an arbitrary amount. For example the station temperature may increase by +20c.

It is mainly important to identify the sensitivity of an exposure unit to a plausible range of climatic variations. In this scenario it is impossible to describe a realistic set of changes for all climate variables that are physically plausible and internally consistent.

3. Scenario from Global Circulation Models:

Global climate models are the only credible tools currently available for simulating the response of the global climate system to increasing green house gas concentrations (IPCC-TGCIA, 1999). Although the output from GCMs is not generally of a sufficient resolution or reliability to be applied directly to represent present day climate or consequently future climate conditions, it is standard practice to use observed data in the form of daily or monthly time series representing the current baseline period (e.g. 1961-1990) and to apply changes derived from GCM information (i.e. the scenarios) to these observed data.

The climate models simulate the present climate for extended simulation periods under present climate conditions without any change in external climate forcing. Then the quality of the simulation is evaluated with observations of the current climate. After the model is evaluated, two different strategies have been applied to make projections of future climate change. The first, so-called equilibrium method is to change, e.g. double, the carbon dioxide concentration and to run the model again to a new equilibrium.

The differences between the climate statistics of the two simulations provide an estimate of the climate change corresponding to the doubling of carbon dioxide, and of the sensitivity of the climate to a change in the radiative forcing. This method does not provide insight into the time dependence of climate change. The second, so-called transient method is to force the model with a greenhouse gas and aerosol scenario. The difference between such simulation and the original baseline simulation provides a time-dependent projection of climate change. This transient method requires a time-dependent profile of greenhouse gas and aerosol concentrations. These may be derived from so-called emission scenarios (IPCC, 2001).

3.3.4 The SRES Emissions Scenarios

In order to best assess the expected climate change impacts on a species, ecosystem or natural resource in a region, climate variables and climate change scenarios must be developed on a regional or even site-specific scale (Wilby et al, 2001).

To provide these values, projections of climate variables must be ‘downscaled’ from the GCM results, utilizing either dynamical or statistical methods (IPCC, 2001)

There are four narrative storylines defined by special report on emission scenario (SRES) team to describe the relationship between the driving force of green house gas and aerosols emission and their evolution in the next century, labeled as A1, B1, A2 and B2. The storylines can be summarized as follows;

A1 scenario family: - reflects the world as very rapid economic growth, global population Peaks in the mid-century and decline thereafter, and rapid introduction of new and more efficient technologies.

B1 scenario family: - reflects the world as a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resource efficient technologies.

A2 scenario family: - reflects the world as continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

B2 scenario family: - reflects the world in such a way that the world emphasis goes to local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.



Figure3.2 the four IPCC SRES scenario storylines

3.4 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 4° 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.

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.

Reviews typically group downscaling methodologies into four main types: a) dynamical climate modeling, b) synoptic weather typing, c) stochastic weather generation, or d) transfer-function approaches. Each family of techniques is briefly described below.

1. Dynamic downscaling

There are two categories of climatic downscaling, namely dynamic downscaling and statistical downscaling. Dynamical downscaling involves the nesting of a higher resolution Regional Climate Model (RCM) within a coarser resolution GCM. The RCM uses the GCM to define time-varying atmospheric boundary conditions around a finite domain, within which the physical dynamics of the atmosphere are modeled using horizontal grid spacing's of 20–50 km. The main limitation of RCMs is that they are as computationally demanding as GCMs (placing constraints on the feasible domain size, number of experiments and duration of simulations). The scenarios produced by RCMs are also sensitive to the choice of boundary conditions (such as soil moisture) used to initiate experiments.

2. Weather typing

Weather typing approaches involve grouping local, meteorological data in relation to prevailing patterns of atmospheric circulation. Climate change scenarios are constructed, either by re-sampling from the observed data distributions (conditional on the circulation patterns produced by a GCM), or by generating synthetic sequences of weather patterns and then re-sampling from observed data.

Weather pattern downscaling is founded on sensible linkages between climate on the large scale and weather at the local scale. The technique is also valid for a wide variety of environmental variables as well as multi-site applications.

However, weather typing schemes can be parochial, a poor basis for downscaling rare events, and entirely dependent on stationary circulation-to-surface climate relationships.

Potentially, the most serious limitation is that precipitation changes produced by changes in the frequency of weather patterns are seldom consistent with the changes produced by the host GCM (unless additional predictors such as atmospheric humidity are employed).

3. Stochastic weather generators

Stochastic downscaling approaches typically involve modifying the parameters of conventional weather generators such as WGEN, LARS-WG or EARWIG. The WGEN model simulates precipitation occurrence using two-state, first order Markov chains; precipitation amounts on wet days using a gamma distribution; temperature and radiation components using first-order trivariate auto regression that is conditional on precipitation occurrence. Climate change scenarios are generated stochastically using revised parameter sets scaled in line with the outputs from a host GCM. The main advantage of the technique is that it can exactly reproduce many observed climate statistics and has been widely used, particularly for agricultural impact assessment.

4. Transfer functions

Transfer-function downscaling methods rely on empirical relationships between local scale predictands and regional scale predictor(s). Individual downscaling schemes differ according to the choice of mathematical transfer function, predictor variables or statistical fitting procedure. To date, linear and non-linear regression, artificial neural networks, canonical correlation and principal components analyses have all been used to derive predictor-predictand relationships.

The main strength of transfer function downscaling is the relative ease of application, coupled with their use of observable trans-scale relationships. The main weakness is that the models often explain only a fraction of the observed climate variability (especially in precipitation

series). In common with weather typing methods, transfer methods also assume validity of the model parameters under future climate conditions, and the downscaling is highly sensitive to the choice of predictor variables and statistical form.

Given the limitations of GCM grid-point predictions for regional climate change impact studies, an alternative option to using direct GCM-derived hydrological output is to downscale the GCM's climate output for use in hydrological models. Two categories of climatic downscaling, namely, dynamic approaches (in which physical dynamics are solved explicitly) and empirical (the so-called 'statistical downscaling') exist, and are discussed in the following sections.

3.4.1 Relative Skill of Statistical and Dynamical Downscaling

The wide range of downscaling techniques (both dynamical and statistical) has prompted a growing number of model comparisons using generic data sets and diagnostics. Until recently, these studies were restricted to statistical-versus-statistical or dynamical-versus-dynamical model comparisons.

However, some studies are now undertaking statistical-versus-dynamical model comparisons and Table 3.1 summarizes the relative strengths and weaknesses that have emerged.

	Statistical downscaling	Dynamical downscaling
Strengths	• Station-scale climate information from GCM-scale output • Cheap, computationally undemanding and readily transferable • Ensembles of climate scenarios permit risk/ uncertainty analyses • Applicable to 'exotic' predictands such as air quality and wave heights	• 10–50 km resolution climate information from GCM-scale output • Respond in physically consistent ways to different external forcing • Resolve atmospheric processes such as orographic precipitation • Consistency with GCM

Weakness	• Dependent on the realism of GCM boundary forcing • Choice of domain size and location affects results • Requires high quality data for model calibration • Predictor–predictand relationships are often non–stationary • Choice of predictor variables affects results • Choice of empirical transfer scheme affects results • Low–frequency climate variability problematic • Always applied off–line, therefore, results do not feedback into the GCM	• Dependent on the realism of GCM boundary forcing • Choice of domain size and location affects results • Requires significant computing resources • Ensembles of climate scenarios seldom produced • Initial boundary conditions affect results • Choice of cloud/ convection scheme affects (precipitation) results • Not readily transferred to new regions or domains • Typically applied off–line, therefore results do not always feedback GCM
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Table 3.1 Main strengths and weakness of statistical and dynamical downscaling

3.5 Hydrologic Model

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 (Juraj M, 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

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.

3.5.1 Hydrological 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-dependent (and therefore subjective), such as the personal preference for graphical user interface (GUI hereafter), computer operation system (OS), input-output (I/O) management and structure, or user’s

addonexpansibility. Among the various project-depended selection criteria, there are four common, fundamental ones that must be always answered:

1. Required model outputs important to the project 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 sequence of flows, ...?),
2. Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating regulated reservoir operation, snow accumulation and melt, 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?).

3.5.2 Introduction to HBV-96 Model

The HBV-model (Hydrologiska Byråns Vattenbalansavdelning) is a general-purpose hydrologic model developed at the Swedish Meteorological and Hydrologic Institute (SHMI). The HBV model is a standard forecasting tool in nearly 200 basins throughout Scandinavia, and has been applied in more than 40 countries worldwide.

The model is designed to run on a daily time step (shorter time steps are available as an option) and to simulate river runoff in river basins of various sizes. The basin can be disaggregated into sub-basins, elevation zones, and land-cover types.

Input data include precipitation, air temperature (if snow is present), monthly estimates of evapotranspiration, runoff (for calibration) and basin geographical information. The treatment of snow accumulation and melt in HBV is based on a simple accounting (degree-day) algorithm (SHMI, 2003). The existence and amount of snowfall is predicted using meteorological input data extrapolated to the mean elevation of each sub-area of the basin. A simple model based on bucket theory is used to represent soil moisture dynamics (Lindström et al, 1997).

There is a provision for channel routing of runoff from tributary basins, using a modified Muskingum method. Outflow from lakes is usually specified by a stage-discharge rating curve but can be given by a lookup table to allow for power station operating rules. The HBV model can be linked with real time weather information and river monitoring systems.

3.5.3 HBV 96 Model Performance

While calibrating, it is important to have a good method of evaluating the results. In IHMS/HBV this is mainly done in three different ways:

1. Visually inspecting and comparing the calculated and the observed hydrograph
2. Calculating the explained variance, R^2 :

$$R^2 = 1 - \frac{\sum_{i=1}^n (Q_{sim} - Q_{obs(i)})^2}{\sum_{i=1}^n (Q_{sim(i)} - Q_{obs(i)})^2}$$

3. By calculating the relative volume of error

$$R.V.E = \frac{\sum (Q_{obs} - Q_{sim})}{\sum Q_{obs}} * 100$$

3.5.4 Model Structure

The HBV model can best be described as a semi-distributed conceptual model. Over the years only minor changes in the basic model structure have been made. Input data have been kept as simple as possible, normally only daily mean-values of temperature and precipitation are used.

Despite its simplicity, its simulation performance is commendable, and the original use for hydrological forecasting has expanded to applications such as filling gaps in measured time series, simulation of stream-flow in ungauged rivers, design flood calculations and water quality studies input data. The flexible structure of the HBV/IHMS system allows the model to make necessary sub-divisions with respect to different climate zones, land-use, density of the hydro meteorological network etc. In connection with spillway design studies for hydropower reservoirs in Sweden, SMHI has worked with river models for regulated rivers including up to 200 sub catchments.

The basic modeling philosophy behind the model is

- ✚ The model shall be based on a sound scientific foundation;
- ✚ Data demands must be met in typical basins;
- ✚ The model complexity must be justified by model performance;
- ✚ The model must be properly validated;
- ✚ The model must be understandable by users.

For the first two decades, only minor changes in the basic model structure were made. In the beginning of the 1990s a comprehensive re-evaluation of the HBV model routines was carried out (Lindström et al., 1997). It resulted in the HBV-96 version, which is the version described in this manual.

The model consists of subroutines for snow accumulation and melt, soil moisture accounting procedure, routines for runoff generation and finally, a simple routing procedure

It is possible to run the model separately for several sub basins and then add the contributions from all sub basins. Calibration as well as forecasts can be made for each sub basin. For basins of considerable elevation range a subdivision into elevation zones can also be made. This subdivision is made for the snow and soil moisture routines only. Each elevation zone can further be divided into different vegetation zones (forested and non-forested areas). A schematic sketch of the HBV 96 model version is shown in Figure 3.3.

Input data are observations of precipitation, air temperature, vapour pressure, wind speed and estimates of potential evaporation. The evapotranspiration values used are long-term monthly averages. Air temperature, vapour pressure and wind speed are used for calculations of snow accumulation and melt.

Discharge observations are used to calibrate the model, and to verify and correct the model before a runoff forecast.

In the following description of the model routines, variables that correspond directly to model parameters are marked in *italic*.

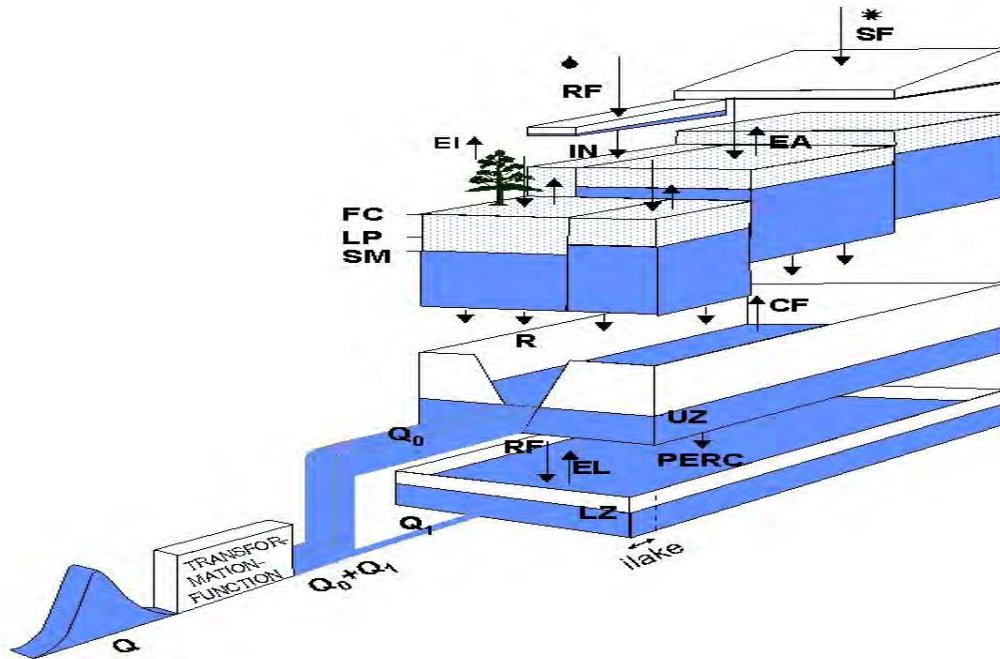


Figure 3.3 Schematic representations of HBV model for one basin

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, Q₀; direct runoff from upper reservoir, EL; lake evaporation, PERC; percolation capacity, LZ: lower zone reservoir and Q₁: base flow lower reservoir.

The general water balance of HBV-model can be described as follows;

$$P - E - Q = d/dt\{SP+SM+UZ+LZ+Lake (Reservoir)} \dots\dots\dots 1$$

Where,

P: Precipitation, Q: Runoff, SP: Snow pack, SM: Soil moisture, UZ: Upper groundwater

Zone, LZ: Lower groundwater zone, and lake (Reservoir): Lake (reservoir volume)

Precipitation calculations are made separately for each elevation/vegetation zone within a subbasin.

To separate between snow and rainfall a threshold temperature is used:

$$RF = pcorr \cdot rfcf \cdot P \text{ if } T > tt$$

$$SF = pcorr \cdot sfcf \cdot P \text{ if } T < tt$$

$$RF = \text{rainfall}$$

$$SF = \text{snowfall}$$

$$P = \text{observed precipitation (mm)}$$

$$T = \text{observed temperature (oC)}$$

$$tt = \text{threshold temperature (oC)}$$

$$rfcf = \text{rainfall correction factor}$$

$$sfcf = \text{snowfall correction factor}$$

$$pcorr = \text{general precipitation correction factor}$$

3.5.4.1 Snow Routine

The snow routine is based on a simple degree day relation. A threshold temperature (tt) which is usually close to 0 °C is used in this routine to define the temperature above which snow melt occurs.

$$\text{Snow melt} = cfmax \cdot (T - tt),$$

Where, T is the temperature in the elevation zone and cfmax the melting factor. If the parameter focfmax is used different melting factors will be applied for forest zones and other zones. The threshold temperature is normally also used to decide whether the precipitation falls as rain or snow, but it is possible to have different thresholds (then use the parameter dttn). If the parameter ttint is used the threshold is extended to an interval and within this interval precipitation is assumed to be a mix of rain and snow (decreasing linearly from 100% snow at the lower end to 0% at the upper end).

The snowpack is assumed to retain melt water as long as the amount does not exceed a certain fraction (given by the parameter whc) of the snow. When temperature decreases below tt , this water refreezes according to the formula:

Refreezing melt water = $cfr \cdot c_{fmax} \cdot (tt - T)$, where cfr is the refreezing factor.

Glacier melting will occur only in glacier zones and is taken into account by the same type of formula as is used for snow melting:

Glacier melt = $gmelt \cdot (T - tt)$, where $gmelt$ is the melting factor. No glacier melt occurs as long as there is snow in the current zone.

3.5.4.2 Soil Routine

The soil moisture accounting routine is the main part controlling runoff formation. This routine is based on the three parameters, β , lp and fc , as shown in Figure 2-2. β controls the contribution to the response function ($\Delta Q/\Delta P$) or the increase in soil moisture storage ($1 - \Delta Q/\Delta P$) from each millimeter of rainfall or snow melt.

The ratio $\Delta Q/\Delta P$ is often called runoff coefficient, and ΔQ is often called effective precipitation. $\Delta Q/\Delta P$ can also be expressed as R/IN (using the symbols in fig 2-1). lp is a soil moisture value above which evapotranspiration reaches its potential value, and fc is the maximum soil moisture storage (in mm) in the model. The parameter lp is given as a fraction of fc .

The specified input potential evaporation values can be corrected by the general evaporation correction factor, $ecorr$, and by specific factors for forest ($cevpfo$) and lake zones ($cevppl$).

A snow fall distribution can be made in each zone by subdividing it using the parameters $class$. This parameter determines the number of subareas with different snow accumulation. The distribution is given by the parameters $sfdistfo$ and $sfdistfi$.

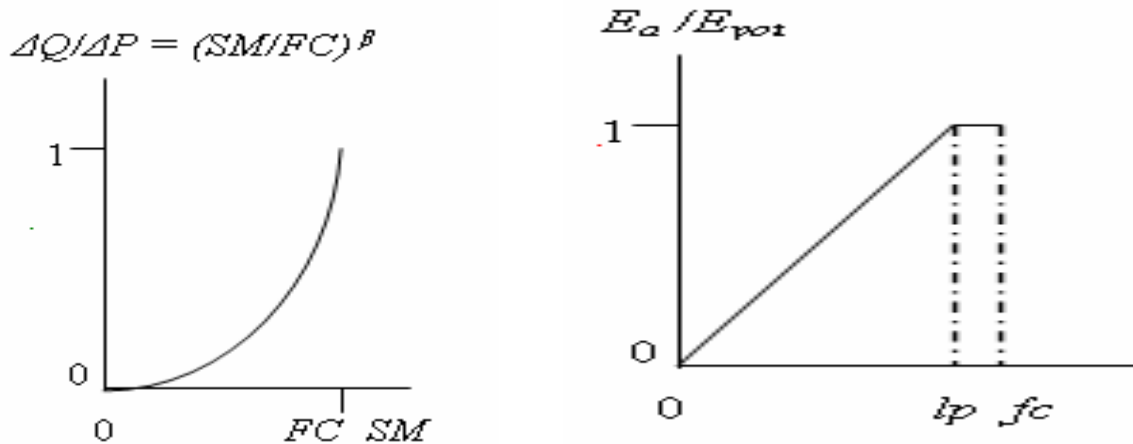


Figure 3.4 the soil moisture routine

3.5.4.3 Response Routine

The runoff generation routine is the response function which transforms excess water from the soil moisture zone to runoff. It also includes the effect of direct precipitation and evapotranspiration on a part which represents lakes, rivers and other wet areas. The function consists of one upper, non-linear, and one lower, linear, reservoir. These are the origin of the quick and slow runoff components of the hydrograph.

The yield from the soil moisture zone, i.e., the effective precipitation, will be added to the storage in the upper reservoir. As long as there is water in the upper reservoir, water will percolate to the lower reservoir according to the parameter perc.

At high yield from the soil, percolation is not sufficient to keep the upper reservoir empty, and the generated discharge will have a contribution directly from the upper reservoir which represents drainage through more superficial channels. The lower reservoir, on the other hand, represents the groundwater storage of the catchment contributing to the base flow.

The outflow from the upper reservoir is described by a function corresponding to a continuously increasing recession coefficient

$$Q0 = k \cdot UZ (1 + \alpha)$$

$Q0$ = reservoir outflow upper reservoir (mm)

UZ = reservoir content upper reservoir (mm)

k = recession coefficient upper reservoir

3.5.4.3 Transformation Function

The runoff generated from the response routine is routed through a transformation function in order to get a proper shape of the hydrograph at the outlet of the sub basin. The transformation function is a simple filter technique with a triangular distribution of the weights. The time base of the triangular distribution is given by the parameter $maxbaz$. $Maxbaz$ is the new parameter for the transformation function and shall be used in all new calibrations since it is independent of the time-step. $Maxbas$ is the old parameter and is kept so that old calibrations can still be used.

3.5.4.3 Calibration and Validation

Input data for the calculations are daily values of precipitation and air temperature (if there is snow in the basin) for stations representative for the basin. In case of shorter time steps, these data must be given for each step. For the potential evaporation, normally monthly mean estimates are used, either measured or calculated. During the calibration period observed discharge values are required for each time step.

Observed discharge can be discharge measured at the basin outlet, but it can also be total inflow to an outlet lake. In that case, an already prepared inflow data sequence can be entered into the data file, or measured outflow and water stage of the lake may be entered as two sequences and the corresponding inflow will be computed by the program. It is also possible to calibrate a part of the basin (an upstream part of the basin excluded), if observed inflow from the excluded part is known.

4. METHODOLOGY

4.1 Methodology

As was indicated in previous portion, the objective of the study is to evaluate the impact of climate change on the Gilgel Gibe III reservoir. The methods used include desk study of the previous study on the Basin (if any), data collection from institutions such as Ministry of water resource, national meteorological agency and etc. After collecting the necessary data for the research filling of missed data and quality checking have been made. Downscaling climate variable (precipitation, maximum temperature and minimum temperature) were carried out using statistical downscaling model (SDSM). Thiessen polygon is drawn at different sub catchments to determine the areal rainfall by using Arc view GIS. Rainfall runoff model at different sub catchments also developed by using Hydrologiska Byrans Vattenbalansavdelning (HBV) software for determining runoff resulted from intervening rainfall to evaluate the performance of gilgel gibe III reservoir.

4.2 Material Used

The material used for this research is

- ✚ Arc GIS and Arc view GIS 3.3 version to obtain hydrological and physical parameter and information
- ✚ Stastical downscaling Model version 4.2
- ✚ DEM Data
- ✚ Hydrological Data
- ✚ Meteorological Data
- ✚ Microsoft office excel spread sheet
- ✚ Global Mapper 7 Software
- ✚ CROPWAT-8 Software
- ✚ SWAT software to catchment delineation
- ✚ HBV-96 Software

The approach taken in the climate change analysis consists of two parts – climate analysis to propose potential values for temperature and precipitation change and runoff analysis to provide corresponding estimation of changes in net water yield or inflow to the reservoir.

4.3 General Circulation Model (GCM)

Global atmospheric general circulation models (GCMs) have been developed to simulate the present climate and have been used to predict future climatic change. While GCMs demonstrate significant skill at the continental and hemispheric spatial scales 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.

Even if global climate models in the future are run at high resolution there will remain the need to ‘downscale’ the results from such models to individual sites or localities for impact studies

When considering the impacts of global climate change the focus is primarily on societal responses to the local and regional consequences of large scale changes. The conflict between GCM performance at regional spatial scales and the needs of regional-scale impact assessment is largely related to model resolution in such a way that, while GCM accuracy decreases at increasingly finer spatial scales, the needs of impacts researchers conversely increase with higher resolution(Chong-yu Xu,1999)

General Circulation Models (GCMs) indicate that rising concentrations of greenhouse gases will have significant implications for climate at global and regional scales. Unfortunately, GCMs are restricted in their usefulness for local impact studies by their coarse spatial resolution (typically of the order 50,000 km²) and inability to resolve important sub-grid scale features such as clouds and topography.

The climate model is a mathematical description of the Earth’s climate system, broken into a number of grid boxes and levels in the atmosphere, ocean and land.

At each of these grid points equations are solved which describe the large-scale balances of the momentum, heat and moisture. Based on this, a wide range of climate models are developed.

The relative performance of GCMs can depend on the size of the region (i.e. small regions at sub-grid scale are less likely to be well described than large regions at continental scale), on its location (i.e. the level of agreement between GCM outputs varies a lot from region to region) and on the variables being analyzed (for instance, regional precipitation is more variable and more difficult to model than regional temperature) (Carter, 2007).

Even though it is often recommended to use different GCMs and emission scenarios in order to make comparison between different models, this study does not include such comparison due to limited amount of time available to complete the study. For this study the model output of HadCM3 was employed for the A2 (Medium-High Emissions) and B2 (Medium-Low Emission) Scenarios. HadCM3 is a coupled atmospheric-ocean GCM developed at Hadley Centre for Climate Prediction and Research, UK. The atmospheric part of HadCM3 has a horizontal resolution of 2.5° latitude x 3.75° longitude, and has 19 vertical levels. The ocean component of the model has 20 vertical levels with horizontal resolution of 1.25° latitude x 1.25° longitude. HadCM3 is applied in this study because the model is widely applied in many climate change impact studies and the model provides daily predictor variables which can be used for the Statistical Downscaling Model.

4.4 Statistical Downscaling Model

SDSM which is designed to downscale climate information from coarse-resolution of GCMs to local or site level is applied here to downscale the precipitation, maximum and minimum temperatures for the study area. SDSM uses linear regression techniques between predictor and predictand to produce multiple realizations (ensembles) of synthetic daily weather sequences. The predictor variables provide daily information about large scale atmosphere condition, while the predictand described the condition at the site level.

It is appropriate to use this software when the impact assessments is require at small-scale or regional level, provided that quality observational data and large scale daily GCMs climate variables are available. Additionally, the mode can also produces a range of statistical parameters such as variances, frequencies of extremes and spell lengths for the downscaled climatic parameters (R.L. Wilby, 2007).

SDSM software is published in different version at various times, among them the latest version is adopted for this particular study (i.e. version 4.2.2 SDSM software coded in Visual Basic 6.0).

The main reasons to apply the SDSM model for the study are;

- ✚ It is widely applied in many regions of the world over a range of different climatic condition.
- ✚ It can be runs on PC-based systems and has been tested on Windows 98/NT/2000/XP.
- ✚ The availability of the software (i.e. new users can register and download freely the software package at <https://co-public.lboor.ac.uk/cocwd/SDSM/>)
- ✚ Compared to other downscaling methods, the knowledge of atmospheric chemistry required by the SDSM is less.
- ✚ The required time for simulating the surface weather parameter is low.
- ✚ The ability of the model to permit risk/uncertainty analyses by using the generated ensembles.

4.4.1 Drawbacks Related SDSM

The limitation related to SDSM model can be summarized as follows;

- ✚ The relationship between the predictor and predictand is achieved by only considering the data statistical condition, i.e. the model does not take in to consideration the physical nature of the catchments (major drawback).
- ✚ It requires high quality data for model calibration;

- ✚ The model is highly sensitive to the choice of predictor variables and empirical transfer scheme.

4.4.2 SDSM Modeling Approach

The downscaling of the GCMs data using SDSM was done following the procedures in the flow chart (Figure 3). Before starting the main SDSM downscaling operation, quality control of the data was undertaken to check an input data file for missing and unreasonable values. Scatter plot analysis was performed and it was checked that all the predictands were normally distributed; hence transformation operation was found unimportant. The other operations performed for downscaling are dealt in detail in the following sections.

The SDSM software reduces the task of statistically downscaling daily weather series into seven discrete steps:

- 1) Quality control and data transformation;
- 2) Screening of predictor variables;
- 3) Model calibration;
- 4) Weather generation (using observed predictors);
- 5) Statistical analyses;
- 6) Scenario generation (R.L. Wilby and C.W.Dawson, 2007)

4.4.3 Screening of Downscaling Predictor Variables

The screen variables option used to select the appropriate downscaling predictors for model calibration. The screening of variables was done by trial and error procedure and it was the most time consuming activity in the downscaling process.

For maximum and minimum temperature downscaling an unconditional process was selected as the predictor-predictand process is not regulated by an intermediate process where as for the precipitation as the amount depends on wet-dry day occurrence, a

conditional process was selected. The significance level which tests the significance of predictor-predictand correlation was set to the default ($P < 0.05$).

The correlation analysis was used to investigate inter-variable correlations for specified periods (monthly, seasonal, or annual).

The correlation matrix gives a report for the partial correlations between the selected predictors and predictand which helped to identify the amount of explanatory power that is unique to each predictor. Using the partial correlations statistics, predictors which showed the strongest association with the predictand were selected. The scatter plot operation was also performed for visual inspection of inter-variable behavior for specified sub-periods (monthly, seasonal, or annual). The scatter plots were used to see the nature of association (linear, non-linear, etc) between the predictor and predictand which was important to decide whether or not data transformation was necessary.

4.4.4 Model Calibration

The NCEP reanalysis data which was used to calibrate and validate the model has a range of data from 1960-2001 and the observed data collected from the Ethiopian National Metrological Services Agency (NMSA) was from 1971-2001. Hence, the data from 1971-1986 was used for model calibration and from 1987-2001 was used for model validation. The calibrate model process constructs downscaling models based on multiple regression equations, given daily weather data (predictand) and regional scale, atmospheric (predictor) variables. The ordinary least squares optimization technique was preferred against the dual simplex to calibrate the SDSM because the modeling process was slowed down when chow test was performed with the dual simplex optimization.

An unconditional process was selected for the maximum and minimum temperature and conditional for the precipitation owing to the presence of intermediate processes. A monthly temporal resolution of the downscaling model was chosen to derive different model parameters for each month.

Upon completion of the appropriate selections, the model was calibrated. The resultant model calibration parameter (*.par) file generated was attached at the end of this paper for the precipitation, maximum and minimum temperature.

4.4.5 Weather Generator

The Weather Generator operation generates ensembles of synthetic daily weather series given observed (or NCEP re-analysis) 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.

4.4.6 Scenario Generation

The Scenario Generator operation produces ensembles of synthetic daily weather series given atmospheric predictor variables supplied by a climate model (either for present or future climate experiments), rather than observed predictors. 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. The input files for both the Weather Generator and Scenario Generator options need not be the same length as those used to obtain the model weights during the calibration phase.

The structure and operations of SDSM can be best described with respect to seven tasks as indicated in bold box in the following figure (R.L. Wilby and C.W.Dawson, 2007).

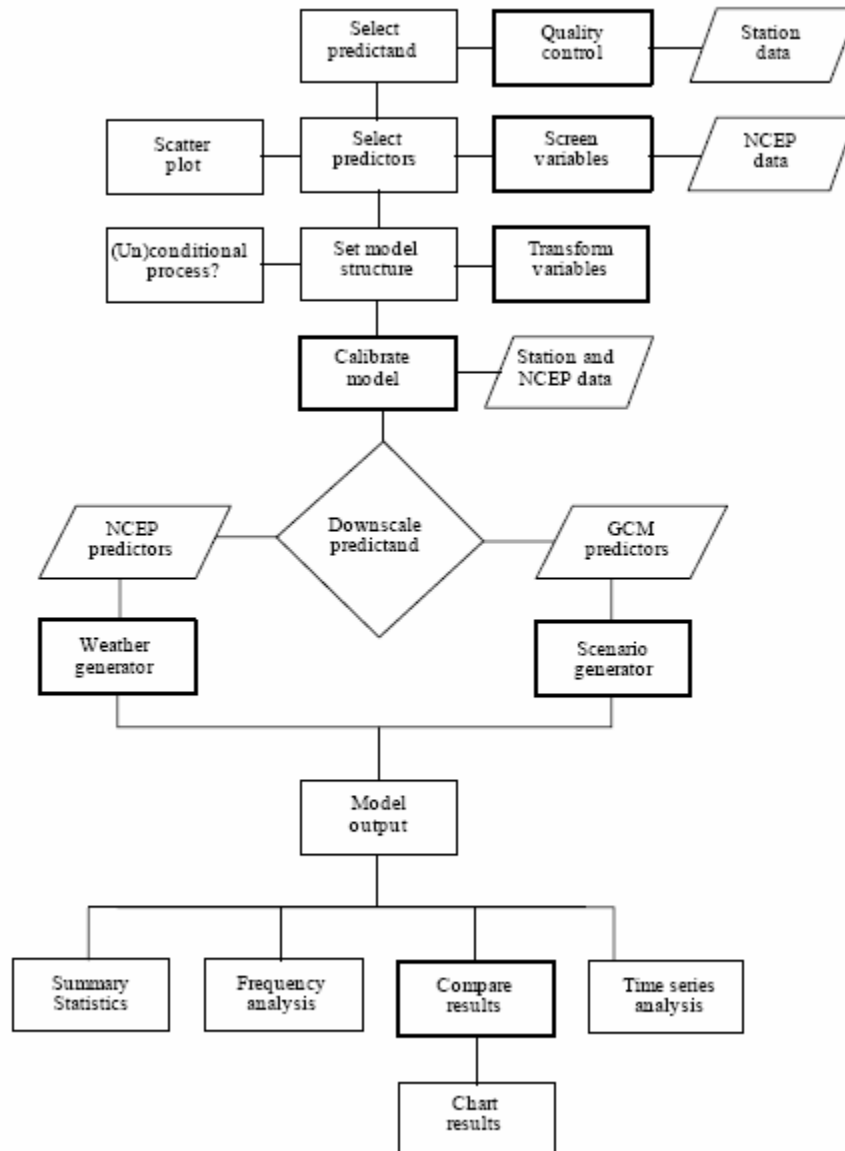


Figure 4.1 SDSM (version 4.2) Climate scenario generations

4.4.7 Model Setup

General Circulation Models (GCMs) indicate that rising concentrations of greenhouse gases will have significant implications for climate at global and regional scales. Unfortunately, GCMs are restricted in their usefulness for local impact studies by their coarse spatial resolution (typically of the order 50,000 km²) and inability to resolve important sub-grid scale features such as clouds and topography.

(I) Predictor and Predictand File

Statistical downscaling involves developing quantitative relationship between the predictor and the predictand. The predictor represents large-scale atmospheric variables, where as the predictand represents local surface variables such as temperature and precipitation.

The predictor variables used for the SDSM model input can be downloaded (<http://www.cics.uvic.ca/scenarios/sdsm/select.cgi>) from the Canadian Institute for climate studies website for model output of HadCM3. The predictor variables are supplied on a grid basis so that after selecting the Africa window and the location of site on the grids, the zip file will be available

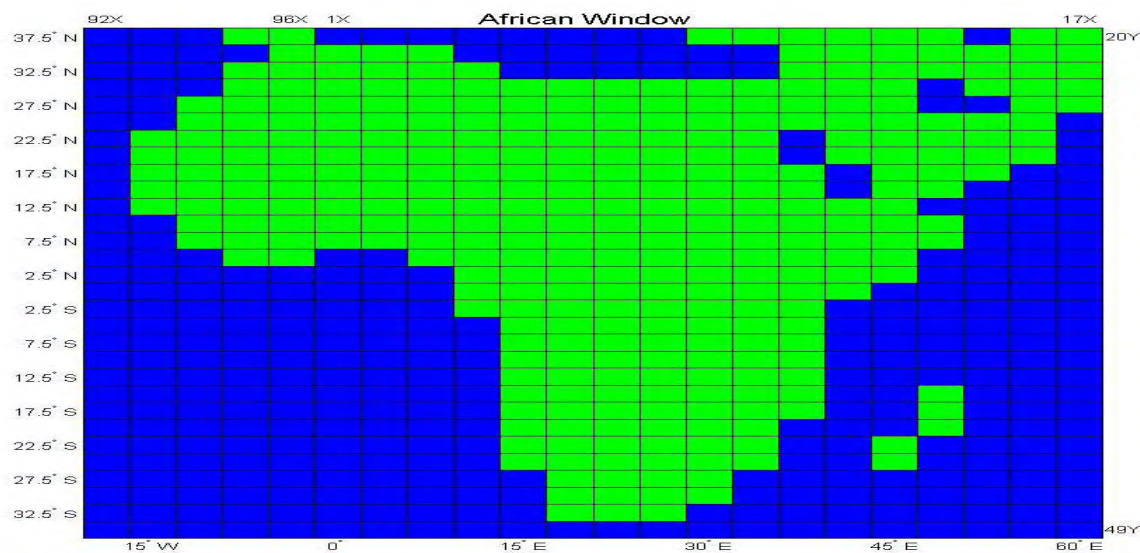


Figure 4.2: The Africa Continent window with 2.5° latitude x 3.75 longitude grid size

When the downloaded zip file is unpacked, it gives the following three directories:

NCEP_1961-2001: This directory contains 41 years of daily observed predictor data, derived from the NCEP reanalyses, normalized (with respect to the mean and standard deviation) over the complete 1961-1990 period.

These data were interpolated to the same grid as HadCM3 (2.5° latitude x 3.75° longitude) before the normalization was implemented.

H3A2a_1961-2099: This directory contains 139 years of daily GCM predictor data, derived from the HadCM3 A2 (a) experiment, normalized over the 1961-1990 period.

H3B2a_1961-2099: This directory contains 139 years of daily GCM predictor data, derived from the HadCM3 B2 (a) experiment, normalized over the 1961-1990 period. NCEP data are re-analysis sets from the National Centre for Environmental Prediction which was regridded to match with the grid system of the HadCM3. These are the data used for model calibration. Both the NCEP and HadCM3 data have daily predictors. The predictor variables which are available for both NCEP and HadCM3 are shown in Appendix A.

The predictand (maximum temperature, minimum temperature and precipitation) for a specific site can be prepared in the same format as predictor with single column text file to use as input for the downscaling model.

(II) Setting of the Model Parameter

Year length: The normal calendar year (366) which allows 29 days in February every fourth year is used whenever dealing with predictand and NCEP predictor whereas the year length of 360 days is used in the scenario generation part since HadCM3 uses model years consisting of 360 days.

Event Threshold: The event threshold is set to zero for temperature and 0.1 mm/day for precipitation to treat trace rain days as dry days.

Model Transformation: The model transformation is applied to the predictand in conditional models. The default (None) is used for the predictand that is normally distributed as in the case of daily temperature and fourth root transformation is applied for precipitation since the model is conditional and the data is skewed.

Variance inflation: Variance inflation controls the magnitude of variance inflation in the downscaled daily weather variables. This parameter can be adjusted during the calibration period to force the model replicate the observed data.

The default value (i.e.12) produces approximately normal variance inflation prior to any transformation and is applied to maximum and minimum temperature. For precipitation this parameter can be adjusted during the calibration period and is set to 18.

Bias correction: Bias correction compensates for any tendency to over or under estimates the mean of the conditional process by the downscaling model. This parameter is set to 1 (default value) for maximum and minimum temperature since the process is non conditional whereas for precipitation this parameter can be adjusted in order to match the mean of the conditional process and is set to 0.91.

(III) Screening the downscaling predictor variables

The choice of predictor variables is one of the most influential steps in the development of statistical downscaling procedure. Identifying empirical relationships between gridded predictors and single site predictands is central to all statistical downscaling. The screen variable option in SDSM assists the choice of appropriate downscaling predictor variables through seasonal correlation analysis, partial correlation analysis, and scatterplots. One of the approaches is to choose all predictors and run the explained variance on a group of eight or ten at a time. Out of the groups, those predictors which have high explained variance are selected. Then partial correlation analysis is done for selected predictors to see the level of correlation with each other. There could be a predictor with a high explained variance but it might be very highly correlated with another predictor. This means that it is difficult to tell that this predictor will add information to the process and therefore it will be dropped from the list. Finally the scatter plot indicates whether this result is due to a few outliers or it is a potentially useful downscaling relationship.

For example in selecting the potential predictor for maximum temperature, there are five predictors which have high explained variance among the twenty-six predictors.

4.5 HBV -96 Model Setup

4.5.1 General Description

HBV-96 is a mathematical model of the hydrological processes in a catchment used to simulate the runoff properties. It can be described as a semi-distributed conceptual model that allows dividing the catchment into subbasins and the subbasins further divide into elevation and vegetation zones.

The HBV model is today an Integrated Hydrological Modeling System: a modern, well-tested and operational tool. It can be linked with Real Time Weather Information and Forecasting Systems, such as the WebHyPro system developed by SMHI. It can be installed either on standalone PCs, in a client server concept, or integrated with SCADA/EMS-workstations.

4.5.2 Model Input

The model input requirements for the HBV model are daily rainfall, temperature, estimates of potential evapotranspiration, and catchment characteristics of the area.

4.5.2.1 Catchment Data

Since the HBV-96 model works as semi-distributed model, the catchment 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 DEM hydro processing as shown in Figure 4.3 to extract drainage area, drainage network and to divide the area into different subbasins and elevation zones.

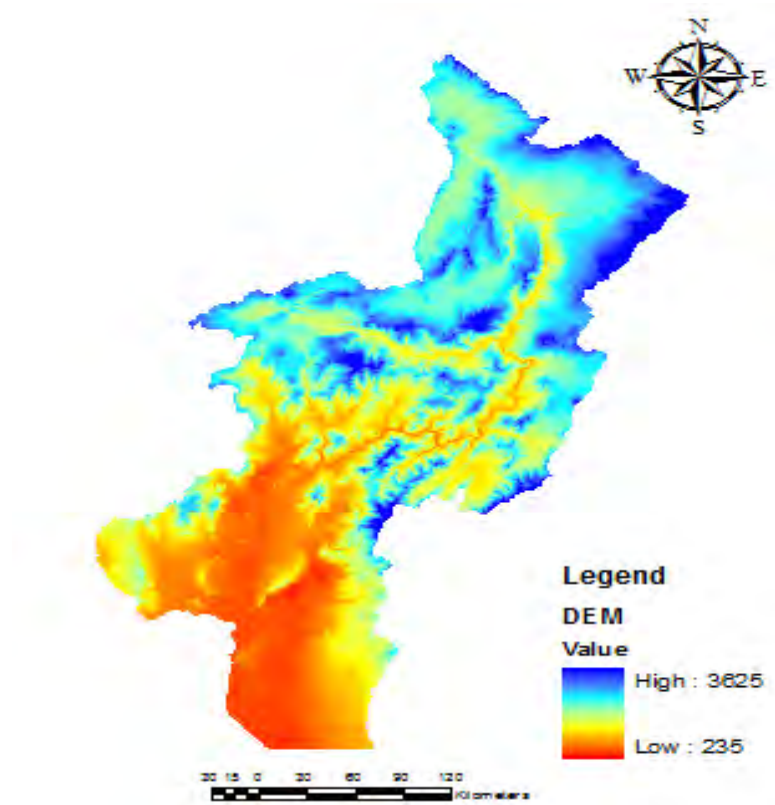


Figure 4.3: DEM of the omo gibe basin

4.5.2.2 Areal Rainfall

The HBV model requires daily rainfall as input. Hence rainfall data for the period of ten years (1996-2005) was prepared for eleven meteorological stations in and around the catchment area. Areal rainfall in the model is computed by multiplying the rainfall by the weight of each station for the subbasin considered in the analysis. The weight of each meteorological station was computed by Thiessen polygon method.

$$\bar{p} = \frac{1}{A} \sum_{s=1}^{s=n} \{A_s * P_s\}$$

Where, $\bar{p}$: Areal average rainfall, P_s : Rainfall measured at sub-region, A_s : Area of sub-region and A : total area of sub regions.

5 DATA COLLECTION AND ANALYSIS

5.1 General

Before undertaking processing of any research data it is imperative to make a rough search for the data. Therefore, the primary assignment of the study was getting relevant information and data of the study area. This sub topic identifies and discusses the types and source of data required for the study, and their analysis.

5.2. Hydrological Data

The most important data required for this research is the long term monthly mean stream flow record. The hydrological data made available comes from different source of area.

- Ministries of water resource (MOWR), daily flow data of 29 stations from 5 to 39years have been collected.
- From different reports which have been done their projects on Omo-Gibe river basin like Omo-Gibe river basin integrated development master plan.

Even though more than 45 hydrometric stations found in the basin, only limited stations data was accessible from MOWR for this study.

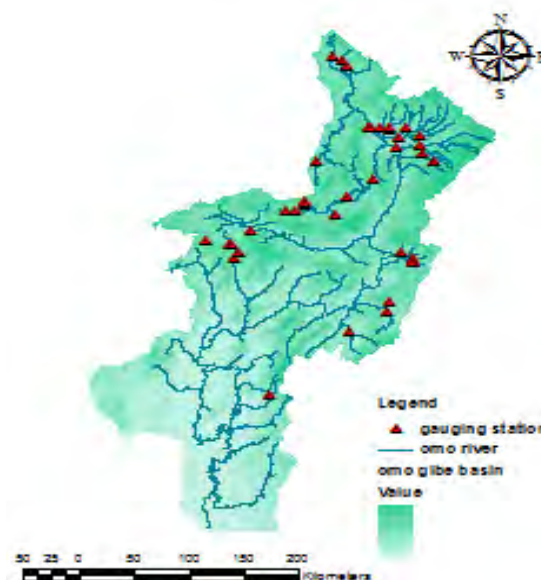


Figure 5.1 Stream gauging stations in the Omo-Gibe River basin

5.2.1 Hydrological Data Analysis

5.2.1.1 Filling of Missed Data

A number of stations in the basin have incomplete records. In order to make use of the partially record data missing values need to be filled in sequence. To fill the missing recorded stream flow gauging data various methods are available. The missing values were filled with multiple station correlation. In some cases, if there exists one or two years missing in the middle, data merging has been done for sites which have long years of record data.

S.No	Missing River Station		Nearby River Station		Correlation Coefficient	Equation	Remark
	River Name	Id	River Name	Id			
1	Great Gibe Nr.Abelti	91001	Gilgel Gibe Nr. Assendabo	91008	0.95	$Y=1.955X^{1.126}$	Filled
2	Deme	92011	Ajancho	92010	0.82	$y=0.5858x^{0.8077}$	Filled

Table 5.1 Regression Equations used for filling Missed Hydrological Data

5.3 Meteorology Data Analysis

The second most important time series data necessary for this research is rainfall data. These data were collected from Meteorological Agency. Even though there are 66 rainfall stations in and nearby of the basin, the only representative 11 rainfall stations of daily PPT were collected for the analysis of areal precipitation for the study area

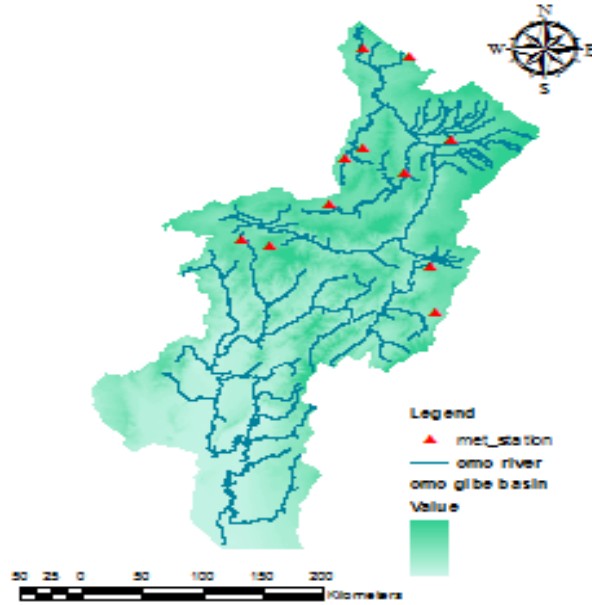


Figure 5.2 Meteorological Stations in the Omo-Gibe river basin

5.3.1 Checking Homogeneity of Selected Stations

In order to select the representative meteorological station for the analysis of areal precipitation on the reservoir at dam site of Gibe III, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations monthly rainfall records were carried out by non-dimensionalizing using equation:

$$p_i = \frac{\bar{p}_i}{\bar{p}} * 100$$

Where:

p_i =Non dimensional Value of PPT for the month i

$\bar{p}_i$ =Over years averaged monthly precipitation for the station i

$\bar{p}$ =the over years average yearly precipitation of the station

5.3.2 Checking Consistency of the Stations

If the conditions relevant to the recording of a rain gauge station have undergone significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. The checking for inconsistency of a record is done by double mass curve technique. [Subramanya, K., 1998]

The double mass curve: - The technique is used to adjust PPT records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge. If a decided change in the regime of the curve is observed it should be corrected.

In order to check the consistency of all the rainfall stations at the selected sites the double mass curve is used. So all the stations were consistent and no need of further correction.

5.3.3 Filling of Precipitation Data

Before using the rainfall records of a station, it is necessary to first check the data for continuity and consistency. The continuity of a record may be broken with missing data due to many reasons such as damage or fault in a rain gauge during a period. The missing data can be estimated by using the data of the neighboring stations. There are two commonly used procedures for estimating daily precipitation depths.

The two procedures for estimating daily totals rely on the data from 'M' adjacent stations. The locations of the adjacent stations are such that they are close to and approximately evenly spaced around the site with the missing data. If the average annual precipitation at each of the "M" adjacent stations differs from the average at the missing data station by less than 10%, the following formula is used to estimate the missing daily data.

$$\overline{p_x} = \frac{1}{M} (p_1 + p_2 + p_3 + \dots + p_M)$$

Where:

$\overline{p}_x$ = Estimated daily precipitation at station X.

$p_1 + p_2 + p_3 + \dots + p_M$ = daily precipitation depth at the adjacent stations 1, 2, 3 and M.

M = Number of stations

If the difference between the average annual PPT at any of the adjacent stations and the missing data station is greater than 10% a normal ratio method is used.

$$\overline{p}_x = \frac{N_x}{M} \left[\left(\frac{p_1}{N_1} \right) + \left(\frac{p_2}{N_2} \right) + \left(\frac{p_3}{N_3} \right) + \dots + \left(\frac{p_M}{N_M} \right) \right]$$

Where:

N_x = Average annual precipitation at the missing data.

$N_1, N_2, N_3 \dots N_M$ = Average annual precipitation at the adjacent site.

Selected Rainfall stations for this analysis, the difference between the average annual PPT at any of the adjacent stations and the missing data stations is greater than 10%. Therefore to fill all the missed rainfall data normal ratio method is used.

5.3.4 Average Depth of Rainfall Over Area

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of precipitation over the area under the area under consideration is one of the most important parameter in hydrological analysis.

The computation of average PPT may be done by the following methods:

- ✚ Arithmetic average method
- ✚ Thiessen polygon method, and
- ✚ Isohytal method

Arithmetic average method: - When the rainfall is uniformly distributed over the area, the average rainfall may be taken as the arithmetic average of the recorded rainfall.

Thiessen polygon method: - Rainfall varies in intensity and duration from place to place. Hence the rainfall recorded by each rain gauge station should be weighted according to the area it is assumed to represent. This method is use full for areas which is not much rugged rather plain and is of intermediate size (750 to 3000km.sq) also rain gauge stations are few compared to the size.

Isohyetal method: - isohyets are a line joining places of equal rainfall intensities on a rainfall map of the basin. An Isohytal map represents an accurate picture of the rainfall distribution over the basin. If the net work rainfall stations within the storm area are sufficiently dense, the Isohytal map will give a reasonably accurate indication of the rainfall distribution zones.

In order to determine the average depth of rainfall contribution to gibe III reservoir stations above the dam site was analyzed using Thiessen polygons method. The respective rain gauge stations (Wolkite, Cheleleki, Bele, Jimma, Gesuba, Gedo, Bako, Wushwush, Shedatura, Saja and Limu Genet) were considered to determine their corresponding aerial rainfall.

The Theissen coefficient of each gauging station for the watershed was determined.

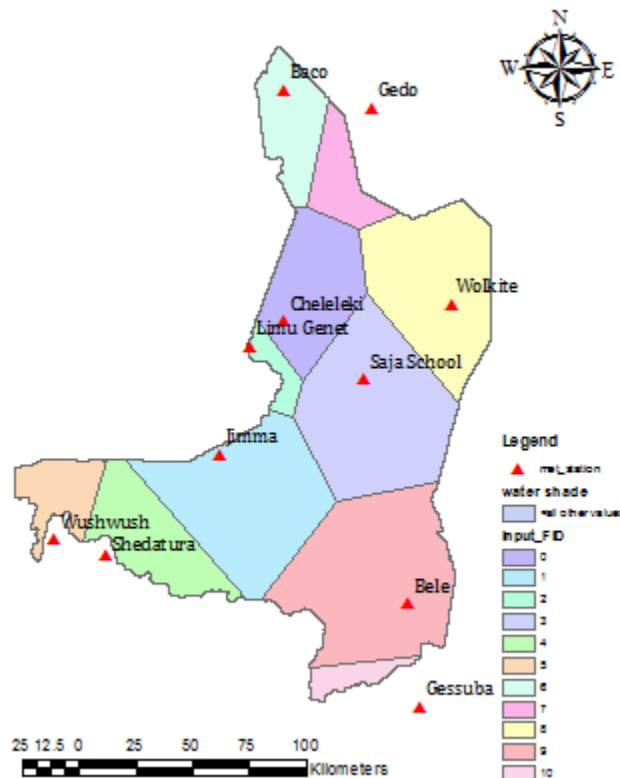


Figure 5.3 Theisson Polygons for Intervening Catchment

S.No	Rain fall Station	Area in km ²	% age of area subtended
1	Wolkite	3739.49	0.15
2	Cheleleki	2243.69	0.09
3	Bele	4487.38	0.18
4	Jimma	3739.49	0.15
5	Gesuba	498.60	0.02
6	Gedo	997.20	0.04
7	Bako	1495.79	0.06
8	Wushwush	997.20	0.04
9	Shedatura	1994.39	0.08
10	Saja	4238.08	0.17
11	Limu Genet	498.60	0.02
	Total	24929.90	1.00

Table 5.2 Rainfall Stations and their Corresponding Subtended Area

5.4 Reservoir Inflow Generation

Most of the time, Rivers are not gauged at the confluence point. The site of water resource development in any of the uses can be at or ungauged site. If gauged data with sufficient record length is available then such data is used. In the absence of sufficient record length data generation can be applied.

To determine the overall discharge at the confluence of Omo-Gibe River, stream flow data was transferred to the site of interest using area ratio methods and convolution equation. The recommended guide lines for area ratio method to assess the available dependable flow for the potential assessment purpose is

$$Q_{ungauge} = \left[\frac{A_{ungauge}}{A_{gauge}} \right]^n * Q_{gauge} \text{-----5.1}$$

Where: - $Q_{ungauge}$ -discharge at the site of interest

Q_{gauge} -Discharge at the gauge site

$A_{ungauge}$ -Drainage area at the site of Interest

A_{gauge} -Drainage area at the gauging site

n- Varies between 0.6-1.2

If the $A_{ungauge}$ is within 20% of the A_{gauge} ($0.8 \leq \frac{A_{ungauged}}{A_{gauged}} \leq 1.2$) then n=1 will be used

The estimated discharge at the site will be within 10% of actual discharge.

When $A_{ungauge}$ is within 50% of the A_{gauge} , two station data are considered for data Transferring, Relation can be developed to estimate a weighted average flow at a site lying between upstream and downstream gauges [Gulliver and Roger, 1991].

$$Q_{ungauge} = \frac{(A_{gauge\ 1} - A_{ungauge}) * Q_{gauge\ 1} + (A_{ungauge} - A_{gauge\ 2}) * Q_{gauge\ 2}}{A_{gauge\ 1} - A_{gauge\ 2}} \quad \text{--- 5.2}$$

Where:-

Gauge₁ =upstream gauging site and gauge₂ =downstream gauging sites.

When the site of interest is more than 50% of the area of gauge, estimate the value of from annual flow data in the basin. The ratio of average annual discharge at the site (estimated) and at gauge (recorded) can be used to transform the flow duration curve from gauge to the site. Flows below Abelti Gauging station were transferred from gauged station to Omo-Gibe III dam site using equation 5.2 and formula. So, these flow data were the main inputs for reservoir simulation model.

5.5 Potential Evapo-transpiration for Model Calibration and Validation

The climatological data around Omo- Gibe III reservoir site, the rainfall, maximum and minimum temperature, Relative humidity, Sun shine hours and wind speed data were collected from Ethiopian Meteorological Agency. Due to the lack of full recorded data within project area, the jimma station was selected for the analysis of evaporation loss from reservoir surface.

Long-term mean values are used as estimates of potential of evapo-transpiration at a certain time of the year. It is thus assumed that the inter-annual variation in actual evapo-transpiration is much more dependent on the soil moisture conditions than on the inter-annual variation in Potential evaporation (IHMS, 2006).

For this specific study CROPWAT 8 Model is adopted to calculate the daily potential evaporation during model calibration and validation. The average potential evapo-transpiration from Jimma station is used for model input.

5.6 Reservoir Evaporation Loss

Through a water free surface, there is always continuous exchange of water molecules to and from the atmosphere; the hydrologic definition of evaporation is restricted to the net rate of vapor transport to the atmosphere. Rates of evaporation vary depending on meteorological factors such as: solar radiation, air temperature, vapor pressure, wind, and minimally by atmospheric pressure. Since solar radiation is an important factor, evaporation also varies with season, time of day, and sky condition. As pressures drop, evaporation rises, but altitude has little effect because of counterbalancing changes in temperature. Fast rates of evaporation at high altitudes are caused, in large measure, by greater wind velocities. This portion describes the estimation of evaporation from the reservoir to be created behind the proposed dam on Omo-Gibe River at Gibe III dam site.

There are several methods for evaporation determination: Water balance, Energy balance, Aerodynamic, Penman and Pan Evaporation methods being the most common [Chow, V.T, 1988]

For the present study, the Penman–Monteith method was selected to determine the monthly evaporation rates. Open water evaporation was calculated by using the FAO CROPWAT Version 8 program which uses the Penman-Monteith method and then applies an aridity correction factor.

The conversion of PET to evaporation of open water, with depth higher than 5 m, clear of turbidity, in temperate climate, would be varied between 0.65 and 1.25. The lower values "correspond to the period when the water body is gaining thermal energy", and the higher to the period "during the fall and the winter when heat is released from the water body". For Ethiopia, the aridity correction factor was estimated to be 1.2(Habtom, 2009).

5.7 Potential Evapo-transpiration for Future Runoff Generation

The potential evapo -transpiration will have different value for the three time horizons (i.e.2020s, 2050s and 2080s) compared to the present potential evaporation that is calculated using CROPWAT-8 software. And since the existing data are the downscaled precipitation and minimum and maximum temperature, the potential evapo-transpiration for future time horizon is calculated by using Hargreaves method (see. equation 5.3).

To be compatible with the method adopted during model calibration and validation, a regression equation is developed to estimate the FAO Penman potential evaporation from Hargreves potential evapo-transpiration Table (4.6)

$$PET_{HG} = 0.023 * R_a * (T_{mean} + 17.8) * \sqrt{T_{max} - T_{min}} \text{ -----5.3}$$

Where,

PET_{HG} =Hargreves potential evapo-transpiration;

R_a = Extraterrestrial radiation (calculated from latitude and time of year);

T_{mean} = Mean temperature;

T_{min} = Minimum temperature; and

T_{max} =Maximum temperature

Regression Equation Developed	Correlation Coefficient(R ²)
$ET_{O-pen}=0.718ET_{O-HG} - 1.072$	0.92

Table 5.3 Monthly Conversion equations to PET (Penman Monteith) from Hargreves PET

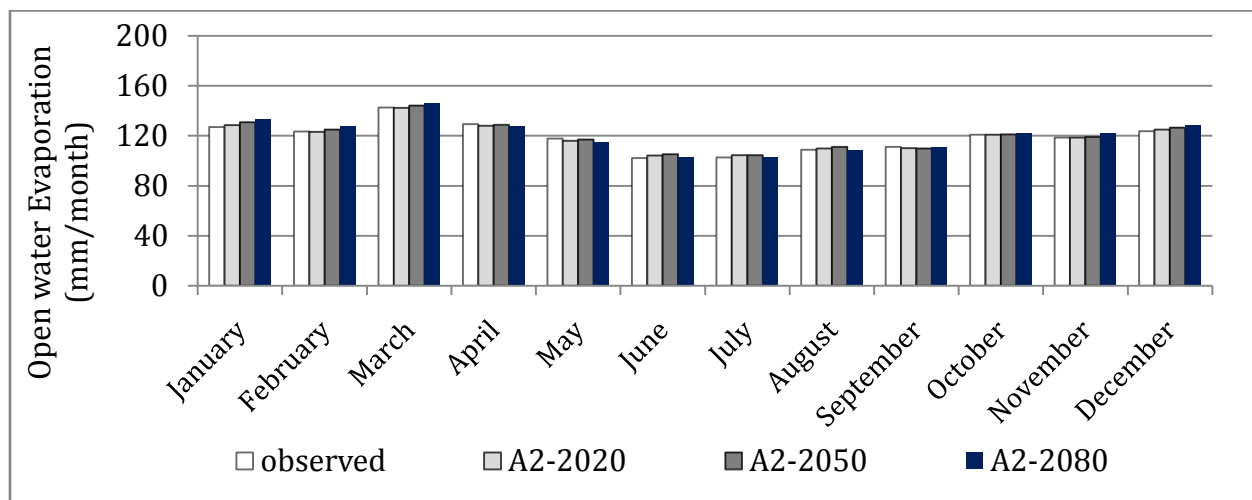


Figure 5.4 Projected PET at different time horizon in mm/month for HadCM3 A2a

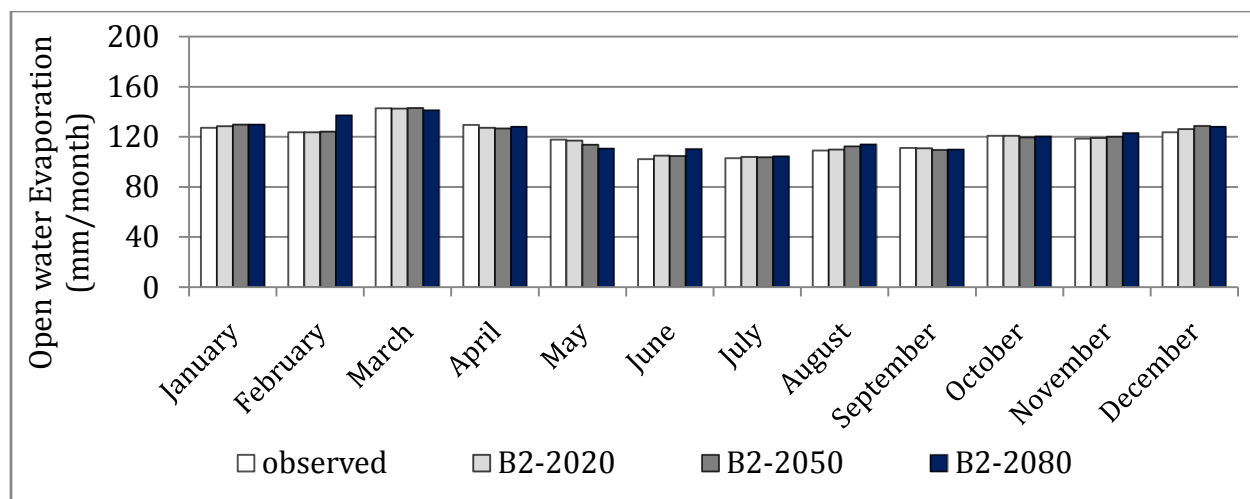


Figure 5.5 Projected PET at different time horizon in mm/month for HadCM3 B2a

6. RESULT AND DISCUSION

6.1 Downscaling the GCM for the Baseline Period

The base line scenarios downscaled for base period for jimma station; 31-year daily data from 1971-2001 was selected to represent baseline for this study. Thus the **hadcm3** was downscaled for the baseline period for two emission scenarios (a2&b2) and the statistical properties of the downscaled data was compared with observed data.

The downscaling experiment was conducted for minimum temperature; maximum temperature and precipitation based on the data from jimma meteorological station which contain observed data for the specified period and the results are discussed in section below.

6.1.1 Predictor Variable Selection

The best correlated predictor variables selected for precipitation, maximum temperature and minimum temperature are listed in table 5.1.

Predictant	Predictor	Symbol
Temperature Maximum	p-uaf	surface zonal velocity
	p-zhaf	Surface divergence
	tempaf	Mean temperature at 2 m
Temperature Minimum	p5thaf	500 hpa wind direction
	p850	850 hpa geopotential height
	rhumaf	Near surface relative humidity
	tempaf	Mean temperature at 2 m
Precipitation	p-uaf	surface zonal velocity
	p-zhaf	Surface divergence
	p5thaf	500 hpa wind direction
	8-vaf	850 hpa meridional velocity
	8-zaf	850 hpa vorticity
	r500	Relative humidity at 500 hpa

Table 6.1: selected predictor variables for the predictands (precipitation, maximum and minimum temperature) at jimma station.

6.1.2 Calibration and Validation

The calibration was carried out from 1971-1986 for sixteen years and the withheld data from 1987-2001 were used for model verification. The model develops a better multiple regression equation parameters for the maximum and minimum temperature than the precipitation. This Result is mainly due to the conditional nature of precipitation. In conditional models, there is an intermediate process between regional forcing and local weather (e.g., local precipitation amounts depend on wet-/dry-day occurrence, which in turn depend on regional-scale predictors such as humidity and atmospheric pressure) (Wilby and Dawson 2004). This can clearly be seen in the R^2 values presented in Table-5

	R^2		
	Precipitation	Max. Temperature	Min. Temperature
Calibration	0.338	0.414	0.69
Validation	0.54	0.62	0.75

Table 6.2: Calibration and Validation R^2 values of the SDSM downscaling of precipitation, maximum and minimum temperature at Jimma station

1. Minimum Temperature

The monthly minimum temperature downscaled for A2 and B2 scenario in the baseline period is shown in Figure 5.1:

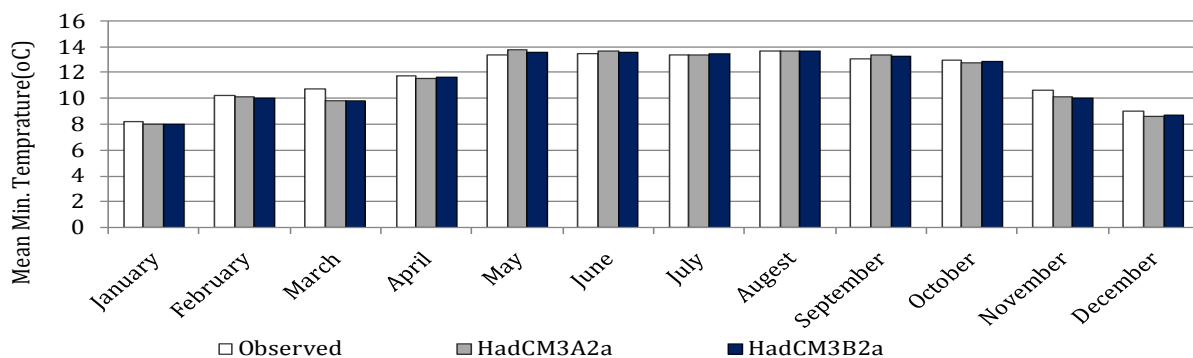


Figure 6.1 Observed and downscaled monthly mean minimum temperature for the baseline period (1971-2001)

The result of downscaling minimum temperature indicates that there is satisfactory agreement between observed and simulated minimum temperature. As shown in Figure 6.2: it was also found that, during the month of July and August the model error is negligible. However, during the month of March the model error is 0.95 °C and 0.92 °C for HadCM3A2a and HadCM3B2a respectively. The model error in each month is less than the projected temperature change in the future.

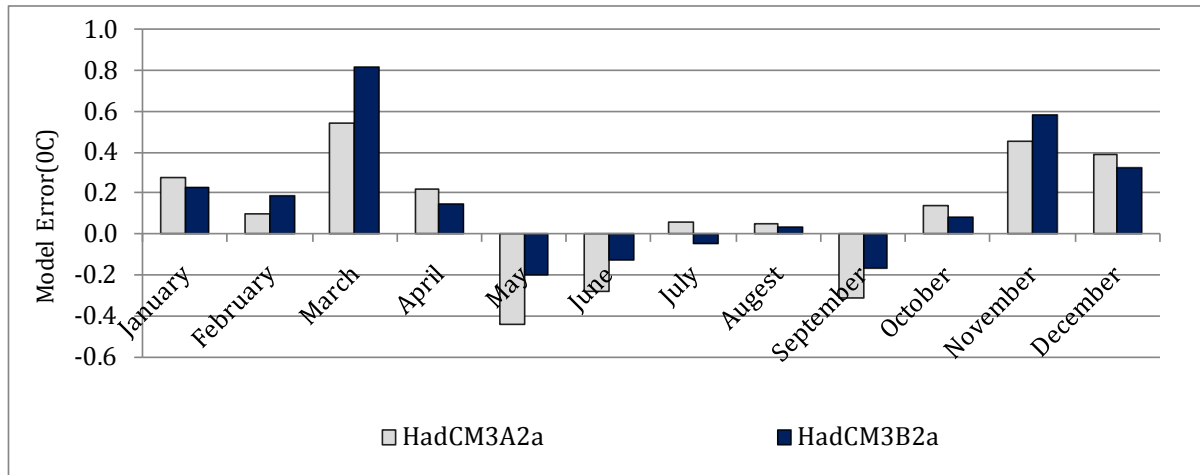


Figure 6.2 Absolute model errors in estimate of monthly minimum temperature

2. Maximum temperature

The monthly maximum temperature downscaled for A2 and B2 scenario in the baseline period is shown in Figure 6.3

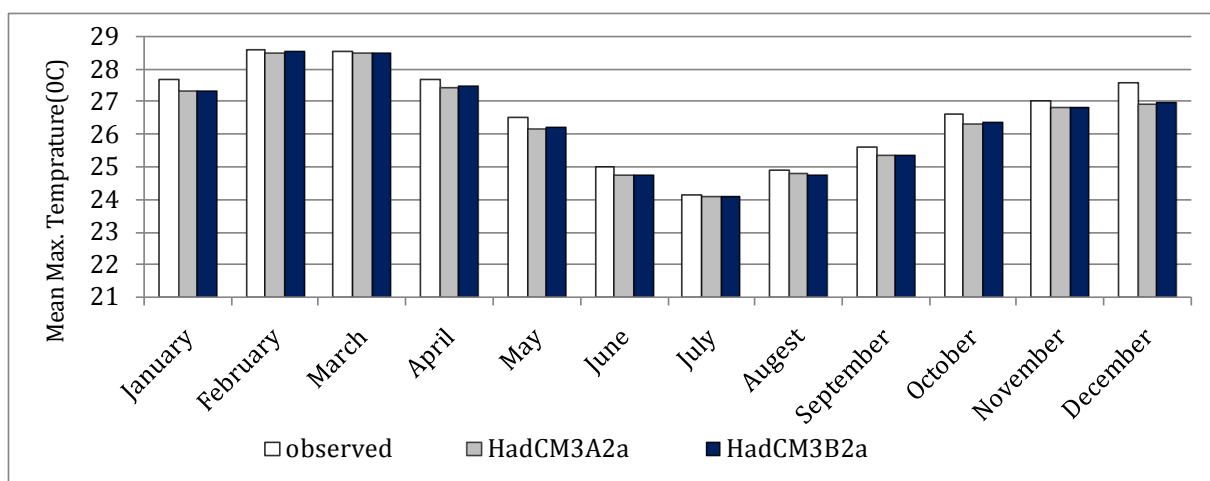


Figure 6.3 Observed and downscaled monthly mean maximum temperature for the baseline period (1971-2001)

The monthly absolute model error of the downscaled maximum temperature for the baseline Period shows almost similar result for both A2a and B2a emission scenarios as shown in figure 6.4

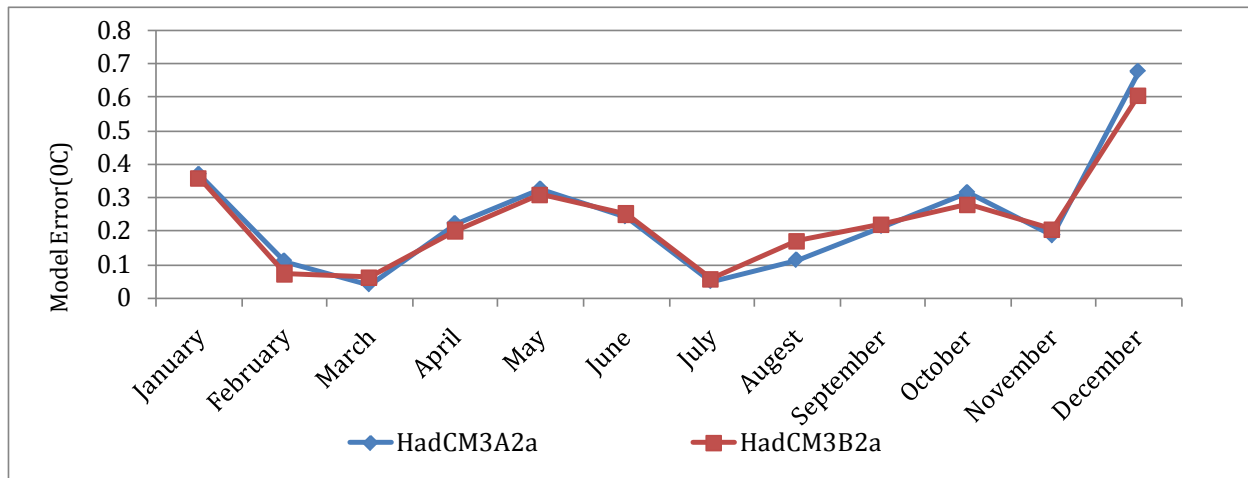


Figure 6.4: Absolute model error in estimate of monthly maximum temperature

3. Precipitation

Relative to the minimum and maximum temperature 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. Climate model simulation of precipitation has improved over time but is still a problematic (Bates et al., 2008). Thorpe (2005) also added that rainfall predictions have a larger degree of uncertainty than those for temperature. This is because rainfall is highly variable in space and so the relatively coarse spatial resolution of the current generation of climate models is not adequate to fully capture that variability.

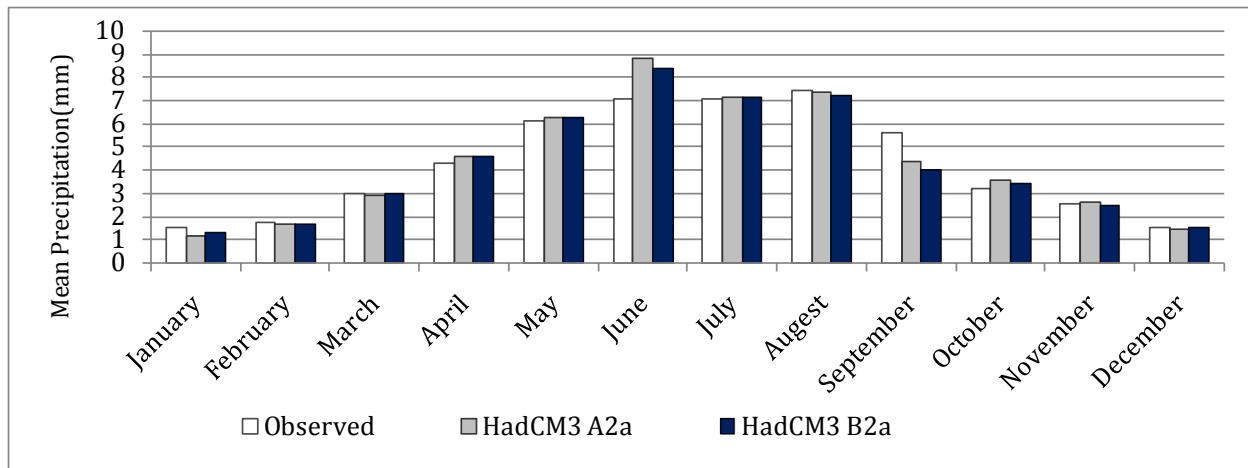


Figure 6.5 Downscaled and observed mean monthly precipitation (1971-2001)

The downscaled precipitation shows an average absolute model error of 0.37 mm and 0.36 mm for A2a and B2a emission scenarios respectively.

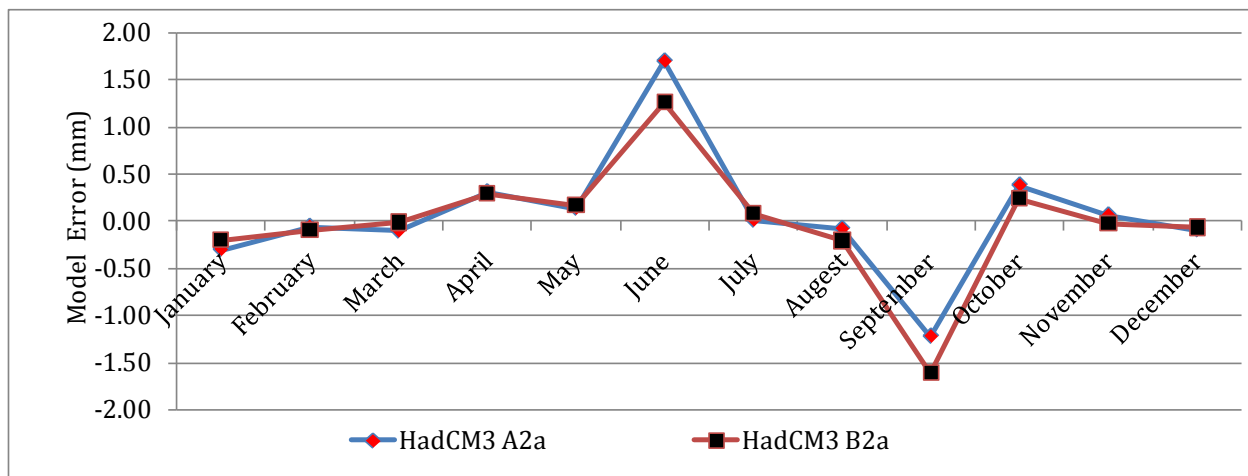


Figure 6.6 Absolute model error for the downscaled precipitation (1971-2001)

6.2 Projected Future Climate Variables (Scenario Generation)

After the calibration and validation of SDSM model carried out, the daily future climate variables are projected for the next century using the HadCM3 Global Circulation Model. Future climate scenarios downscaled for three climate variables (precipitation, maximum and minimum temperature) are shown in the figure 6.7- 6.10.

With the aid of statistical downscaling model the GCMs global predictors are used for development of future climate scenarios and the analysis done for 2020s, 2050s and 2080s for both HadCM3A2a and HadCM3 B2a scenarios.

1. Precipitation

The precipitation projection exhibited an increase trend in annual mean precipitation in the 2020s, and 2080s in both HadCM3A2a and HadCM3B2a scenario. However, in 2050s the mean annual precipitation exhibited an increasing trend in HadCM3A2a and decreasing trend in HadCM3B2a scenarios.

As can be seen in Figure 6.7, in 2020s there may be an increase in precipitation for all months except February, March, June, July and August for HadCM3A2a and HadCM3B2a scenarios.

In general, the A2a scenario showed a monthly mean precipitation decrease up to 11.0% and monthly mean precipitation increase reach up to 9.51%.on the same fashion HadCM3B2a scenario shows a monthly decrease up to 8.0% and percentage increment up to 9.51% in different months.

The overall effects in 2050s is increase of mean annual precipitation by 2.7% in the HadCM3A2a scenario and mean annual decrease up to 1.75% in the HadCM3B2a scenario. Thus the increase in monthly mean precipitation may reach up to 20.2% and 12.3% for HadCM3A2a and HadCM3B2a scenarios respectively and the decrease in monthly mean precipitation reach up to 10% and 15.1% for HadCM3A2a and HadCM3B2a scenarios respectively.

In 2080s, the overall increase up to 3.1% and 2.89% in mean annual precipitation for HadCM3A2a and HadCM3B2a scenarios respectively.

Monthly mean precipitation reach up to 35% and 38% for HadCM3A2a and HadCM3B2a scenarios respectively and the decrease in monthly mean precipitation reach up to 18.2% and 14.5% for HadCM3A2a and HadCM3B2a scenarios respectively.

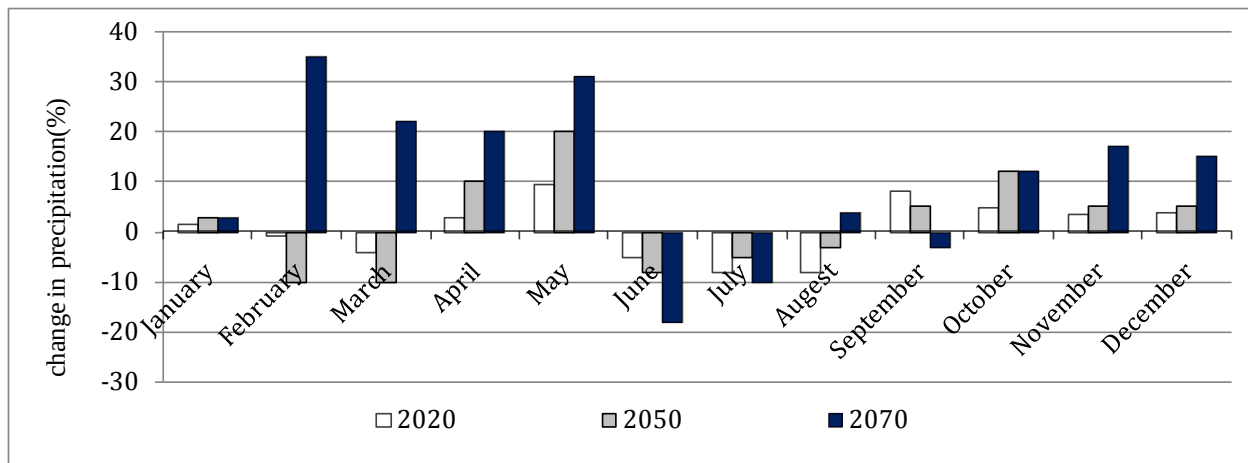


Figure 6.7: (a) Percentage change in monthly precipitation in the future from the baseline period for HadCM3A2a Scenario

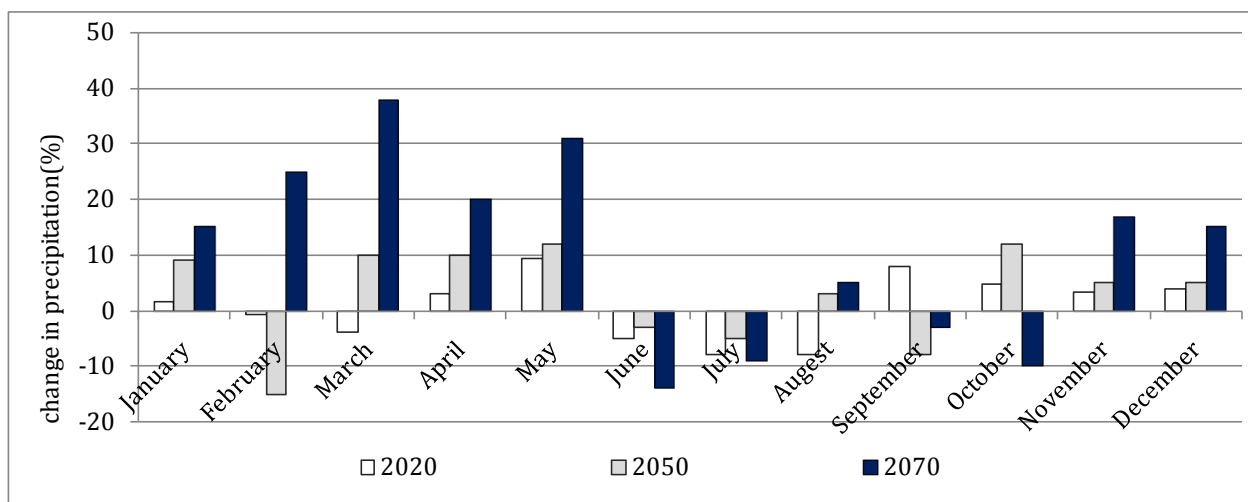


Figure 6.7: (b) Percentage change in monthly precipitation in the future from the baseline period for HadCM3B2a Scenario

2. Minimum temperature

The downscaled minimum temperature shows an increasing trend in all future time horizons for both A2 and B2 scenarios. The projected minimum temperature for future periods for A2a and B2a scenarios are shown in Figure 6.8: a & b.

Even though all months show similar trends in the future climate periods, the highest maximum projected minimum temperature will occur during months of March, April, May and June for both A2a and B2a scenarios in all horizons.

The downscaled minimum temperature in 2020s indicated that the minimum temperature will rise by 1.2°C for both A2a and B2 scenarios. For 2050s the increment will be 2.1°C for A2a and 2°C for B2a scenarios respectively. The increment will be expected to be high in 2080s, which is 3.6°C for A2a and 2.9°C for B2a scenarios respectively.

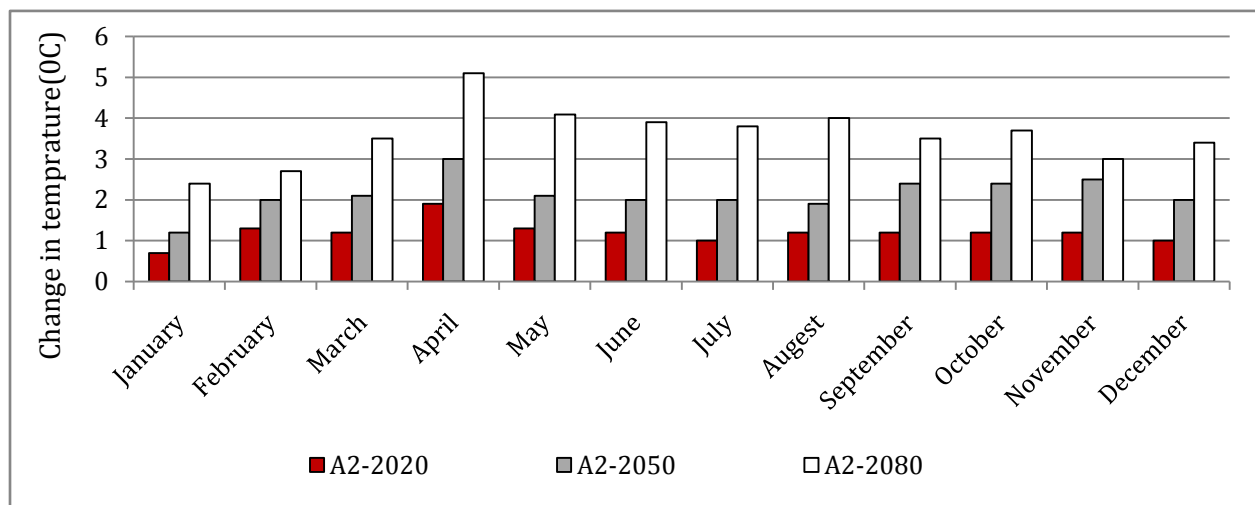


Figure 6.8 :(a): Change of downscaled monthly minimum temperature from the baseline period for HadCM3A2a

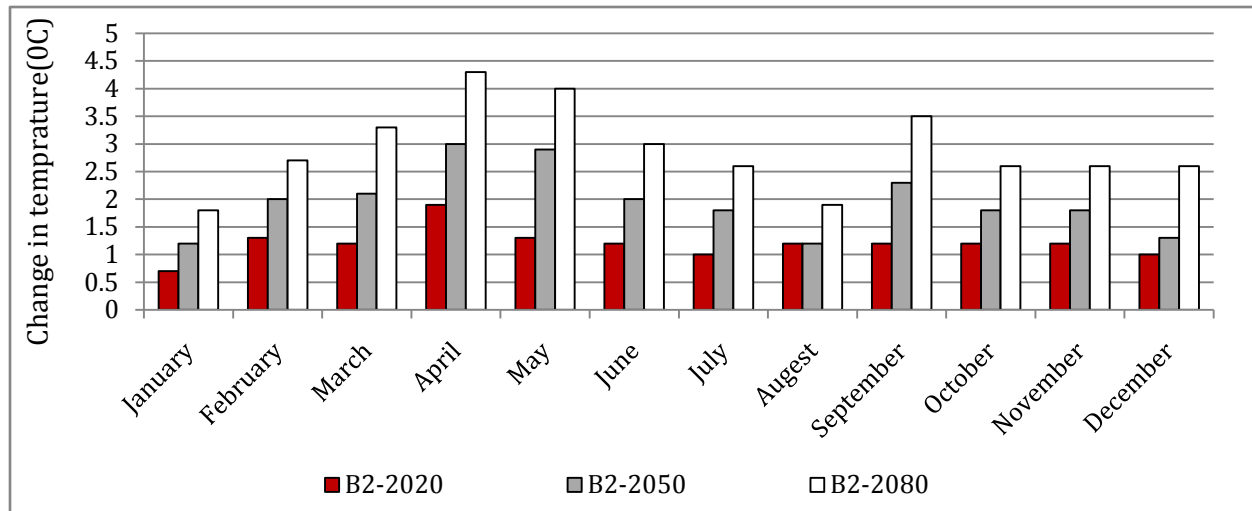


Figure 6.8 (b): Change of downscaled monthly minimum temperature from the baseline period for HadCM3B2a

3. Maximum temperature

Like case of projected average monthly minimum temperature, maximum temperature also reflects increasing trend in future climate periods. The projected maximum temperature in 2020s indicated that maximum temperature will rise by 0.59°C and 0.62°C for HadCM3A2a and HadCM3B2a scenarios. In 2050s the increment will be 1.19°C and 0.99°C for HadCM3A2a and HadCM3B2a scenarios respectively.

Whereas, in 2080s the maximum temperature will be increased by 2.0°C and 1.4°C for HadCM3A2a and HadCM3B2a scenarios, respectively. This shows that the future period will experience increasing trend in maximum temperature for both HadCM3A2a and HadCM3B2a scenarios. However, the increments will be less for HadCM3B2a scenario relative to HadCM3A2a scenario. This is due to the fact that HadCM3A2a represents medium high scenario which produces more CO₂ as compared to HadCM3B2a scenario which is medium low scenario.

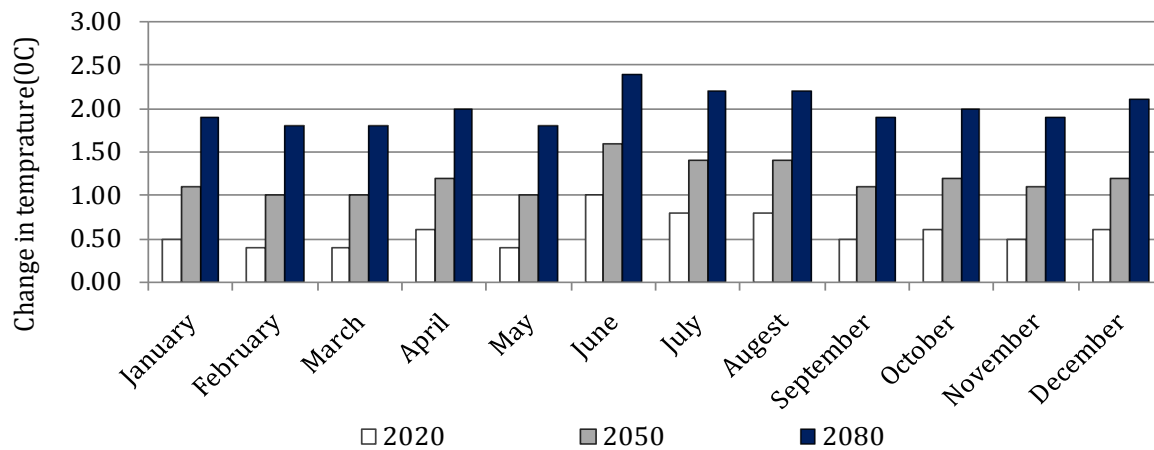


Figure 6.9(a): Change in monthly maximum temperature between the baseline period and future for HadCM3A2a

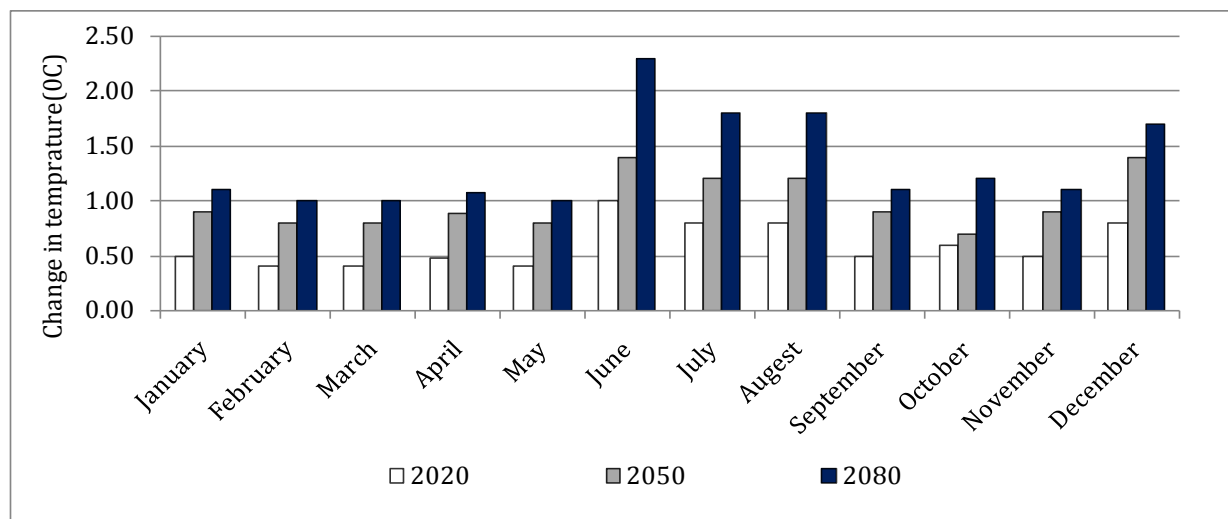


Figure 6.9(b): Change in monthly maximum temperature between the baseline period and future for HadCM3B2a

6.3 Open Water Evaporation

The average annual open water evaporation shows increases in amount by 0.3% in 2020s; by 1.1% in 2050s and 1.3% increase is projected in 2080s under the HadCM3A2a emission scenario. In the case HadCM3B2a scenario the evaporation is expected to increase by 0.4 % in 2020s and by 0.5% in 2050s and 1.9% increase in change is expected by 2080s under B2a scenarios as shown in figure 6.10 (a&b)

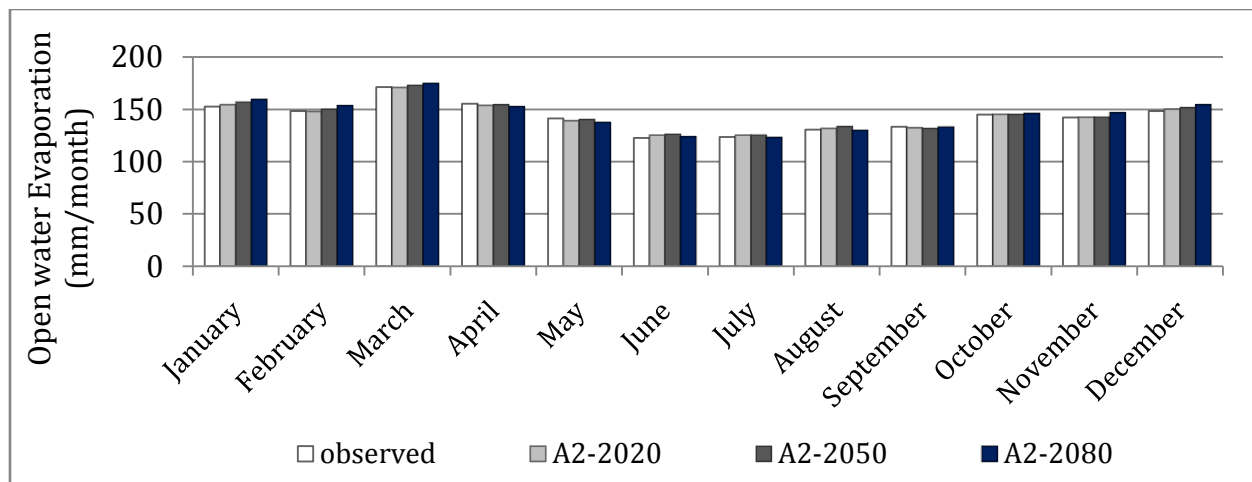


Figure 6.10(a) Projected monthly open water evaporation under HadCM3A2a emission scenario

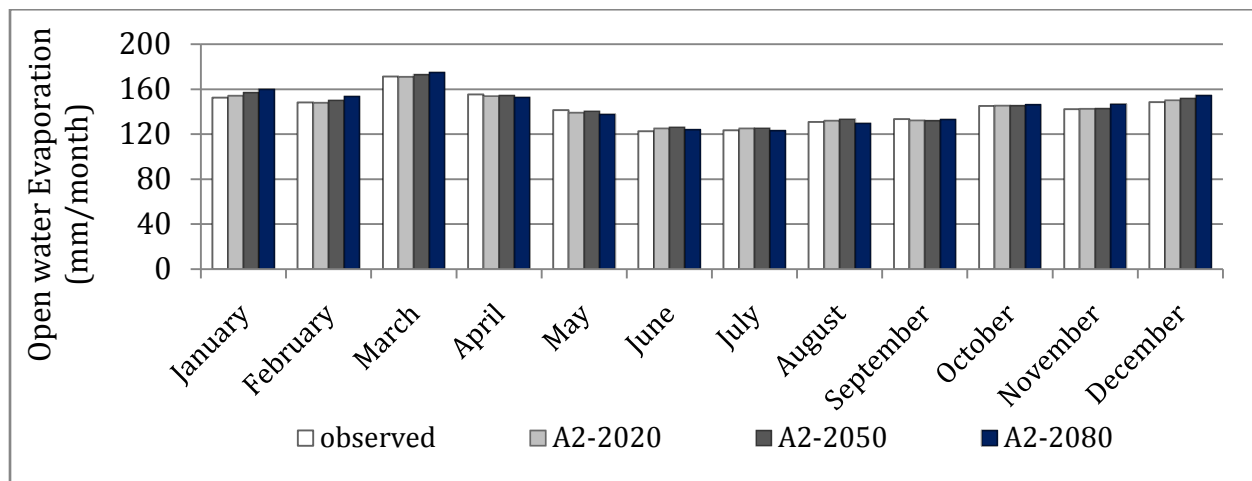


Figure 6.10(b) Projected monthly open water evaporation under HadCM3B2a emission scenario

6.4 Hydrological Model Calibration and Validation Results

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. By Nash and Sutcliffe efficiency criteria
3. By relative volume error

The most optimum parameter set that was used in the calibration is reported in Table 6.3

Parameter	Description	Range	Calibration Value
α	used in equation $Q=K.UZ^{(1+\alpha)}$	0.5 -1.1	1.0
β	exponent in the equation for discharge from the zone of soil water	1.0-4.0	2.0
FC	maximum soil moisture storage capacity in the model [mm]	100-1500	269.0
KH _q	Recession coefficient for the upper response box when the discharge is HQ	0.005-0.2	0.05
K ₄	recession coefficient for lower response box	0.001-0.1	0.00026
LP	Limit for potential evapotranspiration	≤ 1	0.6
Perc	percolation from the upper to lower response box [mm/day]	0.01-6	0.75

Table 6.3 List of optimal parameter set in calibration

6.4.1 Model Calibration

The calibration of the model was performed for six years (1996 to 2001) using daily stream flow data at the dam site. The performance of the model was evaluated daily and monthly using Nash and Sutcliffe efficiency criteria (R^2) and relative volume error (RV_E) statistical measures for both manual and auto-calibration. During calibration monthly result exhibited good correlation than daily result.

Period	Time Step	R^2	RV_E
Calibration (1996-2001)	Daily	0.798	0.060
	Monthly	0.88	0.060

Table 6.4: daily and monthly Calibration result of the model

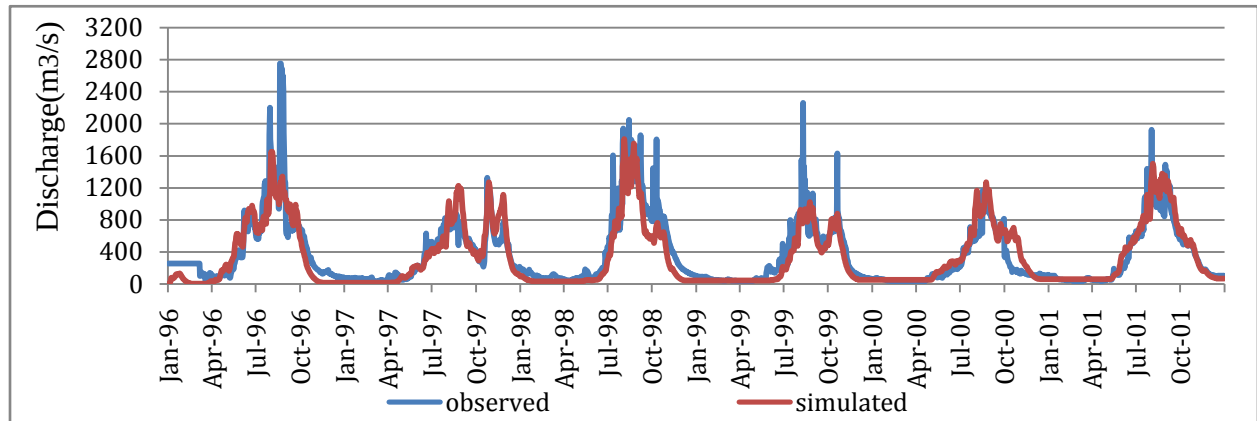


Figure 6.11: Observed and simulated mean daily hydrograph during calibration period

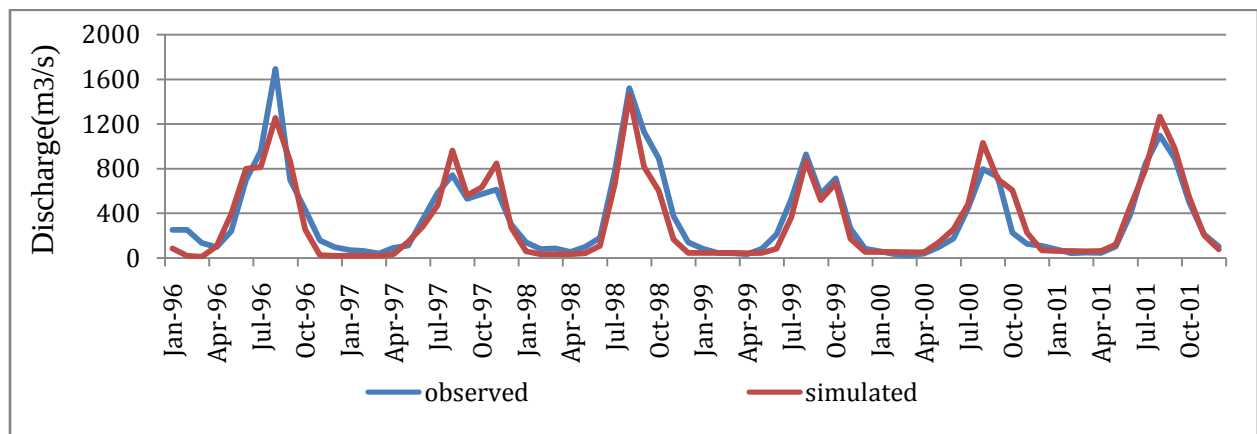


Figure 6.12: Observed and simulated mean monthly hydrograph during calibration period

6.4.2 Model Validation

The validation of the model at the dam site was done for daily data set of four years from 2002 to 2005. Validation of the model showed the model's strong predictive capability through Sutcliffe efficiency criteria (R^2) and relative volume error (RV_E) for both manual and auto-calibration

Period	Time Step	R^2	RV_E
Validation (2002-2005)	Daily	0.804	0.01
	Monthly	0.833	0.010

Table 6.5: daily and monthly validation result of the model

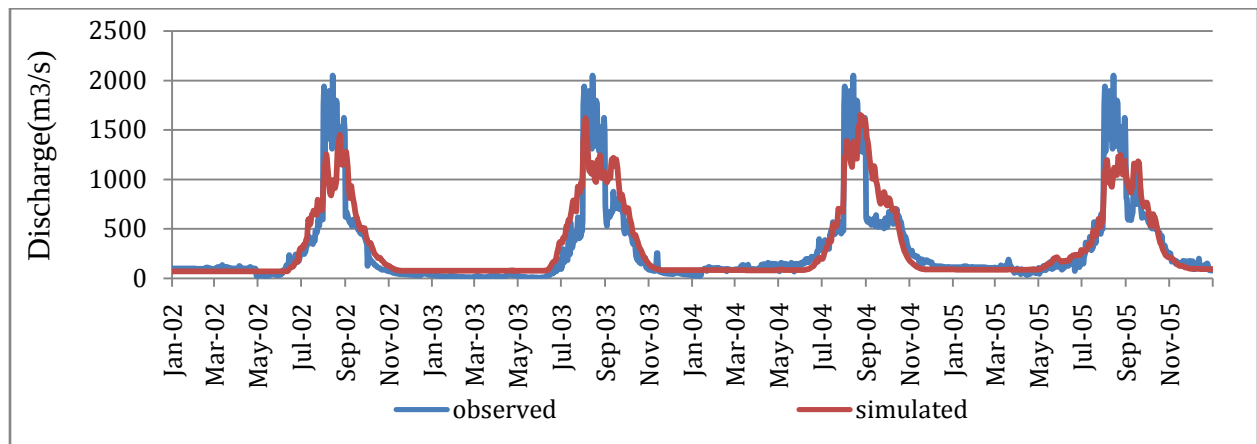


Figure 6.13: Observed and simulated mean daily hydrograph during validation period

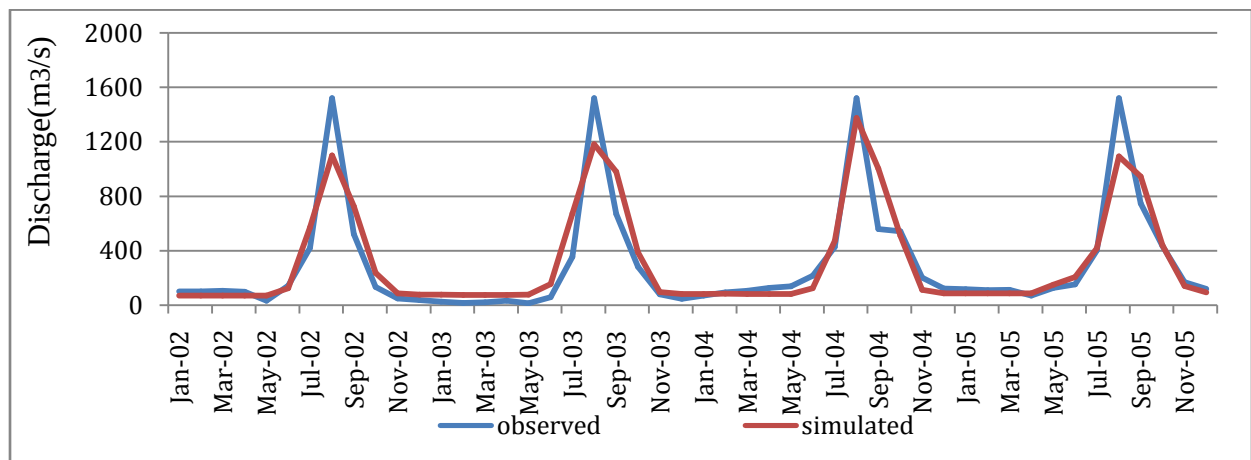


Figure 6.14: Observed and simulated mean monthly hydrograph during validation period

6.5 Impact of Climate Change on the Reservoir Inflow

The impact of climate change on flow volume was analyzed on a monthly, seasonal and annual basis. The results for the analysis were discussed in the following sections and the summarized results are discussed below.

6.5.1 Impact on Monthly Flow Volume

The impact of climate change was analyzed taking the 1996-2005 river flow as the baseline flow against which the future flows for the 2020s, 2050s and 2080s compared. Precipitation, minimum and maximum temperature were the climate change drivers considered for the impact assessment.

The monthly percentage change in flow volume in both scenarios for the period 2020s, 2050s and 2080s are presented in Figure 6.15 and Figure 6.16.

In the 2020s for the A2a scenario, the flow volume may show an increasing for all the months except January, April, August, November and December. In this period a decrease up to 23.55% and an increase up to 21.67% in monthly flow volume may be expected. In the 2020s for B2a scenario, almost the same monthly effect as the A2a scenario of 2020s may be observed. But the decrease in monthly flow volume is expected to reach up to 18.06% and the increase might reach up to 32.57%.

In 2050s for both scenarios, a decrease in flow volume exhibited, this might shows a monthly increase up to 32.06% and 33.43% and monthly decrease up to 23.01% and 32.61% for HadCM3A2a and HadCM3B2a scenarios respectively.

In 2080s, an increasing trend will expect for both HadCM3A2a and HadCM3B2a scenarios. In monthly bases the A2a scenario will expect to increase up to 52.03% and decrease up to 20.95% .However, in 2080s B2a scenario, the pattern of monthly flow volume change may be increase up to 22.70% and decrease up to 21.68%.

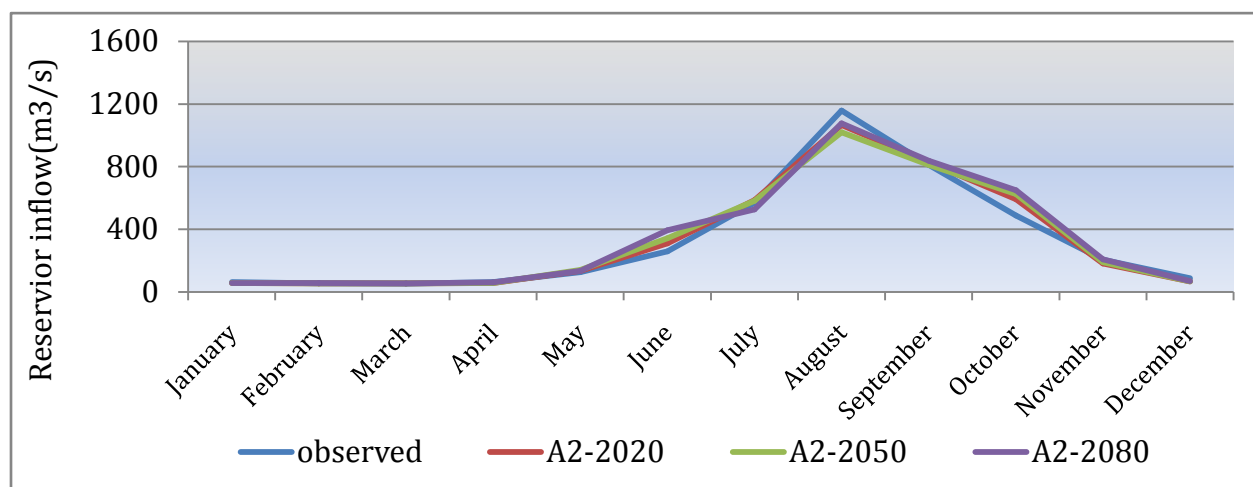


Figure 6.15 Reservoir inflows at different time horizons under HadCM3A2a emission scenario

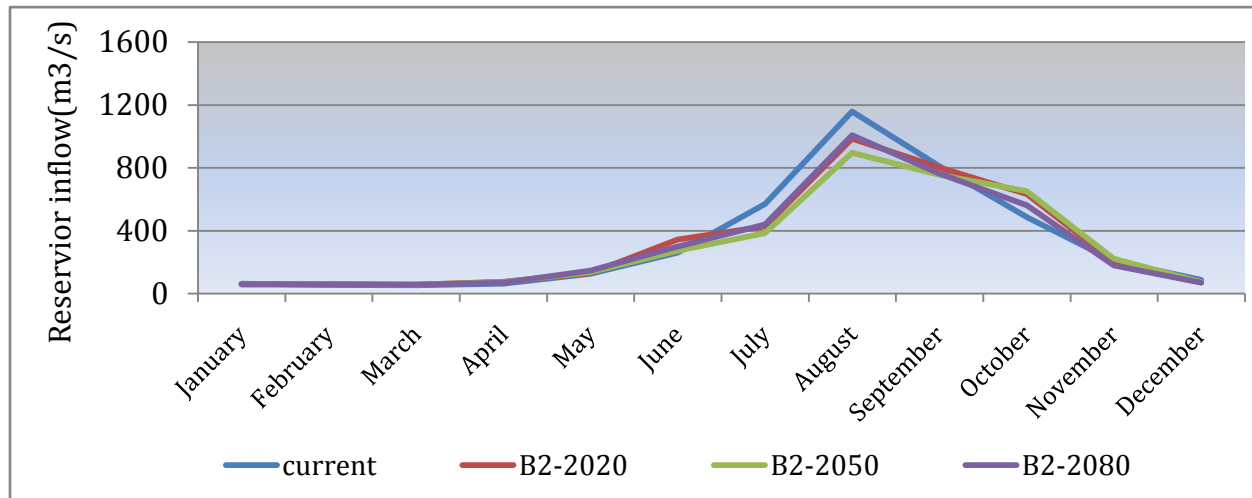


Figure 6.16 Reservoir inflows at different time horizons under HadCM3B2a emission scenario

6.5.1 Impact on Seasonal and Annual Flow Volume

In 2020s, the total average annual inflow in to Gibe III reservoir increase up to 1.2% and 1.28% for HadCM3A2a and HadCM3B2a scenarios respectively.

In 2050s, reservoir inflow increase up to 1.49% and decrease reach 7.79% for HadCM3A2a and HadCM3B2a scenarios respectively.

However, in 2080s the reservoir inflow will increase up to 4.65% for HadCM3A2a scenario and 2.24% for HadCM3B2a scenario annually.

For this specific study, seasonal analysis was taken for three seasons i.e. Bega (October, November, December and January), Belg (February, March, April and may) and kiremt (June, July, august and September).

During Bega season total average seasonal reservoir inflow will increase in all horizons both HadCM3A2a and HadCM3B2a scenarios. Furthermore percentage increment will be high exhibiting 16.48% in 2080s for HadCM3A2a scenario and 18.78% in 2050s for HadCM3B2a scenario.

Belg season inflow volume shows increasing trend in all horizons except in 2050s for HadCM3A2a scenario. In this season maximum increment will be 12.87% in 2080s for HadCM3B2a scenario.

Kiremt season total average seasonal inflow volume shows decreasing trend in all horizons for both scenarios except in 2080s for HadCM3A2a and HadCM3B2a scenarios. Therefore Maximum decrease can be 17.59% in 2050s for scenarios and Maximum increase will be in 2080s for HadCM3A2a scenario. Figure 6.17 and Figure 6.18 shows the implication of climate change on the reservoir inflow in seasonal and annual bases.

Figure 6.17: Percentage change in seasonal and annual reservoir inflow in respect to baseline period for the HadCM3A2a scenario

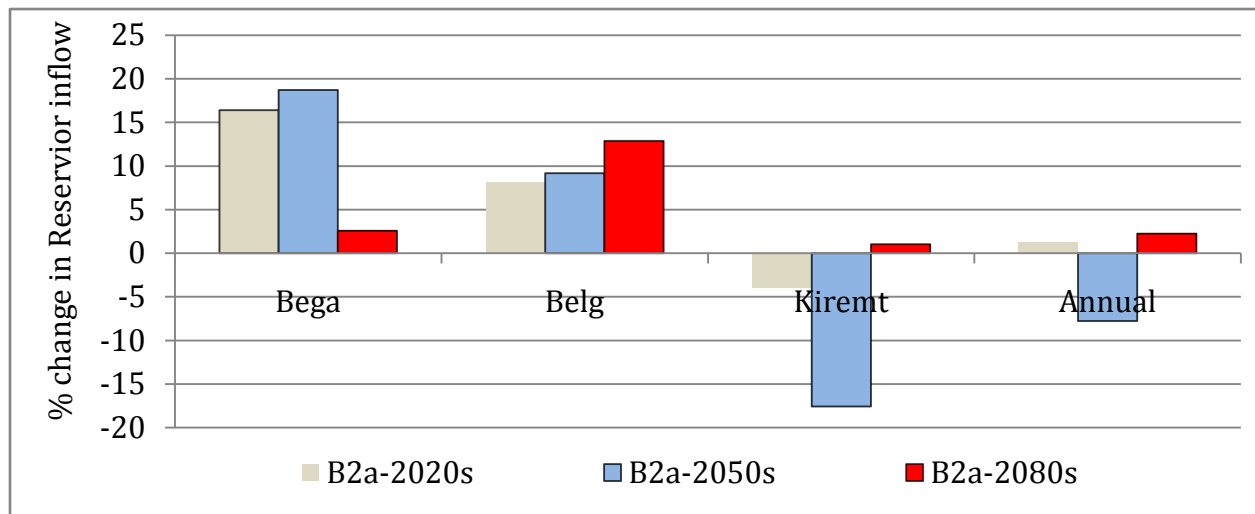


Figure 6.17: Percentage change in seasonal and annual reservoir inflow in respect to baseline period for the HadCM3A2a scenario

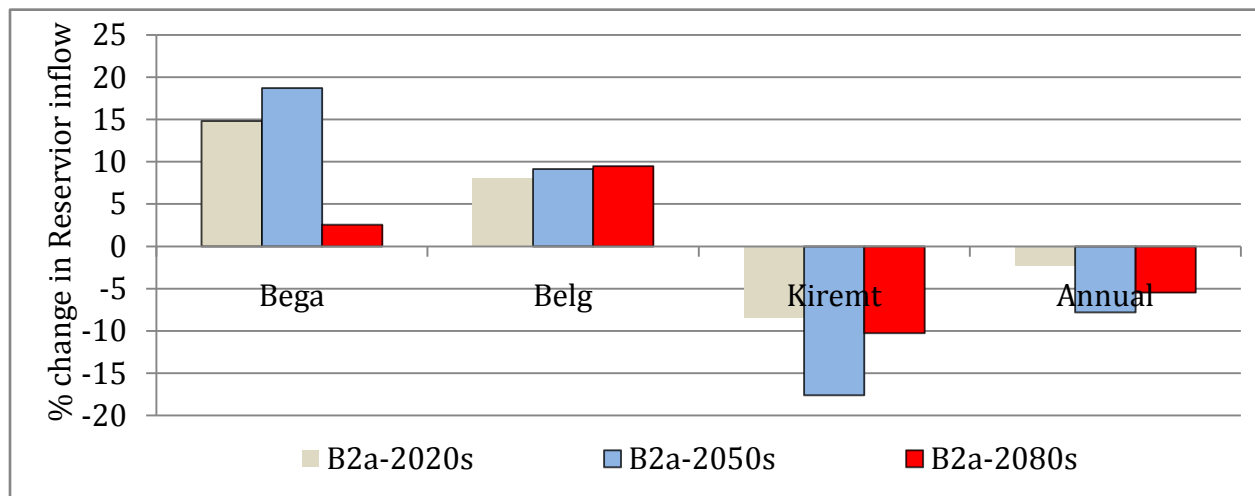


Figure 6.18: Percentage change in seasonal and annual reservoir inflow in respect to baseline period for the HadCM3B2a scenario

7. CONCLUSION AND RECOMENDATION

7.1 Conclusion

The results of the climate projection showed that SDSM is able to replicate the observed maximum and minimum temperature well; however, SDSM couldn't able to replicate well the observed precipitation with the simulated precipitation due its conditional nature and high variability in space. Still the simulated precipitation values follow the same trend as the observed precipitation. Hence, the overall performance of SDSM was considered satisfactory.

The results from the applied statistical downscaling model indicate that both the minimum and maximum temperature show an increasing trend in all future time horizons for both A2 and B2 scenarios. The average annual minimum temperature will be increased by 3.6°C and 2.9°C for A2 and B2 scenario respectively towards the end of this century. The maximum temperature will also increased by 2.0°C and 1.35°C for A2 and B2 scenario respectively within the same time period. Climate change scenarios for Africa, based on the results from several General Circulation Models using the data collected by the Intergovernmental Panel on Climate Change Data Distribution Centre (IPCC-DDC) indicate that future warming across Africa ranges from 2°C (low scenario) to 5°C (high scenario) by 2100. Therefore the result obtained from SDSM lies within the range of IPCC recommendations.

Stastical downscaling showed that in 2020s the mean annual precipitation may show a decrease up to 1.2% (A2a scenario) and 1.28% (B2a scenario). Also it may show a decrease in the 2050s up to 7.79 % (B2a scenario) and an increase in 2080s up to 4.65 % (A2a scenario).

However, in the main rainy season the mean monthly rainfall indicates a decreasing trend in the beginning of the rainy season (May & June) and an increasing trend towards the end of the rainy season (September & October) for both A2 and B2 scenarios in all future time horizons.

The evaporation from the open water generally shows an increasing trend i.e. it exhibits an average annual increase of 1.3 % for A2a emission scenario and 1.9 % increase for B2aemission scenario at the end of the next century.

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 Nash and Sutcliffe efficiency criteria (R^2) are 0.798 and 0.804 during calibration and validation period respectively.

The hydrological impact of future change scenarios indicates that there will be high seasonal and monthly variation of runoff compared to the annual variation. In the main rainy season (June-September) the runoff volume will reduce by 32.97% and 10.06% for 2050s and 2080s respectively in B2a scenarios.

7.2 Recommendation

This study was done in a limited time and resource. Hence the results of this study should be taken as a starting point for further studies especially on omo gibe basin.

The outcome of this study is based on single GCMs and two emission scenarios. However, it is often recommended to apply different GCMs and emission scenarios so as to make comparison between different models as well as to explore a wide range of climate change scenarios that would result in different hydrological impacts.

Hence this work should be extended in the future by including different GCMs and emission scenario. Therefore other downscaling models like Regional Climate Model (RCM) should also be tested to allow assessments based on the result from different downscaling models.

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APPENDIX

Station Information										
S.no	Station	Elevation	Northing	Easting	Prec.	Max. Tem.	Min. Tem.	Relative Humidity	Wind speed	Sunshine Hour
1	Jimma	1725	7.4	38.4	√	√	√	√	√	√
2	Hosana	2200	7.33	37.52	√	√	√	√	√	√
3	wolaita Soddo	1800	6.51	37.45	√	√	√	√	√	√
4	Sokoru	2100	7.55	37.24	√	√	√	√	√	√
5	Areka	1750	7.07	37.42	√					
6	Gesuba	1650	6.4	37.38	√					
7	Gedo	2400	9.04	37.25	√					
8	Bako	1650	9.07	37.05	√					
9	Shedatura	1950	8.04	37.59	√					
10	Cheleleki	1725	8.13	37.07	√					
11	Wolkite	1550	8.16	37.49	√					
12	Limu genet	1650	8.06	36.57	√					
13	Saja	2100	7.58	37.24	√					
14	Wushwush	1950	7.19	36.08	√					
15	Bele	1240	6.57	37.32	√					

Appendix A: List of station name, location and available metrological variables

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	mean
1996	254.7	263.8	132.2	97.0	239.5	692.6	956.7	1692.1	693.9	433.0	157.2	96.8	475.8
1997	71.8	63.5	38.4	90.5	111.7	350.8	583.6	743.5	532.6	572.8	612.2	302.2	339.4
1998	140.5	80.4	83.9	52.4	98.4	179.2	768.7	1526.9	1132.5	891.2	377.1	140.9	456.0
1999	83.2	46.8	42.4	34.1	82.5	211.9	526.7	929.4	573.2	716.2	263.5	83.6	299.5
2000	59.4	34.9	22.7	38.6	95.9	174.0	450.2	797.7	726.0	227.1	124.1	110.3	238.4
2001	77.0	42.0	47.3	44.5	102.7	393.4	843.3	1099.9	895.0	497.1	213.6	103.2	363.2
2002	99.9	100.1	105.7	97.7	31.5	143.8	420.5	1526.9	522.7	133.2	48.9	37.2	272.3
2003	25.1	14.8	19.8	26.7	13.1	57.5	354.2	1526.9	669.6	281.0	79.2	44.2	259.3
2004	69.0	96.3	103.2	125.2	135.4	215.7	429.1	1526.9	560.2	542.5	200.1	122.0	343.8
2005	115.2	110.1	111.6	65.8	118.7	150.9	398.3	1526.9	741.8	434.9	168.0	119.1	338.4

Appendix B: mean monthly flow at the dam site [m³/s]

Month	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Maen
ETO(mm/month)	142	139	158.7	148	142	127	120	125	131	137.6	136	138.9	1645

Appendix C: Long term average monthly potential evapo-transpiration from Jimma station (1996-2005)

No.	Predictor Variable	Predictor description	No.	Predictor Variable	Predictor description
1	Mslpaf	mean sea level pressure	14	p5zhaf	500 hpa divergence
2	p_faf	surface air flow strength	15	p8_faf	850 hpa airflow strength
3	p_uaf	surface zonal velocity	16	p8_uaf	850 hpa zonal velocity
4	p_vaf	surface meridional velocity	17	p8_vaf	850 hpa meridional velocity
5	p_zaf	surface vorticity	18	p8_zaf	850 hpa vorticity
6	p_thaf	surface wind direction	19	p850af	850 hpa geopotential height
7	p_zhaf	Surface divergence	20	p8thaf	850 hpa wind direction
8	p5_faf	500 hpa airflow strength	21	p8zhaf	850 hpa divergence
9	p5_uaf	500 hpa zonal velocity	22	p500af	Relative humidity at 500 hpa
10	p5_vaf	500 hpa meridional velocity	23	p850af	Relative humidity at 850 hpa
11	p5_zaf	500 hpa vorticity	24	Rhumaf	Near surface relative humidity
12	p500af	500 hpa geopotential height	25	shumaf	Surface specific humidity
13	p5thaf	500 hpa wind direction	26	tempaf	Mean temperature at 2 m

Appendix D :Predictor variable present in both HadCM3 and NCEP archive

Appendix E: Parameter Files for the Climate Projection Obtained from the SDSM

1. MAX temperature parameter file

3

1

366

1/1/1971

11323

1/1/1971

7305

#FALSE#

1

1

TRUE

jimmasTMPMAX_vna.dat

ncepp_uaf.dat

ncepp_zhaf.dat

nceptempaf.dat

6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
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6.609	-0.192	-0.113	0.157	0.752	2.417	0.414
-------	--------	--------	-------	-------	-------	-------

C:\SDSM FILE\input data\JIMMA STANDARD DATA\jimmasTMPMAX_vna.dat

[1] The number of predictors

[2] The season code (12 = months, 4 = seasons, 1 = annual model)

- [3] The year length indicator (366, 365, or 360)
- [4] Record start date
- [5] Record length (days)
- [6] Model fitting start date
- [7] Number of days used in the model fitting
- [8] Whether the model is conditional (true) or unconditional (false)
- [9] Transformation (1 = none, 2 = fourth root, 3 = natural log, 4 = log normal)
- [10] Ensemble size
- [11] Auto regression indicator (True or false)
- [12] Predictand file name
- [13-18] predictor files
- [19-30] Model Parameters; the first six columns are the parameters (including the intercept), the last two
Columns are the SE and r2 stastics
- [31] The root directory of the predictand file

2. TMP Minimum parameter file

4

1

366

1/1/1971

11323

1/1/1971

5844

#FALSE#

1

1

TRUE

jimmaTMPMINna.dat

ncepp5zhaf.dat

ncepp850af.dat

nceprhumaf.dat

nceptempaf.dat

1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690
1.764	0.102	0.090	0.352	0.198	0.845	2.049	0.690

C:\SDSM FILE\input data\JIMMA STANDARD DATA\jimmaTMPMINna.dat

[1] The number of predictors

[2] The season code (12 = months, 4 = seasons, 1 = annual model)

- [3] The year length indicator (366, 365, or 360)
- [4] Record start date
- [5] Record length (days)
- [6] Model fitting start date
- [7] Number of days used in the model fitting
- [8] Whether the model is conditional (true) or unconditional (false)
- [9] Transformation (1 = none, 2 = fourth root, 3 = natural log, 4 = log normal)
- [10] Ensemble size
- [11] Auto regression indicator (True or false)
- [12] Predictand file name
- [13-18] predictor files
- [19-30] Model Parameters; the first six columns are the parameters (including the intercept), the last two columns are the SE and r2 statistics
- [31] The root directory of the predictand file

3. Precipitation parameter file

6

1

366

1/1/1971

11323

1/1/1971

5844

#TRUE#

2

1

TRUE

jimmaPREClpna.dat

ncepp_uaf.dat

ncepp_zhaf.dat

ncepp5thaf.dat

ncepp8_vaf.dat

ncepp8_zaf.dat

ncepr500af.dat

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
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0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
-------	-------	--------	-------	--------	--------	-------	-------	-------

0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
-------	-------	--------	-------	--------	--------	-------	-------	-------

0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
-------	-------	--------	-------	--------	--------	-------	-------	-------

0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
-------	-------	--------	-------	--------	--------	-------	-------	-------

0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
-------	-------	--------	-------	--------	--------	-------	-------	-------

0.338

0.324	0.044	-0.076	0.000	-0.138	-0.043	0.027	0.303	0.000
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[illegible]

1.394 1.000 0.031 -0.005 0.000 -0.050 0.003 -0.008 0.473
0.037

C:\SDSM FILE\input data\JIMMA STANDARD DATA\jimmaPREClpna.dat

[1] The number of predictors

[2] The season code (12 = months, 4 = seasons, 1 = annual model)

[3] The year length indicator (366, 365, or 360)

[4] Record start date

[5] Record length (days)

[6] Model fitting start date

[7] Number of days used in the model fitting

[8] Whether the model is conditional (true) or unconditional (false)

[9] Transformation (1 = none, 2 = fourth root, 3 = natural log, 4 = log normal)

[10] Ensemble size

[11] Auto regression indicator (True or false)

[12] Predictand file name

[13-18] predictor files

[19-30] Model Parameters; the first six columns are the parameters (including the intercept), the last two

Columns are the SE and r2 spastics

[31] The root directory of the predictand file

